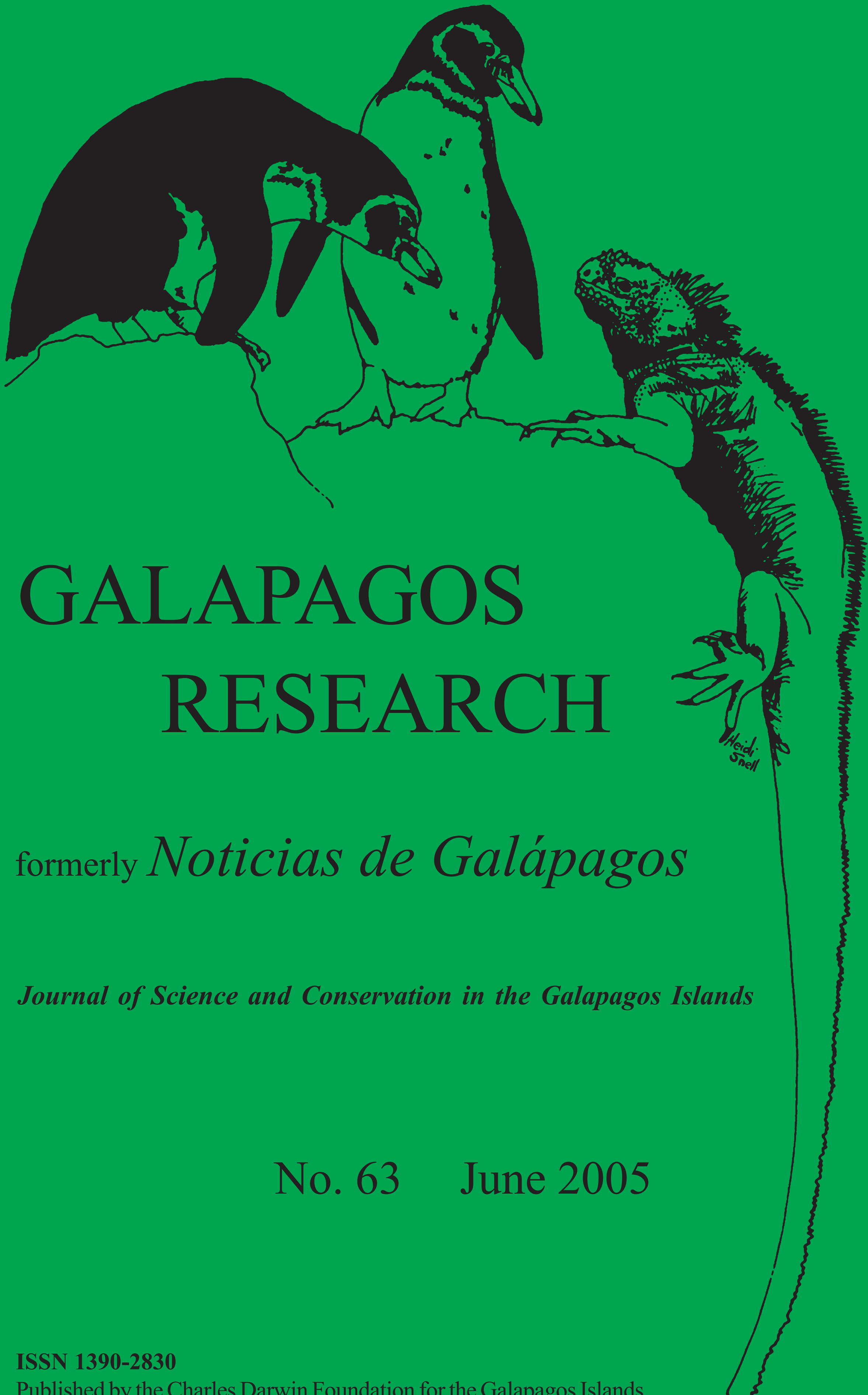

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We are deeply grateful for your steadfast support

GALAPAGOS RESEARCH (formerly *Noticias de Galápagos*)

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***Galapagos Research* (formerly *Noticias de Galápagos*)** is the research journal of the Charles Darwin Foundation for the Galapagos Islands. It is available in printed form, and back issues may be found online at www.darwinfoundation.org.

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CHARLES DARWIN FOUNDATION for the Galápagos Islands

Back cover map: Tom Giermakowski & Howard Snell (University of New Mexico)

Layout: Alan Tye & Heidi Snell.

EDITORIAL

Readers who have come to know and love the Charles Darwin Foundation's journal *Noticias de Galápagos* may initially be dismayed to see that with this issue the name has changed. However, the old name has not gone completely and will be retained as a subtitle, and we hope that any dismay might be short-lived. This is the most conspicuous of a number of changes that have been made to the journal in this issue, and it was the subject of much discussion among staff and members of the Charles Darwin Foundation during the first half of 2004. Many people felt that the title no longer reflected the journal's content. *Noticias* has gradually evolved from the trilingual (English, French, Spanish) newsletter of its first few years, for which the old name was as good as any, to an English-language research journal. It was thus the general view of most people consulted in 2004, including those whose first language was Spanish, that a title in Spanish which means "News from Galapagos" did not well describe a journal of science and conservation, even a Spanish-language one, and certainly not one that is primarily in English. Such a title also did not sit well with the desires and intentions of successive editors to improve the quality of the scientific content, as it was not very attractive to authors of scientific articles.

Since the origins of *Noticias*, other media have been developed to publish the more ephemeral news items from Galapagos, such as the newsletters of the Friends of Galapagos organizations, e-mail lists and our web sites, and this has been reflected in decreasing news coverage in *Noticias* in recent issues. Apart from news, *Noticias* has always carried a mix of two kinds of longer article: academic research papers, and more popular articles and discussion. Intermixing the two has done the authors of neither any good, and a stricter separation, which has been considered from time to time for at least the last 15 years, has finally been implemented in this issue, with the creation of the two sections: "Research Articles" and "Galapagos Commentary", although the current issue has none of the latter. In addition to these, the journal will continue to publish news items of archival value, in a resurrected section "News from Academy Bay", in which we hope to include an annual summary of the research activities of CDRS and its collaborators, as in this issue.

Acceptable material for the journal remains basically unchanged: any topic relevant to science or nature conservation in Galapagos, including natural history, biology, ecology, evolution, systematics, conservation biology, geology, geography, history, human activity, and the management of biological diversity. The new name was chosen to reflect this. The journal is Galapagos-focused, and its main mission is to publish research results, in the broadest sense (not just science). The new Instructions for Authors can be found on the back cover and online at www.darwinfoundation.org/galres/index.html.

The name change should help to improve the journal's image among potential authors and readers. Improving the image is also part of a strategy to increase the impact of research results published in the journal, thereby helping us to maintain and raise standards. We also hope to increase the circulation to libraries and coverage by abstracting services. And for the first time in its history (apparently), the journal has an ISSN number. We have also implemented a consistent standard of peer review of articles, with all Research Articles (and most other submissions) being reviewed by referees (normally two, sometimes more than two, occasionally one for short items), of which at least one will not be a member of staff of the Charles Darwin Research Station. An Editorial Committee has been established, comprising the Heads of the four CDRS science departments and of Communication & Participation (or a permanent delegate in each case), for this issue Eva Danulat, Ana María Loose, Lázaro Roque, Alan Tye and David Wiedenfeld, as well as a former editor, Howard Snell. This committee will coordinate refereeing and consider suggestions for changes to journal policy. Major policy decisions remain the prerogative of the Board of CDF.

There was also much discussion about the language of material in the journal. Since the early issues, where French sometimes dominated, the main language has become English, and the decision was taken that this should not change, because English is the primary language of science, the main international readership requires English, and most authors wish to publish research results in English. However, as from this issue, all Research Articles will be published with a summary in both English and Spanish. The Editorial Committee and CDF Board also recognise that it is desirable to publish a full translation in Spanish, as has been done from time to time in the past, and intend that funding will be sought for this. The most achievable option will probably be to publish eventually a translation on the CDF web site.

Those are the changes that have been adopted in this issue. Little else will change: format and appearance will remain as in recent issues.

Finally, I want to take this opportunity to thank the outgoing editorial-production team, Tom and Pat Fritts and Heidi and Howard Snell, for their work on the last issue and help during the handover. I also thank Johannah Barry and her staff at CDF Inc., and John Simcox and Susanne Richt, successive librarians at CDRS, for their help with sorting out the distribution list, and the referees, who have contributed their time and expertise.

So, we hope you get to know, and continue to love, the same old *Noticias de Galápagos* in its new *Galapagos Research* guise, and help us to maintain and increase its standards by submitting your best work!

Alan Tye

NEWS FROM ACADEMY BAY

CDRS RESEARCH HIGHLIGHTS, 2004

In this section we briefly review some of the main projects and successes of the research programmes carried out by CDRS staff, students and collaborators during the year.

PLANTS

During the year, research by the CDRS Botany Department remained focused on two main objectives, threatened plant conservation and invasive plant control, which comprise the two research programmes of the Department. Within each programme, activities fall into five levels: establishing the baseline of knowledge; monitoring for change; prioritizing the problems; studying the priorities; experimental management.

Research for the conservation of native plants
Further survey work was carried out, contributing to the baseline of knowledge of the status and distribution of native plants, with the focus on endemic and, especially, threatened species. Half of Pinta island was surveyed, and inaccessible areas of Santiago were reached by helicopter, thanks to Project Isabela. Populations of two strange plants were discovered (a *Scalesia* on Santa Cruz and a *Lecocarpus* on San Cristóbal) and work is in progress to find out what they are.

Monitoring of plant communities threatened by goats entered a new phase, now that goat eradication is becoming a reality on both Santiago and Isabela, where staff member Iván Aldaz has been monitoring vegetation changes in permanent plots since 1995. We are now monitoring vegetation recovery, to ensure that the native plant communities re-establish themselves fully.

Prioritization of threatened plants is based on the IUCN red-list system, and we have had a red list of Galapagos vascular plants (flowering plants and ferns) since 2002, with assessments made by CDRS staff working as part of the IUCN Galapagos Plant Specialist Group. In 2004, preparations began for red-listing Galapagos endemic seaweeds.

Staff member Patricia Jaramillo began the first molecular genetic plant study to be carried out entirely within Galapagos, investigating the reproductive biology and population genetics of *Calandrinia galapagosa*, in an attempt to understand the morphological variability seen within this Critically Endangered species. Molecular genetic and phylogenetic projects are being carried out on several other groups of endemic plants, in collaboration with research groups from institutions outside Galapagos. Volunteer Walter Simbaña continued his study of the complex of intermediate populations among the various species of *Scalesia* of Santiago island, with the objective of determining their origins and genetic isolation.

Experimental management of threatened plants comprises protection and restoration. During 2004, endangered populations of several rare plant species were identified, including *Scalesia affinis* on Santa Cruz and *Calandrinia* and *Lecocarpus* on San Cristobal, and protected by fencing, with the work being carried out jointly by CDRS and the Galapagos National Park. The second phase of our Espanola *Opuntia* restoration project began, with a PhD study to be carried out by Ecuadorian student Vanessa Coronel. Vanessa first joined the Department as a work-experience student, and her progress illustrates the success of the CDF's training programmes. She went on to do her undergraduate thesis on the Española *Opuntia*, and is now following that with a PhD at Lund University, Sweden. Restoration projects for *Scalesia cordata* on Isabela and *S. affinis* on Santa Cruz also began.

Research for the control of invasive plants
During 2004, surveys of introduced plants in the inhabited zones of the archipelago continued, with the completion of the survey of Puerto Ayora, the largest area in terms of number of properties. The survey team, comprising staff members Susana Chamorro, Ana Mireya Guerrero, Anne Guézou and Paola Pozo, moved on to begin work in the town and agricultural zone of Isabela towards the end of the year. With the completion of Puerto Ayora, the number of introduced plant species known in Galapagos passed 650.

On San Cristóbal, an introduced plant monitoring scheme for the local community was initiated, in conjunction with the CDRS Dept of Communication and Participation. A leaflet was prepared, asking residents to report new plant species that they find on their farms, and in particular to report particular species that are targets for eradication.

Prioritization of introduced plant problems took a further step towards becoming more objective, with staff member Chris Buddenhagen leading our Weed Risk Assessment system for Galapagos into its test phase. During 2005, all known introduced plants will be run through the system. A new model for estimating the feasibility and costs of eradication was also developed by Australian weed expert Paul Pheloung, working with Chris. This model should facilitate choosing target species for eradication and planning such projects in such a way as to achieve a high probability of success.

Studies of priority invasive species continued, with a study of grass invasions completed by student Ana Lucía

Dávalos. Ecological studies of quinine by Heinke Jäger, and an economic study of quinine control costs by Patricio Yánez, entered their final phase, and a preliminary cost estimate for an eradication attempt for quinine was prepared (see p. 31). The first phase of specificity testing for possible future biological control of the invasive shrub *Lantana camara* was completed by student Jorge-Luis Rentería, working on a potential fungal control agent at CABI in the U.K.

Experimental management focused on twelve experimental eradication projects, which were continued or begun during the year by our field team of Félix Burgos, Manuel Montalván, Manuel Orellana, Guílber Román and Omar Valle. So far, three invasive blackberry species have probably been eradicated from Galapagos already, although confirmation awaits completion of post-treatment monitoring in the control sites.

Staff expertise was contributed to a number of projects outside Galapagos, including Alan Tye leading an IUCN-UNESCO invasive species strategic planning team to Cocos Island (Costa Rica). This mission wrote a framework for long-term invasive species management on Cocos, together with a detailed plan for the simultaneous eradication of six mammal species from the island.

Alan Tye
Head of CDRS Botany Department

SOCIAL SCIENCES

One of the activities of the CDRS Department of Communication and Participation is to increase the capacity of the local community to manage sustainably the natural resources of Galapagos. In the Marine Reserve, one of the major groups of users is the fishermen, and our objective is to encourage them to produce proposals for management of the reserve based on scientific information.

Participative monitoring of sea cucumber and lobster, two of the most important fisheries resources, produces data on density and size, important for taking management decisions. In order to promote participation of the fishermen in this monitoring, and thereby also increase their acceptance of its value, we carried out during 2004 a survey of the knowledge, attitudes and practices of Galapagos fishermen regarding such monitoring, to identify needs for training in analysis and data interpretation.

The survey revealed that some 60% of fishermen did not know what participatory monitoring is. Some 30% of those interviewed did not wish to participate in monitoring of sea cucumber and 60% did wish to take part in monitoring lobster . Almost half had no confidence in the results produced by participatory monitoring, more than one third believed that it was prejudicial to them, and 60% believed that the results are manipulated. Most fishermen agreed that the fisheries cooperatives should carry out and/or pay for monitoring sea cucumbers, and half believed that the fishing sector did not use the results of lobster monitoring. However, most interviewees thought that information from participatory monitoring could be useful for formulating management proposals.

According to the survey results, 60% of fishermen have secondary education and half are in the 35–54 year age group. Training could take place during the five months of the year not occupied by sea cucumber and lobster seasons.

The information from the survey was used to develop, along with the fishing sector, a proposal to improve their participation in monitoring, which was presented to the other user groups of the Marine Reserve at the end of the year.

Ana Maria Loose
Head of CDRS Dept of Communication and Participation

VERTEBRATES

Two programs of eradication and control, which are joint projects with the Galapagos National Park Service, continued to show important results during the year. On Baltra Island, monitoring trips found no signs of cats following the eradication undertaken in 2002–3. Continued dry conditions have aided this project by keeping rat numbers on the island low and reducing the likelihood of survival or reproduction by any cats that might remain. The eradication cannot be considered successful until two full years of monitoring have found no cats, a goal which will not be reached until late 2005.

The eradication of the domestic pigeon advanced in San Cristóbal and Isabela islands. Following pigeon elimination from Santa Cruz in 2002, all pigeons were eliminated from San Cristóbal except for a few remaining in a dovecote of one landowner, who promised to consume them (which he apparently did in early 2005). On Isabela, 400 free-flying and dovecote pigeons were eliminated in 2004, leaving only a small number remaining.

As part of an environmental impact study for a wind-power system being developed for San Cristóbal Island, we studied the flight routes of the endangered Galapagos Petrel and whether they are likely to pass through the area of the wind farm. The project will erect three wind generators on the crest of Cerro Tropezón, capable of producing about 50% of the electricity used on San Cristóbal. The patrel nests in the highlands of the island within 1 km of the proposed site, and there is concern about collisions of petrels with the windmills. Results of five months of study indicated that petrels rarely pass through the area of the wind farm and usually at low altitude, where they are unlikely to collide with the blades. However, the power transmission lines to serve the wind farm pose a serious risk, as they would be placed in areas where petrels frequently fly. We recommended burying some sections of the transmission lines, which would greatly reduce the risk to the petrels.

Studies of the effects of parasitization of bird nestlings by larvae of the introduced fly *Philornis downsi* showed further evidence of the damage caused by these parasites. Work with collaborating scientists showed that chicks in infested nests have greatly reduced growth rates and anemia (as a result of blood loss) at low infestation rates, and increased mortality at higher rates. A survey of the archipelago has indicated that the flies occur on all islands except for Genovesa and Española (Darwin and Wolf islands have not yet been sampled). The parasite was found in nests of two highly endangered species: Mangrove Finch and Floreana Mockingbird.

The study of avian diseases continued, with sampling trips to Floreana, Santiago, San Cristóbal, and Marchena islands. Preliminary results indicate no presence of avian malaria (a disease that devastated the avifauna of Hawaii) or West Nile Virus. Avian pox, however, appears to be distributed throughout the archipelago, although more prevalent at certain sites and on certain islands, perhaps related to the abundance of vectors (mosquitoes and biting flies).

In May, a survey of the Floreana Mockingbird indicated the population was about 152 individuals, a decline of 25% from the 2003 survey, and probably a result of the drought conditions. This species faces threats from diseases and parasites, but not yet from introduced rats, which probably caused its extinction on Floreana Island. Surveys of Galapagos Penguin and Flightless Cormorant indicate that both species remain at about 1500 individuals. The 2004 cormorant count was the second highest ever (records go back to the 1970s). The Greater Flamingo count in January showed numbers to be steady.

Several projects began late in 2004, including a search for previously unknown nest colonies of Galapagos Petrels in the agricultural zone of Santa Cruz Island. We have already found three small colonies and a few scattered nests. A study of efficiency of rat poisoning methods began in November. A study of salinity tolerance in the eggs and tadpoles of introduced frogs was initiated in Puerto Villamil, but due to the drought was having difficulty obtaining a sample large enough for the experiments. We developed a project with high-school students from Colegio Nacional Galapagos in Puerto Ayora to monitor and compare bird populations on lagoons and in the highlands of Santa Cruz Island. About 20 students participated. In conjunction with the Environmental Education Center, nine high school students on San Cristóbal Island participated in monitoring marine iguanas at Puerto Baquerizo Moreno, one student compared San Cristóbal Mockingbird populations at three sites, and two students monitored gecko numbers in the town.

David Wiedenfeld
Head of CDRS Dept of Vertebrate Ecology and Monitoring

INVASIVE SPECIES TOTAL CONTROL PLAN

The development of a Total Control Plan for invasive species is progressing well, in coordination with the four principal institutions involved (CDF, Galapagos National Park, INGALA and the Ecuadorian Agricultural Health Service—Galapagos). A second formulation of the Plan was approved by the Comité de Sanidad Agropecuaria, the body overseeing the implementation of the Plan. The 111-page document includes 10 sub-plans that cover issues from strengthening the capacity of the Galapagos quarantine system, emergency response to the arrival of new pests, eradication and control of introduced species, diffusion of information about invasive species and their management to local, national, and tourist audiences, and increasing the capacity for management of invasive species throughout the archipelago.

