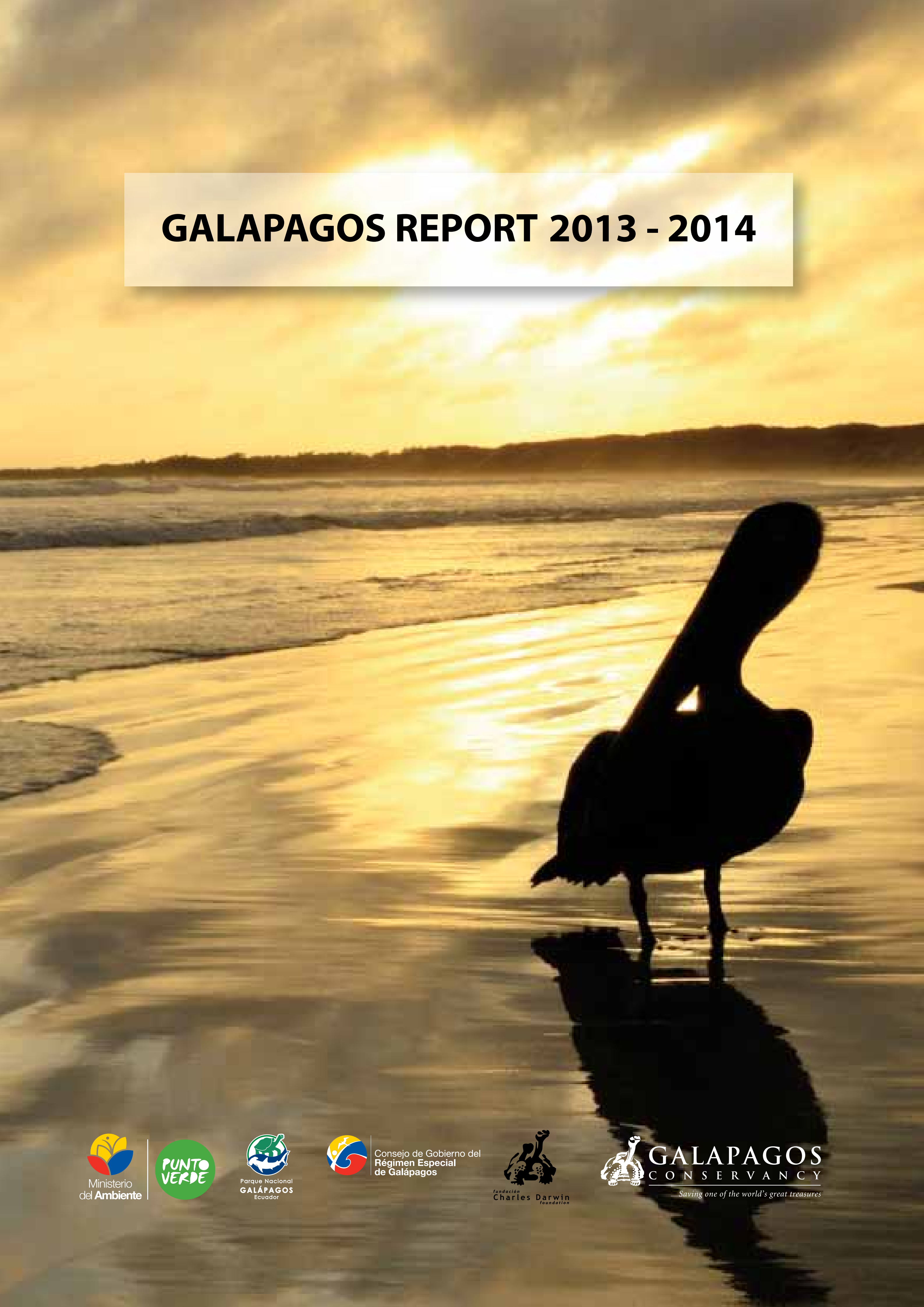
GALAPAGOS REPORT 2013 - 2014



Ministerio del Ambiente

PUNTO VERDE

Parque Nacional GALÁPAGOS Ecuador

Consejo de Gobierno del Régimen Especial de Galápagos

Fundación Charles Darwin Foundation

GALAPAGOS CONSERVANCY
Saving one of the world's great treasures

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*The **Galapagos National Park Directorate** has its headquarters in Puerto Ayora, Santa Cruz Island, Galapagos and is the Ecuadorian governmental institution responsible for the administration and management of the protected areas of Galapagos.*

*The **Governing Council of Galapagos** has its headquarters in Puerto Baquerizo Moreno, San Cristóbal Island, and is the Ecuadorian governmental institution responsible for planning and the administration of the province.*

*The **Charles Darwin Foundation**, an international non-profit organization registered in Belgium, operates the Charles Darwin Research Station in Puerto Ayora, Santa Cruz Island, Galapagos.*

***Galapagos Conservancy**, based in Fairfax, Virginia USA, is the only US non-profit organization focused exclusively on the long-term protection of the Galapagos Archipelago.*

FOREWORD

Photo title page Foreword: © Fabiola Alvarez

FOREWORD

The Ministry of the Environment through the Galapagos National Park Directorate, the Governing Council of Galapagos, the Charles Darwin Foundation, and Galapagos Conservancy are pleased to present the 2013-2014 Galapagos Report. Since 1997, this compendium has been published and shared with decision-makers, opinion leaders, local residents, the Ecuadorian public, public institutions in Galapagos, and the international community. Its contents have stimulated public debate and made it possible to explore more deeply the complex and dynamic socioecological system of Galapagos. We hope that once again the analyses provided in this year's Galapagos Report will continue to serve to guide public policy and the conservation of the Archipelago.

In this edition of the Galapagos Report, several experts explore the topic of managing the protected areas under the overarching concept of *Buen Vivir* or Good Living, highlighting the capacity of the ecosystem to generate services for society. They identify new and innovative management tools that can be used in conjunction with other planning methods to develop a land use plan that addresses all of the social and environmental characteristics of the Islands. Other pressing topics addressed include the use and impact of pesticides, water supply and demand, and new opportunities for implementing sustainable or "bio" agriculture. Significant attention is also given to the marine environment through an examination of the emerging issue of marine invasive species in the Galapagos Marine Reserve.

These analyses are provided by a broad network of authors that includes many who live and work in the archipelago, as well as others from a variety of institutions outside the Islands who help to examine Galapagos from a different perspective. The deep knowledge of the authors and their concern for the well-being of these islands is evident in the breadth and depth of the analyses.

Although there is never sufficient space to produce a document covering all of the critical issues related to the Islands, this volume includes a set of important articles intended to catalyze action and decision-making by bringing priority issues to the forefront of debate and analysis. Our institutions remain committed to working in coordination with all Galapagos stakeholders to ensure the long-term sustainability of this extraordinary natural treasure.

NEW APPROACHES

Photo: © Cesar Peñaherrera

The Management Plan for the Protected Areas of Galapagos for Good Living: An innovative tool that contributes to the integrated management of the Archipelago

Mónica Calvopiña[1], Sandra Chamorro[1], Eliecer Cruz[1], Washington Tapia[2] and Arturo Izurieta[2]

[1]WWF Ecuador, [2]Galapagos National Park Directorate

The *Management Plan for the Protected Areas of Galapagos for Good Living* is a new planning instrument developed between 2011 and 2013, approved by the Ministry of the Environment, and published in July 2014. The plan is presented as an innovative management tool that solidifies the recognition of Galapagos as a socioecosystem, where successful conservation requires integrated management of the protected areas with the populated zones (rural and urban). This includes acknowledging the capacity of ecosystems and their biodiversity to generate services, and contributing to the recovery of those components that have been altered primarily by anthropogenic causes (invasive species, contaminated aquifers, habitat degradation and fragmentation, among others), in ways that guarantee a sustainable human presence and quality of life or good living.

The Management Plan is based on a shared vision: *the Galapagos province achieves good living for the human community by preserving terrestrial and marine ecosystems and their biodiversity through a regional model that integrates protected areas with populated areas (*DPNG, 2014). The achievement of this shared vision is based on general principles (Figure 1), which guide, orient, and prioritize decision-making by natural resource managers as well as all other actors involved in the management of the Archipelago.

Development of the plan began with the formation of a core work group composed of regional and national authorities, who provided significant contributions to the creation of a shared vision for the plan. This group included representatives from: the Ministry of the Environment; the Governing Council of Galapagos (CGREG – Spanish acronym); the Galapagos Provincial Technical Directorate of the Ministry of Agriculture, Livestock, Aquaculture, and Fisheries (MAGAP – Spanish acronym); the Galapagos Provincial Technical Directorate of the Ministry of Tourism; the municipal governments of Santa Cruz, San Cristóbal, and Isabela; parish governments, and in October 2012, the recently created Galapagos Biosecurity Agency (ABG – Spanish acronym).

This is the first time in Galapagos that a single management plan combines two distinct protected areas: the Galapagos National Park (GNP) and the Galapagos Marine Reserve (GMR). This integrated approach seeks to respond to needs identified in the assessments of management effectiveness of the two protected areas. The new plan aims to optimize the management actions of the Galapagos National Park Directorate (GNPD) and to meet the current needs of Galapagos society, as well as respond to the environmental challenges of the Islands.

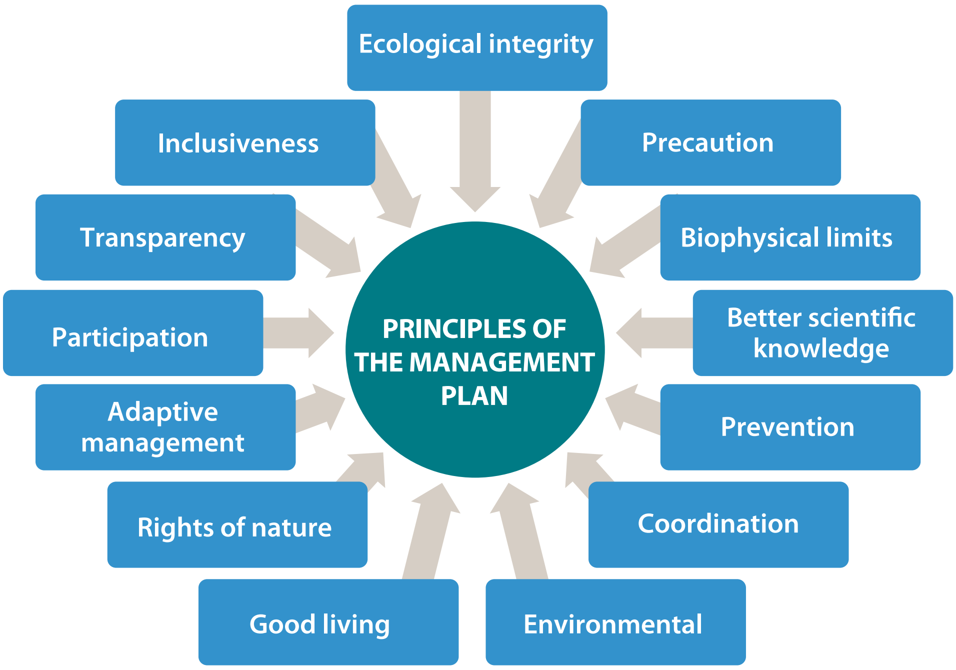

Figure 1. Principles of the 2014 *Management Plan for the Protected Areas of Galapagos for Good Living*.

The conceptual foundation: An integrated and integrating territorial model

The ecological dynamics of Galapagos are complex. So too is its socioeconomic system, which depends entirely on the environmental services provided by the terrestrial and marine ecosystems. Understanding Galapagos as a socioecosystem is essential; it is vital to deepen our understanding of the interactions of the natural and human systems rather than analyze them separately (Figure 2).

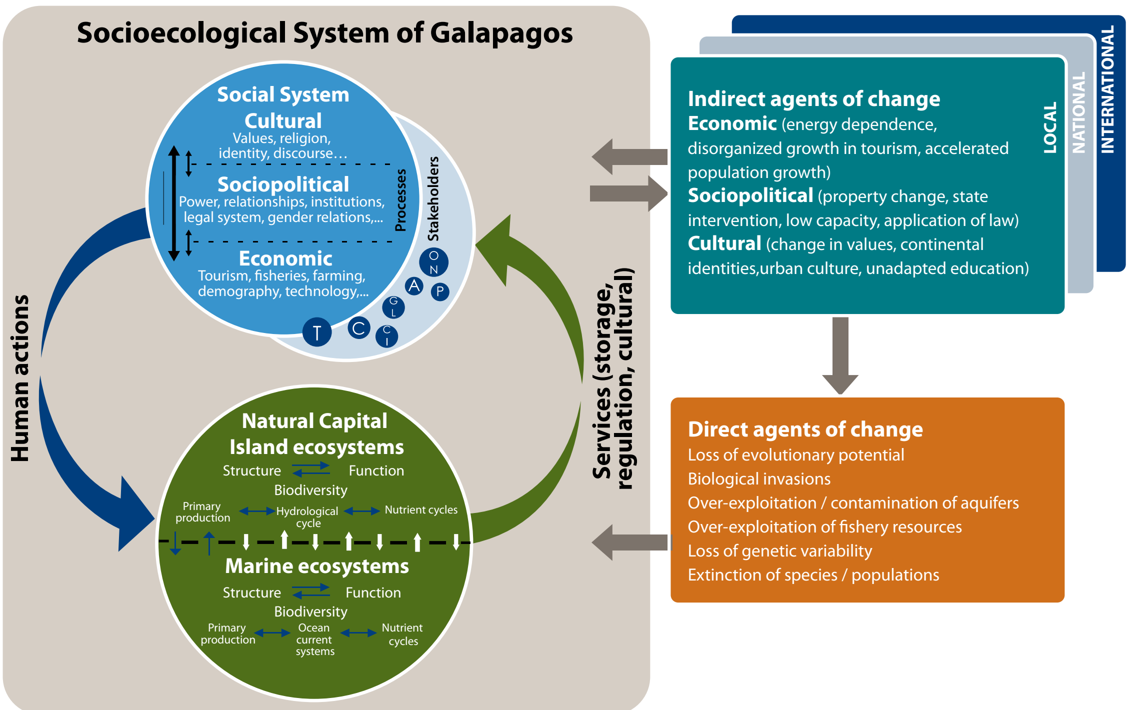

Figure 2. Conceptualizing Galapagos as a socioecosystem helps in understanding the dependent relationship between the social system and the terrestrial and marine ecosystems (protected areas), as well as to identify the actual causes of problems, which are related to the indirect drivers of change (taken and modified from Tapia *et al.*, 2009).

Photo : ©John Garate

The Management Plan rejects the paradigm of constant conflict between conservation and development and accepts that development in Galapagos is not possible without conservation and that effective conservation depends upon the development model chosen. This approach makes it unnecessary to choose between conservation and development and instead recognizes that the two are closely related. Management of the protected areas cannot be separated from management of unprotected areas (urban and rural zones), as many of the direct and indirect drivers of change originate in the populated zones.

To face the management challenges in the protected areas of the archipelago, it is necessary to develop strategies specifically geared toward the conservation of ecosystems and their biodiversity. But management actions must also have a socioeconomic component. It is important to implement a development model that recognizes the dependence of the province on natural ecosystems, and the fact that the resilience capacity of marine and island ecosystems has limits that must not be exceeded.

The Management Plan recognizes the authority of various entities in the province, and seeks greater coordination and collaboration to make their actions more effective.

Developing the Plan

The evaluations of the management effectiveness of the GMR (2011) and the GNP (2012) generated a series of recommendations that highlighted the urgent need for a single management tool to guarantee effective and integrated management of the two protected areas, to optimize planning efforts, and to ensure that those efforts are part of province-wide land management strategies.

The design of this comprehensive Management Plan was launched in 2012 with the creation of two working groups: an internal group consisting of GNPD rangers (referred to as the "technical group") and the second comprised of provincial authorities (referred to as the "core group"). The technical group generated draft proposals related to territorial planning, science and technology, public use and eco-tourism, communication, environmental education, and participation, which were then debated and analyzed by the core group. Once the core group agreed on the conceptual framework, the technical group proceeded to design specific strategies and action plans to implement the shared vision, including basic objectives and management programs.

Action strategy: The management programs

The main areas of intervention of the Management Plan are determined by six basic objectives, which correspond to the objectives of the National Plan for Good Living (SENPLADES, 2013). To achieve the objectives, an action strategy was developed, which encompasses all of the individual management programs (Table 1).

Table 1. Objectives and programs of the *Management Plan for the Protected Areas of Galapagos for Good Living*.

OBJECTIVE 1	**Manage the conservation of Galapagos marine and terrestrial ecosystems and their biodiversity to maintain their ability to generate services.**
Programs	1.1. Conservation and restoration of ecosystems and their biodiversity 1.2. Monitoring ecosystems and their biodiversity 1.3. Control and surveillance
OBJECTIVE 2	**Incorporate and articulate conservation policies for the protected areas into the Plan for Sustainable Development and Regional Planning of the Special Regime of Galapagos to achieve sustainable use of ecosystem services and terrestrial and marine biodiversity.**
Programs	1.1. Conservation and restoration of ecosystems and their biodiversity 1.2. Monitoring ecosystems and their biodiversity 1.3. Control and surveillance
OBJECTIVE 3	**Improve and strengthen the management capacity of the GNPD, providing it with the necessary resources for the effective and efficient administration of the protected areas.**
Programs	3.1. Organizational development 3.2. Management of environmental information
OBJECTIVE 4	**Promote participatory and inclusive social processes to promote good living and an island culture that exhibits environmental responsibility.**
Programs	4.1. Environmental communication, participation, education and interpretation
OBJECTIVE 5	**Increase and integrate interdisciplinary scientific-technical knowledge focused on the management of the interaction between marine and terrestrial ecosystems with the socioeconomic and cultural systems of Galapagos, within the context of global change.**
Programs	5.1. Science of sustainability
OBJECTIVE 6	**Promote national and international cooperation for the conservation of the ecosystems and biodiversity of Galapagos, according to the priorities established by Ecuador in the Plan for Sustainable Development and Regional Planning of the Special Regime of Galapagos.**
Programs	6.1. International relations and cooperation

There are 11 programs based on the conceptual framework of the plan and its management principles. These programs define conservation and/or restoration actions for terrestrial and marine ecosystems in the Archipelago in an integrated, coordinated fashion. These actions are compatible with the rational use of the environmental services generated by the ecosystems for the benefit of all Ecuadorians and of society in general.

Recommendations

At the start of the design process for the Management Plan, the institutions participating in the core work group signed an agreement containing the following points, which are still valid and serve as recommendations:

- Work collaboratively on the Management Plan, with each participating institution contributing to its content.
- Integrate all Galapagos planning tools.
- Link the development of the Management Plan to development and land use planning of the Galapagos Province.
- Take advantage of the planning process to encourage all entities to work together for the sustainable future of Galapagos.
- Agree that the Management Plan is one of the

drivers of fundamental change to collectively build a sustainable future for Galapagos.

- Recognize that the relationship between conservation and development must be complementary in order to achieve good living.
- Maintain good living in Galapagos respecting environmental limits of the terrestrial and marine ecosystems.
- Achieve a shared vision for Galapagos based on a unique regional model that integrates protected and unprotected areas (urban and rural zones).

Immediately following the approval of the *Management Plan for the Protected Areas of Galapagos for Good Living,* the GNPD carried out a process of socialization of the plan within and outside the institution, initiating a chapter of momentous change in the management framework for protected areas in Ecuador.

Acknowledgements

The GNPD would like to thank the institutions that formed the core work group for their valuable contributions and commitment. The GNPD also thanks all of the park rangers who contributed to the conceptual framework of the plan and developed the various management programs; the elaboration of the Management Plan would have been impossible without their help. Finally the GNPD thanks WWF Ecuador for its technical advice and logistical support throughout the process.

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Photo: © James Gibbs

Monitoring the Galapagos ecosystem: A tool for decision-making

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Those with responsibility for the Galapagos Archipelago strive daily to make sound decisions about the fate of the highly complex and ultimately fragile Galapagos ecosystem. They do so without access to insights that could be provided by a set of key, integrated indicators of the "vital signs" of the Galapagos ecosystem. Although targeted monitoring has already played a significant role in advancing specific ecosystem conservation and adaptive management of complex issues in Galapagos, a more holistic approach is needed.

This article provides a synthesis of insights I have derived from two decades of engagement with various ecological monitoring programs around the world. I have had the good fortune to work on ecosystem monitoring programs in Brazil, Russia, Tanzania, the United States, and Galapagos. My intent is not to provide a detailed blueprint for monitoring the Galapagos; this can only be done successfully through an extended and collaborative process. My aim is to provide some novel perspectives on the current state of ecosystem monitoring around the world, which will help advance the discussion on how we might comprehensively monitor the Galapagos ecosystem.

Scientific evidence as the basis for decision-making

An effective program for monitoring the state of the Galapagos ecosystem should be about enabling scientific evidence to be the basis for decision-making. Of course, conservation is mostly about politics. We all know that. But over the last 100 years since the idea of conservation first became established in the western hemisphere, we have learned that ecosystems, species, and ultimately humans are best served over the long-term by decision-making based on the best available science. This has been the model, albeit imperfectly implemented, that has enabled the expansion of environmental conservation as a concern of modern human society. Decision-making based on science is not just good logic but also efficient because science, if done well, can point to useful solutions quickly. Moreover, science can provide an effective "shield" for management authorities trying to meet their long-term mandates in the face of constant political manoeuvres for short-term gain by opponents.

Science versus monitoring

The government of Ecuador has a mandate to protect Galapagos ecosystems and the services they provide. It is perhaps surprising then that there is no integrated scheme in place to monitor the Archipelago despite the recent and exponential rise in scientific studies there. But science is not monitoring. Many researchers travel to Galapagos to pursue their own interests, as the lack of researchers focused on the obvious problems facing Galapagos attests. So much research is done in Galapagos but what of it is relevant to Galapagos? Each study completed usually succeeds in generating interesting publications in prestigious scientific journals. Much of it includes recommendations for environmental management. But use of these scientists' reports by decision-makers is minimal. Unorganized, academic-driven science takes too long to be delivered. And when it is, its form is often incomprehensible to non-scientists and often simply irrelevant to begin with. Tracking what is happening in the Galapagos ecosystem, and forecasting its future, will require a program dedicated to that purpose.

Biodiversity monitoring as a priority

A comprehensive system for monitoring the Galapagos ecosystem would and should have a heavy emphasis on biodiversity monitoring. Many of the ecosystem services we rely on in Galapagos are in fact expressions of biodiversity. As such, the biodiversity of Galapagos contributes enormously to the national and even global economy. Yet it receives relatively little investment in return. This is not to say that biodiversity monitoring should be the sole focus – many physical, social, and economic aspects of the environment must be measured at the same time. But biodiversity monitoring should feature prominently in any monitoring scheme for the Galapagos ecosystem.

Distinguishing human impacts from natural changes

The stakes for sustaining a healthy biota are very high in Galapagos. Much of the Galapagos' economy is linked to its lucrative ecotourism industry. The connection between human welfare and biological health is powerful in Galapagos; perhaps nowhere else on Earth do so many people rely on their government to make good decisions about conserving biodiversity, both for the biota's sake and their own. An integrated and sensitive monitoring system can provide the information feedback loop required for distinguishing human impacts from natural changes, and thereby guiding development of effective management and policy. It can also provide the basis for the long-term forecasting that decision-makers find so useful. The challenge for Galapagos, where natural variability from year to year can be dramatic, is to develop a monitoring scheme that can identify the signal of human impacts among the often overwhelming and "normal" variability in the system associated with natural ecological cycles like El Niño.

Defining indicators through a collaborative process

Many more monitoring programs fail than succeed. And those that fail do so for many reasons. A common cause is that consensus was never reached among stakeholders on what needs to be measured (and paid for). We can't monitor everything. And the indicators we select must be measured in a repeatable and standardized manner to be able to detect change and provide useful information to managers. We must collaboratively develop measures of what we think represent the essence of the system and the interactions among its most important drivers. This assumes we know enough about the ecosystem to measure its most salient aspects and drivers. Defining these indicators collaboratively so that there is general endorsement across stakeholders is essential to the ultimate success of any monitoring program.

Decision-makers need a comprehensive and "scalable" monitoring system

To be useful to decision-makers, monitoring must be comprehensive at the level of archipelago. It is relatively easy to develop a monitoring program focused on a specific component of any ecosystem, optimized to a specific type of organism or spatial scale. But busy decision-makers need information at many spatial scales, from specific sites to the entire archipelago, and for many different kinds of issues. A fragmented approach to monitoring ecosystem components in isolation from one another is destined to fail. Moreover, any monitoring system needs to always take into account the underlying values and mandates that define the ultimate purpose of the monitoring.

The importance of community engagement

Environmental monitoring is most successful when viewed as a community enterprise. More specifically, monitoring programs thrive when linked directly to a variety of local institutions. For example, the museum and botany collections, labs, and ecological, cultural, and sociological studies that are necessarily part of an integrated monitoring system can be made directly relevant and useful to schools, NGOs, citizen groups, and various branches of government. The outcome is general support of the monitoring enterprise because these linkages ensure that monitoring will be part of a larger public scientific inquiry. Establishing these linkages and having clear policies on public data dissemination should be thought through and stated early; monitoring programs without open access to the information generated and broad participation in their development usually fail.

Re-envisioning who does the monitoring

While monitoring has traditionally been done by academic scientists, there are several problems with this "experts only" model. First, there are too few experts to do the work. Secondly, they are too expensive to rely on. Thirdly, they often lack the traditional knowledge and local experience to function well in the field. Local people, on the other hand, who are surrounded by the biodiversity of Galapagos, have accumulated much more knowledge than many academic researchers and are often heavily vested in learning about the environment upon which their livelihoods depend. This is not to say all local people have the time, skills, or inclination to participate, but many do. Identifying them and finding ways to engage them in respectful collaboration can solve many operational problems with monitoring programs. Citizen engagement likely has more potential to inform decision-making in Galapagos than anywhere in the world given the huge number of talented and concerned residents and visitors present in the Archipelago at any given time. Citizen engagement in ecosystem monitoring is also highly consistent with and supportive of national policies such as the Plan Nacional del Buen Vivir (SENPLADES, 2013), of which few other countries have any analog for the expectation of citizen involvement in the generation and interpretation of information for governmental decision-making.

New technology enhances monitoring and is cost effective

Return-on-investment is a perennial concern for monitoring programs. Monitoring is expensive and the data generated not always of obvious value. But technology for cost-effective monitoring is expanding at a tremendous speed. We can now communicate seamlessly and instantly around the world. An image someone in Galapagos takes of a cactus can be stored on a data server in China, measured by a person in Guayaquil, and the data analyzed by someone in Canada, with outputs that can assist decision-makers in Quito or Puerto Ayora. These new methodologies need to be leveraged.

How we gather monitoring data also needs to be re-envisioned. Monitoring is still equated with walking around with a notebook and binoculars, and writing down observations. But doing so is antiquated, expensive, and inefficient. There are stunning new ways of measuring the environment far more efficiently and comprehensively than were available even a decade ago. Sensor arrays, satellites, drones, and time-lapse cameras are examples. The challenge is deploying these new technologies intelligently and converting the ensuing information flood into timely and accessible knowledge.

This said, analysis of the state of the Galapagos environment without a continually refreshed sense of what things look like on the ground is going to fail. A strong connection of observation and data to direct field experience is essential to successfully interpret monitoring data no matter where it emanates from. This is to say that we must leverage the best from new information-rich technologies while continuing to ground truth the results, never losing the intuitive sense of how things work, which can only be gained from direct and frequent personal experience out in the Galapagos environment.

Monitoring costs much more than just data collection

New technology does not always generate a better approach for monitoring the environment. We are awash in information but starving for knowledge. The challenge is to sort through the best that new technologies offer and ignore the rest. We often give little thought to what to do with the data that pours out of monitoring schemes, whether generated by old-fashioned or modern methods. In fact, data management and communication is often an afterthought in the design of monitoring programs. Effectively analyzing the data collected and producing recommendations for management typically requires over half of the budget devoted to any successful monitoring program.

The importance of adaptability

Many have suggested that designing monitoring around a single question with fixed methods that do not change over time is the only way to proceed. But the reality is that methods change and so do the questions we want answers to. A successful system is one that adapts to new questions and new technologies in a timely fashion while serving the demands of the maximum number of stakeholders.

A good monitoring program not only looks backward at a baseline of historic conditions to measure change. It also enables one to look forward at a desired future state and measure where we are in relation to it. Having a clear approach for integrating data that addresses multiple and inevitably evolving questions, extending both backward and forward in time, greatly enhances the utility and longevity of any monitoring program.

Conclusions

The "dashboard" of an automobile, which displays a set of simple, informative, and timely indicators about the state of operation of a very complex machine, provides a good analogy for what we need for tracking the "vital signs" of Galapagos. An "ecosystem dashboard" for measuring what is happening in Galapagos would well serve many decision-makers charged with the responsibility for the fate of the natural ecosystem and the human population of Galapagos, which are ultimately and intimately tied together.

Could we develop a system to improve our understanding of and ability to forecast the impacts of climate change, land use change, visitor impacts, invasive species, and changing economies and human communities on biodiversity and ecosystem function? The program would need to focus on key questions and uncertainties facing Galapagos, be relevant both to specific sites and to the Archipelago as a whole, and rely on novel, cost-effective approaches including public participation. Virtually all data would be open access to enable scientists, educators, planners, and decision-makers to map, understand, and predict primary effects of humans on the natural world and effectively address crucial questions and issues, not just for management but for science.

Is it possible to develop a reliable "ecosystem dashboard" for Galapagos? Do we have a sufficient shared sense of mission to conserve to develop one? Can we think critically and collaboratively about how Galapagos "works" to identify the key indicators we need to measure and monitor? What would it cost? Who and how would we pay for it? What would it deliver and by when?

There is great potential to develop an exemplary, integrated system for monitoring the Galapagos ecosystem. How we track the environment is changing dramatically and there is renewed interest around the world in the importance of monitoring for effective decision-making. Several decades of ecological monitoring have revealed what is problematic and what is useful for decision-making. Based on these experiences, perhaps it is time to proceed with re-envisioning what is required to build an integrated system for monitoring the Galapagos ecosystem and ensure it is an inclusive and relevant enterprise.