A Galapagos Invasive Species website was launched in December (http://www.hear.org/galapagos/). The website contains information in English and Spanish about the various problems and projects concerning invasive species, and should serve as an important reference for those interested in problems of invasive species not only in Galapagos but worldwide.

Gillian Key
Total Control Plan Strategist

TERRESTRIAL INVERTEBRATES

Research for the conservation of native invertebrates
Surveys were carried out to collect baseline data on the status and distribution of native invertebrates and to supplement the growing invertebrate reference collection. Henri Herrera and Nancy Chasiliquín surveyed western Isabela, Fernandina and the islets of Santiago for ants. Invertebrate inventories were also carried out on North Seymour and Gardner-by-Floreana. Previously unexplored areas of Wolf Volcano on Isabela Island were made accessible by helicopter resulting in the rediscovery of *Epiplema becki*, a moth that was thought to be extinct (see p. 19). In addition, at least ten species new to science were recorded as a result of surveys conducted during the year.

Ecuadorian student Ana Maria Ortega finished separating specimens collected from 1997 to 2001 on an altitudinal transect on Alcedo Volcano, Isabela, and is now analyzing these data. This project is an important step towards understanding the insect diversity of pristine habitats and the effect of feral goats on invertebrate communities.

Evaluation of the status of invertebrate species using IUCN red-list system is a priority for the Invertebrates Department, however this is only possible for a few groups where something is known about their ecology. The enormous collecting efforts of Lazaro Roque-Albelo with Bernard Landry (Natural History Museum Geneva) have enabled us to start red-listing Lepidoptera. They analyzed

75 species and found that 19 are threatened. The remaining 65 require study and could not be evaluated. The evaluations will be submitted to IUCN in 2005. This forms part of an ongoing study on the diversity and conservation of Lepidoptera.

Research for control of introduced insects

Surveys have been initiated in the inhabited areas, considered "hot spots" for introduced species. Inventories of insects in the agricultural zones of Isabela, Floreana and San Cristóbal were completed. Liliana Guazman, Alejandro Mieles and Piedad Lincango spent months separating and identifying specimens. This information and new records sent in by specialists brings the count up to 456 introduced insect species in Galapagos. Ranking established introduced species according to their potential invasiveness is essential for prioritizing management, and a study was initiated to develop an Insect Risk Assessment system for Galapagos. This is being developed by Charlotte Causton and Paul Pheloung (Dept of Agriculture, Fisheries and Forestry, Australia). Identifying the pathways for insect introductions is also important and Piedad Lincango and Gabriela Morales developed a procedure to identify organisms that might be imported on foodstuffs to Galapagos and the risks associated with these potential introductions. They also completed risk analyses for 15 of the most common vegetables and fruit and recommended measures for reducing risk. This information will be used by the inspection and quarantine service SESA-SICGAL for revising the list of products permitted for import to Galapagos.

The development of control techniques for priority invasive species continued. Monitoring indicates that the ladybird *Rodolia cardinalis*, liberated in 2002 as a biological control agent, is having a significant impact on the invasive Cottony Cushion Scale *Icerya purchasi* on inhabited islands. No Little Fire Ants *Wasmannia auropunctata* were found on the fifth monitoring trip of the eradication program on Marchena Island, and results show that recovery of native invertebrates has occurred. Baseline data collections were carried out in priority areas such as the Marielas islets (penguin nesting area) and Playa Tortuga Negra, Isabela, (nesting site of endangered Mangrove Finch) to investigate the possibility of applying similar methods to control the Tropical Fire Ant *Solenopsis geminata*. This ant was reported for the first time on Albany, Mao and Bainbridge during surveys on the islets of Santiago. Cecilia Coscarón and Nancy Chasiliquín continued to research control methods for the introduced biting blackfly *Simulium bipunctatum*. Biweekly monitoring was carried out in addition to studies to evaluate the effect of abiotic factors on abundance and distribution. Ecuadorian student Javier Torres completed an inventory of the freshwater fauna found in the streams occupied by the blackfly to help identify non-target interactions that could occur with the implementation of a control program.

Research is also under way to develop an early warning system for detecting new species introductions and spread. A monitoring program with trained staff was set up on Santa Cruz, San Cristóbal, Isabela and Floreana. Fabián Bersosa, Ronald Azuero, José Loayza, José Mora and Clever García focused trapping efforts on priority species that include tephritid fruit flies and the recently introduced Dengue Mosquito *Aedes aegypti*. David Cruz, the technical assessor to SICGAL, is developing rapid response mechanisms for new introductions that are considered a potential threat to Galapagos biodiversity.

Charlotte Causton
Head of CDRS Dept of Terrestrial Invertebrates

PROJECT ISABELA

In 2004, 32 field trips to Santiago were accomplished and a first group of 122 Judas goats was deployed with helicopter support. Later on, another group of 90 Judas goats was deployed. The Santiago goat population has been reduced to extremely low levels, and donkeys are believed to have been eradicated.

On northern Isabela, the base camp for helicopter operationswas constructed. Only aerial hunting was carried out, which has resulted in 90% of northern Isabela being at extremely low goat densities. On Ecuador and Wolf volcanoes, 187 Judas goats were deployed.

Felipe Cruz & Víctor Carrión
Project Isabela

MARINE SCIENCES

The Marine Research and Conservation Department continued to provide technical expertise on the biodiversity of the Galapagos Marine Reserve (GMR) and the sustainable use of its resources. Research in the department falls into three main programmes: Oceanography and Ecosystems, Conservation of Threatened Species, and Extractive Species Research. They are supported by our logistics and operations staff, who organize diving and other at-sea operations, and our representative on the GMR participatory management framework.

Oceanography and Marine Ecosystems

The Galapagos Marine Reserve is dynamic and diverse, a challenge to characterize and follow change. The baseline study of the GMR (published 2002) lay the groundwork for a long term marine ecological evaluation system for the Galapagos National Park Service and user groups. A range of biophysical, socio-economic, governance and protected area design indicators, allow us to follow changes in the ecology of the GMR resulting from different management strategies. In a region heavily influenced by the El Niño cycle, the challenge is to differentiate human impacts from natural variability.

CDF directed a commission created by the Participatory Management Board (PMB), with the GNP and representatives of tourism artisanal fisheries and naturalist guides, to address the provisional zoning of the GMR (take and no-take areas). A series of site clusters comprising each type of management subzone was selected, to represent comparable habitat in each biogeographic zone in the Reserve. October saw a pilot sampling trip to the West (Isabela–Fernandina) and Far North (Darwin–Wolf) site clusters, where > 60 sites were surveyed at two depths for mobile macro-invertebrates, demersal reef fish, and sessile macro-invertebrates and algae. As priority areas harbouring some of the most diverse marine life, from cold upwelled water to warm tropical reef communities, these two areas seem the most under-represented in Galapagos protected zones, and will be discussed in the PMB.

Preparatory work continued for the new NASA-Ocean initiative in collaboration with North Carolina State University (John Morrison) and Goddard Space Flight Centre (Gene Feldman). Designed to characterise the biophysical environment through oceanographic regional sampling over 3–5 years the initiative uses the SeaWiFS and NOAA-16 ocean colour/sea temperature satellite imagery collected daily by the receiving station installed in the Marine Lab in 2001. In December, the NASA-SeaWiFS programme changed to the new, more hyperspectral satellite sensor MODIS-AQUA.

Ex-becaria Margarita Brandt continued working on marine vertical wall communities, with Jon Witman (Brown University, U.S.A.). Taxonomic expertise was provided by Angel Chiriboga and Cleve Hickman (Washington and Lee University, U.S.A.). New staff member Mariana Vera began working on the identification of sessile marine invertebrates, and a fish recruitment study continued in collaboration with F. Rivera (University of Melbourne, Australia): information recorded monthly by collection devices (SMURFS) at six sites around Floreana Island will show seasonal trends in fish populations.

Last year (2004) saw a welcome rediscovery in the west of Isabela of the sea-star *Heliaster cumingii*, the beautiful scallop *Nodipectens magnificens* and the solitary corals *Tubustrea faulkeneri*, *T. floreana*, *T. tagusensi* and *Polycyanthus isabela*. These species were thought locally extinct after the strong ENSO event of 1982–3, but appear to have persisted in certain cold water upwelling areas. During a habitat mapping exercise in the islands, a further seven species of macro-algae were also rediscovered in Fernandina, Isabela and San Cristobal. New records include four species of gorgonians (fan corals) new to science.

Conservation of turtles

The sea turtles project, led by Patty Zárate, has completed the fourth year of systematic monitoring at four key nesting sites of the Green Turtle *Chelonia mydas*. One hundred people were involved in the field data collection during the five-month nesting season: 52 from the local community (high-school students and general public), 37 international volunteers and 11 national volunteers.

The tagging and recapture project registered 1569 nesting females arriving to nesting beaches during the 2003–4 nesting season, which is 19% less than the previous season. Complementing the nesting project, studies over four key foraging grounds has revealed important information on growth, sex ratios, movements patterns, residence, diet and the impact of introduced species and fishing activities upon survival and hatching success.

Extractive Species Research

In 2004, Veronica Toral and Santiago Vega continued with surveys of the commercial sea cucumber *Isostichopus fuscus* before and after the fishing seasons, as part of what is one of the most closely monitored holothurian fisheries in the world. The results showed the severe depletion that we expected and prompted us to recommend complete closure of the fishery during 2005.

Completion of a four-year tagging programme greatly improved our knowledge of the lobster species in the GMR. Growth and mortality rates were estimated for the Red Spiny Lobster *Panulirus penicillatus* and the Galapagos Slipper Lobster *Scyllarides astori*, and combined with fisheries data to evaluate the stocks and their sustainability. The results were presented to the PMB, highlighting the need to respect the minimum size and consider reducing fishing effort to sustainable levels. Survey sites were set up in Santa Cruz, San Cristóbal and southern Isabela, where teams of fishermen and scientists carry out abundance and size structure surveys before and after each fishing season.

Our onboard fisheries observer programme continued, with the collaboration of our partner the University of San Francisco de Quito. Sons of local fishermen were provided with scholarships to study at the university, in exchange for working as fisheries observers during the sea cucumber and lobster fisheries.

Before leaving CDRS to start his Masters Degree at the University of Mérida (Mexico), Juan Carlos Murillo led the publication of the results of the Longline Pilot Study, carried out during 2003. These results showed an alarming level of by-catch, mainly shark species, and will form the basis of local and national discussions regarding the permission of use of this controversial fishing method.

In December, PEW Fellows Rodrigo Bustamante, Lobo Orensanz and Ana Parma spent a week in Puerto Ayora and invited members of GNP, PMB and other institutions to the first of a number of workshops on management and analysis of benthic fisheries. Our work focused on the Fishing Calendar and on the shift from managing benthic fisheries in the traditional fashion, towards treating them as metapopulations, with discrete adult populations and a mixed larval pool. The GMR has been added as a case study for models which are currently being developed in Chile and Argentina.

Stuart Banks, Alex Hearn & Manfred Altamirano
CDRS Dept of Marine Sciences

RESEARCH ARTICLES

MODERN DINOFLAGELLATE CYSTS FOUND IN SURFACE SEDIMENTS OF SANTA CRUZ ISLAND, GALAPAGOS

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SUMMARY

Modern dinoflagellate cysts in surface sediments collected on Santa Cruz Island, Galapagos, are described, along with other palynomorphs such as microforaminiferal linings, tintinnid loricae, copepod eggs and acritarchs including *Domasiella*-like micro-remains and *Halodinium* spp. The dinoflagellate cyst assemblages mainly consisted of *Spiniferites* cf. *scabratus* (gonyaulacoid) followed by *Brigantedinium* spp. and *Selenopemphix quanta* (peridinioids). No gymnodinioid cysts were found. No remarkable differences in cyst composition and densities were recognized between stations. The cyst assemblages were characterized by low species diversity and low cyst concentrations in comparison with the Pacific coast of Guatemala and Peru.

RESUMEN

Quistes de dinoflagelados modernos descubiertos en sedimentos de la isla Santa Cruz, Galápagos. Se describen los quistes de dinoflagelados colectados de sedimentos superficiales de Santa Cruz, en conjunto con otros palinomorfos, entre ellos las recubiertas de microforaminíferas, loricae de tintínidos, huevos de copépodos, y acritarcos incluyendo *Halodinium* spp. y micro-restos parecidos a *Domasiella*. Las asociaciones de quistes de dinoflagelados fueron compuestas en su mayoría de *Spiniferites* cf. *scabratus* (gonyaulacoide) seguido por *Brigantedinium* spp. y *Selenopemphix quanta* (peridinoide). No se encontraron quistes gimnodinioides. No hubo diferencias destacables en la composición ni en las densidades de los quistes entre sitios. Comparado con la costa pacífica de Guatemala y de Perú, las asociaciones se caracterizaron por tener baja diversidad de especies y baja concentración de quistes.

INTRODUCTION

The Galapagos Islands are famous for their unique biodiversity, and a great deal of biological research has been undertaken there. However, only a few studies on phytoplankton have been published, namely Kofoid (1907) on dinoflagellates, and Marshall (1972) and Rampi (1950) including diatoms, dinoflagellates, silicoflagellates and coccolithophorids. Further, no study on marine palynomorphs such as dinoflagellate cysts, microforaminiferal linings and others has been conducted so far. This paper describes the dinoflagellate cyst assemblage found in surface sediments collected at two locations on Santa Cruz Island.

The Galapagos Islands were created by late Cenozoic volcanic activity and have had no land connection to the continent. They are located *c.* 1000 km west of mainland Ecuador, and consist of several major islands, with numerous satellite islets. The main cluster of islands lies between 0°10′N to 1°25′S and 89°10′W to 91°40′W in the Pacific Ocean.

The islands are influenced by several major water currents, namely the cool, relatively oligotrophic Peru (Humboldt) Current, which turns west to become the South Equatorial Current, the warm North Equatorial Current and the Equatorial (Cromwell) Undercurrent (Shen *et al*. 1992). The cool (*c.* 13°C in its core), nutrient-rich Equatorial Undercurrent flows mainly from west to east, and wells up around the islands. During the warm season, the warm Panama flow (El Niño flow), from Central America, develops (Houvenaghel 1978). The islands are thereby divided into four major oceanographic zones: the coolest western zone, including the west of Isabela and Fernandina; the seasonally varying central zone, including the east of Isabela, Santiago and Santa Cruz; the relatively warm tropical zone, including Pinta, Marchena and Genovesa; and the cool southern zone, including Floreana, Espanola and San Cristóbal (Harris 1969). These zones are independent of the influence of South American continental coastal waters.

SAMPLING LOCATION AND METHOD

The selection of sample sites was initially based on the locations of mangrove zones along the coast. Unfortunately, the mangrove areas inspected (in San Cristóbal, Floreana, Santa Fe and Santa Cruz) were lacking muddy sediments, with the exception of two locations on Santa Cruz: the innermost part of Academy Bay (Stations 1, 2, 3), and Caleta Tortuga Negra (Station 5) (Fig. 1). The lack of mud at other sites is probably due to the strong coastal currents impeding the deposition of fine sediments. Indeed the mangrove trees there were growing directly on cracks within the basaltic lava.

Surface sediment samples were collected using a TFO (University of Tokyo, Laboratory of Fisheries Oceanography) corer. In Caleta Tortuga Negra it was deployed from the shore at low tide on 19 December 1999 and in Academy Bay from a boat on 21 December 1999. Dinoflagellate cysts were extracted following the method of Matsuoka & Fukuyo (2000). The 8cm core from Station 1 was sampled every 2 cm and the 0–2 cm and 6–8 cm sections were analyzed. The upper 2 cm of sediment from each of the cores from Stations 2, 3 and 5 were also analyzed. One tenth of each concentrated sample was examined under a Zeiss Axiophoto optical microscope equipped with interference contrast.

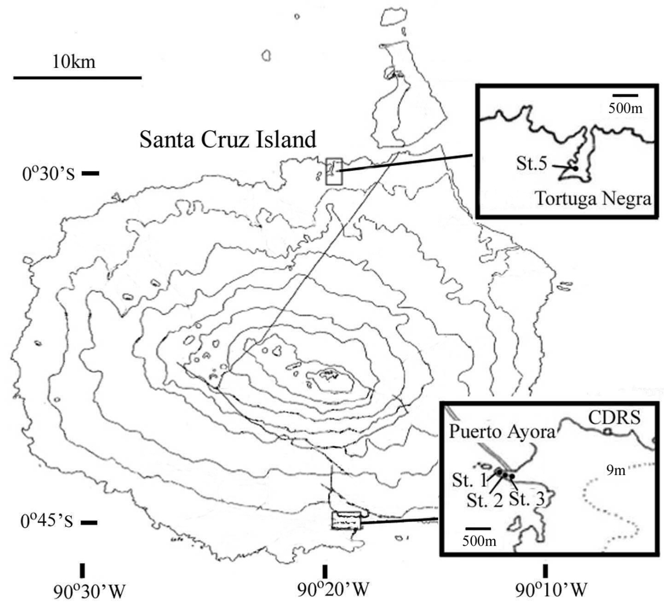

Figure 1. Sampling locations.

RESULTS

Marine palynomorphs composed of dinoflagellate cysts, microforaminiferal linings, tintinnid loricae, copepod eggs and acritarchs including *Domasiella*-like micro-remains were found in these samples (Table 1). Micro-remains, microforaminiferal linings and tintinnid loricae were the most common, followed by spiny copepod eggs. Dinoflagellate cysts consistently occurred in low numbers. The most common were *Spiniferites* cf. *scabratus*, followed by *Brigantedinium* spp. and *Selenopemphix quanta* (Fig. 2). No Gymnodinioid cysts were found. A few spherical and

Table 1. Occurrence of dinoflagellate cysts and other micro-remains in samples.

	Station:	**1 (0–2 cm depth)**	**1 (6–8 cm depth)**	**2**	**3**	**5**
Gonyaulacales cyst	**Plankton name**					
Spiniferites sp. cf. *scabratus*	*Gonyaulax spinifera* complex?	17	13	17	14	1
Spiniferites bulloideus	*Gonyaulax scrippsae*	1				
Spinferites cf. *delicatus*	*Gonyaulax* sp.			1		
Spiniferites hyperacanthus	*Gonyaulax spinifera* complex?		1			
Peridiniales cyst						
Brigantedinium cariacoense	*Protoperidinium avellanum*	1		1		
Brigantedinium spp.	*Protoperidinium* spp.		3	2	1	5
Selenopemphix quanta	*Protoperidinium conicum*		1	2	1	1
No name	*Protoperidinium americanum*			1		
Total cysts		**19**	**19**	**23**	**16**	**7**
Cyst concentration /ml		**101**	**101**	**122**	**169**	**37**
Acritarcha						
Domasiella? spp.		1	2	3	2	3
Halodinium spp.			1	2		
Tintinnid		56	19	25	8	1
Foraminifera						
Uniserial type		5		2	1	1
Biserial type		2	2	1	2	1
Coiled type		47	39	35	33	49
Copepod resting egg		24	15	51	5	1

ellipsoidal cysts also occurred. Dinoflagellate cyst concentration in the samples varied from 37 (Station 5) to 169 (Station 3) cysts per ml of sediment. There was no remarkable difference in cyst composition and densities between all stations. *Spiniferites* cf. *scabratus* was dominant in surface sediments collected from the innermost part of Academy Bay (Stations 1, 2, 3). Also no difference in species composition between the surface and bottom (6–8 cm depth) sediments of Station 1 was recognized. In the sediment of Caleta Tortuga Negra, round brown *Brigantedinium* spp., which are cysts of heterotrophic *Protoperdinium* spp., were relatively abundant.

DISCUSSION

The dinoflagellate cyst assemblage from surface sediments of Santa Cruz Island consisted of three *Spiniferites* species of the Gonyaulacales, more than four species of the Peridiniales and no Gymnodiniales. This assemblage is characterized by low species diversity and low cyst density. In comparison, dinoflagellate cyst concentration in surface sediments off the Pacific coast of Guatemala was approximately 650 cysts per ml of sediment (Rosales-Loessener *et al*. 1996). The low cyst concentration in Santa Cruz may be due to strong coastal currents sweeping out the fine muddy particles from the shallower sea-floor areas. Marshall (1972) listed more than 17 dinoflagellate species, including a few species of *Gonyaulax* and *Protoperidinium*, around the Galapagos. However, none of these species has ever been known to produce a resting cyst. The motile form of *Spiniferites* cf. *scabratus* is not known from the plankton so far. Motile forms of *Selenopemphix quanta* (= *Protoperidinium conicum*) and *S. nephroides* (= *P. subinerme*) were not reported by Marshall (1972). Such differences between

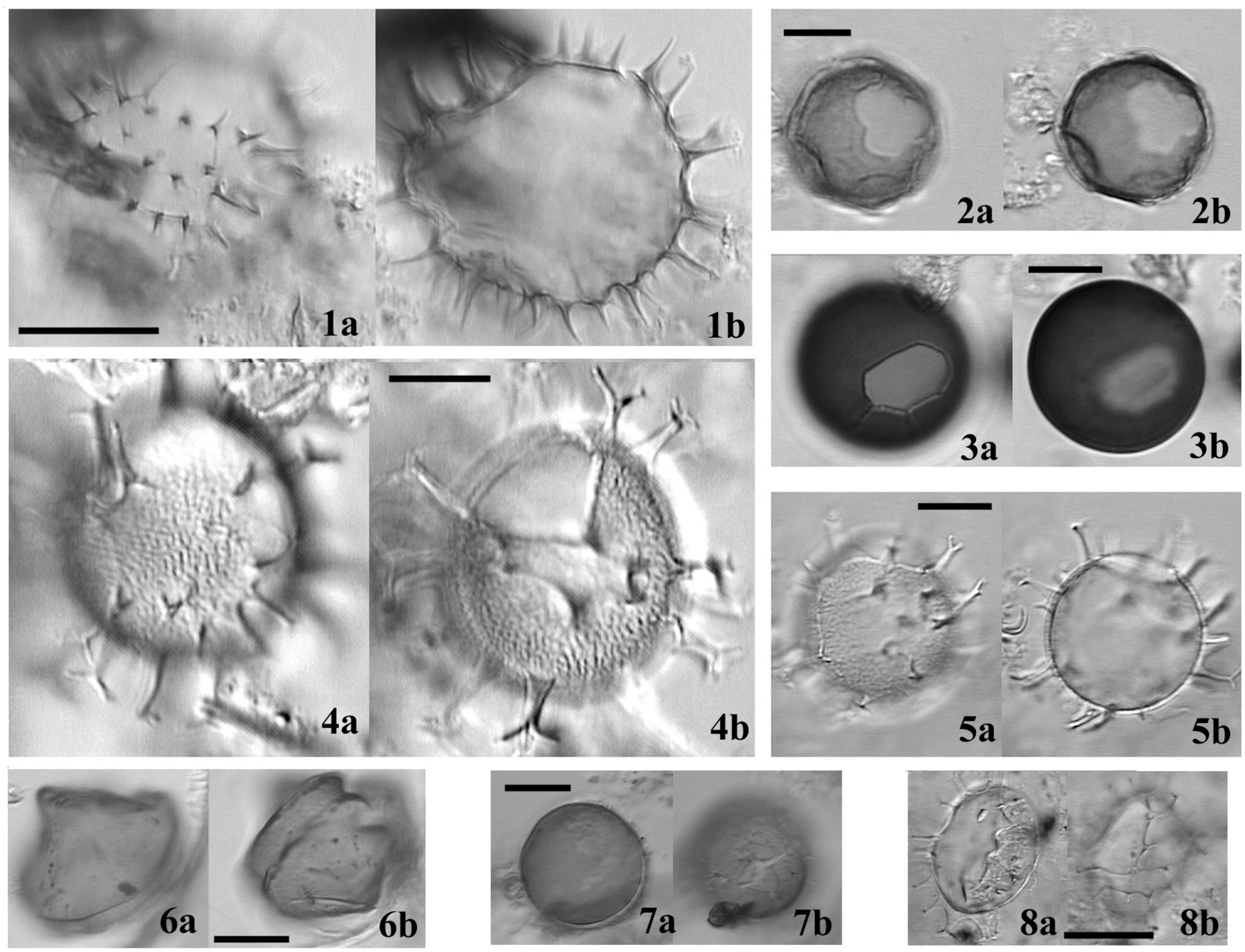

Figure 2. Dinoflagellate cysts found in surface sediments of the Galapagos Islands: 1 *Selenopemphix quanta* (Bradford) Matsuoka (= cyst of *Protoperidinium conicum* (Gran) Balech; 2 *Protoperidinium americanum* (Gran & Braarud) Balech; 3 *Brigantedinium cariacoense* (Wall) Reid (= cyst of *Protoperidinium avellanum* (Meunier) Balech or *P. punctulatum* (Paulsen) Balech); 4, 5 *Spiniferites* sp. cf. *scabratus* (Wall) Sarjeant; 6 *Selenopemphix nephroides* Benedek (= cyst of *Protoperidinium subinerme* Paulsen); 7 *Brigantedinium* sp. indet. (= probably cyst of *Protoperidinium* sp.); 8 *Spiniferites bulloideus* (Deflandre & Cookson) Sarjeant (= cyst of *Gonyaulax scrippseae* Kofoid. Scale bar is 20 µm.

plankton and benthic cyst communities suggest that more intensive surveys are needed. In addition no gymnodinioid cysts were observed, and the gymnodinioid plankton species such as *Gymnodinium oceanicum*, *Gymnodinium* sp. and *Gyrodinium* sp. listed in Marshall (1972) were very rare.

The assemblages of dinoflagellate cysts in surface sediments off the Pacific coast of Guatemala, documented by Rosales-Loessener *et al*. (1996) were more diverse in gymnodinioid, gonyaulacoid and peridinioid cysts, and more abundant. The dinoflagellate cyst assemblage off Peru (Wall *et al*. 1971) was more abundant and diverse, and contained more gonyaulacoid cysts. It is also of interest that the Galapagos assemblages lacked any specimens of the tropical dinoflagellate *Polysphaeridium zoharyi* (= *Pyrodinium bahamense*) which occurs off the Pacific coast of Guatemala (Rosales-Loessener *et al*. 1996) and Peru (Wall *et al*. 1971). This may be an effect of the cool Peru Current.

The occurrence of dinoflagellate cysts around oceanic islands, isolated from continental coastal biological communities, leads to the question of how dinoflagellates might extend their geographical distribution. The Galapagos Islands have never been connected to the continent and ages of the existing islands range from <1 to 5.6 million years (Geist *et al*. 1985). At emergence of the first islands, coastal marine organisms, including dinoflagellates, would not have been present. Thereafter, the coastal biocommunity was presumably transported to the islands as drifting planktonic organisms. Some dinoflagellates can produce a resting cyst as part of their life cycle, especially when they encounter unfavourable conditions, become transported to oceanic islands, and then germinate and repopulate the plankton once environmental conditions become favourable again. Oceanic islands are key places where dinoflagellates can expand their habitat across oceans. In the cyst assemblage of the coastal sediments of Guatemala reported by Rosales-Loessener *et al*. (1996), some gymnodinioid species, such as *Polykrikos* cf. *kofoidii* and *Cochlodinium ?polykrikoides*, were associated with *Speciferites bulloideus*, *Brigantedinium* spp., *Selenopemphix quanta* and others. The lack of gymnodinioid coastal species in surface sediments around Santa Cruz may simply mean that no cysts of these species have reached the islands yet, rather than that environmental conditions there are unfavourable for them.

This transport model could be important when considering the spread of cyst-producing harmful microalgae such as dinoflagellates. As a result of tourism in the Galapagos, ports such as Puerto Ayora and Puerto Baquerizo Moreno have been constructed. Coastal currents weaken in such areas, allowing the deposition of fine muddy particles containing dinoflagellate cysts. This may similarly allow non-native organisms, transported in ballast waters of cargo vessels, to colonise and flourish in these areas.

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STRUCTURE AND DEVELOPMENT OF A *SCALESIA PEDUNCULATA* STAND IN THE GALAPAGOS ISLANDS

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SUMMARY

Stands of *Scalesia pedunculata* in the Galapagos Islands often develop as single-aged cohorts following episodes of mass death and regeneration. We updated earlier studies on a stand that had regenerated soon after the 1982–3 El Niño event. We quantified stem size distribution and dispersion pattern in a 0.56 ha plot near Los Gemelos on Santa Cruz Island. The plot was dominated (95% of basal area) by *S. pedunculata*. The stem size distribution showed the increased mean and variance for diameter (since 1987 and 1991) expected of an aging stand. Stems averaged smaller than in 1981, just before the last mass mortality episode. Large *S. pedunculata* stems were regularly dispersed while smaller stems were clumped and negatively associated with larger stems, implying that intraspecific competition may be important in structuring the stand.

RESUMEN

Estructura y desarrollo de un rodal de *Scalesia pedunculata* en las islas Galápagos. Los rodales de *Scalesia pedunculata* en las islas Galápagos a menudo se desarrollan como cohortes de una misma edad a continuación de episodios de muerte y regeneración masivas. Actualizamos estudios previos en un rodal que se había regenerado inmediatamente luego del evento del Niño de 1982–3. Cuantificamos la distribución por tamaños y el patrón de dispersión de los tallos en una parcela de 0.56 ha cerca de Los Gemelos en la Isla Santa Cruz. La parcela estaba dominada (95% del área basal) por *S. pedunculata*. La distribución por tamaño de los tallos mostró el promedio y la varianza del diámetro mayores (desde 1987 y 1991) como cabría esperar de un rodal envejeciendo. Los tallos fueron más pequeños que en 1981, justo antes del último episodio de mortalidad masiva. Los tallos grandes de *S. pedunculata* estaban distribuidos más regularmente mientras que los tallos más pequeños estaban agrupados y asociados negativamente a los tallos más grandes, lo que implica que la competencia intra-específica podría ser de importancia para estructurar el rodal.

INTRODUCTION

Scalesia pedunculata, a small tree in the Asteraceae, is endemic to the Galápagos Islands. It is found on Santa Cruz, Floreana, San Cristobal, and Santiago Islands. It has declined on all islands due to the creation of agricultural areas and the effects of feral herbivores, and its most extensive remaining forests are found on Santa Cruz (Howell 1941, Itow 1995, Hamann 2001). It grows at higher elevations (150–900 m) on relatively wet or mesic sites (Wiggins & Porter 1971) where volcanic ejecta are well weathered and soils are deep and fertile (Itow 1995). In some places it so dominates the site that the vegetation is called the Scalesia Zone, characterized by an abundance of epiphytes (flowering plants, moss, and others), and scattered shrubs, herbs, and ferns (McMullen 1999).

Where *S. pedunculata* dominates in density and basal area, it sometimes exhibits mass stand mortality with most canopy stems dying in a short period. Such mortality episodes have been suggested to occur every 15–20 years in response to climatic extremes, *e.g.* major El Niño-Southern Oscillation events in the early 1940s and 1982–3 (Lawesson 1988, Itow & Mueller-Dombois 1988, Shimizu 1997, Hamann 2001). Following the collapse of most of the stand, *S. pedunculata* seedlings can grow rapidly to 4–4.5 m height the first year and 7 m the second year (Itow 1995). However, it usually takes 3–5 yr to reach 6–8 m height and start flowering (Hamann 2001). Mortality is high during these first years, apparently due to competition (Hamann 1975, 1979). Hamann (2001) found stand mortality rates of 25% per yr for *S. pedunculata* on permanent plots sampled 1970–99. Neighboring crowns, not new stems, rapidly fill canopy openings caused by the death of individuals (Eliasson 1984, Lawesson 1988). The species is shade intolerant so its seedlings do not grow under its own canopy. Growth continues to about 15–20 m height, 15–20 yr age, and 30 cm dbh (diameter at breast height, where breast height is 137 cm) (Itow 1995). The canopy is a monolayer, forming a mosaic of terminal leaf whorls, each carrying a flower head (Hamann 1979), and with little overlap between adjacent crowns (Shimizu 1997). This structure causes a very uniform light regime and seed rain. Seeds are abundant and adapted to short-distance dispersal (Hamann 1979, Shimizu 1997). They last 1–2 yr on the mature plant and >3.5 yr in the soil (Itow 1995). Mass death of canopy trees leads to a high-density regeneration response by the heliophilous, fast-growing new stems. Human-induced fires and grazing may have had recent effects on this cycle but for the most part it seems driven by occasional severe weather events that interact with the species' patterns of growth and senescence (Lawesson 1988).

Because *S. pedunculata* stands are so strongly dominated by a single species and because they develop so rapidly after a large disturbance, they can be used to test how stem dispersion patterns develop. Dispersion patterns can be influenced by several factors, whose relative influence varies with the environment and changes as the stand ages. If favorable sites for species growth are highly clumped then stems will be highly aggregated. Seed dispersal can lead to clumped distributions, depending upon the interaction of the dispersal agent and the environment. Interspecific competition can lead to clumped distributions, with stems of a species being clustered away from stems of a strong competitor. Intraspecific competition can lead to regular distributions if stems in clumps suffer higher mortality than isolated individuals.

The transition from clumped distributions of dominant stems determined primarily by the environment to uniform distributions determined primarily by competition has been shown for several temperate-zone forests, including both conifer and hardwood stands (Ghent & Franson 1986, Ward & Parker 1989, Ward *et al*. 1996, Runkle 1990, Campbell 1995, Stewart 1986). Chen and Bradshaw (1999) found dominant *Picea* to be aggregated as seedlings on microsites (downed logs) but random as larger stems. Other species were aggregated primarily in canopy openings where *Picea* was absent. Hubbell (1979) found a different pattern in a high diversity, tropical dry forest in Panama with none of the most common species distributed uniformly as adults.

We re-sampled a stand on Santa Cruz previously studied by Itow (1995). Our first goal was to compare the size structure of the stand in 1998 with that at different stages of the preceding stand. This comparison may help identify when a stand is susceptible to a mass mortality event. Our second goal was to investigate interactions among individuals in the stand by examining the dispersion pattern of stems. We hypothesize that intraspecific competition leads to the development of the regular dispersion pattern seen in older stands. We test whether this stand has been regenerating long enough for such a pattern to develop.

METHODS

We studied 600-m altitude cloud forest site on Santa Cruz near two pit craters named Los Gemelos (0°37.14′S, 90°22.95′W). The stand fit the evergreen soft-wood orthophyll forest structural type of Van der Werff (1978) with its almost complete canopy coverage by 5–15-m tall trees, primarily of *S. pedunculata*. Floristically it fit the Alliance Psychotrion rufipedis, Association Acnisto-Ureretum caracasanae, Subassociation scalesio-galietosum (Van der Werff 1978). *Zanthoxylum fagara* was a common associate. Our site had suffered less from human disturbance and invasive introduced plant species than the lower elevation site studied by Hamann (2001).

We recorded the height, dbh, and location (nearest 0.1 m) of all woody stems >1 m height in a 70 x 80 m plot. Field sampling was done 5–7 and 19–22 February 1998.

The Clark-Evans ratio (Clark & Evans 1954) is the observed distance between nearest neighbors divided by the distance expected if the stems are randomly dis-tributed. Converting the ratio to %, a value <100 indicates clumping; 100 indicates randomness; and >100 indicates a regular distribution. These values were adjusted for edge effects and significance levels were calculated using the method of Donnelly (1978: see also Runkle 1990 and Ward *et al*. 1996).

The large plot was subdivided into 224 smaller plots, each 5 x 5 m. The number of living stems of *S. pedunculata* ≤10 cm and >10 cm dbh and the total number of stems of *Zanthoxylum* were totaled for each of those small plots. We used Pearson's correlations to determine whether the three sets of stems were distributed randomly to each other.

We compared our results to those of Itow & Mueller-Dombois (1988) and Itow (1995) from the same area. In 1978 they used a 10 x 3 m quadrat to study a 3–4 yr old stand and a 10 x 20 m quadrat to study a "nearly mature" stand in the same area. They resampled the same stand (though not the same plot) in 1981. In 1987 they measured 39 stems in four cohorts from the same general area. In 1991 they resampled the stand. The exact areas represented by each of their samples and ours varied. Plot sizes varied but we believe that stem densities were high enough for the samples to be comparable. Size distributions of stems were compared using the Kolmogorov-Smirnov two-sample test (Sokal & Rohlf 1995).

RESULTS

Our plot contained 1905 live and 276 dead stems (3402 and 493 stems/ha, respectively). Basal area was 19.4 m^2ha^{-1} for live stems and 1.3 m^2ha^{-1} for dead stems. *S. pedunculata* strongly dominated the stand, with 95% of the basal area and 75% of the density for live stems (Table 1). *Zanthoxylum fagara* was the only other species present in appreciable numbers. *S. pedunculata* dominated the larger sizes (Fig. 1).

Table 1. Relative species importance for Los Gemelos stand, based on 1905 live and 276 dead stems with total basal areas of 19.4 m^2ha^{-1} and 1.3 m^2ha^{-1} respectively. BA = basal area; N = number of stems.

	Live		Dead	
	%BA	%N	%BA	%N
Scalesia pedunculata	95	75	78	63
Zanthoxylum fagara	4	12	22	36
Psidium galapageium	<1	6	0	0
Tournefortia rufo-sericea	<1	6	<1	<1

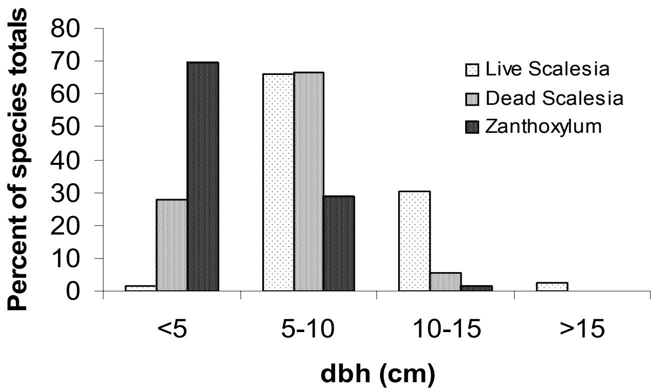

Figure 1. Size (dbh) distributions for *Scalesia* and *Zanthoxylum* in the plot at Los Gemelos. n = 1425 live *Scalesia* stems, 174 dead *Scalesia* and 237 *Zanthoxylum*.

Dead *S. pedunculata* stems were smaller than live ones, suggesting that self-thinning was the main source of mortality. *Zanthoxylum* was most important in the smaller size classes. The size distribution of *S. pedunculata* in 1998 was not significantly different from that in 1978 (Kolmogorov-Smirnov test of differences in cumulative frequency distributions of stem sizes: critical largest difference for $P = 0.05$ was 0.27; observed largest difference was 0.26). The 1998 distribution was significantly smaller ($P \leq 0.05$) than in 1981, shortly before the most recent mass die-back in 1985 (Fig. 2) (Kolmogorov-Smirnov test: critical largest difference for $P = 0.05$ was 0.28; observed largest difference was 0.57). Following that die-back, stem diameters have increased in mean value and variance (Fig. 1), contrasting the 1998 size distribution with those of 1987 and 1991.