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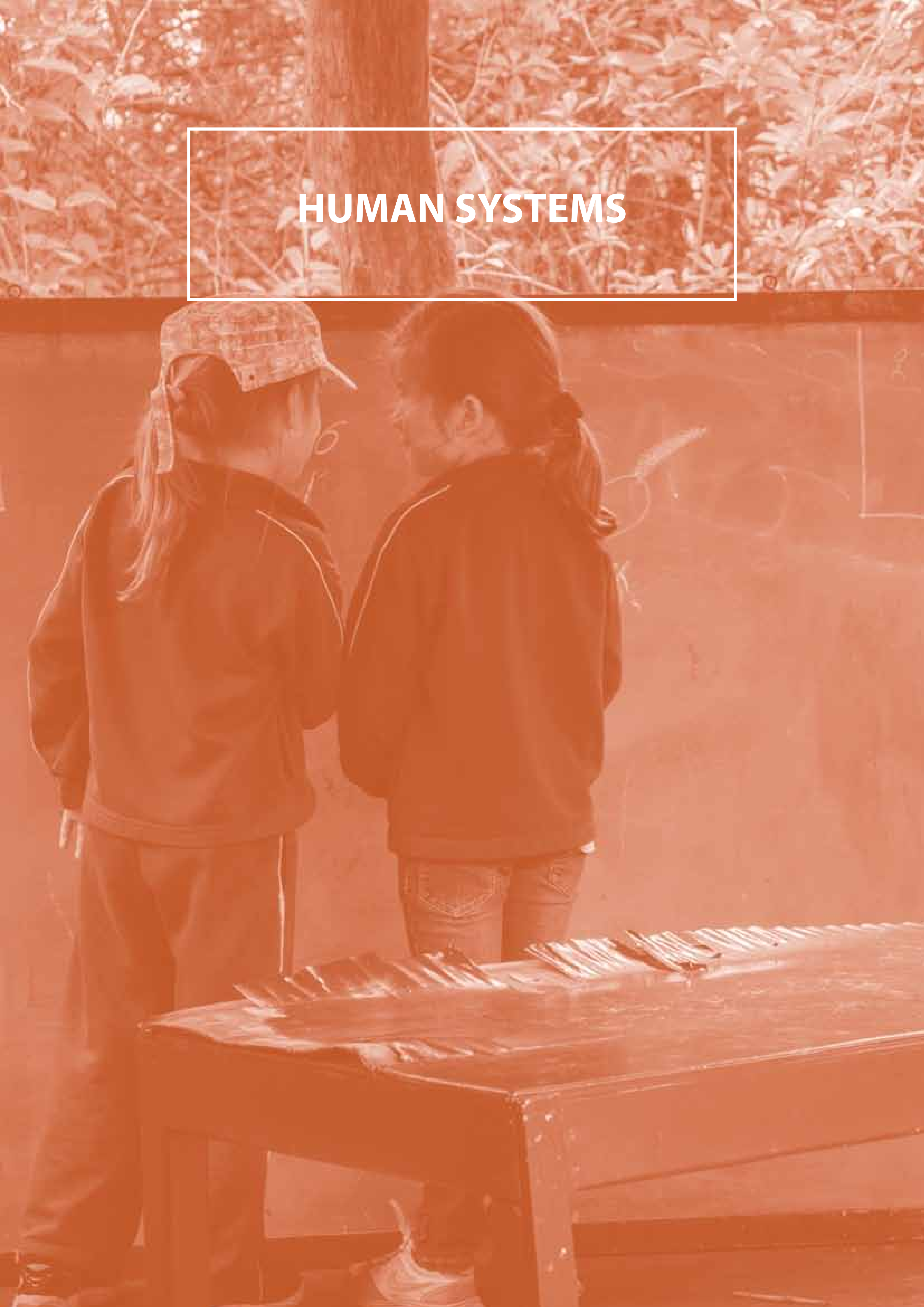
HUMAN SYSTEMS



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Bioagriculture: An opportunity for island good living

Juan Carlos Guzmán and José Enrique Poma

Ministry of Agriculture, Livestock, Aquaculture, and Fisheries

Introduction

In June 2013, the Ministry of Agriculture, Livestock, Aquaculture, and Fisheries (MAGAP – Spanish acronym), in agreement with the Ministry of the Environment, presented to the Presidency of the Republic the guidelines of the Bioagriculture Plan for Galapagos. The purpose of the Plan is to reposition agriculture in Galapagos as an activity that can contribute to food sovereignty of the local population and decrease the incidence of invasive plant species. Agriculture has a direct impact on invasive plant species through control of invasives by farmers, and an indirect impact by providing fresh food to the local market, thereby decreasing food imports from continental Ecuador and the accompanying risk of entry of new invasive species.

For decades, agriculture in Galapagos was seen only as causing the arrival and proliferation of invasive species, so neither the government nor the local community paid it much attention. Information now exists that shows the direct relationship between abandonment of agricultural land and the subsequent increase of area affected by invasive plant species. This article explores the need to implement the Bioagriculture Plan for Galapagos, and describes its key components.

Agriculture and invasive plant species

The abandonment of agriculture in Galapagos is evident, as noted within the context of total population growth, where the economically active population (EAP) working in agriculture has declined significantly (Figures 1 and 2).

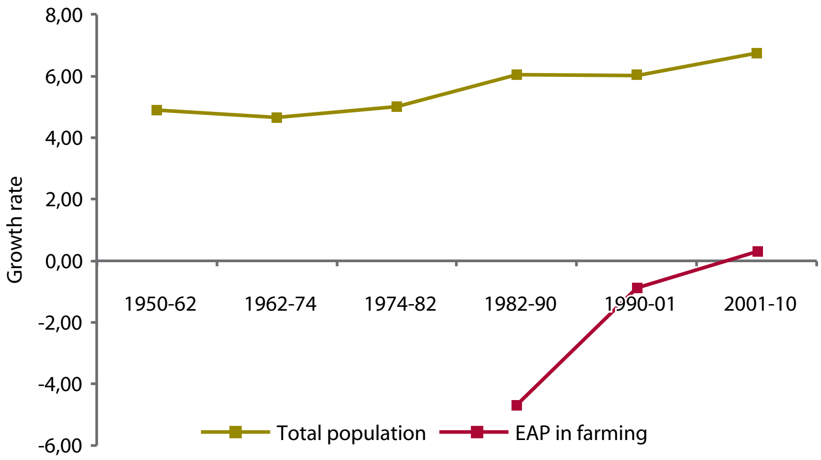

Figure 1. Evolution of the growth rates of the total population and the Economically Active Population (EAC). Source: INEC Censos Nacionales de Población y Vivienda 1950 – 2010; Censo Galápagos 2006.

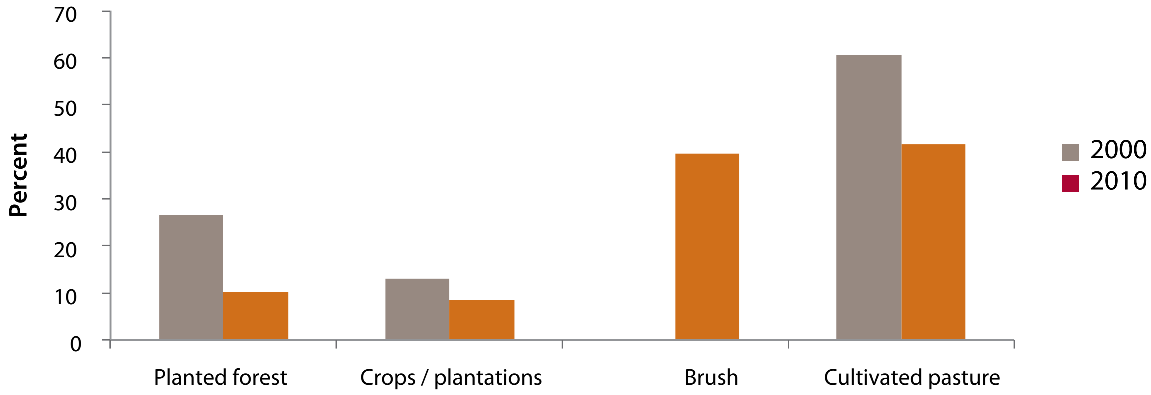

Figure 2. Changes in land use in the agricultural zone between 2000 and 2010. Source: INEC - Censo agropecuario nacional, 2000; Catastro rural SIGTIERRAS, 2010.

The rural cadastre completed by the National System of Information and Management of Rural Land (SIGTIERRAS – Spanish acronym) in 2010 delineates the vegetation cover and land use within the agricultural zone, indicating that 9143 ha (37% of the agricultural zone) are affected by invasive plant species. The situation is most severe in San Cristóbal, where approximately 60% of the agricultural area is affected. Also a lower proportion of the population lives in the rural sector (10.7%) on San Cristóbal, compared to 17.5% in the Galapagos Province in general (INEC, 2010).

Table 1. Land use in the agricultural zone by canton-island.

Land use	Isabela (ha)	Santa Cruz (ha)	San Cristobal (ha)
Mountains and forests	367	2180	1404
Permanent crops	217	822	635
Annual crops	49	72	132
Invasive species	2307	2311	4525
Pasture	2103	5840	1609
Total	**5042**	**11,224**	**8306**

Using the same SIGTIERRAS information and maps developed by the Charles Darwin Foundation (CDF/GNPS, 2006; Gardener *et al.*, 2011), the area covered with the most common invasive species has been determined by island. Within the agricultural area, guava (*Psidium guajava*) is the most widespread species, occupying 63% of the agricultural zone affected by invasive species. The least affected island is Floreana, where only 8% of the agricultural area is affected by invasive species.

However, there is evidence that farmers can manage and control invasive species. It is widely known that in El Cascajo, a farming area on Santa Cruz with small land owners dedicated to the production of vegetables, invasive species are not a problem. In 2001-02, in the sector of San Joaquín in San Cristóbal, 34 families recovered 350 ha of grassland that had been invaded by blackberry (*Rubus niveus*) and guava, with modest support from the IPADE-FUNDAR project. The blackberry was eradicated and any seedlings that sprout in isolation are eliminated as are all other undesired species. The few guava trees purposely left scattered throughout the grasslands form part of a silvopastoral system managed by the farmers.

Labor available to the agriculture sector

According to data from the latest population and housing census (INEC, 2010), there were 762 individuals working in the agriculture sector in Galapagos, which represents one farm worker for every 31 ha of agricultural land. At the national level, there is an average of one worker for every 10 ha.

Even leaving out the agricultural area covered by invasive species, it appears that that the current agricultural workforce in Galapagos is insufficient to meet the needs of the sector. However, these figures may be low because a significant portion of the agricultural workforce comes from family farms where family members often have other occupations and devote their surplus time to agricultural

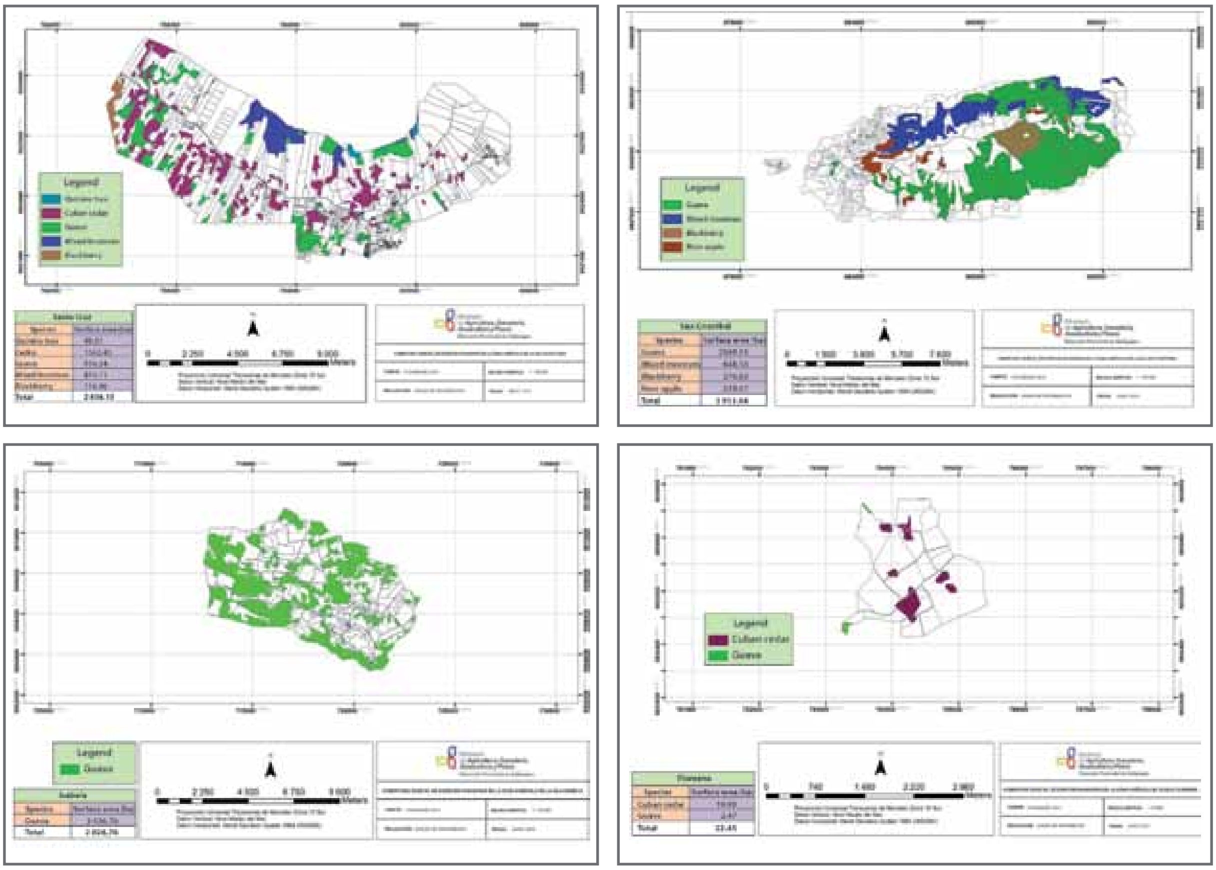

Figure 3. Invasive plant species cover by species and island. Source: SIGTIERRAS, Catastro rural 2010

activities; these family members are not reflected in official statistics. Additionally, a large number of agricultural workers have not established their residence status in Galapagos, which contributes to the lack of clear figures related to "insufficiency of the local workforce."

A set of factors explains, in varying degrees, the shortage of labor in the agricultural sector. Tourism generates 43% of the gross domestic product (GDP) of the province and experienced an average annual growth rate of 19.8% from 2006 to 2011, while the agriculture sector decreased by 31.3% during the same period (Utreras *et al.*, 2014).

Not only are agricultural activities less well paid, in general agriculture is not valued by the society as a whole. In addition, the presence of invasive species, such as ants, creates an inhospitable environment for the activity. Finally, the immigration system in Galapagos involves a series of restrictions for hiring workers from outside the Archipelago.

The Bioagriculture Plan for Galapagos

Effective implementation of the Bioagriculture Plan for Galapagos is essential in order for agriculture to reclaim its important role in Galapagos. Making agriculture profitable requires improving the quality of production, and producing safe and nutritious food using ecofriendly methods. This recovery should also ensure the health of farmers, consumers, and the environment. To achieve this requires the support of the whole of Galapagos society and its institutions. The proposed transition process requires that farmers have access to production factors and continual training opportunities.

Agriculture for life, proposed in the Bioagriculture Plan for Galapagos, relies on the diversification of agro-ecosystems, through polyculture, crop rotation and association, and the design and implementation of agroforestry systems. The Bioagriculture Plan proposes to increase productivity per area, promoting the generation of biomass and nutrient recycling, and contributing to the establishment of microclimates to reduce moisture loss caused by the direct impact of air flow and solar radiation on the ground. It promotes synergetic cultivation and breeding systems that favor trophic redundancy and allow a reduction in the use of fertilizers, pesticides, and other external inputs, as well as generate greater resiliency to changes in climate. Diversification of production systems also provides a variety of food products for personal consumption and local markets, which ultimately builds socioecological resilience (Nicholls, 2013). This approach is widely accepted "as a means of improving the resilience and sustainability of food systems; agro-ecology is supported by an increasing number of experts within the scientific community and agencies and international organizations such as the Food and Agriculture Organization of the United Nations

(FAO), the United Nations Environment Program (UNEP), and Biodiversity International. Also it is gaining ground in countries as diverse as the United States, Brazil, Germany, and France" (UN, 2011).

In this context, Galapagos needs mechanisms that connect producers with consumers. It is essential to reduce the margins earned by commercial intermediaries, which erode the profits of farmers. It is important to actively promote responsible consumption, raise awareness, and motivate and educate at all levels, not just within the formal education system. MAGAP, in collaboration with Conservation International, has begun a campaign involving 18 institutions to promote local production and consumption. Appropriate spaces must be created to facilitate direct contact between producers and consumers and to enable not only the sale and purchase of goods, but also a broader range of relationships to enhance the exchange of knowledge, building identities, strengthening societal cohesion, and reinforcing a sense of citizenship.

The social dynamics and synergies between farmers and consumers differ according to circumstances and context. In continental Ecuador, the majority of production, exchange, and consumer networks have been promoted by producer groups such as the Agro-ecological Network of Loja (RAL – Spanish acronym) or the Ecuadorian Corporation of Biological Producers (PROBIO – Spanish acronym). Some networks, such as the Agro-Ecological Network of the Austro (RAA – Spanish acronym), have been promoted by public-private partnerships. In some of these associations, such as Agro-ecological Producers and Trade Association of Tungurahua (PACAT – Spanish acronym), the public sector plays a leading role. In all cases, there is a clear need and justification for public policies to strengthen and expand the networks (MAGAP, 2014). The special regime of Galapagos creates favorable conditions for participatory design of public policies to promote healthy food production, to make this production available to consumers, and to regulate the entry of foodstuffs that can be produced in the Archipelago.

Three specific objectives of the Bioagriculture Plan for Galapagos are:

1. Transform agriculture into the primary human activity in Galapagos in such a way that it contributes to the conservation of the natural heritage of Galapagos, especially with regards to controlling invasive species, through the design and implementation of highly efficient agro-ecological production systems.

2. Contribute to economic sustainability in Galapagos through the promotion of local markets that function under the principles of a social and solidarity-based economy.

3. Consolidate a research system based on dialogue, sharing knowledge, and expanding local capacity to create and innovate.

Perspectives

The new model of insular production represents a radical change in thinking about the development of the agriculture sector of Galapagos. It begins with an acknowledgement that the intrinsic characteristics of the ecosystem, as well as the will of the local society and the State are all vital to building a sustainable economic system that will address social and solidarity issues and helps achieve the goal of "good living" in Galapagos.

The role of MAGAP in relation to the implementation of the Bioagriculture Plan for Galapagos is to serve as the lead public organization of a multi-sector effort, in direct coordination with the Ministry of the Environment. This process is supported directly by the producers through the Farmers' Citizen Council of Galapagos (CCSC-G – Spanish acronym).

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Photo: © Megan O'Connor

Agricultural use of pesticides on Santa Cruz

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Introduction

Pesticide application within the agricultural sector of the Galapagos Islands has the potential to lead to environmental degradation and loss of ecological uniqueness. Currently, the resident and tourist populations of the Galapagos Islands are heavily reliant on food imports from the continent. The high agricultural demands of a growing community and tourist destination, along with the continual spread of invasive species, have put pressure on Galapagos farmers to adopt pesticides as a necessary tool (Figure 1). Understanding the current state of pesticide use on Santa Cruz is critical to developing appropriate policies and regulations to ensure island sustainability.

The goal of this research is to look at the current use of pesticides and what motivates farmers to use these pesticides. Understanding the factors that influence farmers to use or not use pesticides will benefit agricultural organizations and governmental institutions in policy development.

While there is a lack of research published on pesticide use in Galapagos, research in other Latin American countries demonstrates a series of fundamental influences on the behavior of farmers and their use of pesticides. A study in Costa Rica surveyed local farmers to identify their personal reasons for pesticide use. The study, along with several others, found that the use of pesticides is influenced by multiple factors, which are ingrained within the society's institutions, policies, economy, demographics, and the environmental attitudes of farmers (Galt, 2008; Ecobichon, 2001; Lichtenberg & Zimmerman, 1999).

Methodology

Twenty-seven farmer households in the agricultural region of Santa Cruz, out of a total of about 100 households, were surveyed during July and August 2012. Collectively, the surveyed farmers cultivate 197 ha of land. Each survey included 48 questions about farming experience and practices, economics, and environmental knowledge and attitudes. The sample of 27 farmers was chosen through convenience, but included farms within the three agricultural subsectors of coffee, open-field, and greenhouse farming.

The surveys were supplemented by ten interviews with knowledgeable individuals who offered diverse perspectives on and interactions with the agricultural and economic issues related to pesticide use and organic farming. Workshops were attended at the Ministry of Agriculture (MAGAP - Spanish acronym) and Agency for Quality Assurance of Agriculture (AGROCALIDAD - Spanish acronym) and backed up with extensive literature reviews to understand current policies.

Figure 1. Pesticide bottle in tree on Santa Cruz. Photo: @ Megan O'Connor

Results

Demographics

Demographic information is important for understanding what factors influence a community and where leverage points exist to create effective policies and programs (Table 1).

Of the surveyed farms, 85% sold their crops to the local markets; there is no export market for any of their crops. One organic farmer sold to a tourism venture. Many of the farmers also mentioned using their crops for private consumption, particularly within the households with income from other sectors. For example, many households consisted of three to five adults, not all of whom farmed as a full-time occupation. Many of those households relied on their crops for private consumption, as opposed to income generation.

Table 1. Demographics of the 27 farmer households included in the survey.

ITEM	RESULT	
Average age	47	
Birthplace	**Galapagos**: 15%	**Mainland:** 85% (48% from Loja)
Farming as primary source of income	Yes: 81%	No: 19%
Average size of farm (ha)	14.4	
Average number of adults in household	3.2	
Average number of minors in household	1.5	
Average highest level of education	Secondary school	
Average highest level of education within immediate family	Secondary school	
Agricultural coursework taken	Yes: 67%	No: 33%
Knowledge of organic agriculture	Yes: 89%	No: 11%
Use of pesticides	Yes: 67%	No: 33%

In Galapagos, due to migration regulations and a strong economic incentive to work in the tourism industry, the pool of individuals available for agricultural labor is very small (Lu *et al.*, 2013). Farmers with larger properties are more able to afford the cost of labor (US$25-35/day), which can be almost five times the cost of labor on mainland Ecuador (Pui pers. comm., 2012; Brewington, 2011).

Results of the surveys indicated that the level of education is an important factor determining pesticide use, along with the size of the farm. Three basic categories of education and pesticide use emerged.

Group 1 included farmers with higher levels of education (secondary through university) and large tracts of land (greater than 15 ha). This group was likely to use pesticides. These farmers were often relatively wealthy in comparison to the other farmers. The use of pesticides is often more prevalent when farmers supervise the pesticide application but are not physically involved in it. Therefore, farmers with sufficient capital to hire workers and who own larger tracts of land are more likely to use pesticides. The exception to this was the one organic farm that partnered with a tourism venture to provide natural, organic food, and to give tours to select groups of visitors.

Group 2 included farmers with higher levels of education (secondary through university) but with smaller tracts of land (less than 15 ha). These farmers were less likely to use pesticides. Many of the farmers within this group or members of their immediate families attended university, bringing back effective methods for manually controlling invasive species or alternative means to generate income. Many of these farmers belonged to agricultural groups that worked with MAGAP to develop organic techniques. Awareness of alternative farming methods through coursework and collective action within community groups has helped to shape the decisions and behaviors of these farmers.

Group 3 included farmers with lower education and smaller tracts of land (all less than 15 ha). These farmers had a higher tendency to use pesticides. This could be related to their level of education, but other potential factors included their desire to maintain a high enough yield to sell produce at the local farmer's market and/or that they had multiple jobs and the land they farmed was used to supply food for their entire family.

Invasive species

All of the farmers surveyed reported that invasive species were a problem on their land. The most frequently cited invasive animals included ants, rats, slugs, and wasps, while the most frequently cited invasive plants included blackberry, lantana, guava, and elderberry.

These results correspond with the Galapagos National Park's list of the most aggressive invasive species in Galapagos (GNPS, 2009). With ever-increasing resident and tourist populations, the invasive species problem is likely to expand. A study in 2011 showed that 22% of households that were interviewed had abandoned their farm properties due to invasive species and 84% of interviewed farmers identified invasive species as a threat to their production (Brewington, 2011).

Three farmers reported that they previously used pesticides but had since converted to organic farming. Each claimed they had used pesticides on farms (not necessarily their own) in the past when it was necessary to reduce labor costs or effectively control pests. The six farmers who stated they had never used pesticides cited the following reasons: it is bad for their health, too difficult to do, or too expensive.

The farmers who consistently used pesticides indicated that they used them under the following conditions (numbers in parentheses indicate the number of farmers):

- After the initial planting regardless of evidence of pests (3);
- When problems (pests and plagues) began to present themselves (11);
- To improve the harvests and reduce the costs of production (2);
- To improve the leaves of the plants (1);
- Due to the number of pests/prevent the number from increasing (3);
- For the ability to quickly control pests (12).

Environmental attitudes

Farmers who were concerned about pesticides affecting their health, their family's health, the ecosystem, the wildlife, and the water supply, were predominantly organic farmers who exhibited conservation habits (Figure 2). However, only 33% of those surveyed farmed organically, while 49% of surveyed farmers were worried about the effects of pesticides. This result aligns with previous research, as farmers may worry about pesticide use, but may not be able to change their behavior due to the perception or presence of barriers, including pesticide dependency, invasive species growth rate, or inability to hire help (Lichtenburg & Zimmerman,1999; Tanner, 1999).

Results of the surveys and interviews highlighted a number of variables that influence decisions by farmers regarding pesticide use (Figure 3). While this article predominantly focuses on the individual farming households, it is important to note that the inability of some policy-making

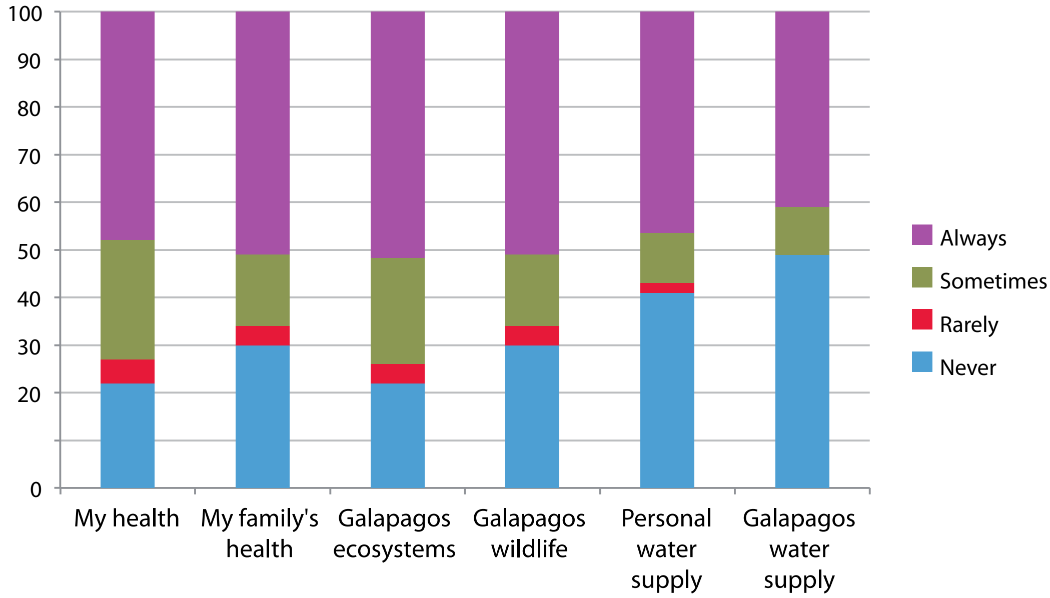

Figure 2. Environmental attitudes of the farmers included in the survey, in response to the statement, "I currently worry about pesticides affecting ..."

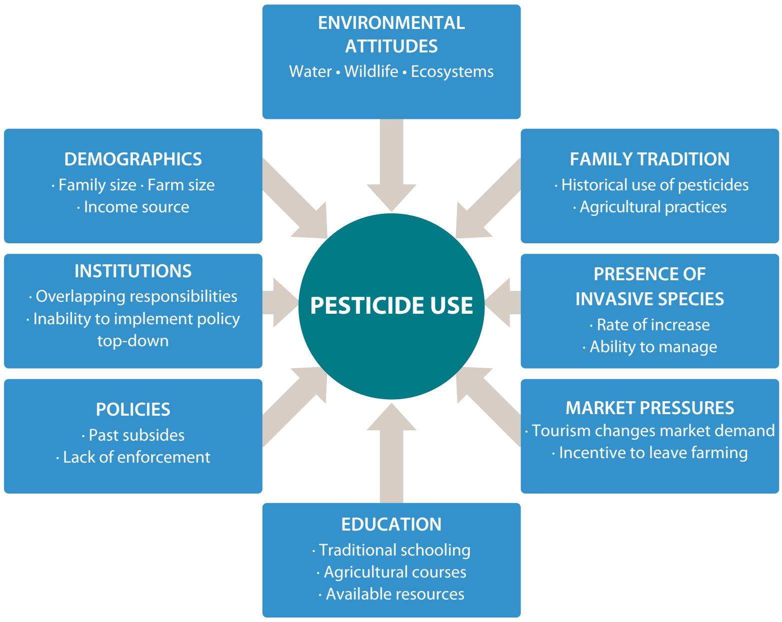

Figure 3. Variables that influence farmers' decisions regarding pesticide use.

institutions on the island to enforce their policies likely plays a role in the availability of banned pesticides and lack of public awareness of updated regulations.