Live *S. pedunculata* were regularly dispersed, especially the larger stems (Table 2). Dead stems were randomly dispersed and small stems were clumped. *Zanthoxylum* was highly clumped. On average, nearest neighbors were only 1–2 m apart. The number of large stems of *S. pedunculata* was negatively correlated to the number of small stems of *S. pedunculata* ($r = -0.32$, $P \leq 0.01$) and the number of stems of *Zanthoxylum* ($r = -0.16$, $P \leq 0.05$). The number of small *S. penduculata* stems and *Zanthoxylum* stems were not correlated ($P > 0.05$).

Table 2. Dispersion patterns for Los Gemelos stand.

	Living?	dbh(cm)	n	D[1]	CE(%)[2]	t	Distribution[3]
All	Live	All	1905	0.9	100	0.2	Random
Scalesia	Live	All	1425	1.0	104	2.6	Regular
Scalesia	Dead	All	174	2.9	99	–0.3	Random
Scalesia	Live	>10	465	2.0	112	4.9	Regular
Scalesia	Live	≤10	960	1.2	95	–3.0	Clumped
Zanthoxylum	Live	All	237	1.8	70	–8.3	Clumped

[1]D = mean of the distances between nearest neighbors.
[2]Clark-Evans index = distance to nearest neighbor divided by expected (random) distance.
[3]Clumped and Regular indicate patterns significantly ($P \leq 0.05$) different from random.

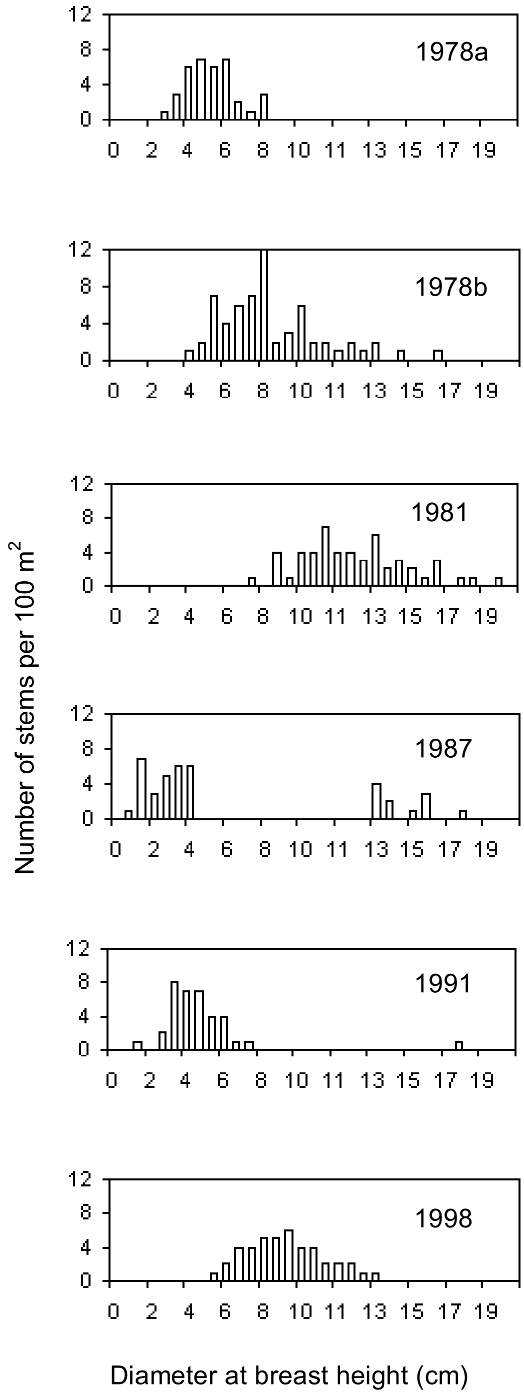

Figure 2. Changes in the size distribution of *Scalesia pedunculata* at Los Gemelos, Santa Cruz. Values for 1978–91 are from Itow (1995), who used circumference in 2-cm classes. His original values were converted to diameter by dividing by π. Rounding the resulting values to whole numbers produces some irregularity in the class values. Individual histogram bars represent 2/π cm classes. The 1978a population was 4 yr old, grown on an abandoned field. The 1978b and 1981 populations were approaching maturity. In 1982–3 most of the old generation died; the 1987 population shows the few large survivors with the mass of new regeneration. The 1991 population shows the latter cohort and the disappearance of most of the older trees. The 1998 population was approaching the mature stage of 1978b and 1981.

DISCUSSION

The present stand probably arose in 1985 (Hamann 2001) so was about 13 years old when we studied it. The severe 1997–8 El Niño event did not lead to an immediate mass die-off of the entire stand at Los Gemelos (Tye & Aldaz 1999). Although Hamann (2001) found that mass mortality was delayed after the 1982–3 El Niño, no mass die-back has since occurred (A. Tye pers. comm.). Our stand may have been too young to suffer mass mortality due to the 1997–8 event. Although we know a great deal about some aspects of *S. pedunculata* and the dynamics of its forests we still do not know the exact interplay between its size and age structure and natural climatic events that leads to mass mortality and regrowth.

The dispersion pattern shown by *S. pedunculata* at Los Gemelos is similar to that seen in other low diversity forests (see Introduction). Large stems are regularly distributed, suggesting that intraspecific competition is important. Negative correlations indicated that small stems of *S. pedunculata* and stems of *Zanthoxylum* were aggregated in places where competition from large stems was relatively low. Because stem densities are high and seed dispersal is relatively uniform (Hamann 1979) these patterns seem due to factors affecting stem growth more than seed dispersal.

Although *S. pedunculata* is a natural dominant at certain locations, it can be harmed by at least two types of human activities. Because seeds are produced episodically, removal of the stand before maturity, as by fire, grazing, or logging, could lead to a lack of regeneration after those disturbances. Also, the introduction of a woody species that can grow faster initially or larger eventually than *S. pedunculata* could shade it to the extent that its reproduction and survival are both diminished. Because of the unique habitats produced by *S. pedunculata* stands, many other species would also be affected.

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VIABILITY OF SEEDS IN FOOD PRODUCTS PROPOSED FOR FIELD TRIPS IN GALAPAGOS

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SUMMARY

Seeds of 14 plant species extracted from food products proposed for field trips in Galapagos were tested for viability. Strawberry *Fragaria ananasa* and Blackberry *Rubus glaucus* jams (Snob and Gustadina brands) contained no viable seeds. Schullo brand granola contained inviable Sesame *Sesamum indicum* seed, but Sesame in granolas prepared in Galapagos was viable. Sesame seed in bread was viable but Flax *Linum usitatissimum* seed in bread was not. Brown Rice *Oryza sativa* and Sunflower seeds *Helianthus annuus* were both viable. Fresh Apple *Malus domestica*, Naranjilla *Solanum quitoense*, Cucumber *Cucumis sativus*, Pineapple *Ananas comosus*, Pear *Pyrus communis*, Bell Pepper *Capsicum annuum*, Tomato *Solanum lycopersicum*, Grape *Vinis vinifera* all contained viable seeds. We recommend prohibiting any product with viable seeds from field trips to uninhabited areas.

RESUMEN

Viabilidad de semillas en productos comestibles propuestos para salidas de campo en Galápagos. Se realizaron pruebas de viabilidad de semillas de 14 especies, extraídas de productos propuestos para viajes de campo en Galápagos. Semillas en mermeladas de Frutilla *Fragaria ananasa* y Mora *Rubus glaucus* (marcas Snob y Gustadina) no eran viables. Granola marca Schullo contenía semillas de Ajonjolí *Sesamum indicum* no viables, pero Ajonjolí en granolas preparadas en Galápagos eran viables. En pan, semillas de Ajonjolí eran viables pero semillas de linaza *Linum usitatissimum* no eran viables. Arroz integral *Oryza sativa* y semillas comestibles de Girasol *Helianthus annuus* eran viables. Manzana *Malus domestica*, Naranjilla *Solanum quitoense*, Pepinillo *Cucumis sativus*, Piña *Ananas comosus*, Pera *Pyrus communis*, Pimiento *Capsicum annuum*, Tomate riñón *Solanum lycopersicum* y Uva *Vinis vinifera* frescos contenían semillas viables. Se recomienda prohibir cualquier producto con semillas viables en los viajes de campo a las áreas no habitadas.

INTRODUCTION

Since the discovery of Galapagos, many alien species have been introduced to the islands by humans, and many species of introduced plant have become invasive, displacing the native flora (Loope *et al.* 1988, Tye *et al.* 2002). This problem is worst on the inhabited islands, although many species have also spread to uninhabited ones (Lawesson *et al*. 1987). Conservation workers, scientists and other visitors may have been responsible for the spread of some invasive plants, such as Hill Blackberry *Rubus niveus*, to uninhabited islands. The Galapagos Quarantine and Inspection System (SICGAL) was initiated in 1999 in an attempt to reduce both the introduction of new species to the archipelago and the spread of introduced species between islands (Zapata *et al.* 2000). As part of this system, a protocol for field trips (Galapagos National Park 2001) has been developed, principally to reduce the spread of introduced species by scientists, park managers and others working in uninhabited areas. Among other regulations, this manual includes permitted and prohibited lists of food products that may and may not be taken into uninhabited areas.

In order to contribute to the effectiveness of these lists, we investigated the viability and germination of seeds of 14 plant species found in 13 food products that are taken into the field, and five products that are currently prohibited.

METHODS

Food products and seeds tested are listed in Table 1. For most products, all seeds tested were extracted from one example (one fruit, one jar of jam etc). In the case of Apple and Pear (with an average of four seeds per fruit) additional fruit were used to obtain the total required for testing. In the cases of Naranjilla, and of Sesame seed in bread, the experiment was repeated with two fruit and two batches of bread owing to equivocal evidence from the first test in each case. These limited samples were considered adequate for a preliminary test, since any positive evidence (seed viability) would call attention to the product as a quarantine risk. A negative result, however, would not necessarily indicate that a product were completely safe, pending replication of the experiment.

Seeds extracted from the products were exposed to one of the following three treatments.

Pre-soak. Seeds were immersed in freshwater at 60°C for 24 h, then placed on damp tissue paper in a large diameter petri dish in daylight and at room temperature (generally 24–28°C) in the botanical laboratory of the Charles Darwin Research Station at Puerto Ayora on Santa Cruz Island. Except in the case of Sunflower, where each dish contained 10 or 15 seeds, all 35 seeds were placed in one dish. The tissue was maintained damp for four weeks and seeds inspected daily.

Direct. As the Pre-soak treatment, but without pre-soaking in warm water (i.e. seeds were placed directly onto damp tissue after extraction from the product).

Tetrazolium. The tetrazolium method (Kearns & Inouye 1993, Baskin & Baskin 2001) was used to determine seed viability by soaking seed in freshwater at 30°C for 24 hours, then cutting the seed open longitudinally to expose the embryo. The open seeds were placed in a 1% solution of 2'3'5' triphenyl tetrazolium chloride in containers covered by aluminium foil (to create darkness) for 3–5 h. Viability was assessed as: stained red = viable; stained pale pink = viable but immature; unstained or yellowish = inviable.

RESULTS

The responses of seeds to the treatments are shown in Table 1. No seeds germinated or were viable in any of the four jams tested. Flax seed in bread was also inviable. Sesame seed in Schullo brand granola was inviable. Sesame in bread and locally made granola was viable but in bread its viability was reduced. The dry grains of Sunflower and Rice were both viable. All of the fresh fruit and vegetables tested contained viable seed.

DISCUSSION AND RECOMMENDATIONS

Seeds in jam were inviable, undoubtedly due to the high temperatures used during jam-making. Flax seed in bread was inviable even though fresh, food-quality Flax seed imported to Galapagos is viable (P. Toscano unpubl.), so baking appears to kill it. Sesame in bread had reduced viability, presumably because baking killed most of the seed, but some survived.

Seeds from some species or products had relatively high viability but low germination rates (Apple, Pear, Grape, Sesame in bread). This does not necessarily indicate that they are "safe" to take into the field, since their seeds may include a period of dormancy longer than the period of our experiment and at least a few seeds germinated even within our experimental period, indicating that they are capable of germination. The higher germination rate for Sesame from local granola indicates that our experimental conditions were adequate for germination of this species, so the low germination rate of Sesame from bread suggests that, despite high viability as indicated by the tetrazolium test, most of the seeds might not actually have been alive or capable of germination.

Our study only examined viability and germination in the laboratory and no studies have been carried out on the germination and survival of any of these species in the Galapagos National Park. However, all of the species tested grow in Galapagos under cultivation. Some have already naturalized in National Park areas (Blackberry, Naranjilla, Tomato, Rice: CDRS Database of the Galapagos Flora), while others, such as Pineapple, are known invasives in other parts of the world with a climate similar to Galapagos (Randall 2002), and may become invaders in Galapagos in the future. Many cultivated varieties of Pineapple are virtually seedless but many contain viable seed (e.g. Holmes 1933). Tomato and Bell Pepper may also cause problems by hybridizing with related Galapagos endemic species (e.g. Darwin *et al*. 2003).

Table 1. Seeds per species/product tested by each treatment.

	Pre-soak		Direct		Tetrazolium	
Species (product)	**n tested**	**n(%) germinated**	**n tested**	**n(%) germinated**	**n tested**	**n(%) viable**
Blackberry *Rubus glaucus* (Snob jam)	35	0	35	0	105	0
Blackberry *Rubus glaucus* (Gustadina jam)	35	0	35	0	105	0
Strawberry *Fragaria ananasa* (Snob jam)	35	0	35	0	105	0
Strawberry *Fragaria ananasa* (Gustadina jam)	35	0	35	0	105	0
Flax *Linum usitatissimum* (bread)	35	0	35	0	105	0
Sesame *Sesamum indicum* (bread)	70	2(3)	70	1(1)	105	35(33)
Sesame *Sesamum indicum* (Schullo granola)	35	0	35	0	105	0
Sesame *Sesamum indicum* (local granola)	35	34(97)	35	29(83)	105	72(69)
Sunflower seed *Helianthus annuus*	35	0	35	29(83)	0	-
Brown rice *Oryza sativa*	35	5(14)	35	21(60)	0	-
Green Apple *Malus domestica*	35	2(6)	35	2(6)	105	98(93)
Red Apple *Malus domestica*	35	4(11)	35	12(34)	105	105(100)
Pear *Pyrus communis*	35	7(20)	35	3(9)	105	98(93)
Grape *Vinis vinifera*	35	9(26)	35	4(11)	105	91(87)
Pineapple *Ananas comosus** (P)	35	29(83)	35	33(94)	105	70(67)
Naranjilla *Solanum quitoense* (P)	70	4(6)	70	3(4)	210	48(23)
Bell Pepper *Capsicum annuum* (P)	35	30(86)	35	21(60)	105	95(90)
Cucumber *Cucumis sativus* (P)	35	0	35	26(74)	0	-
Tomato *Solanum lycopersicum* (P)	35	34(97)	35	35(100)	0	-

*Variety with many seeds, imported from mainland Ecuador.
"P" indicates product specifically prohibited by the current field protocol (Galapagos National Park 2001)

Although the magnitude of the risk may vary for individual species, and the probability of establishment in Galapagos of some of those tested may be low, the simplest approach to prevent establishment of any of these species in the wild is to ensure that food taken on trips into the National Park contain no viable seed of any kind. This is a simple rule which all users may readily understand. Further, even an occasional plant of an introduced species that germinates in an uninhabited area of Galapagos is evidence of human presence and carelessness, and unsightly for that reason in an area where part of the attraction for visitors includes the lack of such evidence.

For these reasons, any product with viable seed should not be permitted on field trips to uninhabited areas.

Fresh fruit and vegetables containing seed, including Pineapple, Apple, Pear, Naranjilla, Grape, Cucumber, Bell Pepper and Tomato, should not be permitted on field trips, nor should they be eaten for 72 hours prior to visiting uninhabited areas, as their seed may survive digestion. Indeed, Tomato seed is known to survive passage through the human digestive tract and through a sewage treatment plant (D. Polster pers. comm.). Of the fresh fruit tested, Apple, Pear and Grape are not currently on the prohibited list (Galapagos National Park 2001), and should be included.

The current field protocol (Galapagos National Park 2001) is not specific on the status of Sunflower and Flax seed, Brown Rice, and seed found in dry products such as bread and cereals. "Seeds" are on the prohibited list, but "dry fruit and nuts" are permitted. Sunflower, Sesame and Flax seeds could be regarded as falling into either of these two categories. This category therefore requires clarification, with these species specifically prohibited. Further, we suspect that Brown Rice would not be regarded as "seeds" by lay persons. It should therefore be specifically mentioned on the prohibited list, and only White Rice permitted for field trips.

Bread is currently permitted without specification of type (Galapagos National Park 2001). Surprisingly, bread apparently does not reach sufficiently high temperature during baking to kill all Sesame seed. We therefore recommend that bread containing seeds should be prohibited, and only white or brown bread made from flour without whole seed permitted.

Products processed at higher temperatures, including jams, are permitted by Galapagos National Park (2001) for field trips. Despite our small sample size, we consider that they may continue to be permitted, given that the generally high temperatures required for making jam are likely to kill any seed of the fruit from which jams are made. However, we recommend testing jams made from other fruit. If evidence is found that some contain viable seeds, the listing may need to be detailed by fruit species or manufacturer.

Cereal products such as granola are currently permitted (Galapagos National Park 2001), but may contain viable seed, so the field protocol should permit only specific brands that have been fully tested by methods similar to those used in our study. So far, the permitted granola should be restricted to Schullo brand, and other granola and cereal products should be prohibited. Given our small sample size, we also recommend further testing of Schullo brand granola.

Testing of additional products is recommended, with two objectives: to identify other currently permitted products (such as other jams and cereal products) which may contain viable seeds and thereby avoid their use on field trips, and to identify additional products and brands that may be explicitly permitted, to increase the variety in diet of persons working in the field for long periods.

We also recommend that the brands that were found in the present study to contain only inviable seed should be re-tested at intervals in case changes in manufacturing procedures result in survival of viable seed.

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THE DISTRIBUTION, CONSERVATION, AND LARVAL FOOD PLANT OF *EPIPLEMA BECKI* HAYES (INSECTA: LEPIDOPTERA: URANIIDAE) ON THE GALAPAGOS ISLANDS

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SUMMARY

Two new populations and the host plant of the rarely encountered Galapagos endemic moth *Epiplema becki* were found on Isabela Island, on Wolf and Sierra Negra volcanoes, with a sighting on Darwin Volcano. The host plant is the native *Duranta dombeyana* (Verbenaceae). The habitats where all known specimens were collected were *Scalesia* forest with *Duranta* bushes. To ensure the conservation of *E. becki*, we recommend control of introduced species in its habitat.

RESUMEN

Distribución, conservación y planta huésped de *Epiplema becki* Hayes (Insecta: Lepidoptera: Uraniidae) en las Islas Galápagos. Dos nuevas poblaciones y la planta hospedera de la mariposa rara endémica de Galápagos *Epiplema becki* fueron encontradas en la Isla Isabela, en los volcanes Wolf y Sierra Negra, con una avistamiento en Volcán Darwin. La planta huésped es la nativa *Duranta dombeyana* (Verbenaceae). Los hábitats donde todos los especimenes conocidos fueron colectados eran bosque de *Scalesia* con arbustos de *Duranta*. Recomendamos control de especies introducidas en su hábitat, para asegurar la conservación de *E. becki*.

INTRODUCTION

Epiplema becki Hayes is a small, inconspicuous moth endemic to the Galapagos Islands, Ecuador where it was first recorded from Fernandina, the type locality, and Isabela islands (Hayes 1975). Hayes (1975) described it from one male and two females. No other records have since been published, and nothing has been published on the host plant or habitat.

We report the host plant and extant populations of *E. becki* on Isabela Island. Because so little is known about the biology of *E. becki*, we provide information on each collecting event and all known localities where the species has been found.

METHODS

We conducted field work from 1994 to 2004 during a survey of Galapagos Lepidoptera. Moths were collected using mercury vapour lamps, ultraviolet lights (UVL), fluorescent lights, and a lightweight mesh net. Specimens are deposited in the Invertebrates Collection of the Charles Darwin Research Station (CDRS), Canadian National Collection, Ottawa, Canada (CNC) and Museum d'Histoire Naturelle, Geneva, Switzerland (MHNG). In addition, Dr Bernard Landry (MHNG) sent data from his extensive survey of Galapagos Lepidoptera since 1989, and further records were obtained from specimens in the Natural History Museum, London (BMNH), and the California Academy of Sciences, San Francisco (CAS).

We used published information (Wiggins & Porter 1971, Lawesson *et al.* 1987) and material in the Charles Darwin Research Station herbarium (CDS) to determine the distribution of the host plant.

RESULTS

E. becki has been collected or seen at only six known localities (Table 1 and Fig. 1).

Fernandina Island

Hayes (1975) selected as holotype a specimen supposedly collected by the entomologist F.X. Williams in 1906. The holotype, now in CAS, is pinned upside down and has six labels: 1 "Holotype"; 2 "Narborough I. Galapagos Is. IV-2–5 06"; 3 "Coll. by F.X. Williams"; 4 "Genitalia slide"; 5 "Holotype B& *Epiplema becki* Hayes Det. A. H. Hayes"; 6 "California Academy of Sciences 13120". It is the specimen figured by Hayes (1975: 160), and when examined in 2001 was in bad condition, missing the abdomen and antennae, and with the left hind wing broken and numerous holes in the other wings.

These labels, which Hayes (1975) correctly reported, appear to indicate that the type locality is Fernandina (= Narborough) Island. However, a review of the CAS archives and related literature (Williams 1920, Slevin 1931) revealed that Williams did not visit Fernandina between 2 and 5 April 1906, but spent that time aboard the ship "Academy" or collecting on Isabela. Slevin (1931) noted: "April 5 …

Table 1. Known records of *Epiplema becki.*

Locality	Date	Collector	n	Collection
Fernandina	2–5 Apr 1906	F.X. Williams	1	CAS
N Isabela (locality unknown)	11 Apr 1902	R.H. Beck	1	BMNH
Isabela, Sierra Negra, Corazón Verde, 360 m asl	Jan 1971	R. Perry & T. de Vries	1	BMNH
Isabela, Sierra Negra, Corazón Verde	23–27 Jun 1974	R. Perry & T. de Vries	1	BMNH
Isabela, Sierra Negra, Corazón Verde	Nov–Dec 1974	R. Perry & T. de Vries	7	BMNH, CDRS
Isabela, Sierra Negra, Corazón Verde	19–20 Dec 1975	R. Perry & T. de Vries	2	BMNH
Isabela, Darwin, 1300 m asl, 0.12091°S, 91.18277°W	6 Mar 2000	L. Roque	1	sighting only
Isabela, Sierra Negra, 8.5 km N of Puerto Villamil, 0.88916°S, 91.0074°W	8 Apr 2004	P. Schmitz	3	MHNG
Isabela, Wolf, 1630 m asl(0.04704°N, 91.34734°W)	15 Apr 2004	L. Roque & A. Mieles	14	CDRS
Isabela, Wolf, 960 m asl (0.06536°N, 91.36358°W)	16 Apr 2004	L. Roque & A. Mieles	2	CDRS

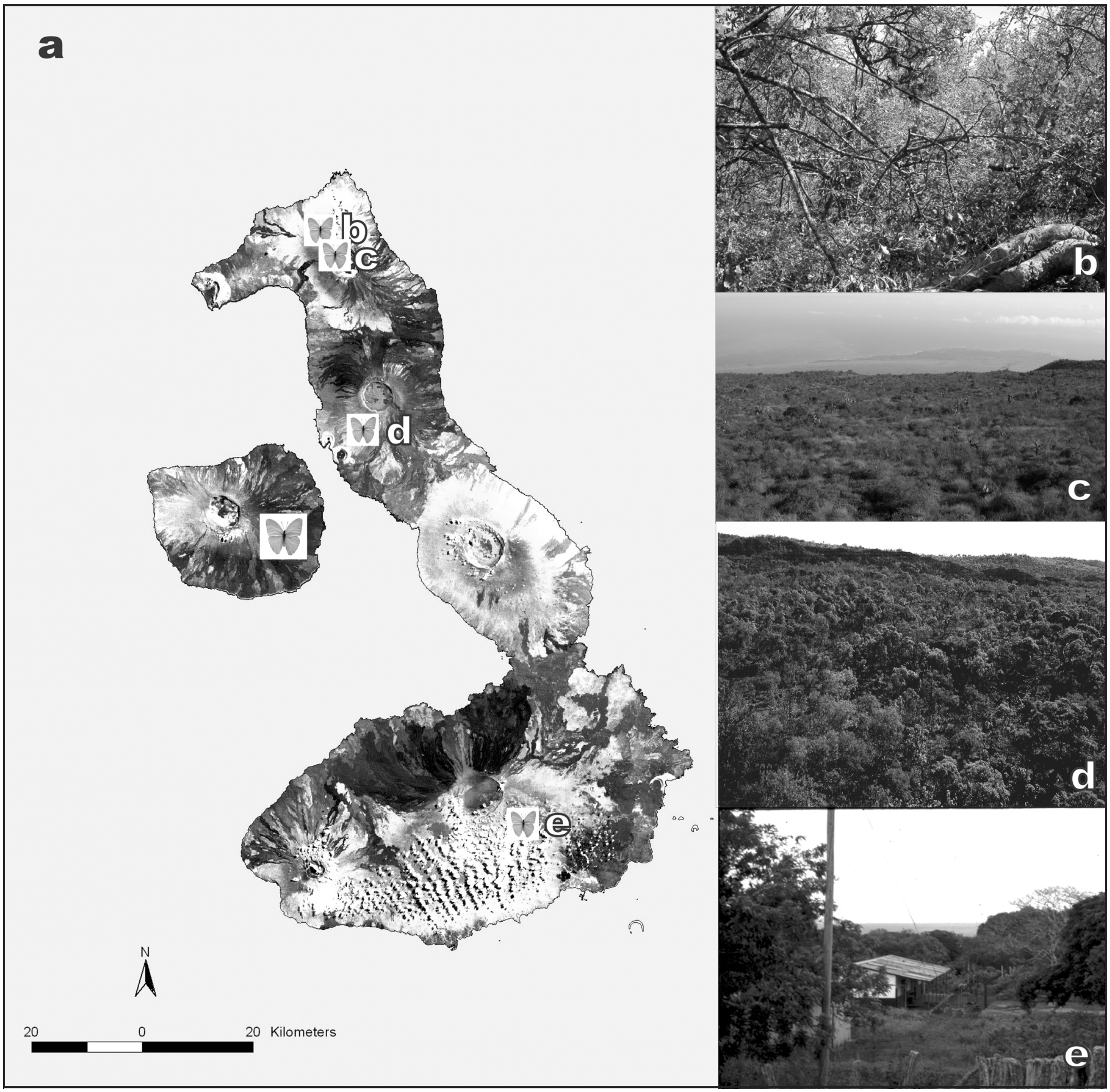

Figure 1. *Epiplema becki* distribution and habitats: (a) distribution; (b) Wolf Volcano 960 m; (c) Wolf Volcano, top locality 1630 m; (d) Darwin Volcano 1300 m; (e) Sierra Negra, Santo Tomás.

Williams and Stewart went inland prepared to camp over night. They made camp at our regular camp tree and were so bothered by mosquitoes they were unable to sleep. Williams spent the night collecting about the camp fire". The "regular camp tree" appears to be midway to the top of Darwin Volcano, and was found by R.H. Beck and Williams on their first trip there on 26 Mar 1906. As described by Slevin (1931: 95): "Part way up the mountain, Beck and Williams, having found a large, green tree with plenty of soil around the base and leaves to shelter them from the sun, made camp."

If Williams did not collect this specimen, perhaps it was collected by Beck, who climbed to the top of Fernandina between 2 and 5 April 1906. It would not be surprising to find an *E. becki* population on Fernandina because the host plant occurs there.

Northern Isabela Island

Apparently, Beck collected the first known specimen of *E. becki*, in 1902 on northern Isabela. It is a female, which Hayes (1975: 152) made a paratype. The label says "N. Abermarle 11 IV 02 R. H. Beck". We were unable to identify the exact location of this collecting event; it could have been on either of Darwin or Wolf volcanoes.

Isabela Island, Wolf Volcano

On 15–16 April 2004, we collected on the top and north side of Wolf Volcano (Fig. 1b, c). We found *E. becki* in abundance at the top (14 specimens collected) and gathered two more specimens at 960 m (Table 1). We also discovered caterpillars under leaves of *Duranta dombeyana* (Fig. 2) a native member of the Verbenaceae. The larvae were encountered singly or in groups of two or three, feeding on old and new leaves. They are green with reddish markings on the last abdominal segments. Developmental observations were not made, but the final instar was 12 mm in length. Some larvae were observed to be preyed upon by adult *Podisus sordidus* (Stal) (Heteroptera: Pentatomidae), a native true bug that is widespread in the archipelago (Froeschner 1985). The moths were observed flying low amongst vegetation early in the morning (6h00–9h00). Two were collected at night with UVL. Adults rest with the wings extended laterally and the antennae folded back below the forewings (Fig. 3).

No signs of goat damage were observed at the sites, but other areas of the volcano have been affected.

Isabela Island, Darwin Volcano

Our field work on Darwin Volcano was carried out in February 1999 and 2000, on the west slope and rim, along an altitudinal transect from Tagus Cove to the western side of the caldera. This way up appears to be similar to that used by the CAS expedition in 1906 and by B. Landry and co-workers in 1992.

On 6 March 2000, one specimen was attracted with UVL but not collected, at the rim camp (Fig. 1d). The habitat is *Scalesia microcephala* forest, and *D. dombeyana* was present. During our 1999 trip very few goats were seen on the volcano, but in 2000, numerous groups were present in several areas but more abundantly in the highlands. Native vegetation appeared to be affected by the goats.

Isabela Island, Sierra Negra Volcano

The second paratype (Hayes 1975) was a female collected by R. Perry & T. de Vries at Corazón Verde, Santo Tomás, Sierra Negra, in January 1971 (Table 1). In 1975, after the publication of his description of *E. becki*, Hayes received a series of specimens from de Vries, which remained undescribed until 1999, when LRA located a Schmidt box containing 11 specimens at BMNH. They were collected between Nov 1974 and Dec 1975 at Corazón Verde, which is the CDRS house in Santo Tomás village in the agricultural zone (Fig. 1e). The area is currently highly modified, mostly pasture and crops, but in 1971 it was less altered, with native vegetation in better condition (J. Gordillo pers. comm.). LRA made Lepidoptera collections there from 1996 to 2004, but never found *E. becki*.

On 8 April 2004, Patrick Schmitz of MHNG collected a male and two females, 8.5 km north of Puerto Villamil, using UVL between 18h30 and 20h00 (Table 1). This

Figure 2. *Duranta dombeyana* at 1630 m on Wolf Volcano, Isabela.

Figure 3. Male *E. becki* resting on leaves of *Duranta dombeyana* at 1630 m on Wolf Volcano, Isabela.

locality is at the lower fringe of the agricultural zone and the vegetation is a mixture of native and introduced plants.

Duranta dombeyana was collected recently at both localities (Table 2), which may indicate that the presence of the larval host plant may not be sufficient to maintain a population of *E. becki*, as shown by its apparent absence at Santo Tomas.

Duranta dombeyana, the larval food plant

Three *Duranta* spp. occur on the islands: *D. dombeyana, D. mutisii* and *D. repens*. They are distributed at higher elevations on Isabela, Fernandina, San Cristóbal, and Pinzón islands (Lawesson *et al.* 1987, Table 2).

Only *D. dombeyana* has been found as a host plant for *E. becki*. It is the most widespread of the three species in Galapagos (Table 2), where it has a patchy distribution, mainly on lava slopes and grassy areas from 300 to 1700 m asl, and is abundant at several localities. In 2003, P. Jaramillo reported several individuals along the trail to Volcán Chico (Sierra Negra). Recently, H. Jäger found a numerous population on a hill west of "El Ripioso" on San Cristóbal Island. In March 2004 we found a good population on Wolf Volcano, in an open area above 1700 m. This is in the upper arid zone, a vegetation zone located above 1630 m, with abundant *Opuntia insularis* and other microphilous plants characteristic of the more widespread low arid zone (*sensu* Wiggins & Porter 1971). *D. dombeyana* was also collected at other localities on Fernandina and Isabela, including the agricultural zone of Isabela (Table 2), but it may be less abundant there. The species appears to be highly affected by goats at several places; for example on the rim of Alcedo Volcano (Isabela), it appears to have declined since 1995 (I. Aldaz pers. comm.). The other *Duranta* spp. appear to be less abundant and less widely distributed (Table 2).

DISCUSSION

The discovery of a healthy population of *E. becki* on Wolf Volcano and the occurrence of extant populations on Sierra Negra and probably on Darwin volcanoes was a pleasant surprise. The species was formerly known from only three specimens and presumed to be very rare. However, there is no doubt that the known populations are vulnerable to extinction, and the species has never been recorded on Alcedo Volcano (between Darwin and Sierra Negra), despite our intensive collecting there since 1995.

The introduction of alien species, the alteration of habitats, and the destruction of host plants are considered the main threats for the conservation of Galapagos endemic Lepidoptera (Roque-Albelo & Landry 2004). Different populations of *E. becki* appear to be affected by these three factors, with goats affecting northern Isabela and habitat destruction important on Sierra Negra, both of which may cause loss of host plants.

In 2004, a goat eradication programme began on northern Isabela. The conservation of *E. becki* there depends on the success of this project. On southern Isabela (Sierra Negra) the survival of the known *E. becki* population is uncertain and every effort should be made to protect the host plant and its habitat.

Future studies should investigate the biology of *E. becki* (including the acceptability of other *Duranta* spp.), establish regular monitoring of the known populations, and investigate the distribution of the host plant and the factors affecting its conservation. In addition, a survey on other islands or volcanoes where populations may occur is required. Although *E. becki* has never been collected on San Cristóbal, a survey on the hills around El Ripioso would be useful.

ACKNOWLEDGMENTS

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Table 2. Distribution of *Duranta* spp. and recent occurrence of *Epiplema becki.*

	Collection dates	Source	*E. becki* present?
D. dombeyana			
Fernandina, Grass crater. 400 m asl.	1977, 1984	CDS	?
Isabela, Sierra Negra, near Cerro Palomas.	1994	CDS	
Isabela, Sierra Negra, 9 km on road from Puerto Villamil to agricultural zone.	1994	CDS	Yes
Isabela, Sierra Negra, road to Bosque de los Niños [close to Corazón Verde].	1996, 2002	CDS	?
Isabela, Sierra Negra, trail to Volcán Chico.	2003	CDS	
Isabela, Alcedo, top, NE side.	1995, 1996	CDS	
Isabela, Darwin, 1300 m asl, W side.	2000	Pers. obs.	Yes
Isabela, Wolf, 1630 m asl, NE side.	2004	Pers. obs.	Yes
San Cristóbal, hill west of El Ripioso.	2004	CDS	
San Cristóbal, hill east of El Ripioso.	2004	CDS	
D. repens			
Isabela, Sierra Negra, caldera floor, 900 m asl and areas close to rim.	1985	CDS	
Isabela, Sierra Negra, SE of the top.	2000	CDS	
D. mutisii			
Pinzón	1963, 1982	CDS	

Honey (BMNH) and Norman D. Penny (CAS) for permission to study the specimens in their collections. We are also indebted to Bernard Landry and Helmuth Rogg for critical review of this manuscript and to Iván Aldaz and Patricia Jaramillo for help with plant identification. We are especially grateful to Zoran and Leonor Stjepic and Barbara West for hospitality and logistical help during LRA's visits to BMNH and CAS. This research was partially supported by the Galapagos Conservation Fund, Galapagos Conservation Trust (London) and the U.K. Government's Darwin Initiative. This is contribution 1010 of the Charles Darwin Foundation for the Galapagos Islands.

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ARTHROPODS IN THE CHARLES DARWIN RESEARCH STATION HERBARIUM, GALAPAGOS, DURING 1999–2001

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SUMMARY

This paper describes the arthropods found in the Charles Darwin Research Station herbarium from 1999 to 2001. Nineteen species were found from four classes. Most individuals were from the families Formicidae (*Paratrechina longicornis* with 777 individuals), Porcellidae (134), Drosophilidae (43) and Corinnidae (38).

RESUMEN

Artrópodos en el herbario de la Estación Científica Charles Darwin, Galápagos, durante 1999–2001. Este artículo describe los artrópodos encontrados en el herbario de la Estación Científica Charles Darwin desde 1999 a 2001. Se encontraron 19 especies de cuatro clases. La mayoría de los individuos fueron de las familias Formicidae (*Paratrechina longicornis* con 777 individuos), Porcellidae (134), Drosophilidae (43) y Corinnidae (38).

INTRODUCTION

In educational and academic collections such as libraries, museums and herbaria there have been few studies to evaluate periodically the presence and abundance of invertebrate pests. The emphasis has been to remove or eradicate pests, to prevent harm to collections, rather than monitoring the population fluctuations of the pest species.

The invertebrate group that has most impact on herbarium collections is the arthropods, in particular insects, whose effects can be serious. Dry botanical samples, glues, cardboard and newspaper are attractive foods for some of these animals. In tropical regions, continuous high temperatures and humidity favour these organisms and facilitate their population growth (Bridson & Forman 1998). On islands, fewer of these species may occur naturally than in a comparable continental region, although many may be present as introduced species, since they commonly co-occur with humans. Galapagos is a tropical oceanic archipelago, with relatively constant high humidity and seasonally high temperatures (Alpert 1963, Jackson 1993).

This study aimed to determine the incidence of arthropods in the Charles Darwin Research Station herbarium (Index Herbariorum code CDS), on Santa Cruz Island, Galapagos. The herbarium is located 5 m above sea level, in a building constructed in 1993–4. In its small physical area (*c.* 40 m^2 x 2.5 m high) at the time of the study, it held some 15000 specimens of 1700 taxa of the Galapagos flora including native, endemic, and introduced vascular and non-vascular plants.

The herbarium is maintained at constant temperature (*c.* 20° C) and humidity (50–60%), suitable for storing plant material (Edwards *et al.* 1980). Occasional equipment breakdowns and power cuts interrupt this climate control. Unfortunately, even such controlled conditions are favourable for the establishment and development of certain insects.

We sampled and identified the arthropods found there, determined their frequency and assessed their actual and potential effects on plant collections. The results were used to choose effective methods for eliminating the arthropods.

METHODS

This investigation began on 7 Sep 1999, when the first set of six Pestokill Insect Monitor® traps (Fig. 1) were placed on the floor in the corners of the herbarium and in the spaces between shelves. These traps are produced for use in museums, sample collections and libraries (Bridson & Forman 1998) and contain glue mixed with starch, which attracts and traps the insects. The adhesive remains effective for up to 90 days. The traps were left in place for approximately three months, then collected and replaced with new ones. Traps were recorded in Dec 1999, Mar, Jun and Oct 2000, and Jan, Apr, Jul and Sep 2001.