Conclusions and recommendations

Based on the results of this pilot study of pesticide use in Santa Cruz, we recommend that a more comprehensive study be carried out to gather information on the actual application frequencies, quantities of applied pesticides, and impacts on soil and water. Although the pesticides reported in this study do not have high environmental toxicities, soil and water sampling may highlight risks related to application patterns and/or interaction with the island's subsurface structure.

The three major leverage points for altering pesticide use in Galapagos are the level of education, environmental attitudes, and the role of the local market. The following two recommendations interact with one or more of these leverage points.

1. Increase learning and training opportunities to expand knowledge and raise awareness of organic

practices, proper application techniques for pesticides, alternatives for pest control, health, and environmental connectivity, and the economics involved with local agricultural markets.

2. Strengthen incentives for partnerships between the tourism sector and organic farmers to create a greater local market for organic produce. A locally implemented organic certification program might involve "participatory guarantee systems" or PGS. Facilitated by the International Federation of Organic Agriculture Movements (IFOAM), PGS is a means for organic farmers to establish a local market with the help of nonprofits and to provide organic produce to shareholders; local farmers are encouraged to collaborate with individuals who will purchase the final organic product (IFOAM, 2014).

Eliminating pesticides in Galapagos through a ban on their use would be premature and could negatively impact farmers at the moment that there is a growing need for local production.

Using the recommendations listed above, appropriate pesticide use and alternative methods of producing high quality crops may in itself reduce the level of pesticides used.

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Maintaining the environmental quality of Galapagos: A commitment of all

Jorge Carrión-Tacuri, Luis Mora Andrade and Daniel Lara Solís

Galapagos National Park Directorate

Introduction

The conservation and responsible use of the natural resources of the Galapagos National Park and the Galapagos Marine Reserve are the responsibility of the Ministry of the Environment through the Galapagos National Park Directorate (ME-GNPD). Three percent of the land area of the Galapagos Islands is occupied by a resident population with one of the highest growth rates in the country. The population, which depends largely on environmental services generated by the protected areas of Galapagos, produces a wide range of impacts, needs, and pressures on these ecosystems and significant challenges for ecosystem managers.

The increase in Galapagos tourism also means an increase in infrastructure to expand capacity (hotels, boats, transportation, access to visitor sites, basic services, etc.). This, in turn, requires an increase throughout the province of commercial, production, and extractive activities (cargo shipments to Galapagos, crops, fisheries, and requirements for sand, gravel, and crushed rock, etc.), which without proper planning and structure can lead to the deterioration of environmental quality in populated and protected areas.

The National Park and the Marine Reserve are protected areas that are unique in terms of their isolation, biodiversity, conservation status, and the environmental services they provide for the human population living in the province. The new Management Plan for the Protected Areas of Galapagos for Good Living (DPNG, 2014) lays out integrated management strategies for both protected and populated areas of Galapagos to protect these environmental services.

In Ministerial Agreement (MA) 065, issued on July 17, 2009, the Minister of the Environment authorized the Director of the Galapagos National Park (GNP) to exercise certain powers regarding environmental quality within the jurisdiction of the Galapagos National Park Directorate (GNPD), specifically the issuance of Intersection Certificates indicating whether a given project intersects with a protected area and review of environmental permits and environmental impact studies. Likewise, in MA 100, published in the Official Registry No. 766 on August 14, 2012, the Minister of the Environment authorized the Director of the GNP to issue environmental permits on behalf of the Ministry, except in the case of projects considered of strategic or national interest. These two ministerial agreements were later repealed and the powers related to environmental quality, issuance of environmental permits, and oversight, have been unified in MA 268 published in the Official Registry No. 359, on October 22, 2014.

In addition, in MA 256, published on August 20, 2014, the Minister authorized the Director of the GNP to exercise the functions of a Natural Heritage Unit of the Ministry, which includes developing technical reports and approving feasibility studies related to projects that intersect with the protected areas of Galapagos.

Environmental regulations related to projects, construction, or other activities in Galapagos and in mainland Ecuador are based on the Catalogue of National Environmental Categorization (CCAN – Spanish acronym) issued through MA 006 on February 18, 2014.

This framework was established based on the potential risk or impact that different activities could have on the social and natural environment (Table 1). These regulations are implemented through the Special System for Environmental Information (SUIA - Spanish acronym) of the Ministry of the Environment.

This article aims to analyze the progress of the GNPD in implementing the powers delegated by the Ministry of the Environment to regulate projects, construction, and other activities in the Galapagos province and to mitigate their impacts.

Table 1. Categories established by the Ministry of the Environment to environmentally regulate all activities carried out in Ecuador, considering the impact or risk of the activities for the environment and human health. Source: Ministerial Agreement 006-2014.

CATEGORY	IMPACT / RISCK	INSTRUMENT	ADMINISTRATIVE AUTHORIZATION
I	Insignificant	Environmental register	Environmental Registration Certificate
II	Low	Environmental data sheet and environmental management plan	Environmental Permit Category II
III	Moderate	Declaration of environmental impact and environmental management plan	Environmental Permit Category III
IV	High	Environmental impact study and environmental management plan	Environmental Permit Category IV

Methods

This article reviews the Ministerial Agreements mentioned previously, as well as the records and databases associated with the Process of Environmental Quality of the Environmental Management Directorate of the GNPD, in order to determine the GNPD's progress in the emission of environmental permits in the province of Galapagos.

For each project, the level of compliance associated with an environmental permit is calculated as a percent, based on assessments of compliance for each obligation. Levels of compliance with environmental management plans (measured in percent) correspond to inspections carried out in 2014.

Environmental regularization and control in Galapagos

The Ministry of the Environment issued 12 environmental permits for projects in Galapagos during the period 2002-09, prior to delegating this authority to the GNPD (Table 2).

Table 2. Number of environmental permits issued per year for projects in Galapagos (2002-2014). Source: Environmental quality GNPD.

Category	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	TOTAL
0	0	0	0	0	0	0	0	0	0	0	0	0	7	**7**
II	0	0	0	0	0	0	0	0	1	0	2	15	21	**39**
III	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
IV	1	0	1	1	3	1	2	11	8	12	15	21	12	**88**
TOTAL	1	0	1	1	3	1	2	11	9	12	17	36	40	**134**

The number of environmental permits issued has increased exponentially since the Ministry of Environment delegated this responsibility to the GNPD, with a total of 134 issued as of 2014, including seven Category I permits (Figure 1).

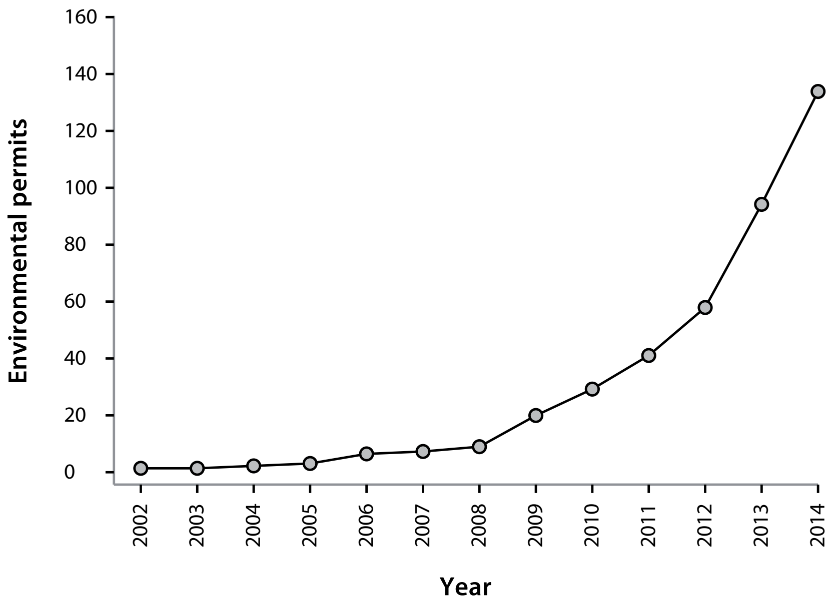

Figure 1. Annual increase in the number of environmental permits issued for development projects in Galapagos; GNPD took over the power of issuing permits in 2009. Source: Environmental Quality GNPD.

Environmental permits are issued in Galapagos in nine well-defined sectors. The majority of permits are issued for the tourism boat sector (45), followed by hotels (14), telecommunications (14), sanitation (13), electrical projects (7), airport (4), hydrocarbons (4), hazardous and special waste management (4), and other infrastructure and roads (29; Figure 2).

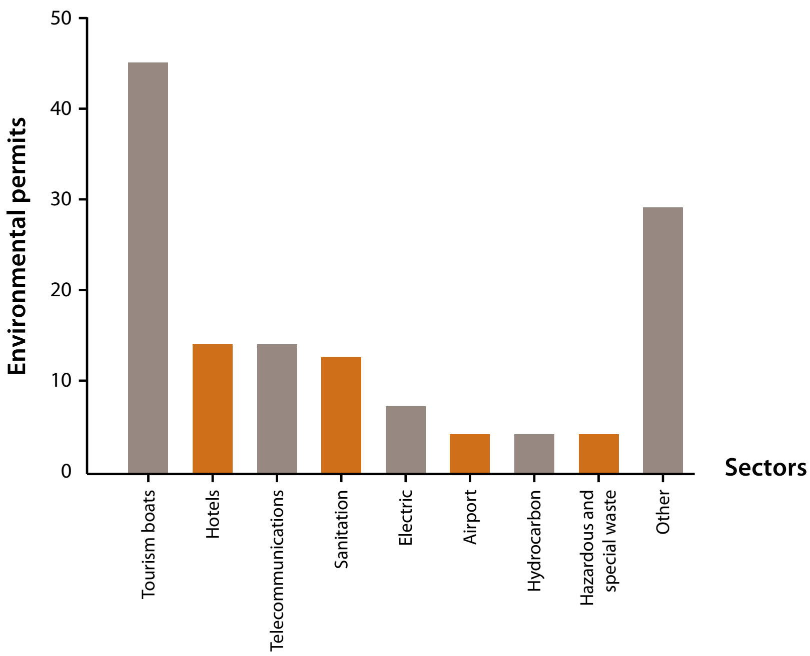

Figure 2. Breakdown by sector of environmental permits issued to development projects in Galapagos from 2002-14. Source: Environmental Quality GNPD.

The increase in the number of environmental permits requires greater environmental oversight and control of compliance with the permits and management plans, which the GNPD exercises through preventive and compliance inspections, responding to environmental complaints, and reviewing self-monitoring reports and environmental audits. The most common obligations associated with environmental permits include: submission of environmental audits; submission of quarterly, biannual, or annual self-monitoring reports (frequency depends on the permit category); maintaining a valid compliance insurance policy for the execution of the environmental management plan; and annual renewal payments. The percentage compliance for each permit and plan is based on the analysis of documentation submitted to the GNPD and the results of on-site inspections.

From 2012-14, compliance with environmental permit obligations increased annually from 33.5% in 2012, to 41.7% in 2013, and 51.0% in 2014. Beginning in 2014, an inspection schedule was implemented to verify the level of compliance with the environmental management plans. The results of 33 inspections revealed an average compliance of 83.9%.

The hydrocarbon sector demonstrated the highest level of compliance with environmental management plans, followed by the tourism boat and hotel sectors. The sanitation sector had the lowest level of compliance (Table 3).

Table 3. Sectors with permitted projects and average percentage of compliance with the environmental management plan. Source: Environmental Quality GNPD.

Sector	Inspections completed	Projects with Environmental Permit	Compliance with EMP (%)
Hydrocarbon	1	4	90,0
Hotel	2	14	89,0
Tourism boat	21	45	88,6
Telecommunications	1	14	87,5
Airport	2	4	82,8
Sanitation	6	13	64,6

Conclusions and recommendations

The environmental management plan associated with the environmental permit issued for each project helps to ensure that a project adheres to environmental regulations and guidelines, and prevents or mitigates negative impacts while maximizing positive effects. Despite resistance by certain sectors, the GNPD is fulfilling the responsibilities delegated to it by the Ministry of the Environment, as reflected by the exponential increase in the number of environmental permits granted. This delegation of authority allows the environmental authority in Galapagos, the GNPD, to maintain greater control over projects that intersect with protected areas, as well as those that pose environmental risks to the same, and with potential impacts on the good living of the resident population.

The hydrocarbon, hotel, and tourism boat sectors have the highest level of compliance with environmental management plans, which translates into eco-friendly project execution that benefits Galapagos ecosystems and their users. The sanitation sector (projects related to sewage, drinking water, etc.) have the lowest levels of compliance, resulting in increased levels of contamination (MAE-DPNG, 2014), which affects environmental quality of ecosystems and human health.

Article 14 of the Ecuadorian Constitution ***recognizes the right of the population to live in a healthy and ecologically-balanced environment that guarantees sustainability and good living, sumak kawsay.*** This is the foundation for policies, laws, rules, and regulations aimed at preserving the natural environment and its environmental services for the benefit of society.

Maintaining the environmental quality of the ecosystems of the protected areas of Galapagos is essential for preserving biodiversity and guaranteeing good living, as stipulated in the Ecuadorian Constitution. However, maintaining environmental quality requires collaborative efforts of those who manage the archipelago and the users of services generated by Galapagos ecosystems.

Based on this analysis, we recommend the following:

1. Advise/train project leaders regarding the process of obtaining environmental permits in order to speed up the process and increase the level of compliance with environmental management plans.

2. Prioritize environmental oversight of activities, focusing on projects with low levels of compliance with their environmental management plans.

3. Establish incentives that reward projects that comply with their environmental management plans and environmental regulations.

4. Increase the capacity of the Directorate of Environmental Management of the GNPD and the Environmental Quality Technical Units of Isabela and San Cristóbal to conduct all environment-related processes in a timely fashion and to track and monitor compliance with environmental permit obligations and the respective environmental management plans.

Photo: ©John Garate

Acknowledgements

The authors extend sincere thanks to the Environmental Quality staff of the GNPD of Isabela, San Cristóbal, and Santa Cruz, whose daily efforts make it possible to fulfill the responsibilities delegated by the Ministry of the Environment, and thus contribute to the conservation of the unique and fragile ecosystems of our province of Galapagos.

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Monitoring environmental indicators on Isabela Island to prevent and reduce pollution

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Introduction

Despite the progress in the conservation of the protected areas of Galapagos, little has been done to determine the status of the environmental quality in human-inhabited areas. Although the urban and rural areas of the Archipelago represent only 3% of the total area, they constitute one of the main sources of environmental pollution. In its recent Management Plan, the Galapagos National Park Directorate (GNPD) recognizes the Archipelago as a socioecosystem where there are permanent interactions between the inhabited areas and protected marine and terrestrial natural areas, and therefore a need for integrated management (DPNG, 2014). The GNPD is also responsible for developing the necessary mechanisms and strategies to achieve the highest standards of environmental quality, in coordination with municipal governments and Galapagos civil society.

Galapagos has lacked proper urban planning and technical capacity since the first human settlements. As a result, the resident population does not yet have basic services, such as potable water, storm drains and sewers, sewage treatment, and hazardous waste management. For example, hazardous waste is not managed as directed by the 142 Ministerial Agreement issued by the Ministry of the Environment (MAE, 2012). Also, studies of environmental contamination sites show evidence of negative impacts in protected areas as well as on human health.

A study in 2007 found that water sources in Santa Cruz and San Cristóbal are contaminated with fecal coliform (Cordova *et al.*, 2007a,b). Since that time no further studies or regular water quality monitoring has been conducted at source points. Water quality studies have also not been carried out at public recreation sites, and no information is available on soil contamination, even though pollution from fuel, oil, paint, solvents, and other substances used by mechanics and in boat maintenance workshops is obvious.

On Isabela one of the main problems is the lack of basic services for a growing resident and visitor population, which is also true for the other three cantons. According to the censuses of 2001 and 2010, the Isabela population grew by 39.3% in nine years, from 1619 inhabitants in 2001 to 2256 in 2010. This growth rate is higher than on Santa Cruz (35.1%) or San Cristóbal (32.7%) during the same period (INEC, 2001 & 2010). The number of tourists increased by 46.7% in the five years from 2003 to 2008 (GADMI, 2010).

Unplanned development can potentially contribute to a deterioration of water, soil, and air quality.

Water: The quality of the water resource is the most vital in terms of public health due to its scarcity and its direct use and consumption by the population. In 2009 it was estimated that approximately 70% of diseases in Puerto Villamil resulted from consumption or exposure to contaminated water (Walsh *et al.*, 2010).

Soil: Soil contamination issues are not perceived to be as urgent or in need of attention as water contamination, because the pollutants do not disperse as quickly in soil as they do in water. However, some highly mobile soil contaminants can reach the water table and contaminate water resources. This is particularly dangerous given that the local geology is characterized by a thin layer of soil and fragmented rock with high permeability.

Air: Air pollution in populated areas is a site-specific problem and depends solely on the location of the few potential sources of pollution (e.g., power plants). However, air pollution can become a public health problem when allowable limits are exceeded at these sites.

In view of the lack of available data, WWF and the Autonomous Decentralized Municipal Government of Isabela (GADMI – Spanish acronym) began a process to develop baseline information on current primary sources of contamination, generate indicators that will allow continued monitoring of pollution levels, and develop environmental management action plans to mitigate these sources of pollution.

Methods

The monitoring sites for examining water, soil, and air quality were defined according to the information provided by GADMI, as well as at potential contamination sites (Figures 1, 2 and 3).

Figure 1. Location of water quality monitoring sites in Puerto Villamil.

Water: To determine the quality of water piped for domestic use, the four water catchment sources were used: Chapin I, Chapin II, Manzanillo, and San Vicente. In some houses, tap water was also examined to identify possible in-transit contamination due to contact with wastewater from leaking pipes. To determine seawater quality at recreation sites, the following sites were selected: the Embarcadero (due to the presence and maintenance of boats) and Estero and Concha de Perla (both tourism sites). It was important to also determine the water quality in the crevice at the municipal workshops (Grieta de los Talleres) because this source provides water to 10 families in the Pedregal neighborhood. Wastewater was also monitored. Sampling was conducted five times over a four-month period, with a total of 240 individual samples collected. The following water quality parameters were analyzed in a certified laboratory: general parameters, heavy metals, hydrocarbons (PAH, TPH), anions, biological parameters (chemical oxygen demand – COD; biological oxygen demand - BOD), total coliforms, fecal coliforms, and chlorophyll a. Direct measurements were also made of: conductivity, dissolved oxygen, total dissolved solids (TDS), pH, redox, and temperature. The water sampling methodology was carried out according to the standards of the Ecuadorian Institute of Standardization (INEN – Spanish acronym)[1].

[1]PAH: petroleum aromatic hydrocarbons; TPH: total petroleum hydrocarbons; COD: chemical oxygen demand; BOD: biological oxygen demand; TDS: total dissolved solids; SOX: sulfur oxides; NOX: nitrogen oxides; MP: particulate matter; O3: ozone.

Soil: Soil monitoring was carried out at the following potential contamination sites: municipal workshops, Governing Council workshops, the gas station, the power plant, and the Embarcadero (for potential oil contamination). In addition, soil samples were collected from the four water catchment sources. Samples were also taken from the mud that accumulates at the sewage discharge site near the treatment plant. In total, two series of soil samples were collected over a period of four months. The samples were analyzed in a certified laboratory for the following: general parameters, heavy metals, and hydrocarbons (TPH).

Air: Air quality was monitored at five passive stations during a 30-day period: the power plant, the Embarcadero, municipal workshops, Governing Council workshops, and the municipal plaza. The towers of Chapin I and a weather station at the old police station were used as control sites. Air quality was determined by measuring the following: general parameters, SOx, NOx, PM, O3, and benzene.

Results of the analyses were compared with established national limits published in the Unified Text of Secondary Environmental Legislation of the Ministry of the Environment (TULSMA – Spanish acronym; MAE, 2003), which indicates the water quality parameters for: human consumption and household use, the preservation of the flora and fauna in marine waters and estuaries, and water discharge into the sea. This legislation also defines soil quality criteria for different uses and general regulations regarding the concentration of air pollutants. In the case of standards not included in TULSMA, parameters were compared with limits defined by INEN or with international standards, when national standards did not exist.

Figure 2. Location of soil quality monitoring sites in Puerto Villamil.

Figure 3. Location of air quality monitoring sites in Puerto Villamil.

Results and Discussion

Water quality

The results of the analysis of water sources varied significantly from site to site. Some samples showed extreme levels of certain contaminants (Table 1). This was expected because recharging the water sources is affected by the tides, and pollutants are diluted or concentrated according to water input (Table 1).

Certain findings require attention because of the deterioration of water quality and potential effects on health. Total dissolved solids exceeded the norm at all water sources in all surveys, due to the intrusion of seawater. The concentration of phosphate in all samples exceeded the limit set by INEN. High phosphate concentrations at water sources can result in a growth of algae that consume dissolved oxygen, which drastically lowers the water quality for human consumption and which can also cause kidney damage if the water is consumed in excess (Lenntech, 2013). Levels of manganese were also above the norm, which can change the taste of the water and stain kitchenware and clothing (OMS, 2006). Excess sodium alters the taste of the water (OMS, 2006). The most obvious contamination problems occurred in the water sources Chapin I and II, due to their proximity to the populated area and the improper design of the water catchment infrastructure.

The presence of fecal coliforms was detected on at least two occasions in Chapin I and II, with concentrations far above the norm (Table 2). The highest concentration of fecal coliform was in Chapin II with 90 MPN/100 mL, compared to INEN standards, which indicate a maximum limit of 1.1 MPN/100 mL. The analysis of the tap water of some houses in Puerto Villamil was characterized by high conductivity values and one of the samples showed the presence of fecal coliform, which can be produced by the contamination of piped water by wastewater due to sewage system problems on the island (Table 2).

Table 1. Analysis of water samples collected between May and July 2013 from domestic use sources indicate elevated levels in some parameters in comparison with the national norms established by TULSMA or in comparison with international standards in cases where no limits are defined by TULSMA.

Site	Chapín I	Chapín I	Chapín II	Chapín II	Manzanillo	Manzanillo	San Vicente	San Vicente	Maximum limit
N°. sample	I	III/V	I	II/III/V	I	III/V	I	III/V	TULSMA*
pH	7,5	s/d	7,2	s/d	6,9	s/d	7,5	s/d	6 – 9
Conductivity µS/cm	6280	6120	3820	3090	2430	1931	2290	1878	N/A
Dissolved solids mg/L	3454	s/d	2101	s/d	1336	s/d	1260	s/d	500
Total hardness mg/L	578	s/d	488	s/d	179	s/d	173	s/d	500
Dissolved oxygen mg/L	7,1	s/d	7,1	s/d	6,2	s/d	7,6	s/d	6
Chloride mg/L	1379	s/d	762	s/d	493	s/d	458	s/d	250
Phosphate mg/L	0,24	0,5	0,4	0,73	0,45	0,7	0,53	0,9	N/A
Chemical oxygen demand mg/L	14	30	18	3	10	5	3	N/D	N/A
Calcium mg/L	101	107	110	74	27	24	24	29	N/A
Strontium mg/L	1,4	1,7	1,0	0,87	0,21	0,17	0,17	0,19	N/A
Manganese mg/L	0,064	0,078	0,77	0,089	0,0029	N/D	N/D	N/D	0,1
Potassium mg/L	49	63	30	25	25	22	20	24	N/A
Sodium mg/L	820	1265	458	358	338	293	290	307	200

*MAE, 2003. Unified Text of Secondary Environmental Legislation of the Ministry of the Environment (TULSMA – Spanish acronym).

Table 2. Results of the analysis of fecal coliforms (MPN / 100mL) at water sources between the months of May-July 2013 (ND = not detected).

Sample	Chapín I	Chapín II	San Vicente	Manzanillo
I	ND	90	ND	ND
III	9,2	2,2	2,2	ND
V	ND	1,1	1,1	2,2

Some crevices on the island are used as a source of water for homes. The crevice located near the municipal and Governing Council workshops is used by 10 families. Presence of fecal coliform, mercury, and TPH was detected in this water source. TPH levels were 600 times above the norm set by INEN. The amount of mercury was above the established limit due to improper practices for managing paints and fuels in the workshops.

Levels of aluminum, copper, and mercury at the Embarcadero were above established limits, due to ship maintenance activities. The level of phosphates and nitrates at the Concha de Perla visitor site and the point of occasional wastewater discharge into the ocean was above the established limits set by the government of Queensland in Australia (Queensland Government, 2009). Phosphate-induced algae growth was confirmed by positive chlorophyll analyses at the point of wastewater discharge. Cesium (a radioactive element) was found to exist above the established limits in the water of Concha de Perla. The origin of this compound in the water is unknown; it could be the result of either natural or anthropogenic causes.

Soil quality

The results of the soil analyses show that copper, total chromium, nickel, molybdenum, lead, and zinc exceeded concentration limits at the workshops, power plant, and gas station. These compounds are present in a variety of anti-corrosive products, lacquers, paints, and fuels, all of which are commonly used at these sites. The presence of TPH in the soil is caused by improper handling of fuels. However, the presence of hydrocarbons at Estero and the Embarcadero requires a more detailed analysis as it could be due biogenic emissions (Campanioni *et al.*, 2007).

Air quality

The results of the air quality monitoring suggest that there are no air quality problems in Puerto Villamil.

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Recommendations

In terms of water resources we recommend:

- Use the water of the catchments Manzanillo and San Vicente for distribution via pipes to the public water system, due to the poor water quality of the water sources Chapín I and II.
- Build a new sewage system in Puerto Villamil. The current system is in poor condition and is potentially contaminating piped water used in houses.
- Regulate activities in the workshops to prevent pollution by hydrocarbons in nearby crevices.
- Regulate collection of used motor oil.
- Treat wastewater to prevent direct discharge into the ocean and prohibit the maintenance of boats in the sector of the Embarcadero.
- Install grease traps in restaurants in the central part of Puerto Villamil to reduce pollution from used vegetable oil.
- Conduct an in-depth study on the origin of cesium in the water at Concha de Perla.

In terms of the soil resource we recommend:

- Regulate the entry of lead-based paints and lacquers into the island.
- Rehabilitate the workshop facilities according to regulations in order to prevent the direct disposal of paints, lacquers, and fuels into the ground.
- Conduct more in-depth studies on the origin of hydrocarbons in sediments at Estero and the Embarcadero.

In order to improve overall environmental quality, we recommend the implementation of the Environmental Management Plan presented to GADMI authorities. This plan outlines prevention, control, and mitigation measures that must be initiated; a year-long monitoring of the environmental matrices; and the development of a manual of monitoring protocols and interpretation of results.

TULSMA is the legal regulation that defines the maximum levels of contaminants; however, it is a very general law and in several respects is inappropriate for the special conditions of Galapagos, which require stricter limits. It is essential to develop Galapagos-specific regulations that take into account human interactions with the ecosystem.

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Water supply assessment on Santa Cruz Island: A technical overview of provision and estimation of water demand

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Introduction

A growing local population and expanding tourism on Santa Cruz Island have increased pressure on natural resources, especially water. The urban population of Santa Cruz, the second largest island in Galapagos, equals nearly 60% of the total of the province and lives primarily in the major urban settlement, Puerto Ayora, and its fast growing suburb, Bellavista, located 7 km inland (GADMSC, 2012). Population growth in Galapagos has increased exponentially, in contrast to population growth in the rest of continental Ecuador (Figure 1). In addition, the number of visitors over the past two decades has increased from approximately 17,000 visitors per year in 1980 to 204,000 in 2013 (DPNG, 2014; Figure 2).

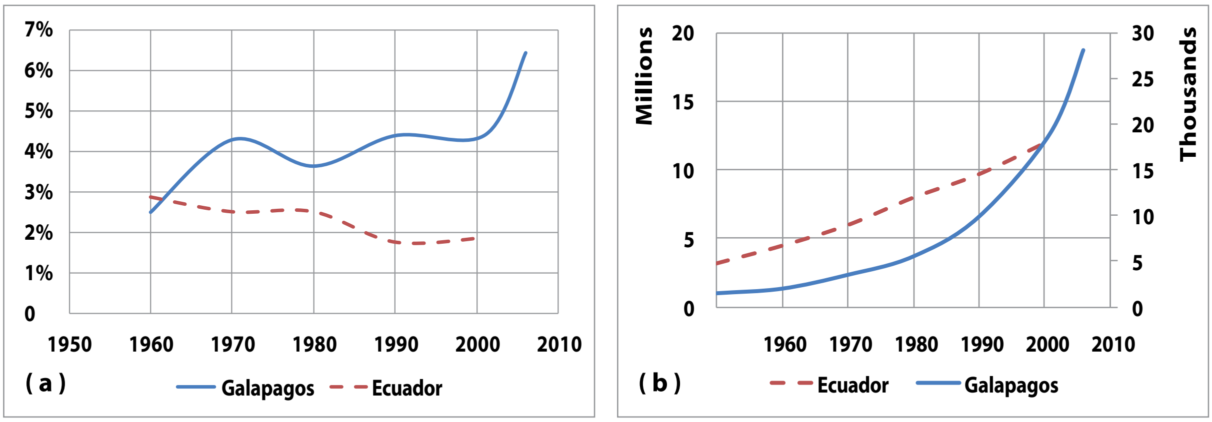

Figure1. Population growth rates (a) and population growth (b) in Ecuador and Galápagos (INEC, 2010).

The elevated immigration from the mainland has resulted in several collateral effects, such as an increased demand for basic services including the need for a reliable water supply system (GADMSC, 2012). Unfortunately, the municipal supply system has had difficulties coping with the current demographic growth due to financial constraints, lack of personnel, and fixed tariff structures. Water is perceived as scarce and service poor. In addition, water conveyed along the network is untreated and of very low quality. The high concentration of chlorides (from 800-1200 mg/L) causes it to be brackish and unfit for human consumption.

Several studies have confirmed contamination by *E. coli* and many water related diseases have been reported (Liu, 2011). Moreover, the water supply system is unreliable and intermittent, operating for an average of three hours per day. This limited service has resulted in inhabitants building their own supply and storage systems.