Figure 1. Pestokill Insect Monitor® trap.

Identifying and counting the trapped individuals sometimes proved difficult, because they commonly became completely stuck or attacked by fungus (Fig. 1). In such cases, we traced around each individual, using different colours for each species, making it easier to count them (Bridson & Forman 1998). In most cases the CDRS Department of Terrestrial Invertebrates made the identifications.

RESULTS

In all, 19 species were found from four classes of arthropods (Table 1). Most individuals were from the families Formicidae (*Paratrechina longicornis*), Porcellidae, Drosophilidae

Table 1. Arthropods recorded in the Charles Darwin Research Station herbarium, 1999–2001.

Class	Order	Family	Species	Dec 1999	Mar 2000	Jun 2000	Oct 2000	Jan 2001	Abr 2001	Jul 2001	Sep 2001	Total
Insecta	Hymenoptera	Formicidae	*Paratrechina longicornis*	6	63	67	435	170	23	13	0	**777**
Insecta	Hymenoptera	Formicidae	*Camponotus macilentus*	0	1	1	1	2	2	1	1	**9**
Insecta	Diptera	Drosophilidae	sp. 1	0	7	1	0	0	4	3	0	15
Insecta	Diptera	Drosophilidae	sp. 2	11	9	6	10	0	2	5	0	43
Insecta	Diptera	Sarcophagidae	sp. 3	0	0	0	1	0	0	0	0	**1**
Insecta	Lepidoptera	Pyralidae	*Nicetiodes apianellus*	0	2	0	6	0	2	0	0	**10**
Insecta	Lepidoptera	Tineidae	sp. 4	0	1	10	2	1	2	8	0	**24**
Insecta	Blattoidea	Blattidae	*Periplaneta australasiae*	0	0	3	12	2	2	1	4	**24**
Insecta	Blattoidea	Blattidae	*Periplaneta americana*	0	0	0	0	0	0	1	0	**1**
Insecta	Blattoidea	Blattidae	*Ischnoptera* sp.	3	0	1	2	1	0	6	1	**14**
Insecta	Thysanura	Nicoletiidae	sp. 5	0	0	0	2	0	0	1	0	**3**
Arachnida	Aranea	Corinnidae	*Corinna cetrata*	0	4	4	0	3	27	0	0	**38**
Arachnida	Aranea	Gnaphosidae	*Camillina* sp.	0	0	0	1	0	0	0	0	**1**
Arachnida	Aranea	Pholcidae	sp. 6	0	0	0	0	3	0	0	0	**3**
Arachnida	Aranea	Scytodidae	sp. 7	0	2	1	0	5	0	0	0	**8**
Arachnida	Aranea	Salticidae	sp. 8	0	3	0	0	0	0	0	0	**3**
Arachnida	Aranea	Heteropodidae	*Heteropoda* sp.	1	0	1	1	1	0	0	0	**4**
Chilopoda	Scolopendromorpha	Scolopendridae	*Scolopendra galapagoensis*	0	0	1	0	0	0	0	0	**1**
Crustacea	Isopoda	Porcellidae	sp. 9	17	30	32	32	0	0	2	21	**134**
Totals				**38**	**122**	**128**	**505**	**188**	**64**	**41**	**27**	**1113**

and Clubionidae. The greatest frequency of pests was recorded at the Oct 2000 and Jan 2001 checks, and the lowest in Dec 1999 and Sep 2001 (Table 1).

DISCUSSION

Most *P. longicornis* individuals were recorded between December and March, which is the hot season, during which this species is generally more abundant (Edward & Barnes 1996). Ant abundance in the herbarium seemed to track that outside, even though temperature and humidity remain constant inside.

Of the two commonest families, ants (Formicidae) feed on live and dead insects, fruits, plant secretions, and many household food items, and may be classified as pests in an herbarium (Bridson & Forman 1998). Woodlice (Porcellidae) eat algae, moss, fungi, tree bark, and decomposing plant or animal material (Ruppert & Barnes 1996). Thysanura (0.3% of individuals) need 75–80% humidity to reproduce, and eat a wide range of substances that contain glue or ink. There are reports them being pests in herbaria, because they damage books, labels, papers, herbarium specimens and textiles (Bridson & Forman 1998). The three species of cockroaches (Blattoidea) recorded (3% of organisms recorded) prefer high humidity and temperatures (Peck & Roth Louis 1992), eat glue, and their faeces can mark the samples (Bridson & Forman 1998). Lepidoptera larvae are often polyphagous and some feed on dried fungi, dried fruit and other dry plant products (Dell'Orto & Arias 1985). However, the species found would not cause harm to the herbarium collections since their entry would primarily be by rare accident and they are not species that are pests of stored products (L. Roque pers. comm.).

Spiders (5%) are predators and mainly eat insects. Little is known of the effect of their presence in the herbarium, but they might eat insects occurring there. They may not be considered as pests, as they may themselves control pest organisms (L. Baert pers. comm.).

Fortunately, no direct damage to specimens has been found that can be attributed to the arthropods found in the herbarium, indicating that the climate and pest control measures in force are adequate for maintaining the collection free of such damage. Since Oct 2001 we have treated the herbarium every three months with the insecticide Piretron (biodegradable, non-toxic pyrethrins), and the quantity of arthropods trapped has since decreased.

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LOCAL DISTRIBUTION PATTERNS OF *OPUNTIA ECHIOS ECHIOS*, *BURSERA GRAVEOLENS* AND *SCALESIA CROCKERI* ON SANTA CRUZ ISLAND, GALAPAGOS

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SUMMARY

We mapped stems of three plant species in a 2.36 ha plot in the arid zone near the coast of eastern Santa Cruz Island, Galapagos, Ecuador, to determine factors influencing their local distribution. The three species were *Opuntia echios* var. *echios* (Cactaceae), a large cactus, *Bursera graveolens* (Burseraceae), a small tree that dominates dry woodland near the coast, and the shrub *Scalesia crockeri* (Asteraceae). In our plot, *Opuntia* was most abundant near the coast, while *Bursera* and *Scalesia* increased in density inland and with increased relief. *Scalesia* also increased in density with increases in *Bursera* and decreases in other woody plants and was most abundant 200–250 m from the coast. Both *Opuntia* and *Bursera* were clumped in the plot as a whole but selected stem size classes were randomly dispersed within homogeneous portions of the sample area.

RESUMEN

Patrones de distribución local de *Opuntia echios echios*, *Bursera graveolens* y *Scalesia crockeri* en la Isla Santa Cruz, Galápagos. Registramos la localización de tallos de tres especies de plantas debtro de un cuadrante de 2.36 ha en la zona arida cerca de la costa este de la isla Santa Cruz, Galápagos, Ecuador, para determinar los factores que influencian su distribución local. Las tres especies son: *Opuntia echios* var. *echios* (Cactaceae) una especie de cactus grande, *Bursera graveolens* (Burseraceae) un árbol pequeño que domina el bosque seco cerca de la costa, y el arbusto *Scalesia crockeri* (Asteraceae). En nuestro cuadrante, *Opuntia* resultó más abundante cerca de la costa, mientras la densidad de *Bursera* y *Scalesia* incrementaban tierra adentro y a medida que aumentaba el relieve. La densidad de *Scalesia* también incrementaba al igual que la de *Bursera* y en tanto que decrecía la densidad de otras plantas leñosas, y llegaba a su máxima a 200–250 m desde la costa. Tanto *Opuntia* como *Bursera* se encontraban agrupadas dentro del cuadrante como conjunto, pero las clases de tamaño de tallo especificas estaban dispersas aleatoriamente dentro de porciones homogéneas del área de muestreo.

INTRODUCTION

Factors determining spatial variation in vegetation vary in importance with the scale of the study. Over a range of centimeters, vegetation is influenced by differences in moisture, light availability, soil type, surface features, and other micro-scale factors. At the landscape scale, vegetation varies with elevation and aspect, which determine more widespread temperature and precipitation regimes. Patchiness within a community is intermediate, over distances of meters to tens of meters. Historic events can operate at any of these spatial scales.

Much of the spatial investigation of vegetation in the Galapagos has emphasized the landscape scale. Broad vegetation zones have been used as a basis for describing species distributions (Wiggins & Porter 1971, Jackson 1993, Itow 1995, McMullen 1999). Other studies have compared plots from different locations (Reeder & Riechert 1975, Van der Werff 1978, Hamann 1981) to define naturally occurring plant communities.

Relatively little attention has been paid to patterns of spatial variation within communities or over short distances. Reeder & Riechert (1975) and Van der Werff (1978) found the Arid and Humid Zones respectively to be characterized by much local patchiness in vegetation. They suggested that substrate conditions may cause much of that patchiness. Reeder & Reichert (1975) also noted that the cactus *Opuntia* often forms a low, open forest on the coastal plain in a relatively narrow zone just landward of the Littoral Zone. We wished to study intra-community patchiness of the Arid Zone and determine factors underlying the transition between this *Opuntia* zone and the rest of the Arid Zone. We examined the distribution of three species (*Opuntia echios* var. *echios*, *Bursera graveolens*, and *Scalesia crockeri*) in two coastal plots differing in substrate.

STUDY AREAS AND SPECIES

We studied the three species on the NE coast of Santa Cruz Island near the hill Cerro Colorado (0°34´S, 90°10´W). The location, across a narrow strait from the Plazas islets, a popular tour destination, allowed convenient access. Previous studies of feral cats (Konecny 1987a, b, Stone *et al*. 1994) showed that the site contained relatively natural vegetation with some substrate heterogeneity and little direct human impact, although feral donkeys and goats have been recorded there (Snell, unpublished field trip reports 1988, 1993, 1994 on file at Charles Darwin Research Station, Santa Cruz, Galapagos; personal observation) and may impact the vegetation. Precipitation in the Arid Zone is highly variable year to year (Snell & Rea 1999). The present study was conducted during one of the wettest episodes in the last 35 years.

The tree-like cactus *Opuntia echios* var. *echios* was most apparent near the coast. The small tree *Bursera graveolens* dominated (in both size and cover) areas further inland. The site also included many species of thorny shrubs (e.g. *Acacia insulae-iacobi*, *Castela galapageia*, *Lycium minimum*, *Parkinsonia aculeata*, and *Scutia pauciflora*) and the shrub *Scalesia crockeri*. Another large cactus, *Jasminocereus thouarsii*, was present in very low numbers. Structurally the site fit the dry-season deciduous forest type of Van der Werff (1978), which he described as leafless most of the year, located from sea level to 150 m altitude on the east coast of Santa Cruz, and dominated by trees 5–10 m tall. Van der Werff (1978) also said of this structural type that *Bursera* is the most common tree species; shrub cover is 70% at 2–4 m height; herbaceous cover occurs between shrub clumps; *Opuntia* is common; and lava boulders cover over 30% of the surface. Floristically, our site best matched the Alliance Burserion graveolentis, Association Abutiletum depauperati, Subassociation abutiletum depauperati typicum, Vicariant Opuntia echios var gigantea (Van der Werff 1978).

The Galapagos endemic *Scalesia crockeri* is a low, rounded shrub found on bluffs and lava crevices, mostly near the shore (Wiggins & Porter 1971, Eliasson 1974), but up to 1 km inland at Cerro Colorado. It grows singly or in small, often widely separated groups (Eliasson 1974). Its seeds have no obvious adaptations for long-distance dispersal. It is one of several *Scalesia* with very restricted distributions. It is found only on the north and northeast slopes of Santa Cruz, and the nearby islands Baltra and North Seymour (Adsersen 1990, Snell *et al*. 1995). It is currently classified as Vulnerable, owing to its small range (Tye 2000, 2002). Its life history has not been studied but may resemble that of *S. helleri* on Santa Fe or *S. baurii* on Pinta (Hamann 1993, 2001).

METHODS

We established a 2.36 ha plot that ran a maximum of 100 m N–S (parallel to the coast) and 300 m E–W (Fig. 1). It reached the ocean approximately 100 m north of Cerro Colorado and formed a transect from the coast inland with relatively little change in elevation from its S edge to its N edge. Although it reached the coast, mangroves and other species characteristic of the Littoral Zone (Wiggins & Porter 1971) were not present. The plot was located on volcanic rock containing cracks, mounding and other lava features. The first 100 m westward marked the rise from sea level to a relatively flat plain. We established a 10-m grid in the plot and mapped all stems of *Opuntia echios*, *Bursera graveolens*, and *Scalesia crockeri* to the nearest 0.1 m. Where several stems of *S. crockeri* were too close together to separate we recorded one central location and the number of stems in the cluster. For each 10 x 10 m section of the plot we estimated by eye the % of bare ground and shrub cover (excluding the three species above) and the local relief (vertical distance from lowest to highest point). These three factors partly indicate the light and moisture regimes available to the target species. They also influence the likely impact of grazing, especially on small plants, because bare rock is easier to traverse than dense, often thorny shrubs and so should be more heavily grazed. High relief is often associated with cracks and crevices that may provide refuges from grazing and relatively moist micro-sites for seedling establishment. We estimated height and measured dbh (diameter at breast height, *i.e.* at 137 cm above ground) for each stem of *Opuntia* and *Bursera*, and counted the number of stems in two height classes (>1 m and ≤1 m) for *S. crockeri*.

We also sampled a 20 x 500 m transect on a sandy plain dominated by burr-bearing grasses and scattered *Cordia lutea* trees, located *c.* 100 m north and upslope from the other plot. The transect lay between GPS-read coordinates 0°34.558′S, 90°10.198′W and 0°34.521′S, 90°10.449′W, starting about 5 m from the bluff overlooking the ocean at this point and running due west. This bluff did not extend into the 2.36 ha plot. Exposed rocks were not present

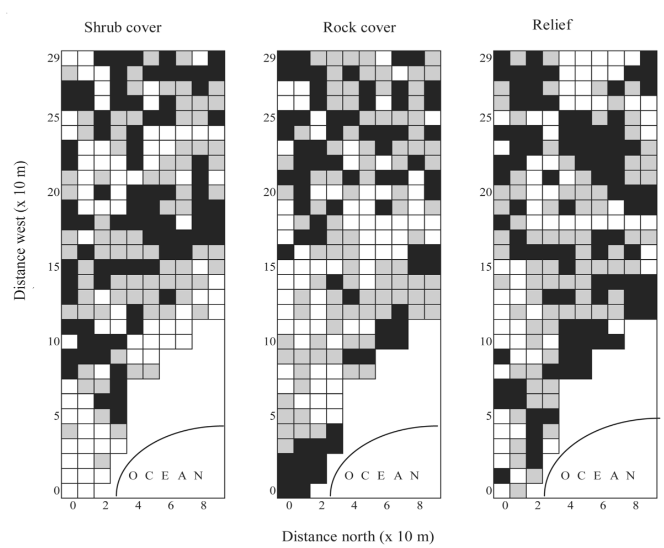

Figure 1. Study plot grid showing variation in shrub cover, rock cover, and relief. For shrubs, white indicates cover ≤20%, shaded 25–45%, and black ≥50%. For rock, white indicates cover ≤10%, shaded 15–40%, and black ≥45%. For relief, white indicates a maximum vertical difference ≤1.5 m, shaded 2 m and black ≥2.5 m.

and local relief was minimal. We recorded the height, dbh, and location of all stems of *Bursera* and *Opuntia*; *Scalesia* was not present.

Field sampling was conducted 18–26 January 1998. We related species densities in each plot to location (west and north of the SE corner of the plot, where west and north refer to the number of 10-m sub-plots in the given direction), shrub cover, bare ground and relief, using stepwise regression (SAS 1985). In this procedure variables are added until the marginal probability of an additional variable is >0.05. Squared terms for distances west and north were included, to check for non-linear relationships. We used stepwise regression to investigate the relation-ships between *S. crockeri* and *Bursera* and between small (≤2 m height) and larger stems of *Bursera* and *Opuntia*. We related shrub cover, rock cover and relief to location (including distances squared). For *Opuntia* and *Bursera*, $\log_{10}$(height in m) was related to $\log_{10}$(dbh in cm) by regression. We related the maximum height of *Opuntia*, in each 10 x 10 m sub-plot that contained *Opuntia* stems >2 m high, to plot characteristics.

The Clark-Evans ratio (Clark & Evans 1954) is the observed distance between nearest neighbors divided by the distance expected if the stems are randomly distributed. Converting the ratio to %, a value <100 indicates clumping, 100 indicates randomness, and >100 a regular distribution. These values were adjusted for edge effects and significance levels calculated using the method of Donnelly (1978; see also Runkle 1990, Ward *et al.* 1996). For some analyses we divided stems into small (≤2 m height) and large (>2 m) size classes. We also divided the large plot into coastal (row ≤10) and inland (row ≥20) regions. We calculated dispersion values for *Opuntia* and *Bursera*, both of which tend to grow as single stems. We did not calculate dispersion values for *Scalesia*, which usually grows in tight clusters.

Some regression equations related parameters to location (north or west in the plot) and location squared. Using calculus, derivatives were taken to determine the distance at which the parameter value reached its minimum or maximum and its value at that distance.

RESULTS

Shrub cover, rock cover, and relief varied over the plot (Fig. 1). Values are related to position within the plot by the following equations:

shrub cover (%) $= 13.1 + 2.59W - 0.05595W^2$ ($r^2 = 0.0794$, $P < 0.0001$);
rock cover (%) $= 45.6 - 2.89W + 0.0978W^2$ ($r^2 = 0.0751$, $P = 0.0001$);
relief (m) $= 1.85 + 0.205N - 0.020N^2$ ($r^2 = 0.0250$, $P = 0.0552$);
where W = distance (in units of 10 m) west of the coast, N = distance (10 m units) north.

According to these equations, shrub cover increased to a maximum of 43% at 230 m from the coast and then decreased further inland. Rock cover decreased to a minimum of 24% at 148 m, about half way through the plot. Relief was largest at about the north midpoint of the plot, with a fitted maximum of 2.4 m at a north distance of 51 m. The low r^2 values for the equations demonstrate pronounced local heterogeneity.

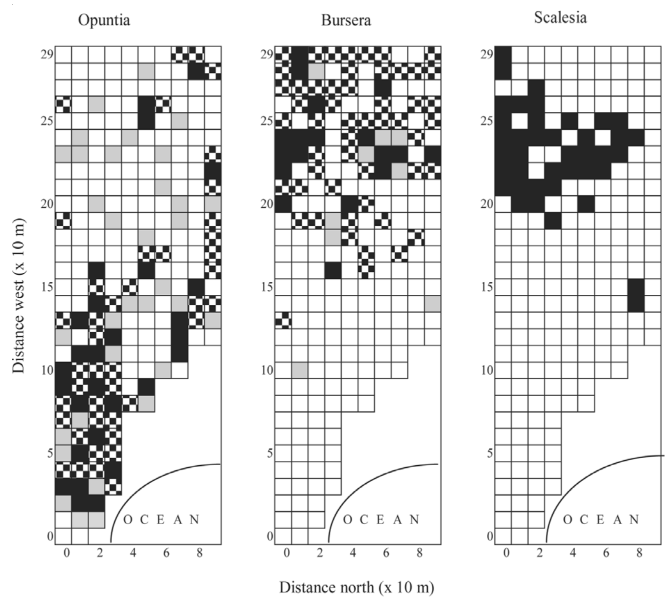

Figure 2. Study plot grids showing distributions of *Opuntia echios*, *Bursera graveolens* and *Scalesia crockeri*. For *Opuntia* and *Bursera*, white indicates no stems present, light shade indicates only stems ≤2 m tall present, dark shade indicates only stems ≥2 m present, and black indicates both small and large stems present. For *Scalesia* black indicates species present.