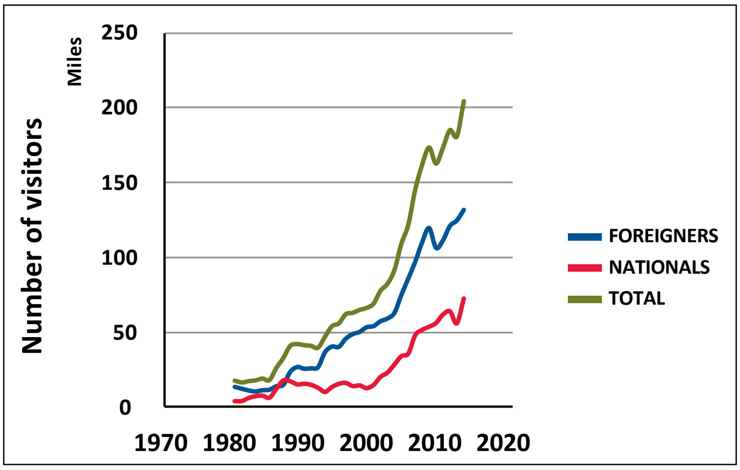

Figure 2. Number of national and foreign tourists entering Galapagos from 1980 to 2013 (DPNG, 2014).

Ever-increasing tourism in Galapagos potentially threatens both natural areas and resources, including water. However, documenting water consumption by large consumers such as hotels, restaurants, and laundries has been a challenge as the information available in public records does not always match reality. The Municipality of Santa Cruz has registered approximately 40 water connections in the hotel category, while the tourist authority (Ministry of Tourism) has a list of approximately 160 entities that provide accommodation. For this study, only information provided by the Municipality of Santa Cruz was used.

Currently, the Islands have low quality, contaminated, and undrinkable water. Furthermore, proper sanitation is lacking as a result of source contamination caused by the proximity of poorly built septic tanks in urban settlements, and aged and unreliable water distribution networks (Liu & d'Ozouville, 2013). These problems are primarily due to a combination of technical shortcomings, a decentralized water supply, lack of consumer awareness of water conservation, and inadequate water tariffs.

The Galapagos Islands are in urgent need of water management solutions. Some studies of water resources in Galapagos have been carried out in the past, but none of them assessed the overall water supply and demand situation in Santa Cruz. As a consequence, the implementation of management measures has been limited. Currently, no systematic solutions have been developed to respond to persisting water supply and sanitation problems. This study compiles existing information and identifies knowledge gaps.

The goal of this research was to analyze the current situation of water demand in the Galapagos Islands by carrying out an assessment of water supply and quantification of demand from surveys of the local population on Santa Cruz Island. The village of Bellavista, where water meters are used and demand is generally known, has more solid data, while surveys completed in Puerto Ayora only provide estimates of water consumption by category and source.

Water sources

Three main sources of water exist in Santa Cruz Island: 1) municipal supply; 2) bottled (desalinated) water, and 3) 'private' extractions.

The Municipality of Santa Cruz provides water through two independent and separate systems, one for Bellavista and the other for Puerto Ayora. Each system has its own extraction source, storage tanks, and network. The water is mainly brackish and consequently considered non-potable according to national and international regulations. Neither system includes water treatment.

Bottled water is the main source of drinking and purified water. In general, private companies desalinate brackish water with small scale, reverse osmosis plants. Costs for this water are elevated; given that drinking water is a basic need, desalination businesses are very profitable.

Several "private" water crevices located on private lands provide water for various premises in Puerto Ayora and Bellavista. Pumping from these crevices is unregulated and lacks monitoring. Therefore, the number of pumps and the amount of water extracted are unknown. This creates a challenge for authorities since water sources belong to the government of Ecuador, while the land belongs to its owner. Some proprietors manage the water sources as their own and consequently distribute it in water trucks or via other systems to the local population (Table 1). Given the lack of monitoring of these private users, approximations of demand are based on scarce information from governmental institutions including the Municipality of Santa Cruz and SENAGUA (National Water Secretariat). Two of these crevices, Barranco and INGALA, used to be the main extraction sites of the municipal network; however, due to the detection of high levels of contamination, the municipal extraction sources were changed.

Table 1. Various "private" water sources located in the urban settlement of Puerto Ayora.

Name of crevice	Uses
Misión Franciscana	Desalination of water for private company
Tortuga Bay (3 crevices)	Hotels and private properties from Punta Estrada neighborhood, laundries, etc.
El Barranco (2 crevices)	Private trucks selling water
Gallardo	Mechanic garage and water desalination company
Martin Schreyer - A&B	Owner's cruise ships and hotels
Pampas Coloradas	Private trucks selling water
Grieta Charles Darwin	Water uses of personnel of Charles Darwin Foundation
INGALA	Pampas Coloradas Stadium, Energy Utility, etc.

Water supply systems in Bellavista and Puerto Ayora

The two public water supply systems of Santa Cruz provide service to Bellavista and Puerto Ayora. Bellavista has a smaller system with only about 444 connections (as of December 2013), serving approximately 2500 inhabitants. The system for Puerto Ayora is more complex, with 2156 water connections, corresponding to approximately 12,000 inhabitants (INEC, 2010).

The water source for Bellavista is a constructed well called *Pozo Profundo* or Deep Well, where water is pumped with a single pump, which extracts 6 l/sec for an average of 12 h/day (Table 2). Water is conveyed from the source to a 300-m^3 storage tank and to a sub-pumping station with a stationary 30-HP pump of horizontal axis with a flow of 12 l/sec during 4 h/day, delivering water to two storage tanks with capacities of 500 m^3 and 100 m^3 (Moscoso, 2009). In 2013, another 1000 m^3 tank was built, and all three are now located on the same site, 218 m above sea level. Water is then distributed to the village by gravity.

Table 2. Specifications of the water supply systems of Bellavista and Puerto Ayora..

Name	Pumping flow (l/s)	Pump power (HP)	Average pumping (h)	Approximate leakage*	Extraction (m^3/d)	Volume supplied (m^3/year)	Water treatment
Deep Well (Bellavista)	6	25	12	15%	259.2	94,608	NO
La Camiseta (Puerto. Ayora)	35 (2 pumps)	50	12	25%	302.4	1,103,760	NO

*Leakage estimates are based on information from the Municipality of Santa Cruz.

The primary water source for Puerto Ayora is the crevice *La Camiseta*, located 2.8 km from town. It has one pumping station with three pumps, with only two pumps working at a time (Table 2). The pumps extract 70 l/sec during 12 hours/day and convey water through a 315-mm-diameter PVC pipe to two storage tanks (600 m^3 and 800 m^3 respectively), located 2.8 km from the source and 64 m above sea level. Water flows from the storage tanks by gravity to the households for an average of three hours per day, distributed by neighborhood (Consulambiente, 2011). According to the Department of Potable Water and Sanitation, 95% of the population of Santa Cruz has direct access to municipal water, while the remaining 5% has indirect access, including provision by water trucks or direct extraction from so-called "private" crevices.

The current municipal supply system in Puerto Ayora is old and in poor condition, primarily due to the lack of regular maintenance, which results in a high Non Revenue Water (NRW) value and high levels of leakage. NRW, according to the International Water Association (IWA), is defined as water that has been produced and is somehow lost before it reaches the consumer. These losses may be caused through leakage, bursting pipes, illegal connections, and metering inaccuracies.

Photo: © Nemanja Trifunovic

Water tariff systems differ between the two supply networks. The system in Bellavista uses water meters and water fees are based on usage (US$1.21/m^3), while in Puerto Ayora each customer is charged a fixed fee according to their demand category, regardless of the volume consumed (Table 3). Puerto Ayora's system of fixed tariffs has persisted over the years because supply is intermittent and the water is of low quality. Raising the tariff while these conditions persist is considered politically unwise.

According to the water department, any change in water fees must be accompanied by a major improvement in system infrastructure. The current water tariffs, established for different categories by the Municipality of Santa Cruz in 2004, were based on an analysis of costs including maintenance and operation. However, the tariffs do not cover 100% of the costs and thus the system must be subsidized by the Municipality. Subsidies are required for both Bellavista and Puerto Ayora, and cover approximately 30% of the total cost of supplied water. These financial restraints result in few improvements, which in turn make any price increase unacceptable to the public due to the poor and unreliable service.

Table 3. Water tariffs and number of connections in Santa Cruz (all are from Puerto Ayora except the first entry).

Category	Number of connections	Fixed value (USD)
Metered (Bellavista)	435	1.21/m^3
Domestic	1152	5.24
Commercial	936	11.24
Industrial/Hotels	14	45
Industrial/Water Industry	2	45
Industrial/ Laundries	5	45
Industrial/Residential	20	28.5
Official Category	28	6.12
Industrial/Pool	1	28.5
TOTAL	2593	--

Source: Water cadastre from Municipality of Santa Cruz (2013).

Photo: © María Fernanda Reyes

Assessment of supply and demand

The water supply assessment in Bellavista was based on information from the records of the Department of Potable Water and Sanitation of Santa Cruz for 2013. Given that Bellavista has a metered water system, it was possible to determine actual use (Table 4).

The monthly average of non-working devices was 32%, which corresponds to approximately 137 water meters out of a total of 434. The high average appears to be mainly due to the significant amount of non-working devices in March and April. The reason for so many dysfunctional meters is unknown. Meters registering zero consumption (non-working devices) contribute to a higher value for Non-Revenue Water, which is then included as leakage and/or water theft. Average demand per premise per month was based on total consumption and number of connections registering consumption (Table 5) and then expanded to include the entire system assuming all water meters to be functional (Table 6). An estimated NRW could then be calculated for both actual measured usage and estimated usage if all meters were functional (Table 7).

Table 4. Water usage in Bellavista for 2013.

Month	Registered consumption (m^3)*	Calculated consumption (m^3)*	No. connections	No. connections registering no consumption	Percent connections registering no consumption
January	5375.6	5454.6	428	79	18
February	5370.2	5453.2	429	83	19
March **	330.2	733.2	429	404	94
April **	440.8	856.81	429	417	97
May	4605.4	4676.74	430	71	17
June	6513	6599	433	72	17
July	6262.2	6342.2	434	80	18
August	5559	5641	435	82	19
September	5653.8	5742.8	437	89	20
October	5653.8	5743.8	438	90	21
November	5097.8	5185.8	441	88	20
December	4964.8	5051.8	444	87	20
TOTAL	55,826.6	45,564.0	5207	1642	
Average/month	4652.2	3797.0	434	137	32

* The first column of consumption refers to the actual consumption registered by meters, while the second column of consumption adds one m^3 of consumption for each dysfunctional meter. The municipality has the policy of charging one m^3 when the reading is zero.

** Months with low consumption due to unknown reasons.

Table 5. Estimation of domestic demand excluding non-working water meters for Bellavista.

Month	Consumption (m³)	No. of connections registering consumption	Average consumption per premise (m³)
January	5375.6	348	15.4
February	5370.2	345	15.6
March*	330.2	25	13.2
April*	440.8	12	36.7
May	4605.4	358	12.9
June	6513.0	360	18.1
July	6262.2	353	17.7
August	5559.0	352	15.8
September	5653.8	347	16.3
October	5653.8	348	16.2
November	5097.8	352	14.5
December	4964.8	356	13.9
TOTAL	**55,826.6**	**3555**	**206.4**
AVERAGE PER MONTH	4652.2	296	17.1

* Months with low consumption due to unknown reasons (consumption not considered for the overall calculation of consumption per premise).

Table 6. Actual and estimated demand per year for Bellavista based on working meters and if all meters were functional.

	Tariff (USD/m³)	No. of connections	Volume of water used (m³/year)
With working meters only	1.21	296	55,826.6
If all meters were functional	1.21	435	55,826.6 + [86 lpcd * 5.7 inhabitants per premise * 137 non-working meters] = 80,339.1

Table 7. Non-revenue water estimates for Bellavista based on working water meter usage data and estimated water usage if all meters were functional.

	System input volume (m³/year)	Revenue water (m³/year)	Non-revenue water (m³/year)	ASR (%)
With working meters only	94,608	55,826.6	38,781.4	40.1
If all meters were functional	94,608	80,339.1	14,244.8	15.1

The average consumption per premise per month is 17.2 m^3 and the consumption per capita per day, assuming there is an average of 5.7 family members per household in Bellavista (based on total population and total number of premises), is approximately 86 liters. While this is a reasonable figure, there is additional water consumption for drinking water.

Water demand in Puerto Ayora was difficult to assess due to the absence of meters and lack of reliable data. The estimates presented here are based on a survey made to 240 households. Demand was also calculated based on questions on volume and filling of storage tanks, frequency of water bought from water trucks, and volume of bottled water purchased (Table 8).

Total water demand corresponding to the different sources and categories was estimated based on surveys made to major consumers from tourist and laundry categories (30 hotels, 30 restaurants, and 16 laundries; Table 9).

Table 8. Estimate of domestic water demand in Puerto Ayora.

Municipal (m^3/year)	Bottled water (m^3/year)	Water trucks (m^3/year)	Total demand (m^3/year)	Demand per capita (lpcpd)	NRW (%)
712,188	7242.7	57,518.1	776,948.8	177.4	35

Source: Surveys conducted from September 2013 to January 2014.

Table 9. Total estimated demand for different sources and categories in Puerto Ayora.

Category	Municipal water demand (m^3/day)	Bottled water demand (m^3/day)	Water trucks demand (m^3/day)	Total demand (m^3/day)
Domestic	1951.2	19.8	157.6	2128.6
Hotels	1107.2	20.6	1788.8	2916.6
Restaurants	69.3	7.6	51.1	128.0
Laundries	28.5	0.0	20.1	48.6
TOTAL	**3156.2**	**48.0**	**2017.6**	**5221.8**

Source: Surveys conducted from September 2013 to January 2014.

Conclusions

This study has compiled results from previous studies and strengthened them by providing a more technical analysis of the current situation of the water systems on Santa Cruz.

Accurate information on water supply and demand in Santa Cruz is impossible to obtain due to faulty water meters in Bellavista and to the lack of metering in Puerto Ayora. Nevertheless, the information available was used to make estimates on water usage and NRW for the municipal source. Even though Bellavista has a meter-based tariff structure and water collection is more organized than in Puerto Ayora, revenues remain insufficient to cover maintenance and necessary improvements, especially due to the high percentage of faulty meters.

A significant percentage of non-working meters in Bellavista contributes to a higher estimate for NRW. With better meter management, the NRW may be lowered to nearer to 15%. Ensuring functional meters throughout the system would also result in more accurate estimates of water demand per capita, as well as increased fees paid to the Water Department, which could then be used to help improve the system.

For Puerto Ayora, the estimates of water consumption from the municipal source suggest a NRW of approximately 35%, which is considered high. According to the demand from different categories, the highest demand belongs to hotels. Also, the high figure for water trucks (from private crevices) highlights the need for further research and the implementation of a metering system in order to confirm estimates.

Water habits and behavior of consumers differ significantly among the two urban settlements, mainly because of the difference in water tariffs. This is shown in demand per capita from the municipal source. Puerto Ayora's demand is estimated at nearly twice that of Bellavista. This difference in consumption could be due to the excessive water waste observed in Puerto Ayora (Guyot-Tephiane *et al.*, 2012). Lack of awareness of water conservation needs is evident. A more complete analysis is required for Puerto Ayora to determine the actual levels of water waste.

Information on municipal water extractions is reliable based on different studies previously done by consultants, but information on desalinated drinking water and extraction from crevices is incomplete. This needs further research and verification in order to estimate and conclude the total water balance in Santa Cruz.

Recommendations

This study has highlighted several problems in the current water distribution systems and in water demand in Santa Cruz. Based on the results we recommend the following:

- Create policies, regulations, and management practices to ensure the conservation of water resources on Santa Cruz Island, defining tasks and responsibilities for each institution involved.
- Strengthen capacity of personnel working in the relevant water management institutions.
- Improve the infrastructure of water systems of the municipality and increase the price of water.

- Improve water meter management and monitoring of water use in Bellavista.
- Verify water demand in Puerto Ayora through the installation of meters in pilot areas.
- Abolish the fixed tariffs in Puerto Ayora in order to create awareness within the population of the value of water; a fixed tariff system results in indiscriminate waste of water.
- Install water meters for each customer in Puerto Ayora and ensure their maintenance and management.
- Carry out additional studies of NRW to identify and eliminate significant losses and leakages.

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Evidence of cultural patterns for sustainability in Galapagos society

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Although human settlement of Galapagos occurred relatively recently, nature has managed to influence the character, customs, and ways of life. Humans in Galapagos are in the process of adapting; it is expected that some cultural characteristics will be lost, habits changed, and new mindsets created.

Humans first arrived in 1535, traveling across the ocean, as did the birds and plants that colonized the Archipelago. The Islands were officially annexed by Ecuador in 1830 by Colonel Ignacio Hernández during the Presidency of General Juan José Flores. Since then, Ecuador has maintained sovereignty of the Islands. In addition to Ecuadorian settlers, groups of European immigrants arrived at different times, and for a variety of reasons all viewed Galapagos as a good place to live.

The population grew slowly until the 1980s and then much more rapidly, reaching a population of 25,124 by 2010 (INEC 2010). Galapagos residents include immigrants from all provinces of Ecuador (61% of the total population), foreigners (2%), and individuals born in Galapagos (37%) (Figure 1).

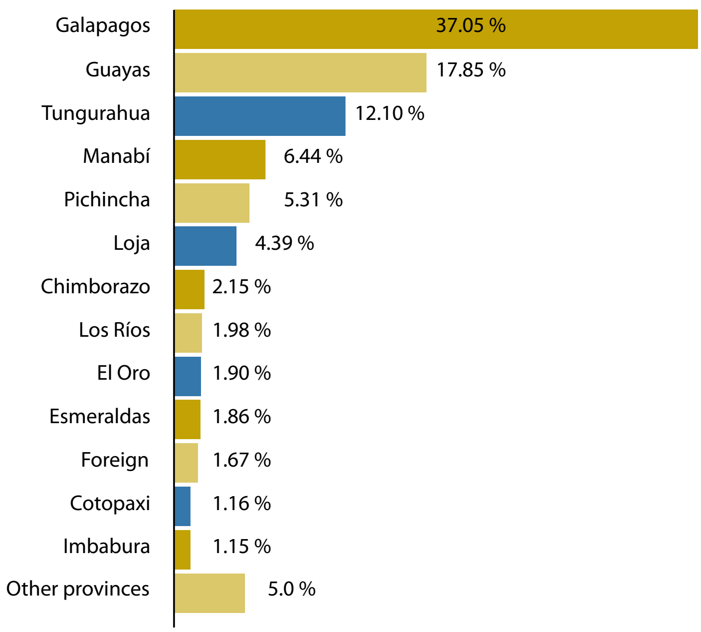

Figure 1. Galapagos population by place of birth. Source: INEC, Censo 2010

Galapagos society is comprised of various sized groups of people with ethnic and cultural characteristics from different regions of continental Ecuador. This cultural mix and the natural environment have led to new models. Although we talk about the culture of the Galapagos population, many support the thesis that no specific island culture exists. This article seeks to challenge that claim by highlighting various cultural patterns present in Galapagos society, which are focused on sustainability and protecting this fragile ecosystem.

Culture is defined as the combination of material and immaterial elements that determine the way of life of a community as a whole, including practices, social patterns, language, and social, economic, political and religious systems. Cultural patterns are those actions that recur by custom, habit, or tradition in a defined society. Finally, social patterns are the habits, including morals, beliefs, and customs, that a person acquires insofar as s/he is a member of a society.

Four cultural patterns have been identified in Galapagos as appropriate to island living: the use of bicycles, respect and care of nature, living together for sustainability, and participation in governance.

Mobility is an essential aspect of human daily life. Given that there is no public transport in Galapagos, every citizen must figure out how to move from one place to another. It is important, therefore, to consider those people who choose to travel by bicycle. Although there are regulations for entry of motorized vehicles into Galapagos, the use of a bicycle is still a personal choice, not an obligation.

The creation of the Galapagos National Park in 1959 and the subsequent establishment of its territorial limits (97% of the Islands' land area) defined the inhabited and protected areas of the Archipelago. From that moment, Galapagos inhabitants have known that what happens in protected areas will impact the populated areas and vice versa.

Galapagos is quite different from other provinces in Ecuador in that those governing the Islands have had to take into account the unique reality of the historically small population. As a result, a strong social participation component was established in the Special Law for Galapagos enacted in 1998.

Use of bicycles

Residents of Puerto Ayora, the largest city in Galapagos, have historically used bicycles for mobilization, especially since the 1980s when the government began to pave the streets. Bicycles are an inexpensive means of transport that are easy to maintain and operate. Over the last decade bicycle lanes have been established on several streets to make bicycle use safer and more convenient. The establishment of bike lanes is an integral part of the land use plan of the municipality of Santa Cruz. In addition to being a means of transport for local inhabitants, bicycles are also used by tourists for independent or guided tours.

Authorities have recognized the importance of bicycles in Galapagos and have included bike path construction along the main roads of the province in their infrastructure planning.

As a result of the constant use of bicycles, cycling has become a popular sport in the Islands. Galapagos is now recognized as a national powerhouse in the sport, with a number of its residents winning national championships.

Bicycles are owned and used by 63.4% of households in Galapagos (Figure 2). In 2011, a baseline survey of terrestrial mobility in Puerto Ayora on Santa Cruz Island showed that bicycles are present in 85% of surveyed households; of these, 64% had more than one bike (Figure 3).

Respect and care for nature

Ecological and environmental terminology has become integrated into the common language of the Galapagos

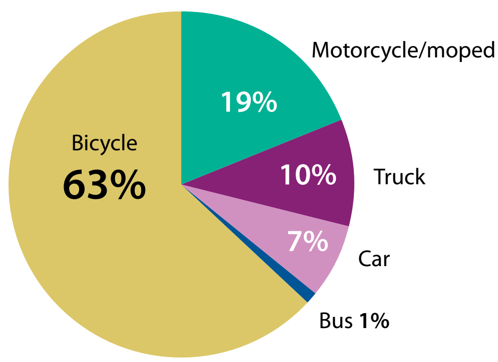

Figure 2. Modes of transport for households in Puerto Ayora, Santa Cruz Island in 2008. Source: Así Vamos Galápagos, Boletín No. 2008.

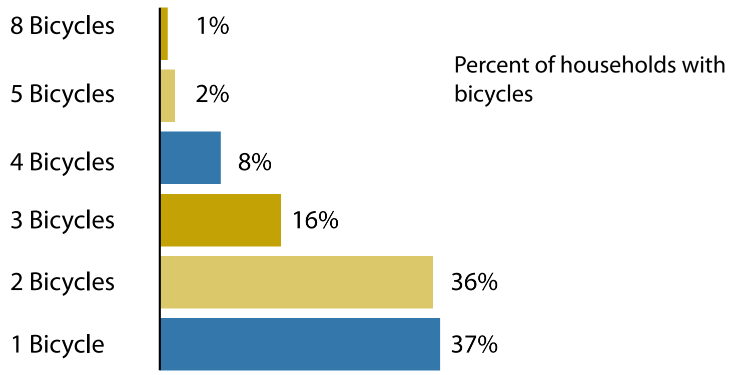

Figure 3. Number of bicycles per household in Puerto Ayora, Santa Cruz Island. Source: Informe Galápagos 2011-2012

population. This vocabulary has been learned in local educational institutions or as part of daily work, given that almost all work activity in Galapagos is related in some way to the natural environment of the Archipelago and its special management needs.

In 2012 and 2013, discussions during the provincial workshops Building a Vision of an Island Culture in Galapagos focused on how residents of Galapagos identify themselves. It was determined that "the only element that unifies people living in Galapagos to identify themselves as Galapagueño is their desire to do so, regardless of race, creed, origin, language, or traditions." Respect and care for nature were highlighted as characteristics that differentiate island residents from those living in other communities.

With this background it can be concluded that a Galapagueño is anyone who feels they are one, and that the natural surroundings of Galapagos are a fundamental factor effecting changes in behavior of those who have made their home or work in the Islands.

During the workshops Audiovisual Production to Strengthen the Culture and Good Living in Galapagos carried out in 2013 on San Cristóbal, Santa Cruz, and Isabela, adolescents and youth also referred to respect and care for nature. Comments included:

- "Being Galapagueño is learning how to conserve an environment that is unique and to enjoy the places we have here."
- "For me, being Galapagueño is not only living in Galapagos but getting involved in conservation and having a vision and an ability to move forward."
- "I feel I am a Galapagueño because I was fascinated by and loved nature from the day I arrived; the quality of life that one leads here, zero stress, enjoying family, children, cannot be found in big cities. I feel privileged to have arrived here."

A sense of caring for the natural environment has a high social importance in Galapagos and is present among all age groups in the province. In this way, it has become a unique characteristic of the Galapagos community.

Social codes for sustainability

Urban planning in the Islands led to the elaboration of Codes for Social Coexistence in 2012. One was developed by the owners of land parcels in the development El Mirador (Santa Cruz Island), who defined their vision for the nature of relationships within their community, and the other by the inhabitants of Puerto Villamil (Isabela Island). In both instances, a high value was placed on the harmonious relationships of those living within the community and on the adoption of sustainability criteria to guide growth. The Codes for Social Coexistence of these two island populations demonstrate that mutual respect and care for the environment are characteristics of Galapagos society (Table 1).

Many of the guidelines outlined in the Codes of Social Coexistence are the result of implementation of local policies related to integrated solid waste management or recycling, the care of native and endemic species of the Islands, and the respect shown for not altering their habitat.

The Islands' first formal recycling effort began in Santa Cruz Island at the end of the 1990s, with the support of the Galapagos National Park Directorate, the Galapagos Foundation, and the municipality. Since then, several other organizations have supported the municipalities in all three cantons to adopt solid waste management systems.

The active participation of Santa Cruz citizens in adopting new waste management practices, such as sorting trash in their homes, has resulted in some noteworthy achievements. Between January 2007 and August 2009, waste recycling increased by 260%, which reduced non-recycled waste by 35% per capita (from 0.62 kg/person/day to 0.4 kg/person/day), and increased both the

Table 1. Citizen testimony regarding the Social Codes in Santa Cruz and Isabela Islands.

El Mirador–Puerto Ayora – Isla Santa Cruz	Puerto Villamil – Isla Isabela
Site description	
I have my home in the development El Mirador; I like to live in peace with my peers and in harmony with nature.	*People walk barefoot in the sandy streets of Puerto Villamil and visit its beautiful landscapes, volcanoes, flora and fauna. Its inhabitants always welcome tourists who come to visit its wetlands.*
Social responsibility of citizens	
In this neighborhood there are people from all over the country, from all races and cultures. We are aware that we are living in a unique natural place, which we want to keep the same for our children's children. We know our neighbors and we respect each other. We are tolerant of diversity; we don't discriminate based on sex, gender, race, religion, ability, or personal or social status.	*As an inhabitant of Isabela Island, good living is always present in my mind and a priority for my family; I follow the rules and regulations that govern my canton, and I am an active member in planning and implementing improvements in our community.*
Use and value of water	
Water is scarce; we must use it sensibly. In our homes we must collect rainwater and store it carefully so that it does not become contaminated.	*I am aware that the water resource is scarce on the island, both for human consumption and for the agricultural sector; therefore I practice water conservation at home, at work, and in public places.*
Waste management, recycling, and not littering	
The waste produced at home must be separated and classified according to recycling regulations. We must avoid the use of disposable bags and containers; we want to reduce unnecessary consumption.	*Sanitation is essential in my island. I will avoid creating pockets of infection by disposing waste in an irresponsible manner. I always put waste in the corresponding garbage can (green, blue, black, or red) and I will remain conscious of the need for my neighbors and the authorities to do the same.*
Protection and care for the flora and fauna of Galapagos, responsibility with pets	
We know and adhere to the list of permitted products, those not permitted, and those that can enter Galapagos with restrictions. *We take great caution in using animal or plant species that could become a pest and alter our environment. We do not want to alter the natural world; therefore we do not feed or touch native and endemic animals. We are responsible for our pets and care for them properly in our home and in public places.*	*To ensure that the animals of my island do not change their behavior, I do not touch or feed them; I mention this rule to those who visit me from outside Galapagos and make sure that they follow it.*
Internal transport	
When we need to go somewhere, we prefer to walk or go by bicycle. Vehicles respect speed limits and show courtesy to pedestrians and bicyclists.	*It is our custom on this island to walk peacefully along our streets; we use bicycles to keep our bodies active. Drivers of vehicles respect speed limits ensuring their own safety and that of pedestrians.*

production of compost and the efficiency of the recycling system by 400% (WWF, 2010).

A culture of recycling and sustainable waste management has grown in Galapagos, making recycling an essential component of efforts to ensure the sustainability of the Archipelago.

Although it is difficult to verify, it is very likely that the respect for and a harmonious relationship with the natural environment expressed by the local population are a result of environmental education provided three decades ago, by the Galapagos National Park Directorate and the Charles Darwin Foundation, which enhanced understanding of the island environment and produced changes in behavior.

Citizen participation in governance

One of the recurring discussions in the province surrounds the question of who is responsible for its management and governance. At various times in the history of Galapagos, concern has been expressed about it being governed from the mainland without taking into account the various stakeholders or the interests of the local inhabitants.

Beginning in the 1980s the Galapagos population became more interested in participating in the development of local legislation and governance. This article does not highlight specific legislation rather it provides several examples of participatory processes through which citizens contribute to improved environmental management.

Photo: © Andrés Tapia.

One of the milestones of social participation was the creation of the Core Group (known locally as the Grupo Núcleo), which functioned from 1997 to 1999. This working group was tasked with developing and reviewing the *Management Plan for Conservation and Sustainable Use of the Galapagos Marine Reserve* (GMR). Representatives of different sectors, such as fishing, tourism, conservation, naturalist guides, and governmental institutions, were involved in this process. The Participatory Management Board (PMB) evolved from these efforts and became the forum for participation of users of the GMR. The PMB, in conjunction with the GNPD, seeks to ensure effective and responsible participation of users of the GMR in its management. The PMB was institutionalized in the management plan of the GMR and the Special Law for Galapagos of 1998, aimed at conservation and sustainability, which is currently in force and is considered effective.

Another key moment for multi-sector participation, dialogue, and debate occurred during the development and discussion of the Special Law, which involved local organized groups and individuals, as well as national institutions and sectors. This high level of local citizen participation included not only contributing ideas and discussing regulations, but also participating in planning and formulating and implementing management regulations.

Currently, a high percentage of the Galapagos population believes that participation is important for the Archipelago, and that due to its remote island setting, it must be administered differently than other Ecuadorian provinces (Zapata, 2013).

In recent years, citizen participation has become the norm in all work related to the development and review of regulations and legislation. The elaboration of the Special Law, management plans, and cantonal plans have all involved strong public participation, which has helped ensure more effective implementation and governance of the province in ways that achieve harmony between humans and nature.

Conclusions

There is clear evidence of aspects of Galapagos culture that are closely related to sustainability, such as: the value, respect, and enjoyment of nature; the adoption of environmental norms in daily life and as part of codes for social coexistence; and citizen participation as a fundamental part of constructing the legal framework, management, and governance of Galapagos.

The diverse origins and cultures of the local population in Galapagos become key elements in developing a shared view of sustainability for the Islands. Understanding this, there are three cultural patterns already present in the Galapagos society that contribute to sustainability:

- Galapagos citizens have adopted several codes for social coexistence, such as those related to the use of bicycles and recycling, etc.

- The local population respects and cares for nature, motivated by the sense of satisfaction they receive from nature and an understanding that nature generates income.

- Citizen participation is a fundamental part of processes related to establishing and reviewing the legal framework, management, and governance of the Islands.

As social and cultural processes evolve, we must strengthen the Galapagos culture in ways that promote balanced and sustainable development without compromising the natural environment and the ecosystem services it generates. With this need in mind, as well as the results of the various workshops referred to in this article, a "code of good living in Galapagos" should be developed in a participatory fashion to serve as the benchmark for the lifestyle and culture of the inhabitants of the Archipelago.

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Education for sustainability in Galapagos: A public-private partnership for strengthening education in the Islands

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The quality of the local education system is among the most important factors that will determine the future of Galapagos. During July 2014, a five-day observation and data collection process was completed to identify priorities for improving preK-12 education in ways that would prepare Galapagos youth to assume their pivotal role in shaping a sustainable society. This work was facilitated by Galapagos Conservancy (GC) and the Scalesia Foundation (SF).

This work began in 2012 following a weeklong, multi-sector visioning workshop in Galapagos funded by the Helmsley Charitable Trust, during which GC, SF, and the Ecuadorian Ministry of Education (MoE) began to explore ways to collaborate to strengthen education in the Islands. In May 2014, the MoE authorized GC and SF to conduct a needs assessment for a school improvement program. GC and SF worked with the Center for Policy Research in Education (CPRE) based at Teachers College, Columbia University, to design a strategy for developing the program.

The first phase of data collection was named the Listening Phase, to underscore the central role school directors, teachers, and other local stakeholders must play in the early phase of project development and planning in any school improvement program.

The Listening Phase was carried out by a team of educators[1] with expertise in priority areas identified by the MoE: natural science, English language, language arts, and educational leadership. Groups of two or three Listeners conducted observations in at least two different schools every morning and participated in two different focus groups (teachers, parents, students, or school leaders) every afternoon. The team visited 14 of the 20 schools offering preK-12 education and interviewed all school directors on Santa Cruz and San Cristóbal.

Framework for observations and analysis

The framework used to guide observations and analysis was based on work by sociologist and organizational development practitioner Marvin Weisbord (1978), and the research of Tony Bryk and colleagues from the Chicago Consortium for

[1] This article summarizes a more extensive report presented to the Ministry of Education (MoE), the Scalesia Foundation (SF), and Galapagos Conservancy (GC), by a team of educators selected by these organizations to conduct an initial assessment of the state of preK-12 education in Galapagos. Team members included the authors of this article and Dr. Jessica Ivonne Duchicela (Universidad de las Fuerzas Armadas, Ecuador), William Stroud (CPRE/Teachers College, Columbia University), Adriana Martín del Campo (Instituto Thomas Jefferson Valle Real, Guadalajara, México) and Amelia Farber (Stanford University).

School Research (Bryk *et al.*, 2010). It focused on seven areas of activity identified as vital to school effectiveness (Figure 1). These include:

1. **School leadership.** Research identifies the following essential leadership tasks: 1) defining purpose; 2) embodying purpose in programs; 3) ensuring quality of teaching and supporting improvements in teaching; 4) defending the organization's integrity, and 5) maintaining order with respect to internal conflict. Studies also highlight the importance of inclusive leadership and the director's ability to cultivate a team of leaders that develop a sense of shared responsibility for school improvement (Burke, 1994; Selznick, 1957; Bryk *et al.*, 2010).

2. **Professional capacity of teachers.** Bryk *et al.* (2010) describe schools as "human resource-intensive enterprises that are only as strong as the quality of faculty, the professional development that supports their learning, and the faculty's capacity to work together to improve instruction."

3. **Relationships within schools.** Weisbord (1978) points to the importance of relationships between peers, supervisors, and subordinates, as well as between units or departments that perform different tasks (Singh, 2010).

4. **Parent and community relationships with schools.** Bryk *et al.* (2010) highlight the importance of trusting relationships between schools, parents, and communities that are focused on strengthening student learning.

5. **Teacher incentives.** Research shows that although both monetary and emotional incentives can be effective motivators, the latter often bring better results (Kotelnikov, 2008, cited by Allred *et al.*, 2008).

6. **Helpful mechanisms.** Bryk *et al.* (2010) highlight the importance of timely access to information on teacher and student performance, and to coherent instructional guidance systems that articulate the "what" and "how" of instruction, such as professional development, teaching materials, and instructional routines.

7. **Outside environment/everything else.** Bryk *et al.* (2010) identified the importance of various aspects of the community context (available resources, social capital, etc.) that can impact school performance. CPRE expands this concept to include external policies and professional cultures potentially crucial to schools in Galapagos.

Results

The Listening Phase provided a snapshot of the state of education in Galapagos. Key findings included:

1. **School leadership.** Listeners described the mode of leadership in most schools as vertical and highly administrative. School directors reported that they

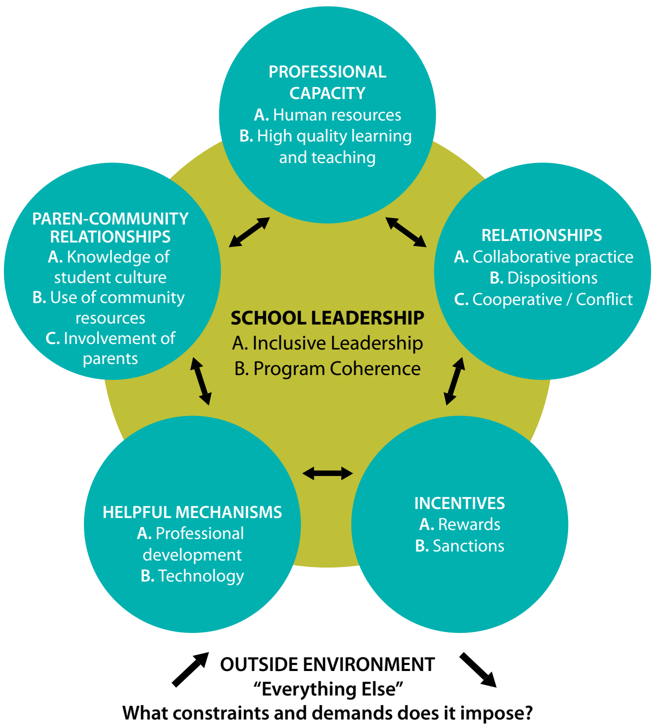

Figure 1. The adapted CPRE (Center for Policy Research in Education) Framework.

dedicate most of their time to administrative duties as opposed to classroom supervision, engaging their faculty in discussions about instruction, or providing professional development. Teachers reported that they tend not to be involved in decisions affecting their work.

In terms of school mission and vision, the MoE requires all schools to develop and submit an Institutional Education Plan (IEP), a strategic plan focused on medium- and long-term actions designed to assure quality learning and a positive school environment. The MoE's new guidelines for developing the IEP[2] call for a collaborative planning process involving directors, teachers, and parents. Based on conversations with these groups, the IPEs are not yet "living documents" for which the entire school community feels a sense of ownership.

In terms of leadership teams, the MoE requires each school to create an Executive Council, Teacher Advisory Board, Teacher Council, Student Council, and Parent Council. These structures were not mentioned by directors, teachers, or parents, suggesting that they are not yet playing their intended role.

Improving education in Galapagos will require considerable attention to the issue of educational leadership and transforming the role of school directors from that of administrator to instructional leader. Most school directors interviewed stated their desire and showed potential to assume such a role with appropriate training and mentoring.

The new IPE guidelines and the structures called for in Acuerdo 382-11 provide a framework through which directors can build the kind of shared purpose and leadership teams needed to shape school improvements.

2. **Professional capacity.** Listeners observed instances of high-quality teaching, but noted that most teachers lack effective teaching strategies; instead they rely on traditional, knowledge-recall techniques that do not prepare students to be critical thinkers. Listeners reported teachers' readiness for dialogue about improving instruction in all subjects. However, teachers will not necessarily embrace professional development opportunities if they are not provided the time, flexibility, and support to do so, and if this training is not linked to pay scales or other formal and informal incentives.

   Both teachers and directors noted the need for better performance evaluation mechanisms to help them understand if they are "doing their jobs correctly" and for professional development to help them improve their practices. Such feedback is essential for educators to improve their teaching skills.

3. **Relationships in the school.** Listeners report that communication between teachers and school leaders focuses mostly on administrative matters. Some schools hold regularly-scheduled faculty meetings, but few teachers valued these; in particular, they objected to the extended time used to explain new MoE requirements without sufficient guidance for implementation or explanation of how these new initiatives contribute to educational improvements.

   Although teachers and directors agreed that collaboration is important, they reported that few formal systems exist for planning with colleagues within schools or between schools. Participants in the teacher focus groups, organized by subject areas, expressed interest in collaborating with their peers at other schools. Creating a culture of collaboration among Galapagos educators is central to improving education in the Islands.

4. **Parent and community relationships with schools.** Listeners reported the following perceptions of parents, students, and teachers:

- Parents expressed concern for teaching quality (especially in English), the lack of a system of teacher evaluation, the need for a Galapagos-centric curriculum, high teacher turnover, and poor communication between parents, schools, and the MoE. Parents in Santa Cruz were enthusiastic about the newly instated English and Science clubs, but noted the need for better organization.

- Students expressed concern that school directors and administrators rarely solicit their input regarding their needs. Although student councils exist, students felt the councils are symbolic and are underutilized as a forum for students to make positive contributions to educational improvements.

- Teachers reported the teaching profession is not valued as much in Galapagos as it is on the mainland. Many teachers feel that they have not been given the tools or orientation needed to implement MoE mandates, such as how to organize academic clubs and ensure that clubs integrate instructional themes. Teachers also noted a lack of support from parents related to academics, such as helping their children with homework.

[2] Guía Metodológica para la Construcción Participativa del Proyecto Educativo Institucional, 2012.

In terms of the broader community, Listeners learned of a number of examples of local organizations partnering with schools to provide learning opportunities for students (Table 1).

Improving education in Galapagos will require greater parental and community engagement. The governance structures called for by the MoE, as well as rights and obligations of teachers, students, and parents laid out in the Organic Law for Intercultural Education (LOEI – Spanish acronym), could help promote such engagement.

Additionally, the expertise of Galapagos-based NGOs and professionals working in science, conservation, and the business community represent a valuable but underutilized resource for classroom learning and professional development of teachers.

Table 1. Local organizations partnering with schools.

Organizations	Activities
Galapagos National Park Directorate (GNPD)	The GNPD has presented proposals to the Ministry of Education to help with micro-curricular design in the area of natural science and to help strengthen the content knowledge of science teachers. The GNPD also works with schools to offer a number of hands-on environmental education activities.
Ecuadorian Navy	The Navy offers marine-related extracurricular education via the Guardians of the Ocean Program (Guardianes del Mar).
Scalesia Foundation (SF)	The SF continues to dialogue with local school directors and Ministry of Education officials regarding its desire to serve as a local champion of education improvements in the Islands. The SF also seeks to develop the Tomás de Berlanga School as a demonstration site of proven educational practices for teachers from throughout Galapagos.
Local NGOs (FUNDAR Galapagos, Grupo GECO, Pasos Equilibrados, and Agentes de Cambio) and International NGOs (Conservation International, Ecology Project International, and Outward Bound)	These NGOs offer programs in areas such as environmental education, entrepreneurship, leadership training, and service learning. Some of these organizations work closely with schools to offer activities related to extracurricular activities that can help sophomores and juniors to fulfill their 200-hour community service requirements.

5 **Teacher incentives.** The MoE's 10 Year Education Plan prioritizes raising the profile of the teaching profession through such means as merit-based pay, better working conditions, and opportunities for professional development. However, while the LOEI lays out specific merit-based incentives, teachers overwhelmingly described a lack of formal and informal incentives associated with their work.

High quality professional development that is directly and immediately relevant to teachers' subject areas, grade levels, and classroom practice, and which will lead to improving student performance, can be highly incentivizing to teachers, especially if connected to the salary structure. In-service training opportunities with schools and universities in Ecuador and elsewhere could represent attractive incentives for Galapagos educators. In addition, teachers' incentives formerly received, such as diplomas and public awards for service, should be revived.

6. **Helpful mechanisms.** The MoE and the National Institute for Education Evaluation (INEVAL – Spanish acronym) administer standardized student evaluations in grades 4, 7, and 10 to measure student learning in math, language and literature, and social studies. The MoE and the Secretariat of Higher Education, Science, Technology and Innovation administer the National Exam for Higher Education (ENES – Spanish acronym), which measures verbal, numerical, and abstract reasoning. While aggregated results of these exams are published by the MoE, directors and teachers do not receive the results in time or in a format needed to adapt curricula or instruction.

Similarly, the MoE reports that teacher evaluations will be conducted annually by INEVAL, using knowledge-based testing focused on the primary subject area of each teacher[4]. The results will be used to identify gaps in knowledge to generate individualized plans for professional development. However, this system has yet to be fully implemented.

Since 2011, most professional development has occurred on the mainland or on-line. Teachers report that accessing professional development outside

[4] Reglamento General a la Ley Orgánica de Educación Intercultural.

Galapagos is both time-consuming and expensive and that on-line training is virtually impossible because of the slow internet connection.

The Listeners repeatedly heard teachers and directors call for professional development designed by subject and grade level as follows:

- Subject area, topic-based instruction to deepen teacher expertise
- Modeling as part of teaching
- Differentiation for children with special needs
- Teaching methodologies
- How to adapt curriculum to island goals
- Ways to engage and motivate students
- Classroom management
- Lesson design
- Integrating technology into curricula
- Conducting labs and inquiry-based lessons
- Organizing and managing science fairs and clubs

Considerable improvements could be made in Galapagos schools if teachers and directors had timely access to data on their performance and that of their students, and if teachers had access to high-quality professional development that is well-connected to Galapagos realities. Local educators would also benefit from observing examples of proven practices in action through model classrooms or a demonstration school in Galapagos.

7. **Outside environment/everything else.** According to Listeners, the following aspects of the school context have a significant impact on school effectiveness:

- Ecuador's ambitious national education reform process. The pace and scope of changes associated with the 10 Year Education Plan are dramatic, and are a source of significant stress and heavy workload among school leaders and teachers. On the other hand, the reform process is rolling out new processes and approaches that should prove helpful over time in addressing many of the challenges noted above.

- The physical and electronic isolation of the Galapagos Islands. The cost and time associated with travel between Galapagos and the mainland, and between islands in the Archipelago, limit access of educators to professional development and hamper the exchange of ideas. Slow internet connectivity in Galapagos limits school operations, student learning, and professional development for Galapagos educators.

- The need for a local champion to support a school improvement program. Research points to the important role played by "middle tier" entities, non-profit organizations that operate between schools and central governments, in support of education improvement programs (Aston *et al.*, 2013). Listeners believe that the physical and electronic isolation of Galapagos heightens the need for such an organization in Galapagos.

In addition to these external factors, the Listening Team learned of several institutions whose missions and mandates impact PreK-12 education (Table 2). These entities are well placed to make valuable contributions to the design of any school improvement program.

Table 2. Institutions with interest/involvement in education.

Organizations	Interest/Involvement in Education
Galapagos Governing Council (CGG)	The CGG is responsible for overall planning and management in Galapagos. It has a strong interest in seeing that education is optimized in ways that strengthen local capacity and "good life" (*buen vivir*). The CGG also oversees Galapagos migration issues, which has direct implications for staffing public and private schools in the Islands.
Ecuador's Ministry of the Environment (MoEn) and the Galapagos National Park Directorate (GPND)	Ecuador's MoEn and the GNPD, in their 2014 *Management Plan for the Protected Areas of Galapagos for Good Living*, recognize education as a key component of protecting the Galapagos environment and commit their support to the formal education sector. The GNPD also carries out a number of environmental education initiatives that could be connected to the learning objectives of the national curriculum, and coordinates research and conservation with international scientists whose expertise could be tapped by Galapagos teachers and local schools.
Municipal governments of Galapagos	The three municipal governments in Galapagos have an increased responsibility to construct, equip, and maintain schools in their jurisdiction. Both the LOEI and draft text associated with the new Special Law for Galapagos describe this evolving role.

Photo: © David Lansdale

Recommendations

Based on these and other observations contained in the Listening Team's full report, the team recommends that GC, SF, and the MoE pursue a five-part school improvement program to be conducted over five years. The proposed activities could be supported by the MoE, fees for service from schools, and grants from individuals, businesses, and foundations. The components and the recommendations follow.

1) **Demonstration school and education support team.** Due to the isolation of Galapagos and the continuous technical support required for an effective school improvement program, it is important to:

- Develop the SF's Tomás de Berlanga School as a demonstration site of effective educational practices, given its relatively small size, its strong focus on English language, and its ongoing efforts to incorporate the Galapagos environment into student learning.

- Develop an Education Support Team (EST) to provide ongoing professional development and to coordinate with the MoE and external consultants. The EST should consist of master teachers/mentors in educational leadership, English language, mathematics, science, and Spanish, who would work directly with directors and teachers at schools throughout Galapagos to promote the adoption of proven educational practices. These positions could be employed and managed within SF's existing structure.

2) **Instructional leadership.** Strengthen school leadership through an instructional leadership program with two components: 1) professional development for school directors to help them become instructional leaders, and 2) formation of instructional leadership teams at each school to set and act on priority school improvements (ideally by strengthening the Teacher Councils and School Improvement Teams mandated by MoE Agreement No. 382-11).

3) **Subject-specific professional development.** Improve instruction in literacy (English and Spanish), math, and science through subject-specific professional development, including workshops and ongoing mentoring connected to the directives of the Ecuadorian curriculum.

4) **Extra - curricular education.** Provide technical assistance to extracurricular education initiatives of schools and other organizations to optimize out-of-classroom learning, especially academic clubs and extracurricular requirements for sophomore and juniors; connect these activities with the learning objectives of the formal curriculum.

5) **Program monitoring and evaluation.** Develop a

monitoring and evaluation program to optimize program delivery, and document impact on teacher and director practices as well as student learning.

These school improvement components must build on MoE priorities and be designed based on research collected from numerous studies over several decades, which identifies those interventions that have the greatest impact on education quality (Corcoran, 2007; Wei *et al.*, 2009; Desimone, 2009; Odden *et al.*, 2002; Timperly *et al.*, 2007).

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EcoHelix: Working toward a smarter, more sustainable Galapagos

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Introduction

Sustainability has been one of the major challenges of traditional development paradigms. Historically, the Galapagos tourism industry has been linked to ecological and social impacts associated with overconsumption of resources, environmental contamination, energy consumption, ecosystem disruption, population influx, economic inequality, and alterations of community interactions. These pressures are mounting as a result of a booming tourism industry, which has not yet managed to balance environmental conservation and economic development (Epler, 2007).

In the previous Galapagos Report, Garcia *et al.* (2013) built a case for ecotourism in Galapagos based on three fundamental principles: maximizing the equitable distribution of local benefits; environmental conservation, and shared social and environmental responsibility. This article introduces the EcoHelix, a multi-sector intervention that will engage Galapagos tourists as agents of change, enabling them to rate Galapagos businesses via their smartphones, vote with their feet by choosing more ecological enterprises, and invest their resources based on information posted by businesses on their websites (Porter & Kramer, 2011).

The goal of the EcoHelix intervention is the development of ecopreneurship, the promotion of ecologically responsible ventures, within each local business community, which will produce sustainable results and generate economic as well as ecological benefits and opportunities. The EcoHelix will promote competition between businesses, which will lead to improved quality in products and services, and increased environmental and hospitality awareness in the local population. The EcoHelix is a model that could be replicated in tourism destinations around the world, with benefits for the local community and the environment.

A new paradigm emerging in Galapagos

The Galapagos Islands, famous for their unique biodiversity, were named the first UNESCO World Heritage Site in 1978. In 2007, however, environmental threats posed by invasive species, over-fishing, and unbridled tourism earned the Galapagos a transfer to the UNESCO List of World Heritage Sites in Danger. Although later removed from that list, tourism levels continue to increase with little control (Figure 1).

Galapagos tourism experienced its first dramatic growth in the 1980s (Figure 1), after regular commercial flights from the continent began. Prior to that time, tourists arrived by boat.

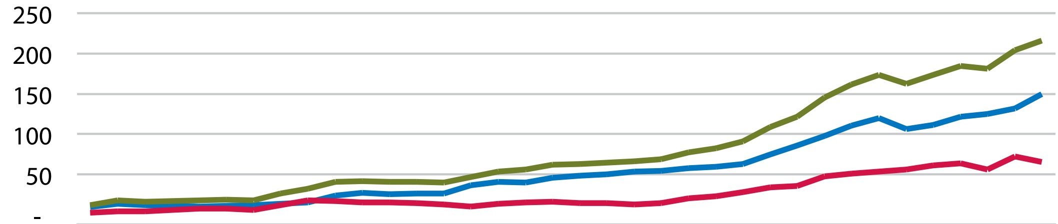
Since the 1980s, cruised-based tourism has been the primary mode used by visitors, equaling at times 80% of tourism activity. However, a new paradigm is emerging with profound implications.

In recent years, the source of tourists has shifted, with the largest group now arriving from Ecuador and the rest of Latin America (Figures 2 & 3). This is due in large part to aggressive promotions by LAN Airlines advertising the Galapagos as an affordable destination. In addition to the shift in origin of tourists, most visitors today seek a community-based experience rather than a cruise (Figure 4). Land-based tourism is growing at high rates (as much as 21% between 2012 and 2013), while cruise-based tourism, in part because of limited lodging capacity, has incipient or negative growth rates (Figure 5). The implications for Galapagos are far-reaching and dramatic. As more tourism becomes land-based, the economic benefit to local residents who provide reasonably priced lodging, food, and services will continue to increase. This increase in economic benefits, however, is juxtaposed against the potential for greater ecological degradation.

The increase in land-based tourism businesses is also creating a serious dilemma for local investment. In 2014, 438 hotels were identified by the Ministry of Tourism (only 111 are legal), representing a capacity for nearly 8000 passengers per night. This represents a 400% growth from the almost 100 hotels registered in early 2010 (Ministry of Tourism, 2015). Preliminary results of a hotel census conducted by the Ministry of Tourism in 2015 reveals that more than 60% of these businesses started in the last five years, a result of growing community-based tourism. However, most lack eco-friendly practices and quality standards, and have occupancy rates as low as 25%.

Ecopreneurship: Defining the balance between economic development and conservation

Ecopreneurship or sustainable entrepreneurship is defined as "the continuing commitment by businesses to behave ethically and contribute to economic development while improving the quality of life of the workforce, their



	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Foreign	10	13	12	11	10	11	12	14	15	24	27	26	26	27	37	40	40	46
Domestic	2	4	4	6	7	8	6	12	18	17	15	16	15	13	10	13	15	16
Total	12	17	16	17	18	19	18	26	33	41	42	41	41	40	47	54	56	62

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Foreign	49	50	53	54	57	59	63	75	86	97	110	120	107	112	121	125	132	150
Domestic	14	14	13	15	20	23	28	34	36	48	51	53	56	62	64	56	72	66
Total	63	65	66	69	78	82	91	109	122	145	162	173	163	173	185	181	204	216

Figure 1. Statistics of visitors (foreign, national, total) to Galapagos, 1979-2014, in thousands. Source: Transit Control Card – Galapagos National Park, Ministerio de Turismo, 2014

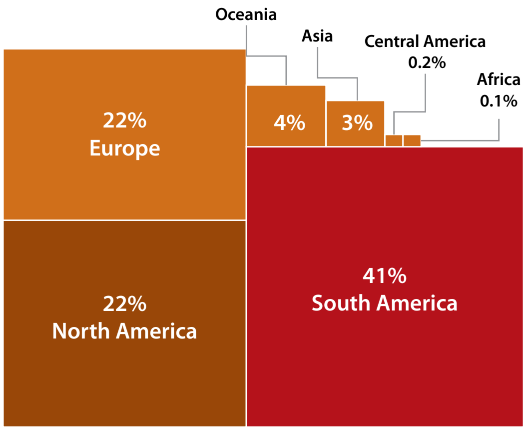


Figure 2. Origin of travelers to Galapagos by region, 2013. Source: Galapagos Tourism Observatory

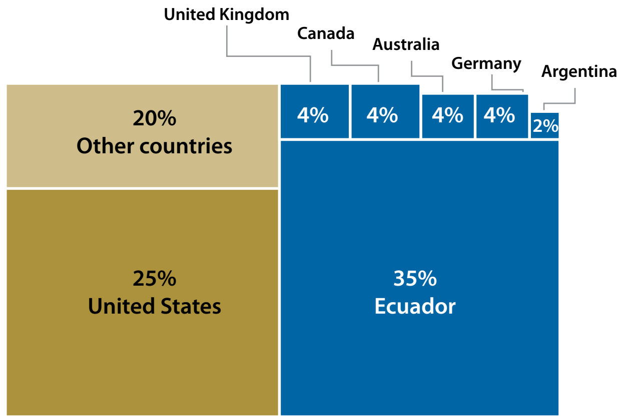


Figure 3. Origin of travelers to Galapagos by country, 2013. Source: Galapagos Tourism Observatory

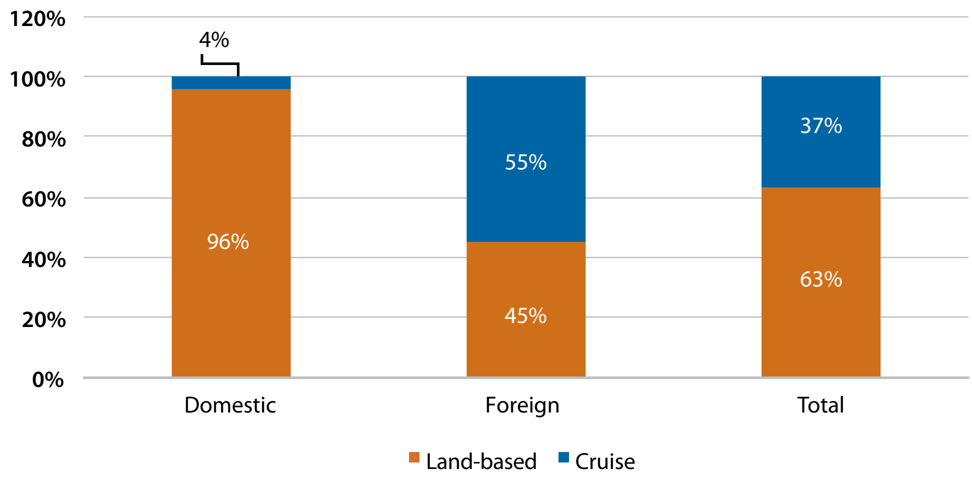


Figure 4. Percentage of tourists (domestic, foreign, total) arriving for land-based tourism versus a cruise in 2013. Source: Transit Control Card – Galapagos National Park, Ministerio de Turismo, 2014

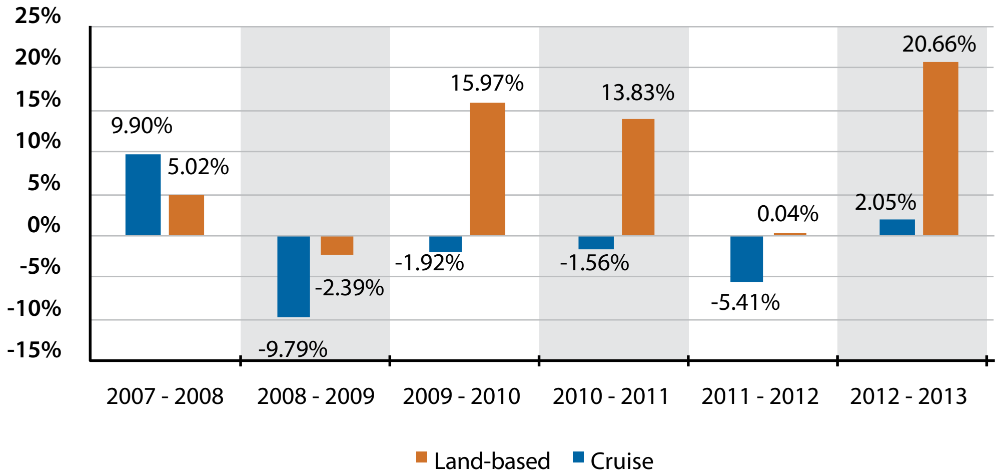


Figure 5. Yearly growth rate for land-based and cruise-based tourism in Galapagos (2007 to 2013). Source: Transit Control Card – Galapagos National Park, Ministerio de Turismo, 2014

families, the local and global community, as well as future generations" (Crals & Vereeck, 2005). It is an innovative business and societal movement that bridges the gap between profit, people, and planet (Allen & Malin, 2008). Factors including environmental awareness, demand for sustainable products and services, finite resources, business risk management, and economic efficiency have propelled the rise of the ecopreneur and the creation of sustainable business models (Dyllick & Hockerts, 2002). Not only is green business effective for large corporations, but small and medium enterprises can also harness the benefits of creating profitable, sustainable businesses to reduce poverty in resource-dependent economies. As Allen & Malin (2008) highlight, green entrepreneurship can "allow the problems of poverty and natural resource dependency to be more thoroughly and intelligently approached," and "can be a driving force for a new economic start for modern economies." Examples of effective ecopreneurship have been developed over recent decades in Costa Rica, where tourists can enjoy facilities that recycle, compost, and offer locally grown coffee or tea on the premises (Di Minin *et al.*, 2013).