The three species studied had different distributions (Fig. 2). Most *Opuntia* were on the slope between the coast and a relatively flat upland area: densities were 1–4.5 stems per 100 m^2 on the slope but <1 further inland (Fig. 3). *Bursera* began to appear *c.* 160 m from the coast and soon reached a steady level of 1–2.5 plants per 100 m^2 plot. *Scalesia crockeri* was most abundant 200–260 m from the coast.

Densities were significantly related to plot characteristics. Letting n = number of live stems per 100 m^2 sub-plot, R = relief (vertical distance in m between the

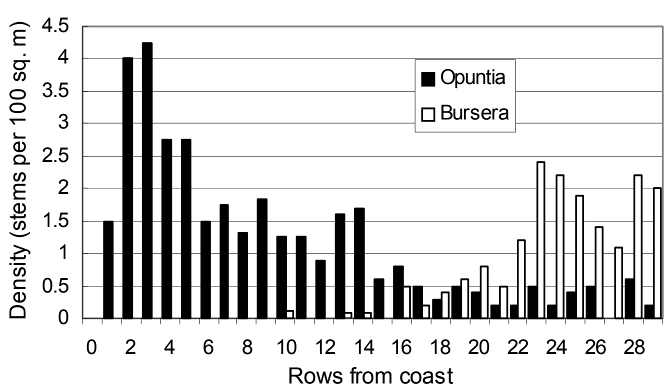

Figure 3. Species densities as a function of distance from the coast for *Opuntia* and *Bursera*.

highest and lowest points within each sub-plot), and S = % of the plot covered by woody plants other than the three target species, we obtained the following fitted stepwise regression equations:
Opuntia $n = 2.7 - 0.16W + 0.00026W^2$ ($r^2 = 0.22$, $P < 0.0001$);
Bursera $n = -0.63 + 0.0033W^2 - 0.14N + 0.35R$ ($r^2 = 0.35$, $P < 0.0001$);
Scalesia $n = -1.8 + 0.26W - 0.36N + 1.0R - 0.46S$ ($r^2 = 0.13$, $P < 0.0001$).

Thus *Opuntia* is influenced mostly by distance from the coast, declining inland (the equation above extrapolates to a minimum at row 31, beyond the edge of the actual plot). *Bursera* increases sharply with distance from the coast and is found more on the south part of the plot. *Bursera* is also found more often on sub-plots with greater relief. The local relief in sub-plots was up to 7 m (mean ± SD: 2.2 ± 1.1 m).

S. crockeri, like *Bursera*, was more abundant in the west (inland) and south parts of the plot. It was more strongly positively associated with relief than *Bursera* and was negatively associated with shrub cover. *S. crockeri* and *Bursera* were positively associated with each other (Spearman $r_s = 0.46$, $P < 0.05$). A stepwise regression relating *Scalesia* density to the environmental features listed above plus the density of *Bursera* resulted in:
Scalesia $n = 2.1 + 1.4B - 0.0349S$ ($r^2 = 0.12$, $P < 0.0001$), where B = *Bursera* density.

Thus, the relationship with *Bursera* was stronger than that with any other environmental variable (*Bursera* was added first to the stepwise regression), suggesting that *S. crockeri* is favored under the open canopy of *Bursera* or that both prefer the same open, rocky substrates where relatively few other species grow. Of 45 *S. crockeri* stems whose heights were measured, 29% were ≤1 m and 33% were >1.5 m (max. height 2.5 m).

Most *Bursera* and *Opuntia* stems were ≤5 m tall (Fig. 4). Stepwise regressions relating the density (number per100 m^2 sub-plot) of small stems (≤2 m high) to environmental features plus the density of larger stems for each species are:
Opuntia (small stems):
$n = 1.5 - 0.11W + 0.0022W^2$ ($r^2 = 0.15$, $P < 0.0001$);

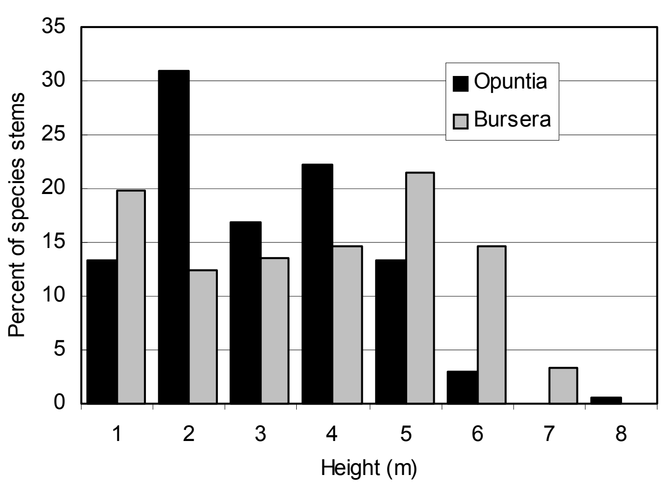

Figure 4. Height distributions of *Bursera* (n = 177) and *Opuntia* (n = 203).

Bursera (small stems):
$n = -0.88 + 0.032W - 0.066N + 0.28R + 0.0071K$ ($r^2 = 0.21$, $P < 0.0001$); where K = % rock.

Thus, for both species, the distribution of small stems was more closely related to the physical environment than to the density of large stems. The equations for small stems are similar to those for all stems except that small stems of *Bursera* tend to occur where much bare rock is visible.

Opuntia height (m) was significantly related to dbh (cm) according to the equation:
$\log_{10}\text{height} = 0.79\log_{10}\text{dbh} - 0.57$ ($r^2 = 0.31$, n = 161, $P < 0.0001$). Maximum height of *Opuntia* stems was not significantly correlated with the plot characteristics measured. *Bursera* height was significantly related to diameter according to the equation:
$\log_{10}\text{height} = 0.35\log_{10}\text{dbh} + 0.23$ ($r^2 = 0.73$, n = 138, $P < 0.0001$).

Opuntia (living and dead stems) and *Bursera* were both clumped (Table 1). However, for more homogeneous parts of the plot (coastal 0–100 m; inland 200–300 m), *Opuntia* was randomly distributed except that large inland stems were clumped. For the inland plots small *Bursera* were clumped and large *Bursera* were randomly distributed. Nearest neighbors for both *Bursera* and *Opuntia* were usually 4–6 m away except that inland *Opuntia* were usually 11–14 m apart (Table 1).

S. crockeri requires rocky substrates and complex local relief and was absent from the grassy plain transect. Both *Bursera* and *Opuntia* were much less abundant on the transect than on the rockier plot. On the plain we found 39 *Bursera* (=39 per ha), 19 live *Opuntia* (19 per ha) and five dead *Opuntia* (5 per ha). We found 32% of *Opuntia* stems and 5% of *Bursera* stems to be ≤2 m tall but no stems of either species <1 m tall. In contrast, proportionally more small stems were found in the plot, where 44.3% of 203 *Opuntia* stems were ≤2 m high and 11.8% were <1 m high, and 32.2% of 177 *Bursera* stems were ≤2 m high and 16.9% <1 m high.

DISCUSSION

Opuntia echios

Opuntia decreased rapidly away from the coast and occurred at very low densities on the flat grassy plain. Wiggins & Porter (1971) say it grows on thin soil and bare lava near the coast. Reeder & Riechert (1975) found it most abundant only to an altitude of 5 m and present only to an altitude of 79 m in their transect located on the SSW of Santa Cruz Island. The maximum plant height at Cerro Colorado (Fig. 4) fits into the pattern noted by Hicks & Mauchamp (1996): 10 m on the S side of Santa Cruz (var. *gigantea*); 5–6 m near Cerro Colorado (our data); 4 m on the north side of Santa Cruz (var. *echios*); <4 m on islets just north of Santa Cruz (vars. *echios* and *zacana*). Hicks & Mauchamp (2000) did not find *Opuntia* maximum height to vary between the lower and upper Arid Zones, although they did find it to be significantly greater in the Transition

Zone. Hamann (1979) measured height growth at 7 cm per year and estimated that a 2.8 m stem would be about 50 years old. Therefore, the largest stems we sampled could be close to 100 years old. Other Galapagos Opuntia taxa may live up to 150 years, with adult mortality rates of only 2–6% per year in most years (Hamann 2001). In our sample, dead stems (74) totaled 37% the number of live stems (203). This seemingly high fraction may be related to the observations of Hamann (1993), Snell *et al*. (1994), and Tye & Aldaz (1999) that high *Opuntia* mortality occurs during high rainfall (El Niño) years. We found proportionally fewer small stems than in areas with fewer introduced browsers (Hicks & Mauchamp 1996, 2000). Recruitment is sporadic and may depend on high rainfall years such as the major El Niño events of 1982–3 and 1997–8 (Hicks & Mauchamp 2000). During these events more of the area may be suitable for growth than usual, leading to the pattern we observed of small stems in the interior being more randomly dispersed than large stems, which are perhaps clumped in sites favorable for long term growth. However, large stems near the coast were also randomly dispersed. Conditions may be more uniformly favorable there, perhaps associated with the lower shrub cover. Hicks & Mauchamp (2000) also found stems to be more clustered inland than near the coast.

Bursera graveolens

Hamann (2001) found adult mortality of *Bursera* to be only 1–2% per year in studies from 1970 to 1998 and suggested that its life expectancy may thus be up to 200 years. Our observed distribution of *Bursera* (near but not on the coast; at higher densities on lava rocks than the grassy plain) fits descriptions in Reeder & Riechert (1975), who found it on exposed lava at 15–70 m altitude, and Porter (1971), who found it on inclined lava flows and shallow soils. Wiggins & Porter (1971) found extensive open forests of nearly pure stands of *Bursera* on several islands, including the north slopes of Santa Cruz. It has a capsular drupe with edible pseudaril (Wiggins & Porter 1971), which is eaten and the seed dispersed by birds, land iguanas and endemic rats (Clark & Clark 1981). Although most seeds fall under adult canopies, Clark & Clark (1981) found that 86% of juveniles were ≥3 m from an adult. They found the median dispersal distance to be 20 m and the maximum 35 m. Combining juveniles and adults we found nearest neighbors to be 4–5 m apart. Clark & Clark (1981) found seedlings in a variety of substrates, with 40% between rocks, where we also found many small stems. *Bursera* juveniles did not obviously avoid other woody plants (Clark & Clark 1981) but may even be helped by a moderate vegetative cover (Hamann 1993). Our largest individuals (Fig. 4) were similar in size to those described in Clark & Clark (1981) and Hamann (1979).

Bursera was positively associated with topographic relief, cracks and other partly protected sites for germination and growth. No relationship to shrub cover was found. Small inland stems were clumped, presumably responding to the clumping of micro-sites favorable for their initial establishment. The impact of El Niño events on this pattern is not clear (Hamann 2001). Mature stems were randomly distributed.

Table 1. Dispersion patterns at Cerro Colorado.

Genus	Living?	Ht[1]	Location	Distrib.[2]	CE(%)[3]	n[4]	n/ha	D[5]
Opuntia	Live	All	All	Clumped	79	203	86	4.4
Opuntia	Dead	All	All	Clumped	64	74	31	6.0
Opuntia	Live	All	Inland	Random	101	32	32	9.7
Opuntia	Live	All	Coastal	Random	97	92	230	3.4
Opuntia	Live	>2	Inland	Clumped	64	13	13	11.3
Opuntia	Live	≤2	Inland	Random	98	19	19	13.7
Opuntia	Live	>2	Coastal	Random	95	51	128	4.6
Opuntia	Live	≤2	Coastal	Random	82	41	102	4.4
Bursera	Live	All	All	Clumped	72	177	75	4.3
Bursera	Live	>2	Inland	Random	97	105	105	5.0
Bursera	Live	<2	Inland	Clumped	66	52	52	4.9

[1]Ht = height (m).
[2]Clumped and Regular indicate patterns significantly ($P \leq 0.05$) different from random.
[3]Clark-Evans index.
[4]n = number of individuals.
[5]D = mean of the distances between nearest neighbors.

Scalesia crockeri

We found *S. crockeri* most abundant 200–250 m from the sea. It was associated with high relief (where crevices associated with lava features occurred) and low cover of other shrubs. It was found in many of the same areas as *Bursera* though was not as abundant as *Bursera* >270 m from the shore or in the sandy plain. This distribution fits the general species description from the literature given earlier.

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THE COST OF QUININE *CINCHONA PUBESCENS* CONTROL ON SANTA CRUZ ISLAND, GALAPAGOS

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SUMMARY

We analyse the cost of controlling the invasive quinine tree *Cinchona pubescens* Vahl in the highlands of Santa Cruz Island, Galapagos. Control costs in ten 400 m^2 plots formed the basis for estimating the cost of control over the whole island. In the plots, densities were 2100–24,000 stems/ha (stems >150 cm tall) and 55,000–138,000 stems/ha (all size classes combined). Control involved uprooting small plants, and applying of a mix of metsulfuron methyl and picloram to cut stumps or to machete cuts in the bark of larger trees. These methods are presently used by Galapagos National Park field crews to control quinine. Costs (in man hours, herbicide and US$) were related to stem density; the density of stems summed across four height classes was a better predictor of costs than density of any one size class. Regressions (on all size classes combined) formed the basis for predictive models of costs. Costs ranged from $14 to $2225 per ha depending on stem density. The amount of herbicide (active ingredient/ha) that must be applied to high density stands of quinine is higher than typical rates of application in an agricultural setting. The cost of treating all existing plants once across quinine's known range on Santa Cruz Island (*c.* 11,000 ha) was estimated at *c.* US$1.65 million.

RESUMEN

Analizamos el costo de controlar quinina *Cinchona pubescens* Vahl, en la zona alta de la Isla Santa Cruz, Galápagos. El costo de efectuar el control en diez parcelas de 400 m^2 formó la base de una estimación de los costos de controlarlo en toda la isla. En las parcelas la densidad fue de 2100–24.000 tallos/ha (tallos con altura >150 cm) y de 55.000–138.000 tallos/ha (todas las clases de tamaño combinadas). El control consistió en arrancar de raíz juveniles, y aplicar herbicida (mezcla de metsulfuron metil y picloram) a tocones o a cortes de machete en la corteza de tallos mayores. Estos métodos son los utilizados actualmente para combatir esta especie por las cuadrillas del Parque Nacional Galápagos. Los costos (en horas-hombre, herbicida y US$) fueron relacionados con la densidad de tallos (todas las clases de tamaño combinadas); la densidad de tallos total (todas las clases de tamaño combinadas) fue el mejor factor determinante del incremento de los costos de control, más que la densidad de los tallos en alguna de las categorías de tamaño en particular. La regresión (usando todas las clases de tamaño combinadas) fue utilizada para crear modelos predictivos de los costos de control. Los costos variaron entre $14 a $2225 por ha, dependiendo de la densidad de los tallos. La cantidad de herbicida (kg de ingrediente activo/ha) que debe ser aplicada a rodales densos de quinina es más alta que la típica para controlar malezas en campos agrícolas. El costo para controlar todas las plantas de esta maleza en su rango actual conocido en la isla Santa Cruz (*c.* 11.000 ha) sería de *c.* US$1,65 millones.

INTRODUCTION

Since its introduction to Galapagos in 1946 (Hamman 1974), quinine *Cinchona pubescens* Vahl has spread to more than 11,000 ha on Santa Cruz Island, heavily impacting agricultural land and native plant communities, including those dominated by the endemic shrub *Miconia robinsoniana* Cogn. (Jäger 1999, Rentería 2002). Quinine forms dense stands (Fig. 1), and was first recognized as a threat to the Galapagos National Park (GNP) in the 1970s, when it probably occupied *c.* 2000 ha. A satellite image taken in 2001 was used to determine the areas of arbitrarily defined densities: 376 ha were densely infested and 1366 ha had medium density (Buddenhagen *et al.* 2004). Currently the total infested area is probably *c.* 11,000 ha (Rentería 2002). GNP controlled 110 ha between 1998 and 2003 (Buddenhagen *et al.* 2004); since then even more area has been controlled but probably still < 2% of the total infested area.

Quinine is difficult to control; an effective labor-intensive manual method requires trees to be pulled (small ones) or dug out of the ground. Such treatment of large trees causes severe disturbance to the soil and nearby plants. Control can be complicated because many trees have multiple stems connected by a network of roots, individual trees sucker when cut and pulled stems left in contact with the ground may set root. Apart from the high costs of labor, at high densities the impact of a purely manual method on native plants is considered unacceptable. An effective control method using herbicides, which leads to slow death of standing trees, is preferred and cheaper, mainly due to lower labor cost. In practice, a combined manual-chemical method is most effective, with small plants hand-pulled and larger ones treated with herbicide. Amongst dozens of herbicides and application methods that have been tested over almost 25 years, only one herbicide combination was found to be

≥ 80% effective: the application by "hack and squirt" of a mix of metsulfuron-methyl and picloram to connecting machete cuts around the trunk (Buddenhagen *et al.* 2004). The GNP has used this method with 1g metsulfuron and 60 g picloram per liter of water, since 2001. In this paper we investigate the cost of controlling quinine using the methods currently employed by the GNP.

METHODS

Study area

Santa Cruz is one of the largest islands in the Galapagos archipelago. It has an estimated maximum age of 3.6 million years, with shallow soils (Geist 1996). It reaches an altitude of 860 m above sea level. Quinine occupies a range from 180 m asl to the top of the island but is particularly dense in the area above 400 m, in the Miconia and Fern-Sedge Zones (*sensu* Wiggins & Porter 1971) both of which are now dominated by quinine. Our study was undertaken in the Miconia Zone and in the transition zone between Miconia and Fern-Sedge Zones, in areas with quinine density levels "medium" and "high" as identified by Buddenhagen *et al*. (2004) (Fig. 1).

Quinine densities in the experimental plots

We wanted to measure costs of controlling quinine at high density (worst case) and medium density, in the area that currently forms the focus of control by the GNP. Five 20 × 20 m plots were marked out in the medium density area and five more in the dense area. The plots were placed systematically at 20-m intervals along trail sides. We were only interested in the relationship between density or basal area of quinine and the effort required to control it, so random placement of plots was not considered necessary. The plots were sub-sampled using ten 2 × 2 m plots arranged from corner to corner (Fig. 2) to estimate the density of stems of quinine in four height classes, 0–20 cm, 21–100 cm, 101–150 cm, and >150 cm, as used by Jäger (1999). Diameter at breast height (dbh) was measured for all stems >150 cm tall. The proportion of stems >150 cm tall was compared between high and medium density areas.

Control methods

All the quinine in the plots was controlled using a combination of three methods: (1) for stems >150 cm tall and with dbh > 8 cm, the hack and squirt method described by Buddenhagen *et al.* (2004) was applied using a mix of metsulfuron 1g/l and picloram 60g/l of water; (2) stems >150 cm tall with dbh < 8 cm were cut through and the same herbicide mix applied immediately to the cut stump; (3) stems <150 cm tall were uprooted manually. Control was carried out by a team of 4–7 field staff from the GNP and the Charles Darwin Research Station (CDRS).

Relationships of costs with stem density

Several regressions were tried to find the best model for the relationships between stem density and man hours, herbicide, and cost in US$. A curved quadratic function was considered, as this is likely to be a better empirical description of some of these relationships than a linear function, since there are diminishing returns with progressively lower stem densities, *i.e.* more time is needed to find each stem at lower densities.

For man-hours, regressions were made using a quadratic function available in Sigma Plot 2000, with the y intercept restricted to 4 h, which is the average time required for searching and controlling 1 ha (average of several different terrains and densities of non-target vegetation) for plants at very low densities, using systematic search methods employed by CDRS (unpubl. data). For herbicide use, a linear regression with the y intercept restricted to 0 (the amount of herbicide needed to control zero stems) seemed logically appropriate, assuming that size structure is uniform in different density areas. However, a quadratic function was also tested and found not to be a better predictor than a linear function.

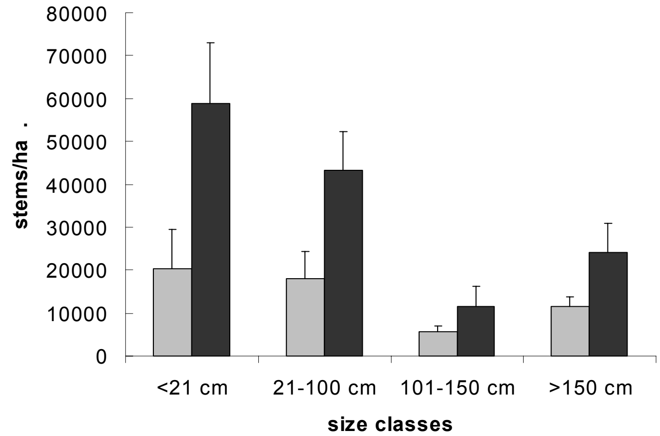

Figure 1. Size class distribution of *Cinchona pubescens* in the medium (grey) and high (black) density plots (standard error bars).

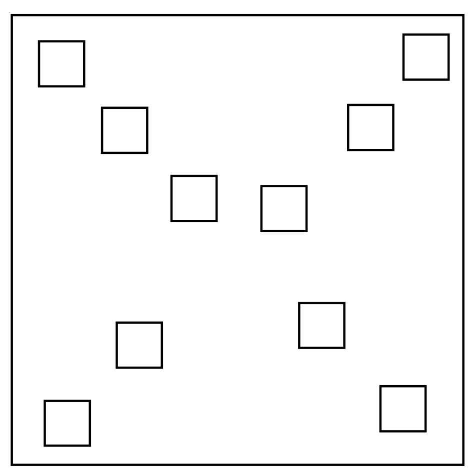

Figure 2. Precise arrangement of 2 × 2 m plots inside the 20 × 20 m plots, as used to estimate density of quinine in four size classes (irregularity designed to avoid overlap).

Monetary cost estimates were based on a labor rate of \$3.50 per h (the current standard rate for field staff in Galapagos) and the cost of the herbicide product (Combo ®) in mainland Ecuador at the time of writing (\$33.70 per l of mixture). Combo is distributed as 1 l of a liquid component containing 240 g of active ingredient picloram, plus 15 g of an emulsifiable powder of metsulfuron that is mixed at the time of use with the liquid component, before dilution with water to application concentration. Each liter of undiluted herbicide was mixed with 13.98 l of water.

We noted additional factors (apart from stem density) that contribute to the cost of control, including time to reach the control sites and distance to nearest water sources.

Density and total cost estimates

Buddenhagen *et al.* (2004) estimated the spatial extent of "high", "medium" and "low" density quinine on Santa Cruz Island at 376 ha, 1366 ha and 9258 ha respectively. Our plots were situated in the same high and medium density areas visible in the satellite images that were used to estimate these areas. We assumed the average stem density (all size classes) in the relatively small high density area to be the same as that in our plots there (138,000 stems/ha). However, we are less confident of the representativeness of our five plots in the medium-density area, due to localised previous manual control operations that may have resulted in unrepresentatively high stem densities in our plots. Because of this, we calculated an average density for the medium density area based on both our plots and five 20 × 20 m randomly located plots near to ours (H. Jäger unpubl. data). The remaining area we classified as low density. In this area, H. Jäger (unpubl. data from eight 20 × 20 m plots randomly located in the Fern-Sedge Zone) recorded an average of 728 stems per ha, which we used to calculate the cost of a complete control pass through the area. Regression equations derived for costs on stem density in the plots were used to determine costs of controlling all stems once, in the three density-level areas.

RESULTS

Control costs and stem density

Effort (man-hours) required to control an area was closely related to both density of all stems (all size classes summed) ($r^2 = 0.96$) and stems >150 cm tall ($r^2 = 0.89$) in the plots (Fig. 3). Since density of all stems was a slightly better predictor, this was used for the calculation of total costs in Table 1.

This was also true for liters of herbicide (all stems $r^2 = 0.87$; stems >150 cm tall $r^2 = 0.76$) (Fig. 4) despite a significant difference in the size class distribution between medium and high density plots (stems >150 cm in height made up 20% of all stems in medium density plots and 17% in high density plots; $\chi^2_1 = 200.752$, $P < 0.001$). Basal area of stems >150 cm tall varied between 3 and 27 $m^2.ha^{-1}$ in different plots. Despite this, basal area of stems >150 cm tall was a poor predictor of herbicide use ($r^2 = 0.62$, Fig. 5) compared with stem densities (Fig. 4).

US\$ costs were therefore graphed using a quadratic func-tion of the density of all stems (Fig. 6) since the cost estimate is based on herbicide and effort combined and should reflect diminishing returns of search effort at lower densities.

Water for mixing with the herbicide (13.98 l per l of herbicide product) was carried from sources 0–250 m from each plot. The effect of distance to water source on costs (the time required) is included in the total time measured for the control of each plot.

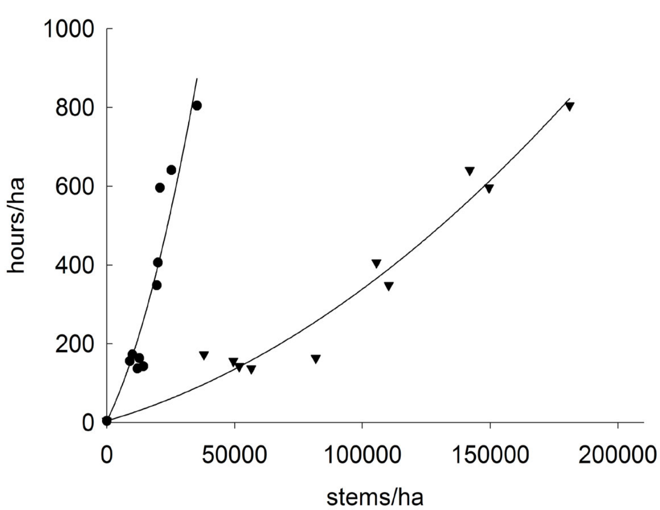

Figure 3. Man-hours per ha (by a team of four) to search for and control *Cinchona pubescens* at a given density of stems >150 cm tall per ha (circles, $r^2 = 0.89$, $y = 4 + 0.013162x + 3.26 \times 10^{-7}x^2$) or in all size classes (triangles, $r^2 = 0.96$, $y = 4 + 0.00190373x + 1.45 \times 10^{-8}x^2$).

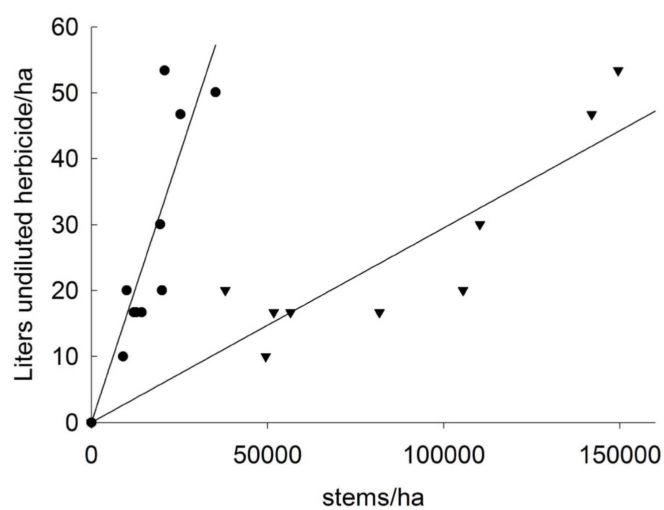

Figure 4. Liters of herbicide (before dilution) required to control *Cinchona pubescens* at a given density of stems >150 cm tall (circles, $r^2 = 0.76$, $y = 0.00162414x$) or of stems in all size classes (triangles, $r^2 = 0.87$, $y = 0.000295077x$).

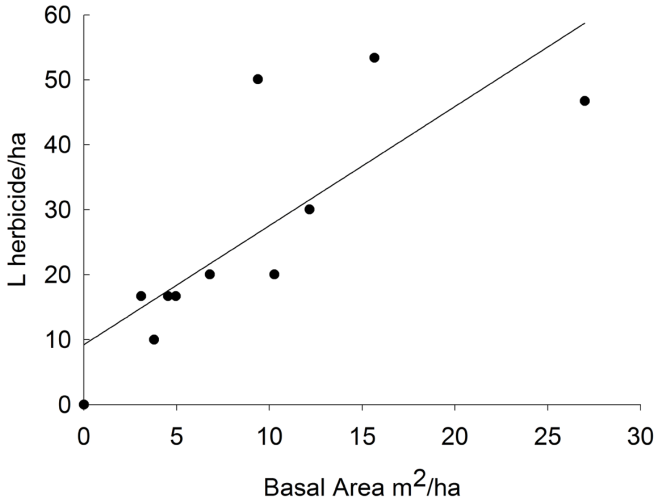

Figure 5. Liters of undiluted herbicide required to control *Cinchona pubescens* at a given basal area of *C. pubescens* stems >150 cm tall ($r^2 = 0.62$, $y = 9.22 + 1.83x$).

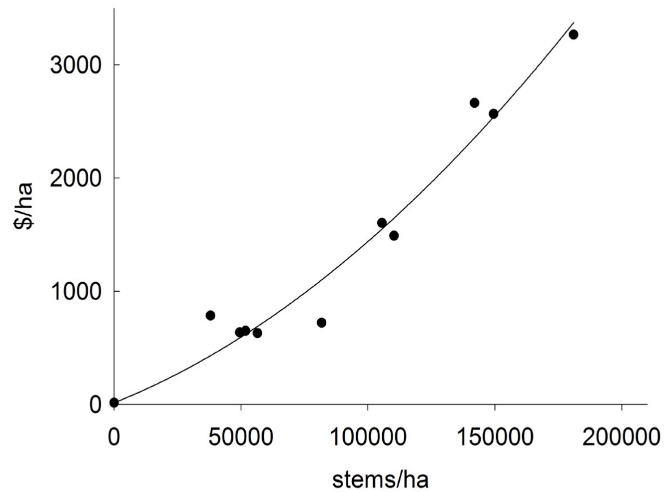

Figure 6. Cost of labor plus herbicide (US$) required to control *Cinchona pubescens* at an average density of stems in all size classes ($r^2 = 0.96$, $y = 14 + 0.0089x + 5.32 \times 10^{-8}x^2$).

Partial cost estimate of controlling known infestations

The cost of control over the estimated range of densities found in the infested areas on Santa Cruz ranged from $21 to $2255 per ha (Table 1). However, based on the average cost of systematic searching (unpubl. data), costs could be as low as $14 (4 man-h) per ha in areas where few or no quinine stems are found. The overall cost of controlling (one pass through) the known infested areas (no overheads, no travel costs, 2004 rates) is estimated at just over US$1.1 million (Table 1).

In the high density area, herbicide application rate was equivalent to 9.7 kg active ingredient per ha of picloram and 0.61 kg a.i. per ha of metsulfuron methyl.

DISCUSSION

Costs not accounted for in the models

Our estimates of costs are restricted to the cost of control work at the control site. These provide a partial estimate of the costs of a practical control program. Additional, so far unestimated, direct (transport *etc*.) and indirect costs (overheads) would have to be estimated to obtain the total cost of a control program. Such factors include time taken to hike to and from the nearby parking area to the plots, which varied between 17 and 37 min., and could be longer, and transport costs from town (a 20-min. drive each way). Costs associated with getting to and from the infestations depend on a number of interacting factors such as weather, distance, terrain, availability of access points and trails, all of which affect the time available for control in a given day. In this study, transport from Puerto Ayora to a convenient access point and the subsequent hike to each work site, together took up to 2 h per day (25% of a working day), and could vary from 1–4 h per day, depending on the distance to work sites. Herbicide costs are based on the cost in mainland Ecuador; cost of importation to Galapagos has not been included. All these costs are difficult to predict, but should be considered in a more complete cost analysis.

Total cost of controlling known infestations

In 2004, GNP paid $800 per ha to contractors to control quinine (F. Correa pers. comm.). According to our calculations, this would be a reasonable price at infestation levels up to about 60,000 stems/ha but inadequate in the densest areas, where costs are likely to exceed $2000 per ha (Table 1). However, it would be generous in the lowest density areas where costs could be little higher than $14

Table 1. Costs to control the estimated area of infestation of *Cinchona pubescens* (one pass through the entire area). Costs were estimated using the equations given for the regressions from Figs 3–5.

Density level	Average density (stems per ha all size classes)	Number of ha	Man-hours	Undiluted herbicide (l)	Total cost (US$)	Water (l)	Cost per ha (US$)
Low	728[1]	9258	49,901	1296	189,882	18,120	21
Medium	6352[2]	1366	22,785	1721	99,281	24,062	73
High	138,000[3]	376	203,807	13,995	848,008	195,646	2255
Total	48,362	11,000	276,493	17,012	1,137,170	237,828	103

[1]Based on unpubl. data from H. Jäger. [2]Based on unpubl. data from H. Jäger combined with our data. [3]Based on counts in our study plots.

per ha. Of course contractors would have to cover overheads that are not accounted for here.

Table 1 provides a first estimate of the total cost of controlling the known infested areas on Santa Cruz. Our estimates of the density and extent of quinine over the island are approximate, but represent the best information at hand; more detailed and accurate information would permit refining the cost estimate. The model from this study could contribute to a detailed management plan for quinine, be that a large-scale control program or the first phase of a complete eradication attempt. According to our estimates, the cost of field work, *i.e*. searching for and controlling quinine, in the first phase of an eradication program would exceed US $1.1 million (Table 1). Adding indirect and unaccounted costs mentioned above might take the actual cost to 1.5 times our estimate, or *c.* $1.65 million. It takes approximately two years for quinine trees to reach maturity (J. Rentería pers. comm.), so the first control pass should ideally be completed in <2 yr, and repeated every year thereafter, to prevent seeding of trees. It is not clear how long an eradication program would need to continue, perhaps 10–20 years. In planning such a project, other costs, such as travel time and a logistical-administrative overhead, obviously still need to be estimated in more detail.

The number of work hours per person per year is *c*. 1700. Our estimate of man-hours required for a first control pass is therefore equivalent to >150 man-years of work. A staff of at least 75 (preferably up to 200) field operatives would therefore be needed to complete the control pass with confidence within two years.

The application rates at the highest stem densities, equivalent to 9.7 kg active ingredient per ha of picloram and 0.61 kg a.i. per ha of metsulfuron methyl, are many times higher than label rates recommended for use in agriculture, *i.e*. 0.14–1.8 kg per ha (picloram) and 0.014–0.17 kg per ha (metsulfuron). This may be surprising considering that the application method is targeted to cuts in the trunk and volumes of mixture applied to individual trees are small, but may be explained by the high concentrations needed to control large trees, and the high stem densities encountered, as compared with herbaceous weed control typical of agricultural situations.

ACKNOWLEDGMENTS

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Galapagos Research (Noticias de Galápagos)

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Locality names should be widely recognised and in current use where possible. Articles citing older names, or localities that are not widely known, should contain a map or gazetteer, including all such localities mentioned. **Scientific names** should follow a recognised authority, which should be cited in papers dealing with taxonomic issues or lengthy species lists. Scientific names of **plants** should follow P.M. Jørgensen & S. León-Yánez (1999) Catalogue of the Vascular Plants of Ecuador. *Monographs in Systematic Botany from the Missouri Botanical Garden* 75 (see http://mobot.mobot.org/W3T/Search/vast.html for database), unless sound reasons for following a different scheme are presented.

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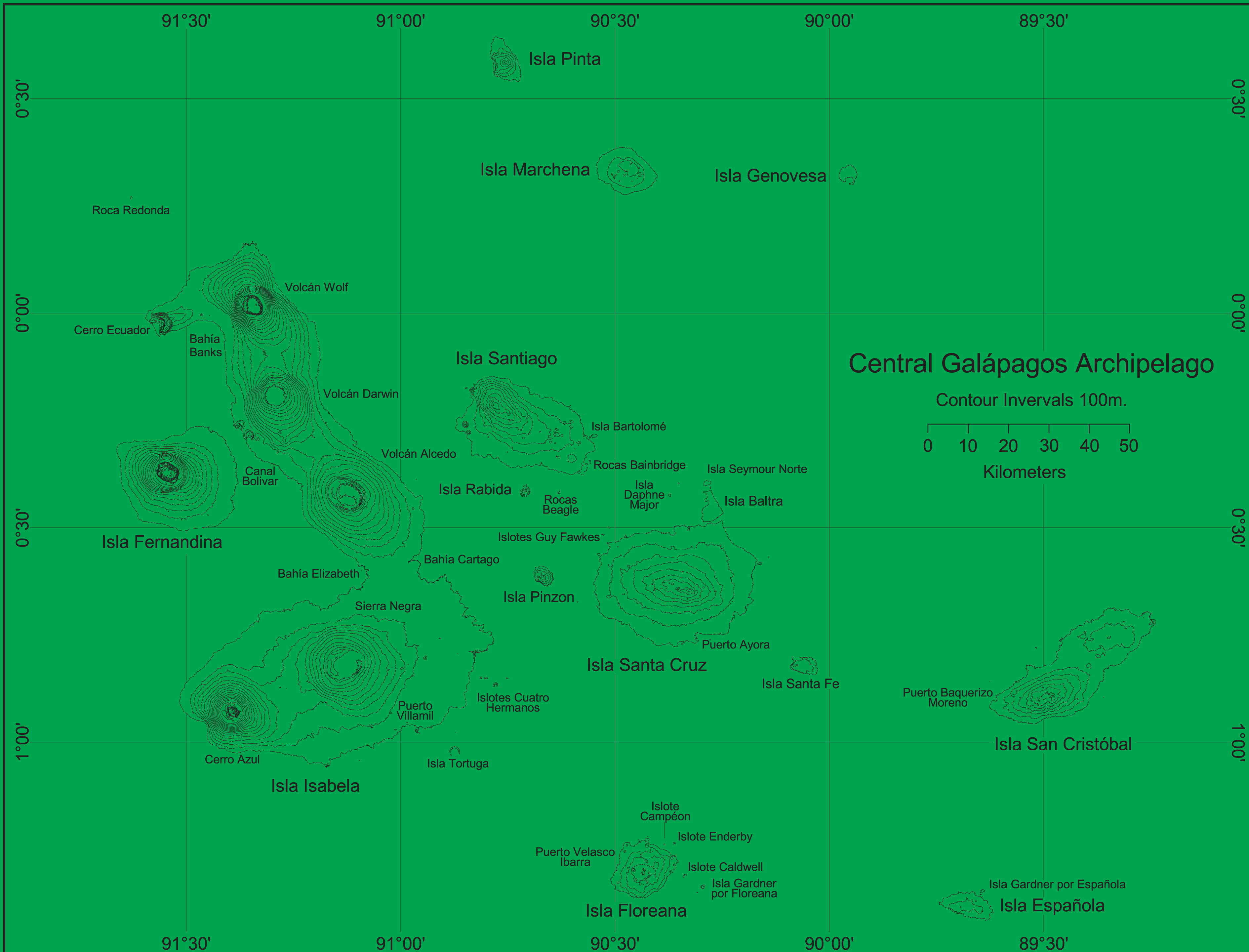
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Bahía Banks
Volcán Darwin
Isla Santiago
Isla Bartolomé
Volcán Alcedo
Rocas Bainbridge
Isla Seymour Norte
Canal Bolivar
Isla Rabida
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