The EcoHelix: A multifaceted proposal to address a complex challenge

The EcoHelix is an innovative intervention introduced to Galapagos by the Beyond Chacay Foundation; it aligns and mobilizes stakeholders from the private, public, civic, and academic sectors in the pursuit of entrepreneurial and sustainable solutions to complex challenges related to development and conservation. In Galapagos, the EcoHelix is designed to engage tourists and local stakeholders in promoting and strengthening sustainable tourism businesses. The components of the EcoHelix include:

- A rating system that enables tourists to evaluate Galapagos businesses based on criteria such as quality of product or service, cleanliness, green practices, etc., providing useful information for other tourists as well as valuable feedback to business owners;

- A voluntary certification process that helps ventures document their business model, profitability, and financial and technical needs, and to share this information with interested visitors, some of whom could be potential investors, volunteers, or technical consultants, based on the Lean Startup Model (Blank, 2013);

- A web-based platform (www.ecohelix.com/galapagos) and an accompanying smartphone application that enable visitors to access information about Galapagos businesses, rate them, and access information about services, products, business opportunities, and technical assistance needs in each community.

The EcoHelix will:

- Provide online marketing, publicity, and reservation mechanisms that will help Galapagos businesses tap into national and international tourist markets;

- Help connect tourists interested in investing their time, knowledge, and wealth in local ventures seeking to become more sustainable;

- Help Galapagos businesses improve their services to attract more tourists and sell their services at a higher price, while minimizing environmental impact.

Perhaps the greatest challenge of the EcoHelix model is providing information on the level of ecological responsibility of businesses. Originally, the model proposed inviting tourists to rate businesses based on four criteria: energy and water conservation, waste management, and the use of local products. Given that ratings would be highly subjective, a new approach is being explored: asking the municipalities and ElecGalapagos, the electrical company, to provide data about monthly energy consumption of each business, then calculating its ecological responsibility based on a ratio of energy consumption per number of clients. The co-creation of value for both tourists as clients and local business owners as providers is extremely promising, with both acting as stewards of the Galapagos by investing in its improvement (Porter & Kramer, 2011; Prahalad & Ramaswami, 2002).

An additional dimension of the EcoHelix, in collaboration with Fundación Fuente de Vida, is the invitation to tourists and local businesses to plant and adopt a tree, as an investment in the conservation of the islands. Groasis Technology, already a proven intervention on Santa Cruz, makes it possible to plant trees in extremely challenging settings like the Galapagos, where water is extremely scarce (Hoff, 2013). The tourist will plant and adopt a native tree, such as *Scalesia*, and the business will agree to monitor its growth, sharing information through the EcoHelix platform. This bilateral commitment creates both a short- and long-term relationship promoting conservation based on collaboration of tourists and local entrepreneurs. Smartphones will make it possible to record the planting and monitoring of the trees by uploading information to the platform.

The EcoHelix pilot

Puerto Baquerizo Moreno, the capital of the Galapagos Archipelago, was selected as the site for an initial test of the EcoHelix. In August 2013, 55 high schools students worked closely with 12 university student government leaders to gather data from a variety of businesses, including basic information (name, contact, address, RUC – the Ecuadorian business ID number, hours of operation,

Figure 6. Screenshot of www.ecohelix.com/galapagos.

etc.); GPS location; and a photo and brief history of the business. Using a train-the-trainer approach to build a corps of future project leaders, based on Bandura's Self Efficacy theory and its four pillars of mastery, modeling, social persuasion, and adaptation (Bandura, 1997), the university students were trained to coach the high school students who then worked directly with business owners (in many cases parents, family members, and neighbors of the students) to help them understand the benefits and opportunities associated with the EcoHelix and to collect data for the master website. A total of 148 businesses participated, more than 80% of the total. The Ministry of Tourism is also mapping every registered and unregistered hotel and guesthouse (a total of 128); this information will be incorporated into the platform.

Additional data were collected from business owners during the summer of 2014 on the three other populated islands: Santa Cruz, Isabela, and Floreana. As on San Cristóbal, high school students were trained by a cohort of university student leaders to collect data and to promote the benefits associated with sustainable business practices (see http://www.ecohelix.tumblr.com). Municipalities, nonprofits, government agencies, and school leaders are currently being invited to collaborate in an expansion of the EcoHelix throughout Galapagos. On Santa Cruz, the City Planning Department complemented data collection by providing access to its own database. Mayors on each island, along with city council members, are enthusiastic about the initiative, and have offered support by proposing collaboration through a part-time webmaster to update the information monthly.

The website provides basic information for each business, along with the option of rating quality of service (Figure 4). The online platform will emphasize the importance of "voting with your dollar," to encourage tourists to support businesses with better environmental practices. Users will also be able to purchase products and make reservations online, and include their own ranking, comments, or photos while traveling or once back home.

Consider the example of Lucky's, a small but popular restaurant that provides lunches and dinners for local residents and visitors. Using a SIM card or downloaded application, tourists would locate and choose Lucky's based on ratings provided by previous clients and additional information contained in Lucky's online profile (comparable to the Trip Advisor model). At the end of the meal, the visitors would be invited to rate their experience (quality of food, service, cleanliness, green practices, etc.). The information would become part of Lucky's growing database and profile. This feedback could motivate the owners to make improvements, as would their competitors.

The EcoHelix tourist interface is currently being refined for testing with tourists during the summer of 2015. The Municipality of San Cristóbal, in collaboration with the National Telecommunications Agency, will set up four kiosks (at the new airport, the public dock, in front of the municipality offices, and at the Galapagos National Park Interpretation Center) where tourists can purchase a SIM card, activate the application, and later contribute to the quality of service and healthy competition in the community by rating the establishments they visit.

Conclusions and recommendations

The Galapagos Islands are at a critical crossroads (Durham, 2008; Quiroga, 2015). The EcoHelix offers a powerful, interdisciplinary solution to help ensure a local economy based on environmental sustainability, one of the major challenges in emerging market economies with environmentally fragile destinations. Galapagos provides a valuable test case that could be replicated elsewhere in Ecuador and around the world.

The success of the EcoHelix initiative will be determined by the degree to which key stakeholders from each sector provide their support and collaboration (Carayannis & Campbell, 2012). Each municipality, which will ultimately have the responsibility of maintaining the system for their island, is committed to providing monthly updates. The Ministry of Tourism through the Galapagos Tourism Observatory is planning to integrate survey systems into the platform to develop statistics that will inform public policy.

Student government leaders who participated in data collection during the previous two summers have been extremely enthusiastic, with equally significant results among high school sophomores and juniors. The initiative has been especially well received by educational leaders; principals from the Liceo Naval and Colegio Humboldt (San Cristóbal), Colegio Nacional Galápagos (Santa Cruz), and Colegio Azkúnaga (Isabela) have invited teachers and students to participate through classes and extracurricular activities.

The following recommendations will help ensure that Galapagos benefits fully from the EcoHelix:

1. Ensure that the entity charged with maintaining the website has the capacity for continual updates and maintenance, and will continue to increase the number of businesses participating.

2. Identify a legal entity to make it possible for tourists to invest in selected businesses, based on existing micro-lending and crowdfunding models (KIVA, Kickstarter, etc.); the creation of a local trust fund and collaboration with existing local cooperatives are being considered.

3. Identify and implement ways to work around the weak Internet connection in Galapagos, which limits the effectiveness of web-based tools. One solution is to create an intranet on each island, which would enable tourists to have access to local information. Another is to provide SIM cards where the information needed resides on the device used by the tourist, be it a smartphone or pad. Both options are currently being assessed in consultation with the national telecommunications network and the Governing Council.

4. Invite high school administrators, teachers, and students to play a more active role in the implementation of EcoHelix, and provide follow-up with interested participants in each community.

5. Promote the use of the EcoHelix in improving both intra- and interisland communication, which could provide additional opportunities for governmental institutions and others to post and exchange information ranging from activities to policies to opportunities, to prepare local citizens for the growth of community-based tourism on the islands.

6. Produce a video for all commercial flights to Galapagos, which presents information on the geology, geography and biodiversity of the Archipelago, and highlights its vulnerability in the face of growing tourism. The video should challenge each tourist to become an agent of change during their visit and to continue once their visit ends.

The Galapagos Archipelago is more vulnerable than ever before, given that a majority of visitors are choosing the more affordable, island-hopping tourism, which lacks strict regulations. The EcoHelix seeks to harness and mobilize technology, inviting business owners and tourists to play a more active role in the promotion of a sustainable model that addresses ecological and economic interests. The data have been collected, the platform and the application are being tested, and key stakeholders have been invited to collaborate. The challenge lies in the socialization and adoption of the EcoHelix to create a more sustainable future.

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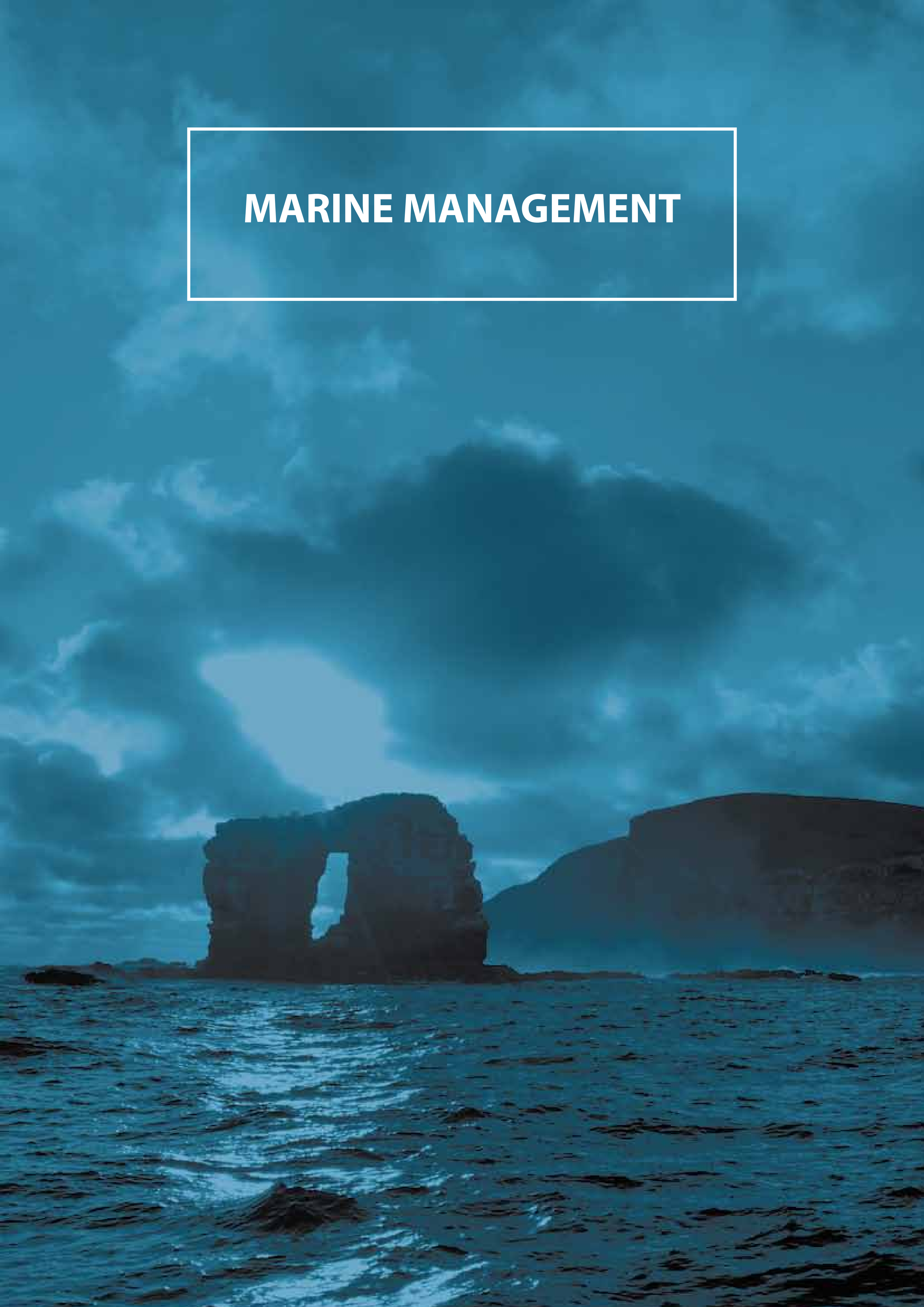
MARINE MANAGEMENT



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How do users of the Galapagos Marine Reserve imagine it?

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What is the first image that comes to mind when you hear the word Galapagos? For most people, the image of the Archipelago evokes "the untouched, pristine, wild, and natural" (Celata & Sanna, 2010). These images, built around the idea of "wilderness" or wildlife (Castree & Braun, 2001), were created by western visionaries within the consumer culture of the post war era (Kleese, 2002). For others, the Islands represent the hostile (Ahassi, 2003) or the possibility of "getting rich quick" (Camhi, 1995), a response to the bonanza resulting from sea cucumber fishing. According to Moscovici (2000), this is because social representations are linked to cultural and historical contingencies and societal value systems, ideas, and practices.

The creation of the Galapagos Marine Reserve (GMR) is an example of these social constructions. Initially associated with the idea of protecting the luxuriant marine biodiversity and intimately linked to scientific knowledge, this image has been used as cause célèbre by local forces, and continues so even now when images that are contradictory to the ideal of protection and conservation of biodiversity in the GMR have been developed (Watkins & Cruz, 2007; Salcedo-Andrade, 2008).

The diversity of images created by the users about the GMR has great relevance in the management and long-term viability of the Reserve. According to the Interactive Governance Theory (Kooiman *et al.*, 2005; Bavinck *et al.*, 2013), these images can determine greater or lesser GMR governability. They represent normative and cognitive aspects of users in relation to resource use (Song & Chuenpagdee, 2014). These images are useful when struggling with issues of conservation, management, and governance of resources, the environment, marine protected areas (MPAs), and fishing (Axelrod, 1994; Stern & Dietz, 1994; Pita *et al.*, 2011; Chuenpagdee & Jentoft, 2009). They are useful for decision-making because they illustrate the relationship between those who govern and those who are governed (Bavinck *et al.*, 2005). Finally, they increase the transparency of the process, the user´s willingness to take part in participatory practices (Chuenpagdee, 2011), and provide information regarding user attitudes and behavior in relation to the GMR, illustrating the reasons for their support or opposition to specific management measures (Fischer & Van der Wal, 2007).

Unfortunately, despite the advantage of integrating users´ images within the context of the management of MPAs, the images of the GMR have been traditionally and effectively hidden. This is a result of the dominant "hard science" approach of the research endeavor in Galapagos, in detriment to a more humanistic approach to the functionality of the GMR (Tapia *et al.*, 2009). As a result, it has been shown that this positivist approach has not solved the governance difficulties in the GMR; neither has it been as objective as believed.

The implementation of management actions, decision-making, and policy development have been primarily and exclusively based on science, influenced by theories, values, and power (Longino, 1990), which has proved to be inappropriate and risky.

But what do these "images" related to interactive governance refer to? They are what people think about the GMR, what they think should be done, or what is perceived can happen, based on interpretations of reality by the society, which in turn forms the public discourse. This reality, or our view of it and its social constructions, is expressed as visions, meanings, ideas, representations, cognitive elements, knowledge, facts, judgments, assumptions, hypotheses, convictions, purposes, and goals (Kooiman & Jentoft, 2009; Buijs, 2009; Buijs *et al.*, 2012).

This study illustrates the images that users have of the GMR, its management, and current state, within an interdisciplinary field at a meta-level scale. The research contributes to the literature on governance and governability of MPAs, clarifying the role, usually imperceptible, of images associated with human practices (Kooiman & Jentoft, 2009). This article proposes to: a) illustrate the most common images of the GMR; b) explore how they were formed, and c) describe how they influence governance of the GMR. Finally alternatives are presented to improve governance of the GMR.

Methods

A qualitative methodological paradigm was applied by using a case study to illustrate the phenomenon of interest, without generalizing the results outside the context of this investigation, nor towards other individuals or places, nor testing hypotheses in a universal sample (Stake, 1978; Gomm *et al.*, 2000; Stern, 2008; Golding, 2012; Robinson, 2014). On the contrary, I looked for patterns and meanings in the reasoning of the participants toward the GMR. Combining several methods or "triangulation" (Clifford & Valentine, 2003), I integrated semi-structured interviews, informal discussions, and participant observations at public meetings and consultation sessions. Relevant documents (e.g., journals and grey literature) and other sources of information (e.g., TV and local press) were extensively reviewed. Data collection lasted five and a half months with separate phases during 2010, 2011, and 2012. "Thematic Analysis" (Braun & Clarke, 2006) was used, including theoretical or deductive codes (Crabtree & Miller, 1999; Brinkmann, 2013). These coded data were related to the most common types of images encountered in the governance of marine resources literature. The images were grouped under four philosophical dimensions: expressive, normative, cognitive, and affective (Swart *et al.*, 2001; Keulartz *et al.*, 2004; Stern, 2008).

The data were obtained from 39 interviews with members of seven sectors of direct users of the GMR: eight small-scale fishers, ten tourism operators, seven dive centers, a naturalist guide, five scientists, five resource managers, and three maritime transport operators. Three potential participants refused to be interviewed, indicating a lack of knowledge related to the subject, or distrust and discomfort at being interviewed.

Results

What does the GMR mean to you?

Responses to the initial question, "What does the GMR mean to you?" were grouped into 34 image categories and 13 related topics (Table 1). The images fall mainly under the cognitive dimension, which refers to knowledge (e.g., "what is it?", "what does it do?", "what benefits does it provide?"), and the normative dimension, dealing with regulations and laws related to the GMR (e.g., "how is it managed?", "what are you allowed to do?"). Other images had affective (e.g., sense of belonging) and esthetic (e.g., beauty) connotations. The results show that knowledge about the GMR, regulations, affections, and values associated with the MPA are at the core of the images of the users. In a more practical and administrative context, these images could be "goals," "ends," and "judgments," related to concrete actions to be developed or implemented using management instruments.

Where do the images of the GMR originate?

The images regarding the GMR can originate directly or indirectly. Indirect images were developed mainly through the media, and through family or friends. Interestingly, scientific information and researchers appeared to have less dominant roles in the creation of images than previously thought. No interviewee made reference to scientific sources (e.g., articles in scientific journals or experts) for knowledge of the GMR.

On the other hand, direct images were obtained in situ after visiting the area or through personal experiences (e.g., working in the area). Thus, the relationship of the interviewees with the GMR is considered as a direct mechanism that enables the creation of images. In this case, five main types of interactions were identified: "fishing in the GMR," "tourism" (including divers and agencies), "through their own businesses," "research," and "working for the GMR." Additionally interactions between users and the GMR showed variations as to whether they are unique (e.g., a person is only a naturalist guide) or multiple (e.g., an entrepreneur could also be a fisher; a fisher could also be a dive guide). In addition, the level of engagement of users with the GMR varied over time with some users greatly or little involved in the period when the GMR was created (e.g., either in the establishment of the MPA or currently in its management), or in the level of intensity of interaction through direct (e.g., implementing conservation actions) or indirect (e.g., financially supporting a third party) involvement.

Discussion

Images of the GMR represent different things for the different people who form them. Interactive governance allows us to recognize that the GMR is highly complex, diverse, dynamic, and operates at multiple scales, all of which influence the diversity of images of the GMR being developed. For this reason, as Kooiman *et al.* (2005), we recognize the images of the GMR, along with instruments and actions, as elements that influence, deeply and significantly, the governance of this MPA.

Table 1. The 34 categories and 13 themes for the images resulting from the question "What does the GMR mean to you? "The images primarily correspond to the cognitive (in light gray) and the normative (in dark gray) dimensions. Affective and esthetic images are indicated in black.

Category (Song & Chuenpagdee, 2014)	**Theme** (Song & Chuenpagdee, 2014)	**Type of Image** (Kooiman & Jentoft, 2009; Buijs, 2009; Buijs *et al.*, 2012)	**Associated philosophical dimensions influencing the images** (Swart *et al.*, 2001; Keulartz *et al.*, 2004; Stern, 2008)
Protected Area (location/size/sector) Marine Protected Area Preservation/protection Conservation	Protected Area/protection/ preservation	Goals, ends	Cognitive
Resources/species (flora/fauna)/ preservation/protection Marine protection	Environment/habitat/ resources/protection/species	Goals, ends, knowledge	Cognitive/Normative
Characteristics of the MPA Management and legal framework Protection of the MPA by staff Multiple use zoning Decision-making model (consensus) Management Plan	Management strategy/ instrument	Goals, ends, knowledge, judgments, hypotheses, facts, perceptions	Cognitive/Normative
Mandated/limited use of resources Prohibition/exclusion of industrial fishing Exclusive use by locals	Control/regulations/ exclusion/resource use	Goals, ends, judgements, meaning	Normative
Vulnerability Insufficient patrol/control Risk of extinction	Governance limitations	Judgments, perspectives, ideas	Normative
Risk of extinction	Conservation limitations	Judgments, perspectives, ideas, presuppositions	Normative
Artisanal fishing Tourism Scuba *Snorkel**	Profitable tourism activity	Goals, ends, knowledge, meaning, representations	Normative
Scientific research Management Conservation	Nonprofit human activity	Goals, ends, knowledge, meaning, facts	Normative
Diversity Uniqueness Value Local/global/national/international scale Time scale	Richness/value	Knowledge, facts, representations	Affective/Esthetic/ Cognitive
Source of income Tourism means work	Source of income	Judgements, perspectives, ideas, meanings	Affective/ Cognitive
Feelings about the activity Snorkel* Life at sea Individual /personal significance Our province Pride Idyllic scenario	Affection/sense of belonging	Judgements, meanings, representations	Affective
Attraction Snorkel* Uniqueness	Esthetic	Goals, meanings, perceptions, ideas	Affective/Esthetic
Provincial status	Political/administrative status	Goals, ends, representations	Cognitive/Affective

* It is assumed as not necessarily lucrative, because it may also have recreational interest, without economic benefit.

This research does not seek to find, propose, or define "good and correct" or "bad and incorrect" images. Instead I seek to contribute, in a practical manner, to the use of these "other" dimensions, different from the cognitive and normative, which at the same time play an influential and significant role in the formation of GMR users' images. A more inclusive vision that goes beyond the "marine resource management" approach is needed to meet the goals set for the GMR. I therefore propose the adoption of a broad paradigmatic image of "island governance" for Galapagos (including terrestrial and marine environments).

Cognitive and normative images were dominant among the participants, probably inasmuch as they are generated through mechanisms used to know the Reserve. Undoubtedly, communication media (i.e., cognitive) and MPA regulations (i.e., normative) have played an important role in the creation of the images and have served to establish links between means (image generation) and generation of knowledge. This idea, coinciding with Kooiman (2003), shows the decisive role of the means, not only in the creation of images, but also in their transmission and evolution. In this case, little or nothing has been done to resolve conflicts between users of the GMR linked with emotional or esthetic aspects.

The intensity of interactions between users and the GMR varies. It has been seen that being "involved" with the GMR does not necessarily imply an active role on the user´s side. In fact, neutral or inactive interactions were also recorded (e.g., memberships or associations) and form an interesting niche that conservation strategies should target. Another singular form of interaction is the "no interaction." This represents non-existing interactions, for example, through passive resistance or failure to respect laws (e.g., ignore, infringe, or violate regulations of the MPA), or even participation in illegal or arbitrary activities. This means that the obvious images aren't the only ones with which users (particularly authorities) must deal. Those hidden images that are socially accepted, explicitly or by implication, are also worthy of attention (e.g., "break the rules and prohibit participation may be tolerated, depending on who is excluded or what rule is violated").

The multi-temporal attribute of users´ images (i.e., during the creation of the GMR, when they heard of it for the first time or by experience) shows the dynamic complexity of the image formation process; in this case, their creation based on knowledge acquired through "media," "family/friends," "visiting an area," or through "personal experiences." In addition, it seems that relations between users and the GMR are determined by individual (or family) objectives (goals and aims) to develop, for example, small-scale fishing, tourism, personal business initiatives, research, or even being part of the MPA management staff. At the normative level, the fact of being able or unable to develop activities has a great influence on the creation of images, for example, when explaining the concept of the GMR as a function of the existing restrictions, rules, and regulations.

Conclusions

The link established by the interviewees between cognitive- and normative-based images was imperceptible and never explicitly mentioned. This shows that the "final" image of GMR by the user has no clearly defined domain. In this way, it invites a reassessment of various elements to ultimately achieve the objectives of the MPA.

It is therefore concluded that:

- The images of the GMR show an immense variation, including both matching and contradictory images. There is no "right" or "standard" image of the GMR, not even within the scientific, small-scale fisheries, tourism, or maritime transport sectors. The images are contrasting and recognize the humanity of the MPA systems thus showing how users "imagine the GMR."

- Clarifying hidden images or negotiating opposing images does not necessarily imply that the interactions between those governing and those being governed must be free of discrepancies. It is suggested that those disagreements serve as negotiation mechanisms to find common ground and establish commitments among users. For example, a way must be identified to not only achieve greater community support but also to maintain that support.

- The dominant effect of the media used in the creation and transmission of images should serve as a mechanism to reassess and rethink the goals of the GMR.

- The images of the GMR spread by the media that indicate that it is an "untouched" and "pristine" area should be amended. There is enough evidence showing the negative side of human activity, for example tourism, and which shows that this MPA is not the ecotourism model par excellence that is promoted.

- The images created by users have given us a guideline of what is, in general, the philosophical background for their formation. However, none of the images has a single element nor can we talk about the "purity" of the images. Each image is a combination of aspects surrounding the four philosophical pillars that influence its creation. For this reason, the attempt to reduce conflicts between users and improve governance, for example, must of necessity take into account these four dimensions to attack the problem in a comprehensive way.

Recommendations

Including cognitive and normative domains, as well as affective and esthetic attributes, in the planning and development of activities in the protected area is recommended because much of the user behavior originated in the latter two. The mechanisms currently in place to manage the GMR should be adapted to propose, negotiate, mediate, resolve, and maintain measures that promote nature sustainability and the community's wellbeing in Galapagos. New strategies focusing on the four philosophical pillars that form part of the behavior and feeling of people should be used when designing a renewed and responsible public debate to decide if Galapagos should continue with the voice of rational conservation or if it is necessary to rethink a radical change in the management paradigm toward governance, in political, economic, and scientific agendas in the GMR (Watkins, 2008; Tapia *et al.*, 2009). This would help to improve the GMR governance system, thus increasing its governability over the long term, promoting the common wellbeing, and achieving the awaited equilibrium.

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Photo: © Macarena Parra

Marine invasive species in the Galapagos Marine Reserve: A case for additional research, improved management, and policy review

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Introduction

Biological invasions occur when species enter a new environment, become established, and impact native species populations, disturbing the balance of plant and animal communities (Emerton & Howard, 2008; Williamson & Fitter, 1996). The introduction of alien species has been identified worldwide as the second most important reason for biodiversity loss after habitat destruction; in oceanic islands, it is undisputedly the first (IUCN, 2011). Marine invasions are currently a widespread problem throughout the world's oceans with significant impacts to the environment, the economy, and health (Campbell & Hewitt, 2013).

The rate of biological invasions has increased during recent decades, mostly due to increasing global trade, transport, and tourism, which allow an accelerated spread of species by overcoming natural barriers, such as currents, land masses, and temperature gradients (Seebens *et al.*, 2013; Hilliard, 2004). Climate change and extreme climate events can alter vital aspects of the environment through significant changes in temperature and precipitation, which allow invasive species to establish and spread more easily than if the system were stable and more resistant to invasion. El Niño Southern Oscillation (ENSO) events can often have devastating effects on the flora and fauna of an area by facilitating transport and/or invasion of non-native species. Algae and corals can die off, creating niches that the opportunistic invasive species can occupy faster than the recovering native species. The connectivity of oceanic currents combined with the lack of control measures make it very easy for new invasions to occur.

The Charles Darwin Foundation (CDF), in close collaboration with the Galapagos National Park Directorate (GNPD), the Galapagos Biosecurity Agency (ABG – Spanish acronym), and the Ecuadorian Navy and their Oceanographic Center (INOCAR – Spanish acronym), began the Marine Invasive Species Project in 2012, with the support of the University of Dundee and the University of Southampton in the UK. The project aims to minimize the impact of invasive species on the biodiversity of the Galapagos Marine Reserve (GMR) by creating risk assessment tools for the prevention, early detection, and management of invasive marine species along with rapid response protocols.

Established marine invasive species in the GMR

All existing literature was reviewed and underwater surveys conducted by the marine invasive species team of the Charles Darwin Foundation (CDF, 2013) A preliminary list was produced indicating six invasive species that are now established in the GMR (Table 1).

Potential marine invasive species for the GMR

Data collected on marine invasive species worldwide highlighted 18 high risk species (species that could negatively impact the biodiversity of the GMR) with potential to arrive in the GMR through various vectors (Table 2).

Table 1. List of established invasive species in the Galapagos Marine Reserve.

Scientific name	Common name
Cardisoma crassum	Blue crab
Bugula neritina	Brown bryozoan
Pennaria disticha	Christmas tree hydroid
Caulerpa racemosa	Grape algae
Asparagopsis taxiformis	Red sea plume
Acanthaster planci	Crown of thorns

Table 2. List of potential invasive species for the Galapagos Marine Reserve.

Scientific name	Common name	Scientific name	Common name
Asteria amurensis	Northern Pacific seastar	*Hypnea musciformis*	Hook weed
Chthamalus proteus	Caribbean barnacle	*Acanthophora spicifera*	Spiny seaweed
Mytilopsis sallei	Black-striped mussel	*Chama macerophylla*	Leafy jewelbox
Undaria pinnatifida	Japanese kelp "Wakame"	*Diadumene lineata*	Orange-stripped green anemone
Carijoa riisei	Snowflake coral	*Didemnum candidum*	White didemnid
Caulerpa racemosa var. cylindracea	Grape algae	*Haliclona caerulea*	Blue Caribbean sponge
Codium fragile	Sponge weed	*Carcinus maenas*	European green crab
Asparagopsis armata	Harpoon weed	*Lutjanus kasmira*	Blue stripped snapper
Gracilaria salicornia	Red alga	*Pterois volitans*	Lionfish

Examples of high potential invasive species that are already established in the GMR include grape algae (*Caulerpa racemosa*; Figure 1) and red sea plume (*Asparagopsis taxiformis*; Figure 2).

Photo 1. Grape algae (*Caulerpa racemosa*), Fernandina. Photo: © Noemi d'Ozouville

Photo 2. Red sea plume (*Asparagopsis taxiformis*), Cabo Douglas, Fernandina. Photo: © Inti Keith

Several species with a high potential to be introduced to the islands, such as the snowflake coral (*Carijoa riseii*; Figure 3), have already been reported in continental Ecuador and in the island of Malpelo, Colombia (Sanchez *et al.*, 2011).

Photo 3. Snowflake coral (*Carijoa riisei*). Photo: ©Fernando Rivera.

Marine traffic

Marine organisms have spread from their native regions through human transport and have managed to establish populations in different parts of the world (Cohen & Carlton, 1998). It is thought that marine traffic is the main cause of species translocation worldwide (Kolar & Lodge, 2001; Hulme, 2009), and it is estimated that 10,000 species are transported around the world in ballast water every day, due to the increasingly larger and faster cargo ships (De Poorter, 2009; Hutchings *et al.*, 2002; Bax *et al.*, 2003). The large amount of traffic that already exists combined with the rapid expansion of this industry increases the danger of species being transported and invasions occurring.

The study conducted by Seebens *et al.,* (2013) identifies the major shipping routes and number of journeys worldwide during 2007 (Figure 1).

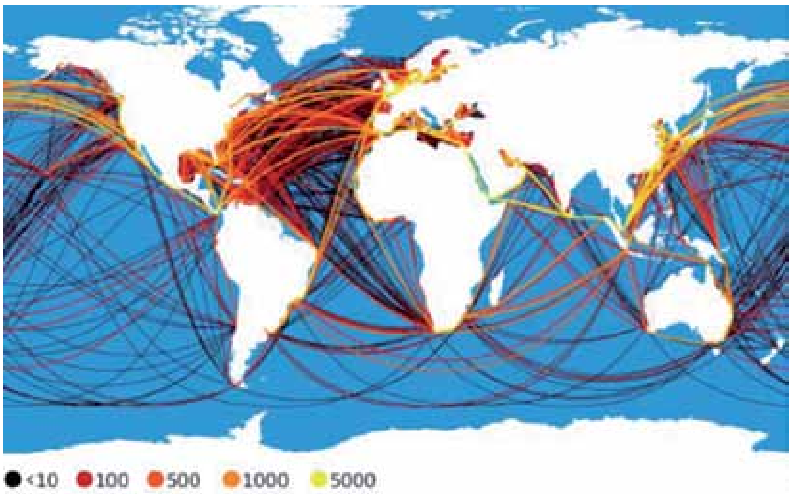

Figure 1. Worldwide shipping traffic in 2007 (Seebens *et al.*, 2013).

The history of the maritime traffic in the GMR is extensive, which makes it more difficult to know with certainty if some species existed naturally or if they where introduced by humans in the past. Since their accidental discovery in 1535 and through the 17th and 18th centuries, the Galapagos Islands became a haven for pirates. Then in the 19th century, whalers were attracted by the richness of the sea surrounding the Islands. The first introductions of domestic animals and invertebrates occurred during these centuries. Various marine species could also have been introduced at this time. A possible example is *Bugula neritina*, a brown bryozoan that has a worldwide distribution, which is thought to have been transported on wooden hulls (Eldredge & Smith, 2001) and could have arrived in the Galapagos through this mechanism in centuries past. Industrial-fishing boats arrived during the 1940s and 1950s (Cruz *et al.*, 2007), and in 1942 during the Second World War, the United States of America constructed a naval base on Baltra Island, which increased the number of vessels in the area.

Today the marine traffic that navigates regularly in the GMR waters includes the following categories: tourism, transport, cargo, fishing, private, scientific, patrol boats, and oil tankers (Figure 5). The movement of these vessels increases the threat of marine invasive species entering and spreading within the GMR. In the Galapagos Islands, tourism is the main economic base (Piu & Muñoz, 2008); 61% of tourists visit onboard boats. There are several different itineraries and routes that are managed by the GNPD and the Ministry of Transport. The number of inter-island vessels that operate fluctuates according to demand. During the first semester of 2007, approximately 1900 journeys were made between populated islands (Cruz *et al.*, 2007). A study conducted between February and November 2012, a period of only ten months, indicated 8685 departures and arrivals of inter-island vessels recorded on Santa Cruz Island by the Ecuadorian Navy (Parra *et al.*, 2013), showing a marked increase. Fishing, private, scientific, and patrol boats are harder to enumerate, as they do not have fixed itineraries or routes.

The number and frequency of cargo ships and other vessels sailing between mainland Ecuador and the Galapagos Islands has also increased in recent years, as has the number of private yachts arriving from different parts of the world. Between 2002 and 2006, four cargo ships transported goods to the islands approximately 68 times each year. In 2006, an additional boat began operating bringing the total to five cargo ships (Cruz *et al.*, 2007). During 2011, due to new regulations, only four cargo ships travelled to and from the islands with a total of 224 trips (Bigue *et al.*, 2013).

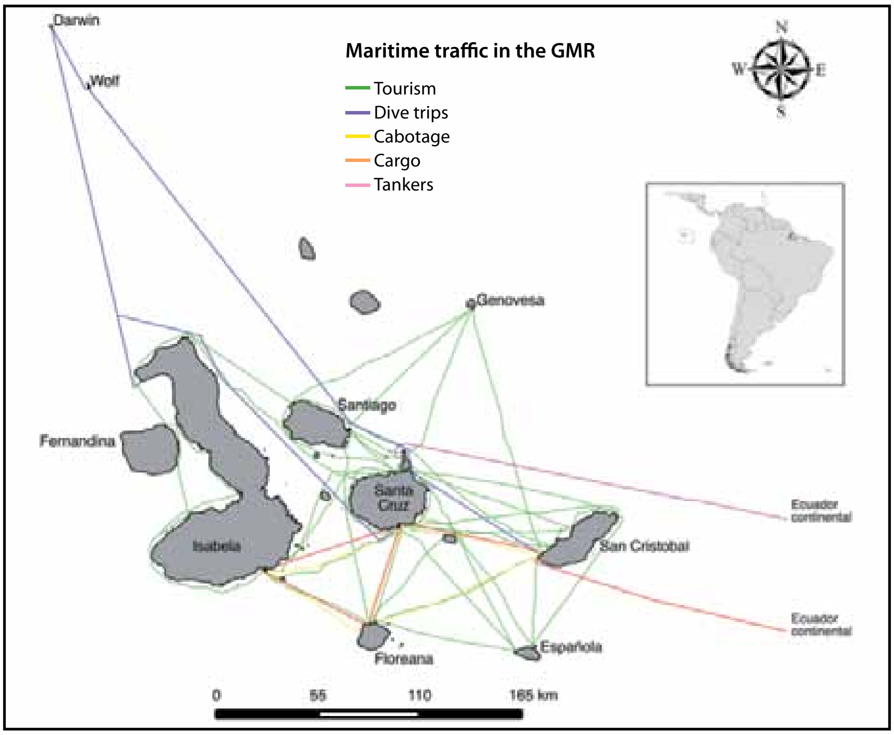

Figure 5. Main marine traffic routes in the GMR in 2014.

Reducing marine invasion risk

The possible invasion of marine species to the GMR, given the connectivity that exists within the Eastern Tropical Pacific (ETP), the increase in marine traffic, and climate change, is a reality that should not be ignored. Invasive species and climate change are two of the most prevalent issues biodiversity is facing (Rahel & Olden, 2008). When a habitat changes, for example through climate change, invasive species can often become established and spread more easily than in a stable system; native species often struggle to adapt to new conditions, while many invasive species are excellent in adapting quickly (Emerton & Howard, 2008). In extreme cases, climate-driven invasions could completely transform ecosystems to where non-native species dominate ecosystem processes, species richness, or both, leading to reduced diversity of native species (Mack *et al.*, 2000; Walther *et al.*, 2009).

Studies show that marine ecosystems in the Galapagos are not well adapted to extreme thermal impacts (Edgar *et al.*, 2010). Whether one talks about climate change or ENSO events it is clear that changes in sea surface temperature can affect the ecosystems in the GMR. Understanding the human influences that affect the GMR is a high priority in order to protect the biodiversity of the Archipelago. Oceanic currents heavily influence trans-oceanic dispersal, often moving species between widely separated areas, especially species capable of long-distance larval transport (Hickman, 2009). The historical geographic isolation of the Galapagos Islands once limited immigration of new species, allowing the established species to evolve with few strong competitors and predators. Due to the oceanographic connectivity that the Archipelago has with the rest of the Eastern Tropical Pacific (ETP), it is important to improve our understanding of the various human factors that influence the GMR. The potential loss of biodiversity and risks to ecosystem processes are mainly due to factors such as climate, fisheries, maritime traffic, pollution, and extreme natural events (Banks, 2002). The ever-increasing marine traffic in the GMR and the ETP is putting the Galapagos Islands under more and more pressure as they become more geographically accessible and the potential for marine biological invasion intensifies.

The growth of tourism and immigration associated with the islands in the last 20 years has led to a dramatic increase in the number of exotic species introduced (CDF & WWF, 2002). The majority are terrestrial species but some marine species have been introduced; an example is the blue crab (*Cardisoma crassum*), which was introduced to the islands when live crabs escaped from a hotel in Puerto Ayora where they were being cooked for the captain of a tourist boat (Hickman, 2000). The number of private vessels arriving in the Galapagos from different parts of the world has increased in recent years. As more yachts arrive to the Islands, the higher the risk of a marine species invasion. An efficient policy to support conservation and social sustainability must act on the connections between Galapagos, continental Ecuador, and the rest of the world, to reduce the flows that enter and leave the Archipelago (Grenier, 2010).

Recommendations

The Charles Darwin Foundation, in strong collaboration with local authorities, is working to minimize the negative impacts that marine invasive species can have on marine biodiversity, ecosystem services, and the health of the RMG. Recommendations based on this analysis include:

- Implement monitoring and early detection systems for marine invasives for the main ports of the populated islands along with rapid response protocols.
- Create a multi-institutional dive team to carry out inspections of marine invasive species in sensitive areas and in the main ports.
- Create a multi-institutional coordination committee to establish a network of professionals to address the problem of marine invasive species in the GMR and in continental Ecuador.
- Study the regulations that are in place in the Eastern Tropical Pacific (ETP) and establish the necessary documentation for the inspection of vessels in Galapagos.
- Conduct studies on the distribution, abundance, and interactions of introduced marine species and their dispersal potential using oceanic modelling.
- Disseminate information of the potential threats and impacts of marine invasive species and preventive measures that can be put in place along with rapid response protocols.
- Work within the scope of the Convention on Biological Diversity as the focal point of the Ministry of the Environment.

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Marine wildlife health surveillance in the Galapagos Islands: First year results of the Rapid Response Network

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[1]Charles Darwin Foundation, [2]Galapagos National Park Directorate

Introduction

Marine wildlife, especially marine mammals, act as sentinels of ocean and human health, providing early essential information regarding threats and impacts to marine ecosystems, which enables the establishment of preventive conservation strategies (Bossart, 2006).

Galapagos is home to a unique natural environment but various factors resulting from an ever-increasing expansion of human activities are threatening the health of many iconic species. Concerns within the marine environment include increased pollution, maritime traffic, the importation of goods from the continent, the impacts of introduced species, overfishing on some commercial species, and changes in ecosystem structure and resource availability due to climate change (Álava *et al.*, 2009 & 2011). Previous health research in Galapagos wildlife has focused on detecting diseases in avian and sea lions populations, and on anthropogenic impacts on sea turtles and birds (Salazar, 2006; Salazar *et al.*, 2007; Deem *et al.*, 2008; Zárate, 2009; Jiménez-Uzcátegui, 2010; Parra *et al.*, 2010). However, these programs had a limited duration due to lack of funding.

Until 2013, despite many isolated reports of injured animals that were handled by the Galapagos National Park Directorate (GNPD), there was no formal emergency network in place to rapidly detect and respond to sick, injured, or dead marine wildlife in the Galapagos Marine Reserve (GMR), nor was there a systematic program for health and disease monitoring and treatment. Many animals that came ashore were simply left or buried on the beach. Data collection was often inconsistent and little effort was made to determine the cause of death and the health status of the populations.

In 2012, the first Marine Wildlife Health Surveillance Program was initiated by the Charles Darwin Foundation (CDF) to implement a long-term health surveillance program and determine the most relevant threats to the iconic marine species of the GMR, such as sea lions, fur seals, sea turtles, sea birds, marine iguanas, and cetaceans. In 2013, a bi-institutional agreement between GNPD and CDF was established to develop effective methodology and organization for a Rapid Response Network (RRN), including standardized protocols, capacity building, and outreach (García-Parra, 2013), thus establishing the basic tool for a passive health surveillance program.

This program aims to respond to new cases and provide GNPD managers relevant information on wildlife health status and threats, to facilitate decision-making to ensure long-term conservation of marine biodiversity and environment. Results of the first year of the RRN operation are presented here.

Methods

Passive health surveillance

Passive surveillance involves collecting data and samples from injured, sick, or dead animals found onshore in order to identify pathologies and causes of death, which could be related to emergent, punctual, or mass mortalities due to natural or anthropogenic causes. In order to rapidly detect animals, the RRN operates a 24/7 emergency hotline, which activates a network of natural resource managers, park rangers, veterinarians, and local volunteers. Standardized action protocols were designed for both live and dead animals (Figure 1). When a live animal's injuries are caused by human activities, clinical veterinarian assistance is provided according to established ethical criteria appropriate to and developed with the GNPD. Complete necropsies are performed on dead animals if the carcass presents suitable conditions. Necropsy samples are preserved using three methods (10% formalin, RNA-later, and freezing at -20ºC) and then sent to specialized international laboratories to perform histopathological, microbiological, and toxicological analyses to determine the causes of death.

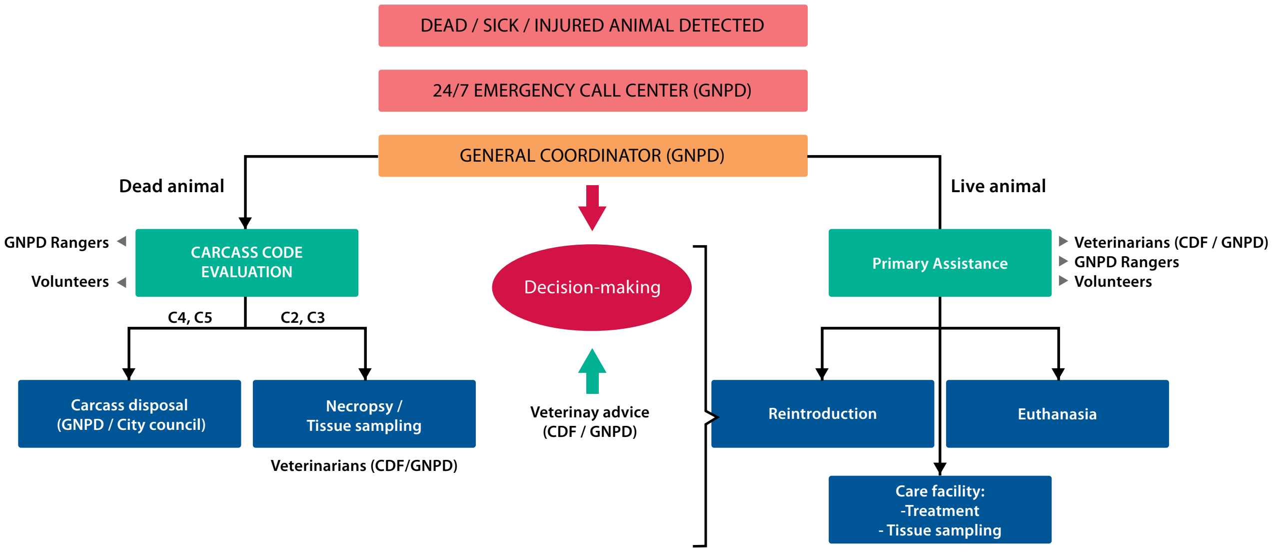

Figure 1. Diagram of the Rapid Response Network (RRN) operating system, © Carolina García, CDF 2013.

Training and outreach campaign

Two training workshops on "Rapid Response Network Operation and Protocols" were held in July-August 2013. Seventy-five park rangers participated and received training in RRN protocols, live marine wildlife handling and first aid, standardization of data collection, and identification of marine species. In order to increase the effectiveness of the RRN, 550 Galapagos naturalist guides were informed about the Wildlife Health Surveillance Program, the RRN project achievements, and preliminary data, as well as the role of naturalist guides as potential members of the network.

Results

During 2013, the RRN responded to 74 animals: 33 live animals and 41 dead animals. The live animals included 19 (58%) birds, 7 (21%) mammals, and 7 (21%) reptiles. The dead animals included 26 (63%) reptiles, 9 (22%) birds, and 6 (15%) marine mammals (Table 1). Although the health surveillance project was originally focused on marine wildlife, terrestrial wildlife was also assisted during 2013; the results are included here.

Of the 74 animals detected, 45 (61%) showed no indication of source of injury and thus were considered to be affected by unknown causes, 23 (31%) presented clear signs of anthropogenic impacts, and 6 (8%) were identified as natural causes. Human-related causes included: rodenticide intoxication (22%), dog attack (18%), car crash (17%), propeller impact (9%), and collision due to excessive glare (9%) (Figure 2). Marine iguanas (6 cases, 26%), sea birds (5 cases, 22%), and land birds (5 cases, 22%) were considered the most affected among species injured by human impact (Figure 3).

Fifty-eight of 74 RRN responses occurred on Santa Cruz Island, with a concentration of responses at Pelican Bay (Figure 4).

Unusual mortality event in marine iguanas

In early September 2013, Galapagos naturalist guides reported vomiting and deaths among marine iguanas at Tortuga Bay, Santa Cruz Island. The GNPD and the CDF, with support of the Biosecurity Control and Regulation Agency for Galapagos (ABG - Spanish acronym), conducted complete health assessments on 300 individuals. Between

September and December 2013, about 200 individuals were found dead: in Santa Cruz (~100), Española (16), and Floreana (82). CDF staff performed necropsies on 20 dead specimens, revealing oral ulcerations, compacted stomachs full of undigested red and green algae, severe esophagitis, gastritis, and enteritis.

Histopathological examination (performed by ZooPath) of 16 individuals confirmed severe necrotizing glossitis and esophagitis, mild interstitial pneumonia, acute congestion in the liver and spleen, and mild renal tubular necrosis in kidneys. Nine of the studied animals presented herpesvirus-like lesions, suggesting an infectious disease. Endotoxic shock was associated with death. Molecular analyses (performed by University of Florida) identified a novel herpesvirus but further research is needed to establish the clinical significance of the documented unusual mortality event. Results on the biotoxin determination are pending.

Table 1. Live and dead species detected by the RRN during 2013.

Class	Species		Habitat		No. of Animals	
	Scientific name	Common name	Terrestrial	Marine	Dead	Live
Birds	*Asioflammeus galapagoensis*	Short-eared owl	X		0	1
	Buteo galapagoensis	Galapagos hawk	X		5	0
	Coccyzus melacoryphus	Dark-billed cuckoo	X		1	0
	Gallinula chloropus	Common gallinule	X		0	1
	Geospiza spp	Finches	X		0	1
	Leucophaeus fuliginosus	Lava gull		X	0	1
	Nyctanassa violacea pauper	Yellow-crowned night heron	X		0	3
	Pelecanus occidentalis urinator	Brown pelican		X	3	4
	Phaethon aethereus	Red-billed tropicbird		X	0	1
	Pterodrom aphaeopygia	Galapagos petrel		X	0	1
	Puffinus subalaris	Galapagos shearwater		X	0	6
Mammals	*Tursiops truncates*	Bottlenose dolphin		X	0	1
	Zalophus wollebaeki	Galapagos sea lion		X	6	6
Reptiles	*Amblyrhynchus cristatus*	Marine iguana		X	22	4
	Chelonia mydas	Green sea turtle		X	1	2
	Chelonoidis spp	Galapagos giant tortoise	X		1	0
	Conolophus subcristatus	Galapagos land iguana	X		2	1
Total					**41**	**33**

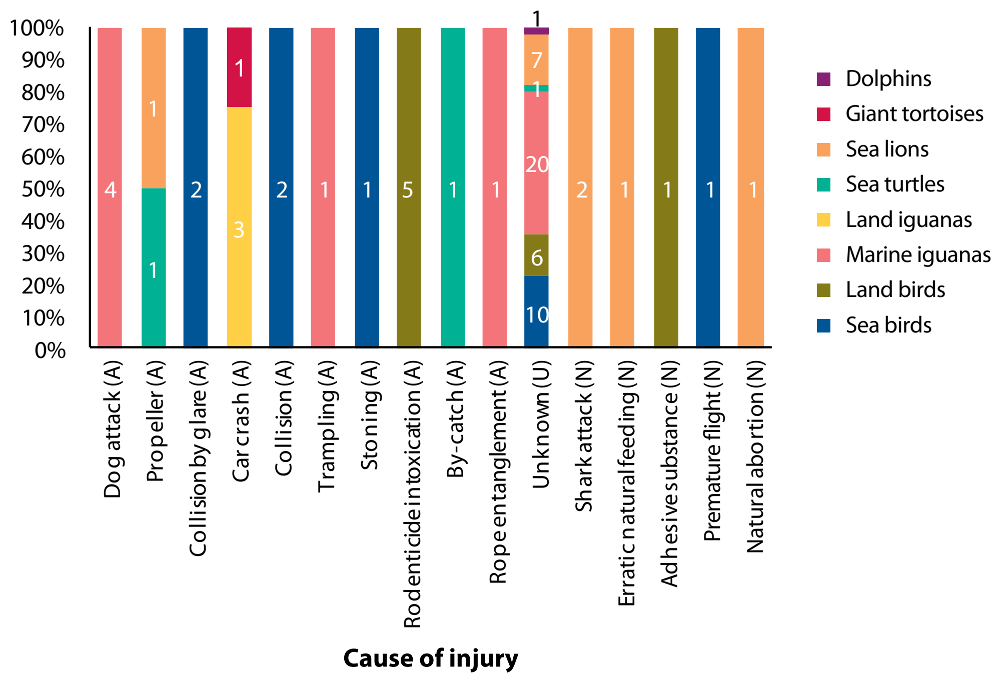

Figure 2. Causes of injury detected by the RRN in wildlife in 2013 (A= Anthopogenic; U= Unknown; N= Natural).

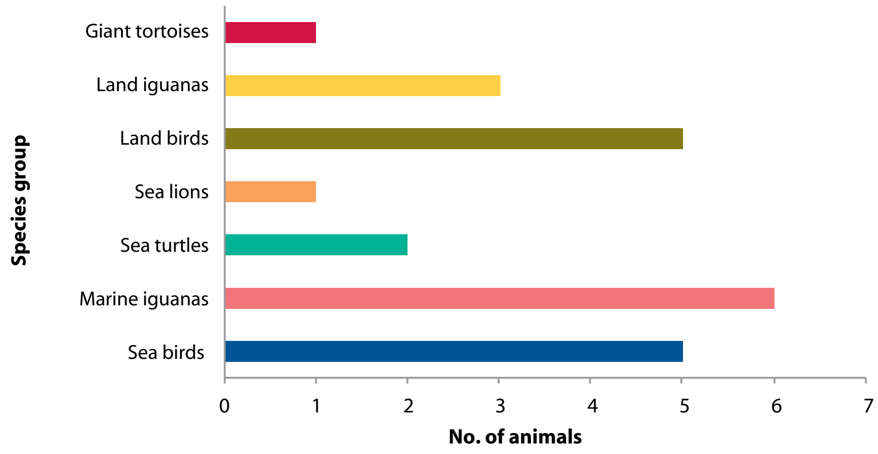

Figure 3. Number of animals injured or killed due to anthropogenic causes in 2013.

Recommendations

Nearly a third (31%) of the animals detected by the RRN was confirmed to be injured by anthropogenic effects. This should be considered a warning for conservation managers and stimulate an increase in mitigation strategies and efforts. According to 2013 results, management strategies should focus on:

Pelican Bay: Despite GNPD's ban, fishermen and tourists continue to feed wildlife. As a consequence, sea birds (especially pelicans) and sea lions frequent this site on a continual basis resulting in some being injured by fishermen in an effort to avoid fish stealing or by improper food items offered, such as tuna bones. There are also potential human health risks (bites, zoonosis, etc.). Educational and informative campaigns should be implemented to raise awareness among fishermen and tourists to reduce human-wildlife contact at Pelican Bay. At the same time, the DNPG should increase its surveillance efforts.

Marine iguanas and dog attacks: Control of domestic dogs is essential for endemic species. Marine iguanas are especially vulnerable during the reproductive, nesting, and hatching seasons. Educational and pet training campaigns should be improved and coordinated among conservation management institutions.

Road traffic impacts on iguanas and birds: Traffic control and subsequent penalties should be

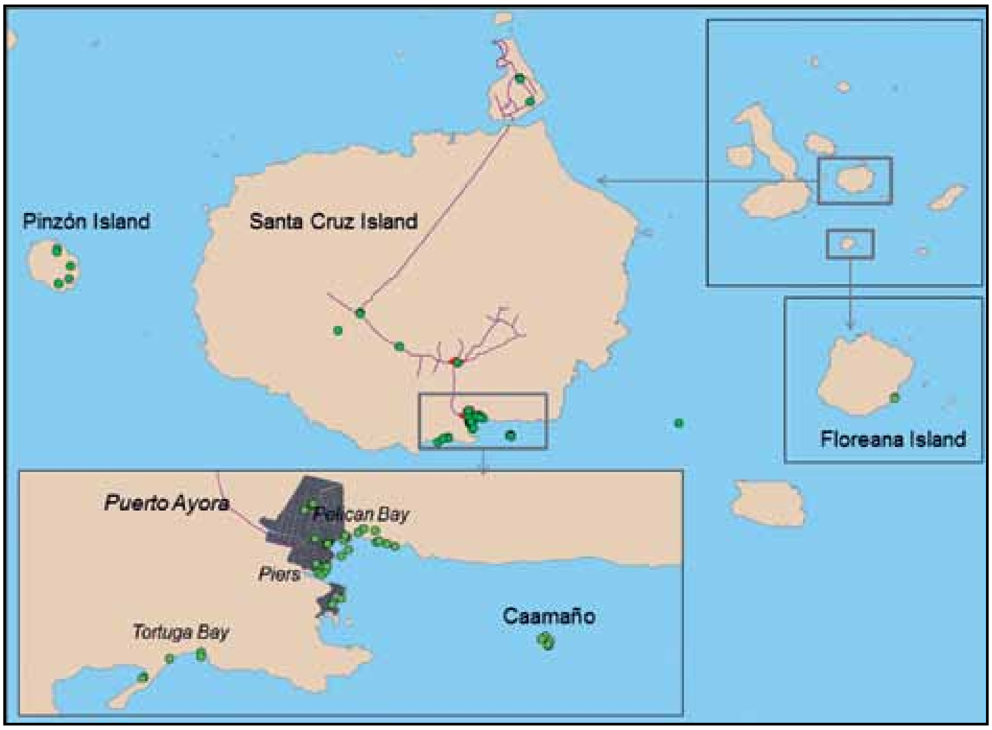

Figure 4. Distribution of animals detected by the RRN in 2013.

Photo: © Alan Kriegsfeld

increased on airport access roads and in urban areas to reduce wildlife injuries and deaths. Educational campaigns should parallel these efforts.

Boat strikes on sea lions and sea turtles: Boat traffic regulations should be improved and reinforced. Recommendations include reducing speed limits within three miles off the coast, improving control, and increasing educational and informational campaigns.

The Rapid Response Network is a useful tool for surveying wildlife health. However to ensure its long-term success, the GNPD must increase its capacity to oversee the program in perpetuity, maintain veterinarian service within the organization, and identify funds to support it. Suitable and equipped permanent facilities to assist live animals, perform necropsies, and laboratory routine analyzes are needed not only in Santa Cruz, but also in San Cristóbal and Isabela Islands.

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Evaluation of the incidence of boats impacting green turtles (*Chelonia mydas*) along the southern coast of Isabela, Galapagos

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After Mexico, the Galapagos Archipelago has the second largest reproductive stock of green turtles, the most abundant sea turtle species in the Galapagos Marine Reserve (GMR) and the most important of the Tropical Eastern Pacific (NMFS/USFWS, 1998; Seminoff, 2004). The Islands provide important feeding areas for the resident population (NMFS & USFWS, 1998; Seminoff *et al.,* 2007), which is concentrated in the coastal zone, while some turtles migrate to feeding areas in Central and South America (Seminoff *et al.,* 2007).

A significant portion of the population of the East Pacific green turtle depends on the nesting beaches and feeding sites of Galapagos. While the Islands provide good conditions for the green turtle, the increase in anthropogenic activities in both feeding areas and nesting sites threaten the local turtle population (Zárate, 2009). Threats include being hit by boats, interactions with fishing activities, and intake and consumption of waste (Zárate & Carrión, 2007; Zarate, 2009; Parra *et al.,* 2011; Denkinger *et al.,* 2013).

The objectives of this project were to provide information on the use of the nesting zones by female turtles at Quinta Playa, Isabela - the largest nesting site in the Archipelago, to determine the distribution of marine traffic in or close to this nesting beach, and to determine the incidence of boats hitting reproductive females. This article presents the data related to the impact of tourism on turtles. The results generated provide important information for the Galapagos National Park Directorate (DPNG) to use in developing future management strategies to support the conservation of this species in Galapagos.

Methods

Study site

Quinta Playa, the largest nesting site of green turtles in the Galapagos Archipelago, is a beach on southern Isabela Island, approximately 13 km west of Puerto Villamil. Quinta Playa is part of an important green turtle nesting area that consists of the following beaches: Puerto Villamil; Barahona Bay; and Segunda, Tercera, Cuarta and Quinta Playas.

Quinta Playa is located approximately 10 km to the east of two popular marine tourist attractions of Isabela, Los Túneles y El Finado, where experiential artisanal fishing, a tourism activity, is permitted (Figure 1). In recent years, the growth of daily tourism activities has resulted in an increase in boat traffic between Puerto Villamil and these tourism sites, an area that covers the entire nesting zone of green turtles.

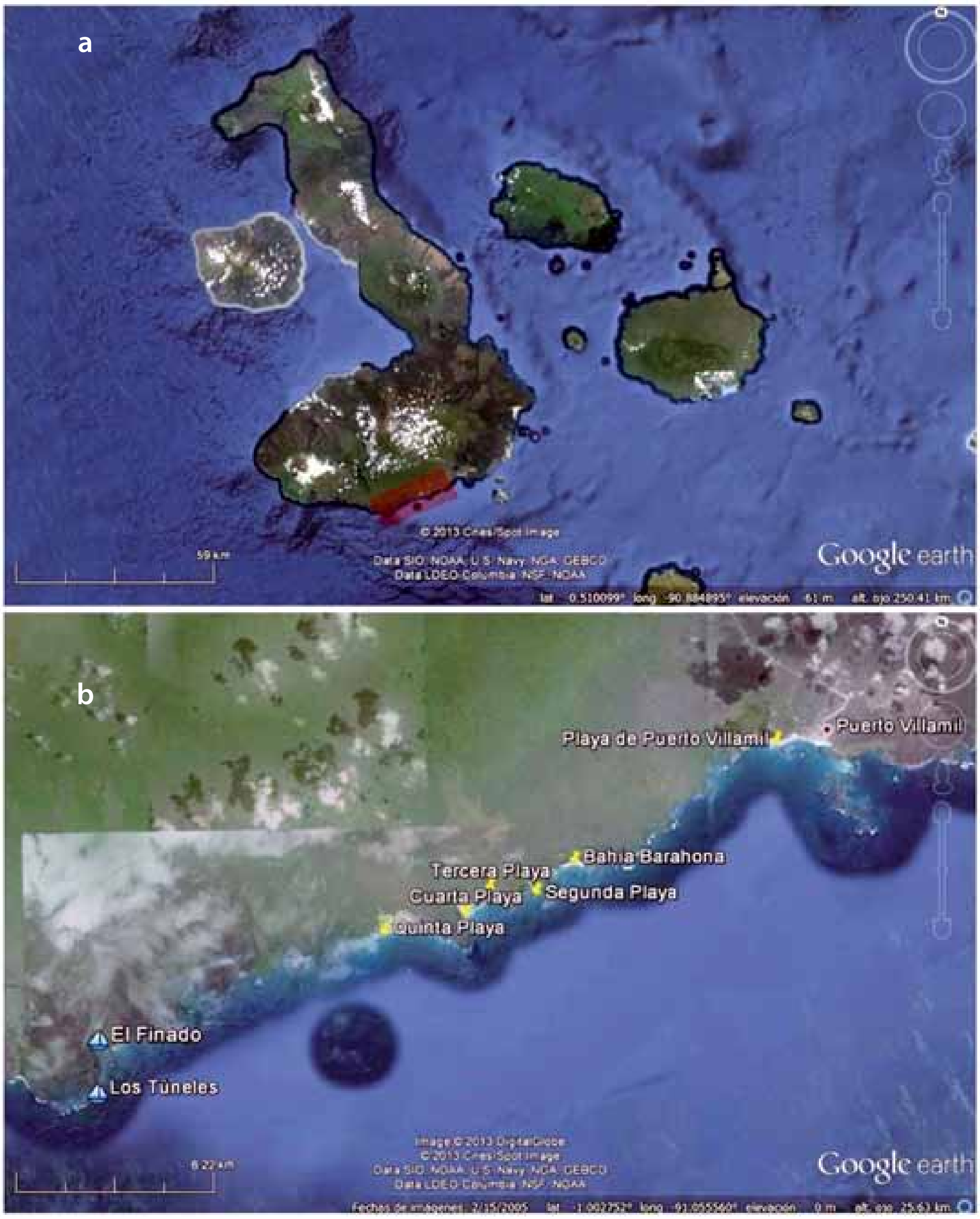

Figure 1. Map of the Galapagos Archipelago and Isabela Island green turtle nesting areas. a) General map of the Islands; the red polygon represents the area of green turtle nesting beaches. b) Map of the southern coast of Isabela Island; the yellow dots represent the six nesting beaches from east to west: Puerto Villamil Beach, Barahona Bay, Segunda Playa, Tercera Playa, Cuarta Playa and Quinta Playa; the map also indicates the urban area (Puerto Villamil) and the visitor sites El Finado and Los Túneles.

Monitoring day tour boats

Ten Mobile Action® tracking devices (GPS I - GoTU GT – 600) were used to determine the distribution and velocity of the speed boats used for day trips to Los Túneles and El Finado. The devices, carried by passengers, captains, or crew members, were programmed to automatically record geo-referencing information during each trip. When the devices were returned, the data were downloaded and analyzed using the Postgres – PostGis program, detailing the route and velocity during the trip.

Records of tour boats heading to Los Túneles and El Finado provided by the Technical Office of the Galapagos National Park in Puerto Villamil were used to determine the frequency of tour boats visiting the sites in question.

Habitat use by nesting females

Five female turtles nesting at Quinta Playa were followed with satellite tags (FastLoc F4H 47IA © Sirtrack) to determine habitat use and spatial distribution (Figure 2). The information for each female was downloaded from the Argos website (https://argos-system.cls.fr/cwi/Welcome.do) and then processed using the AdehabitatHR tool of the R statistical software to calculate range of activity of each turtle.

Figure 2. Turtle with satellite transmitter attached at the moment of release.

Incidence of impact of boats on nesting females

Nesting females were evaluated for any injuries during the monitoring of nesting turtles on Quinta Playa from December 15, 2012 to May 30, 2013. Each turtle was thoroughly examined for lesions on the carapace as well as on front and rear flippers, and around the head and neck area. Injuries for each female were recorded on a full body image, noting the following details: location, length, depth, and type of injury (cut, fracture, hole, lack of a piece of carapace, mutilation of limbs).

Based on criteria established in the literature, the following injuries were considered to have been caused by an impact with a boat: wounds or scars that corresponded with cuts, fractures, holes in the middle of the carapace, or loss of a portion of the carapace with a length or diameter greater than 4 cm (Phelan & Eckert, 2006; Sapp, 2010; Heinrich *et al.,* 2012; Norton *et al.,* 2013). Lesions were also classified as recent (when the injury was fresh) or old (when the injury was healed), in order to help distinguish injuries that occurred during the nesting season from those that occurred in feeding areas and/or during migration to the nesting site.

Evaluation of the risk of impact from boats

To analyze the risk of tour boats hitting turtles, the movements of the tagged turtles were mapped together with the routes of the tour boats monitored during trips between Puerto Villamil and Los Túneles and El Finado to identify areas of overlap.

Information on the frequency of tour boats on these routes was compared with the abundance of nesting turtles at Quinta Playa over time to identify the periods of the year with greater probability of interaction between turtles and boats.

Results

Monitoring of boats

Between November 2012 and June 2013, a total of 160 days of marine-based tourism records (the number of tour boats leaving port headed out for a day trip) were analyzed. Eighteen boats were identified, with an average of at least three vessels leaving port each day. From a total of 605 trips, it was possible to determine that the most visited destinations during day trips were Las Túneles and El Finado (74% of all trips, n = 447). The remaining 26% (n = 158) of trips corresponded to other destinations such as Cuatro Hermanos (1%, n = 8), Islote Tortuga (8%, n = 51), and trips with no specified destination (16%, n = 99).

The movement pattern was similar for all boats, with each trip starting in Puerto Villamil at approximately 8h00. The boats followed the coastline to Roca Unión where they made a brief stop, then continued on to Las Túneles, where they stopped for a short shore visit and snorkeling, then continued towards El Finado for snorkeling, and subsequently returning to Puerto Villamil at around 14h00. Average travel speed was approximately 22 knots (Figure 3).

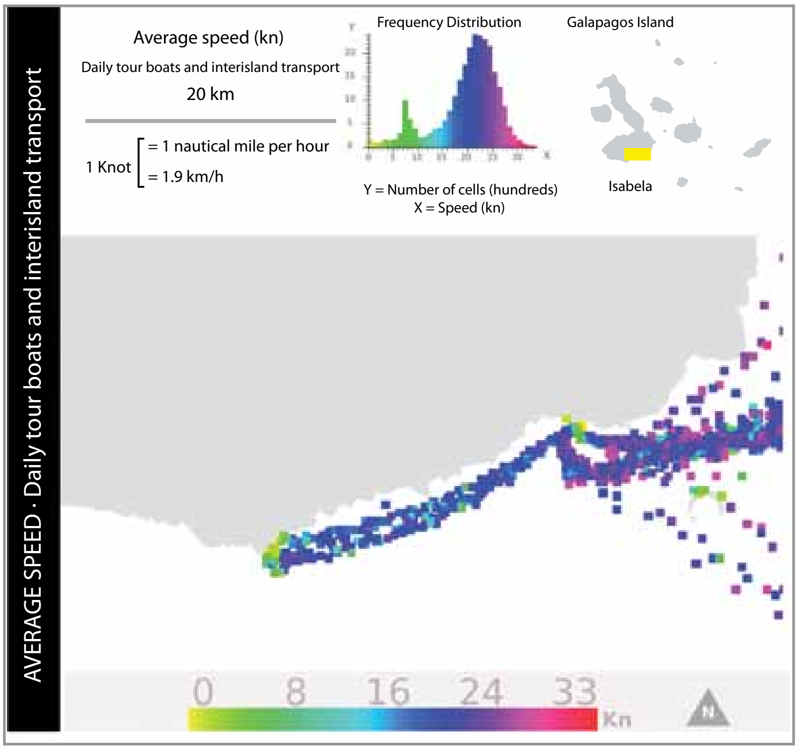

Figure 3. Speed of the day-tour boats travelling between Puerto Villamil and Los Túneles and El Finado.

Habitat use by nesting females

Telemetry data from five female turtles showed that they moved within a range of 10 km parallel to the coast, with greater movement to the east of Quinta Playa (Figure 4). The majority of turtle activity was found in areas close to the coast, with increased activity within the first three miles. Activity decreased with increasing distance from the coast. Telemetry data were obtained most frequently during two periods of the day (09h00-10h00 and 14h00-16h00), demonstrating greater surface activity (surfacing to breathe, rest, or for thermoregulation) during these time periods.

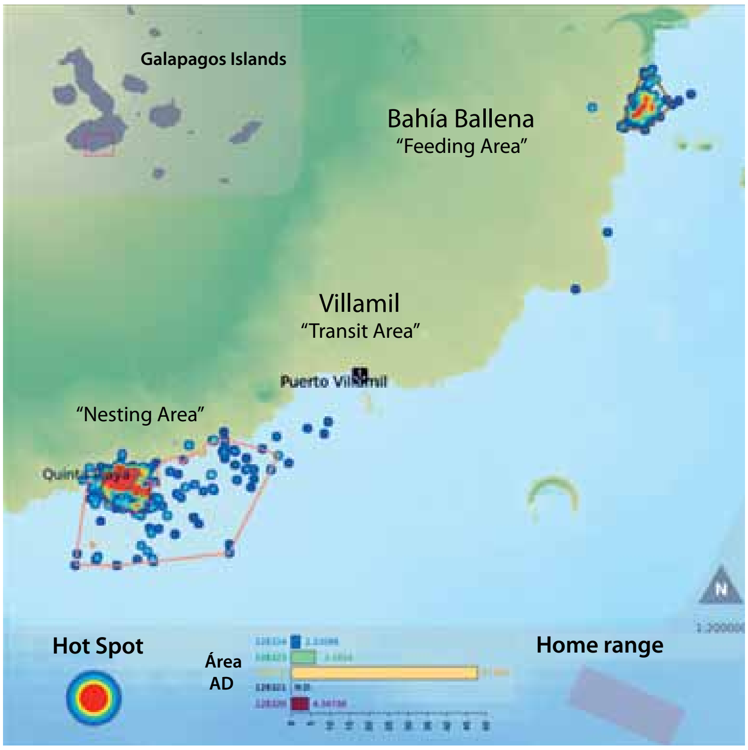

Figure 4. Distribution of turtles followed by satellite, showing an area of concentration opposite the nesting beaches. The graphics and polygons for each concentration area indicate the distribution range for each turtle.

Determining the incidence of boats hitting green turtles

Assessment of injury to turtles at the nesting zone was carried out between December 15, 2012 and May 30, 2013, during which time a total of 1458 nesting females were examined (Table 1). Of the examined turtles, 25% (n = 366) presented injuries, mainly in the carapace, with 12% (n = 170) identified as having signs of impact by boats. The most frequent injuries observed were holes in the carapace (29%, n = 49) and cuts (28%, n = 47).

Table 1. Incidence of the different types of injuries grouped in categories of injury due to impact with a boat.

Type of damage	Number of cases	%
Cut	47	28
Cut and fracture	10	6
Cut and hole	9	5
Cut and malformation	4	2
Cut and mutilation	4	2
Cut, hole, and malformation	2	1
Missing piece of carapace	4	2
Missing piece of carapace and mutilation	2	1
Fracture	21	12
Fracture and hole	5	3
Hole	49	29
Hole and malformation	3	2
Hole and mutilation	1	1
Malformation	8	5
Mutilation	1	1
Total	**170**	**100**

Risk assessment of impact by boats

Mapping the movements and distribution of satellite tagged turtles, as well as the movement and distribution of the tour boats, showed areas of overlap (Figure 5). The analysis of the relationship between the abundance of turtles and the frequency of boat trips (Parra *et al.*, 2013) showed a greater abundance of turtles in or close to the nesting areas from November to May, which when combined with increased activity of boats traveling to the nearby tourist sites increases the probability of accidental injuries to turtles. The DPNG data show that March is the month with the greatest frequency of trips from Puerto Villamil to Los Túneles and El Finado; this increased traffic coincides with peak nesting at Quinta Playa (Figure 6).

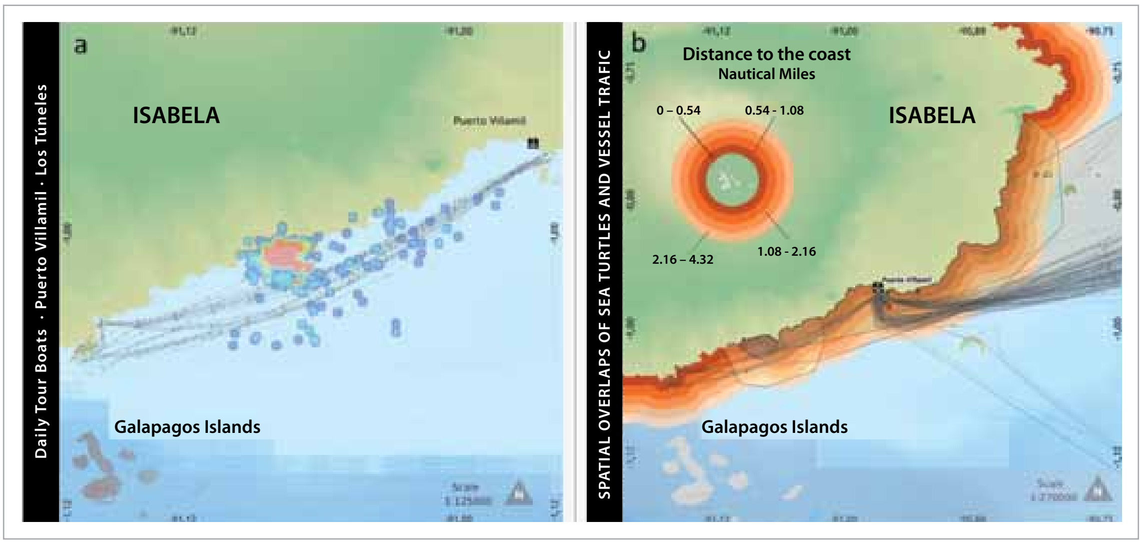

Figure 5. Map indicating the areas of interaction between sea turtles and tour boat routes. Figure "a" shows the concentration of turtles in front of the nesting areas at Quinta Playa and Barahona Bay, off southern Isabela Island, and the routes of tour boats traveling between Puerto Villamil and Los Túneles. Figure "b" shows the distance intervals of interaction between turtles and boats.

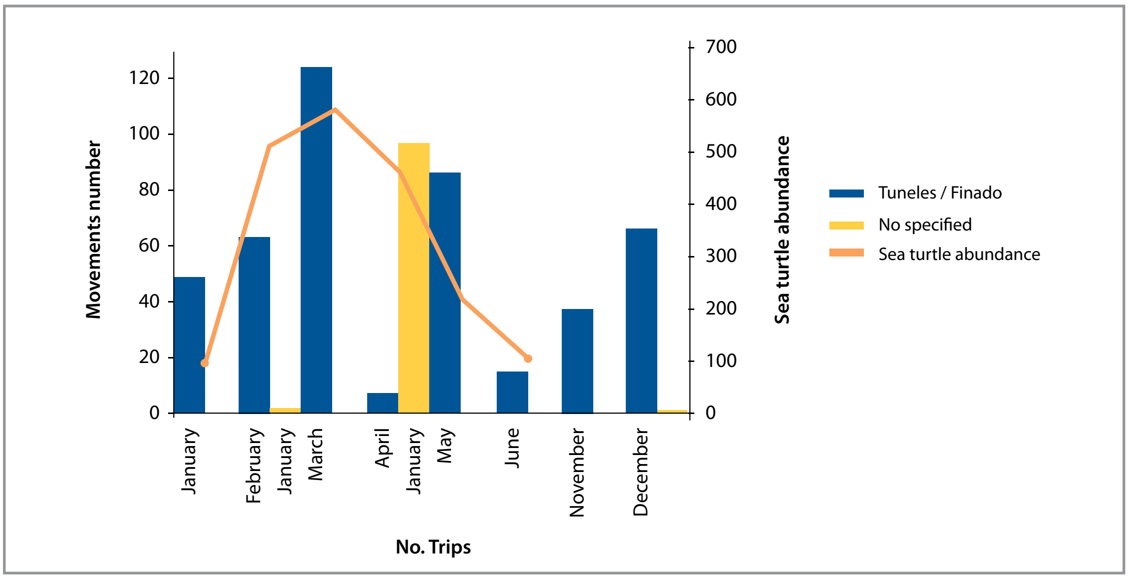

Figure 6. Movement of boats and abundance of sea turtles during the breeding season. The bars represent the number of trips per month from Puerto Villamil (Isabela Island) to the visitor sites Los Túneles and El Finado. The green bar represents trips with no defined destination, but which according to unofficial sources did make the trip to Los Túneles and El Finado. The line represents the abundance of active nesting turtles at Quinta Playa.

The period of increased surface activity of turtles, determined through satellite monitoring, coincides with the trip schedules for boats traveling between Puerto Villamil and Los Túneles (between 09h00 and 14h00).

Recommendations

This study shows that there are areas of interaction between sea turtle habitat and routes used by tour boats (day tours) within the GMR and that turtles are distributed primarily in coastal areas (within the first four miles from shore). The percent of incidents of boats impacting nesting females around Quinta Playa (12% of turtles examined) is within the incident ranges of similar incidents reported in various studies in other parts of the world, which range from 1.9-60% (Norem, 2005; Chaloupka *et al.*, 2008; NMFS/USFWS, 2008). Likewise, in a prior study in the GMR in a sea turtle feeding area near San Cristóbal Island, 19.4% of turtles examined had lesions attributable to impacts by boats (Denkinger *et al.*, 2013), which is comparable with the incidence found in this study.

Based on the findings, we recommend:

1. Develop management measures to regulate marine traffic within the GMR, accompanied by continued monitoring and evaluation of any injuries to sea turtles over time to determine the effectiveness of the management measures taken.

2. Develop a management protocol to move marine traffic four miles from the coast to minimize the number of boats in areas where sea turtles are concentrated.

3. Increase management measures during the sea turtle nesting season from November to May.

4. Implement marine transit zones for different types of boats, along with a maximum navigation speed of 10 knots in areas with higher incidence of interactions between wildlife and boats (see management plans for other sites, such as the Moreton Bay Marine Park, Australia).

5. Conduct a study of the use of propeller guards to determine whether the use of such equipment would be sufficient to minimize damage to turtles. It is important to know, however, that injuries to turtles caused by boats also include bumps, bruises, and fractures of the carapace, which are generated by hitting the boat hull or transom.

Acknowledgments

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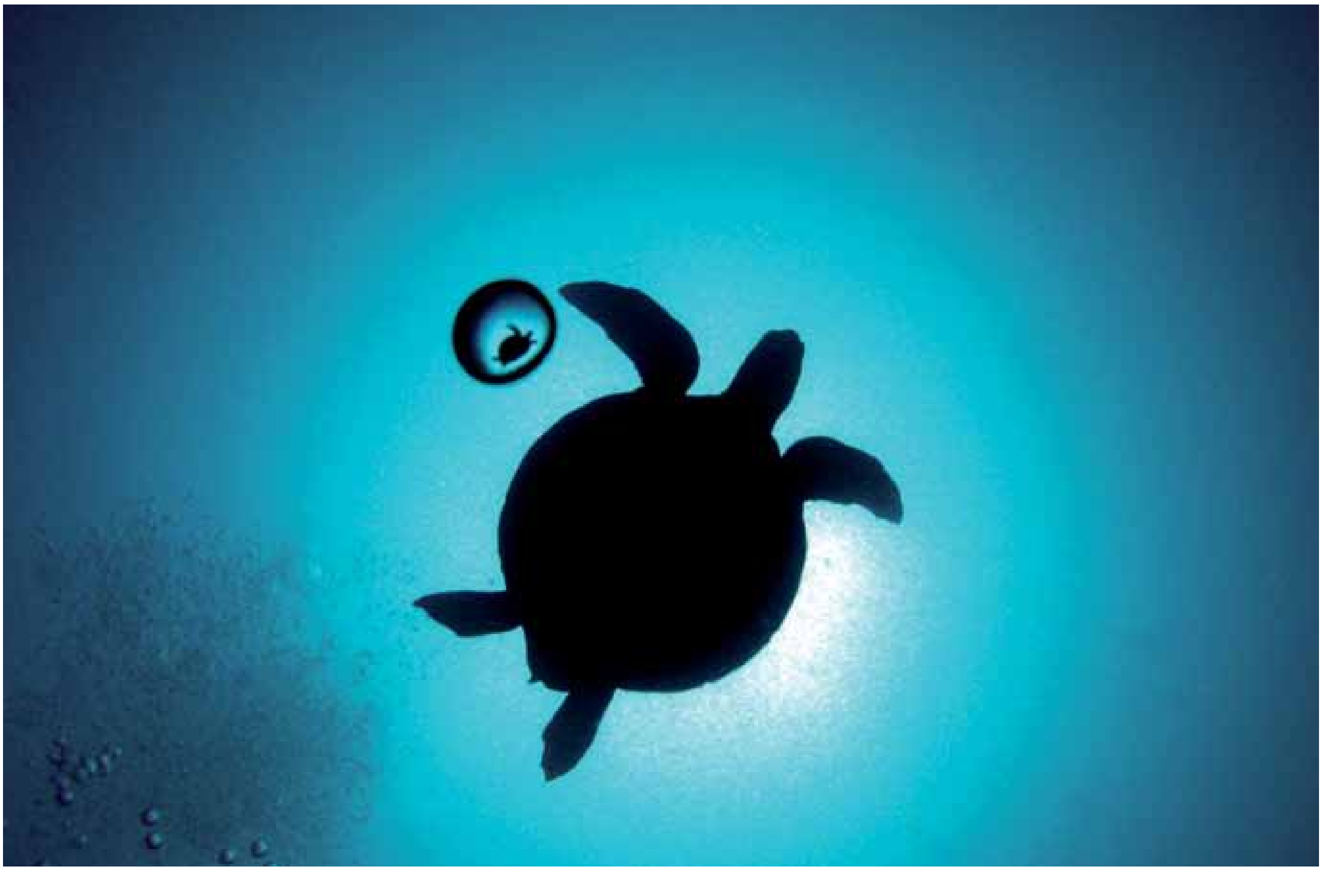

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Nursery grounds of blacktip sharks (*Carcharhinus limbatus*) in mangrove-fringed bays in the central part of the Galapagos Archipelago

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Mangrove forests are areas of great ecological value and provide numerous ecosystem services (Bennett & Reynolds, 1993; Clough, 1993). These sites are characterized by having high primary and secondary productivity, as well as the presence of a large number of microhabitats, which play a major role in the life cycle of many aquatic species (Beck *et al.,* 2001). Globally, mangrove-fringed bays have been shown to serve as nursery grounds for a large number of bony fish and sharks, and to provide a rich source of food and protection against predation (e.g., Robertson & Duke, 1987; Simpfendorfer & Milward, 1993; Ashton *et al.*, 2003; Knip *et al.,* 2010).

Under the current zoning scheme of the Galapagos Marine Reserve (GMR), the majority of bays with mangrove forests are listed as subzones for extractive use or fishing (2.3), thus they are visited frequently by fishermen to catch mullet (Mugilidae) and bait for high seas fishing (Andrade & Murillo, 2002; Murillo *et al.*, 2004; Peñaherrera-Palma, 2007). While sharks are protected throughout the GMR (Subsecretaría de Recursos Pesqueros, 1989), their wide distribution makes them susceptible to permitted fishing activities. Sharks are the top predators in the food chain and have a critical role in maintaining the health of marine ecosystems (Myers *et al.,* 2007). They also have a high economic value as one of the biggest attractions for dive tours in the GMR (Espinoza & Figueroa, 2001; Peñaherrera *et al.,* 2013).

In order to provide key information to ensure the proper management of fisheries and the protection of sharks, the Galapagos National Park Directorate (GNPD) began a process of identification and monitoring of essential shark habitats within the GMR. Based on observations by fishermen, four mangrove bays of San Cristóbal Island were studied and a surprising abundance of juvenile blacktip sharks (*Carcharhinus limbatus*) were found (Llerena, 2009). Since these results demonstrated the existence of nursery areas for this species, the GNPD established permanent monitoring in mangrove-fringed bays in southeastern Santa Cruz Island, with the goal of identifying other potential nursery grounds for sharks. In addition, the GNPD collaborated on other satellite projects in the central area of the Archipelago (Jaenig, 2010; Hirschfeld, 2013).

This article summarizes the most important results of the monitoring project on the nursery grounds for blacktip sharks in the GMR, compares the results to similar studies, and reviews management implications as they relate to the current coastal zoning scheme.

Methods

According to Heupel *et al.* (2007), three criteria are needed to identify an area as a nursery ground for sharks: i) sharks are found more often in the area than in other areas; ii) sharks tend to remain in the area or return for extended periods; and iii) the area or habitat is used repeatedly by sharks over the years. To determine if these criteria exist and to understand how juvenile blacktip sharks use mangrove bays, different types of monitoring were implemented using experimental fishing and acoustic telemetry (Table 1).

Table 1. Classification of separate information sources used for analysis.

Type of monitoring	Source	Location	Study site	Study period
Experimental fishing				
Systematic monitoring	GNPD	Santa Cruz (southeast)	Garrapatero, Saca Calzón, Punta Rocafuerte and Tortuga Bay	January 2010 - December 2012
Seasonal monitoring	Llerena (2009)	San Cristóbal (central-northwest)	Cerro Brujo, Manglecito, Puerto Grande, Rosa Blanca and Tortuga	January - April 2009
	Jaenig (2010)	Santa Cruz (northwest)	Bahía Borrero, Caleta Tortuga Negra, El Edén and Venecia	November 2009 - March 2010
Random monitoring		Baltra (south)	Itabaca Channel	Random monitoring in April 2012 and March, April, May, June, July 2013
		Fernandina (east)	Puerto Copiano and Punta Mangle	
		Isabela	Bahía Elizabeth, Caleta Negra, Cartago Chico 1, 2, 3, 4, 5, Cartago Grande 1, 2, Piedras Blancas, Poza de los Tiburones, Puerto Las Tablas and Punta Albermarle	
		San Cristóbal	Puerto Grande	
		Santiago	La Bomba, Poza de las Azules and northeastern Santiago	
Acoustic telemetry				
Continuous monitoring	Hirschfeld (2013)	San Cristóbal	Puerto Grande	April - August 2012 and November 2012 - February 2013

The experimental fishing monitoring methodology (seasonal, systematic, and random) was standardized by Llerena (2009). It is based on bottom-setting a gill net, similar to those used by artisanal fishermen, for one hour in the inner areas of the bays (details in Llerena *et al.,* 2011). Results are expressed as CPUE (catch per unit effort), representing the number of individuals captured during each sampling hour for each gill net set (ind/h*net). This provides a measure of the relative species abundance, which can then be compared between studies. The most important difference among the three types of monitoring is time of execution, with systematic monitoring involving the greatest duration and scientific rigor (monthly samplings at each site for three consecutive years). Seasonal monitoring was conducted for one or two contiguous seasons, while random surveys were completed on one or two occasions in the central, southern, and western parts of the Archipelago (Table 1).

Acoustic telemetry was used to evaluate daily behavior and site fidelity of eight blacktip sharks captured in Puerto Grande, San Cristóbal. Each shark was monitored continuously for up to 45 hours, using a small boat and special equipment (Hirschfeld, 2013).

Results

A total of 972 blacktip shark juveniles were caught and released alive during the systematic monitoring carried out in southeastern Santa Cruz, with a rate of 312 individuals per year and an average of 5.6 ind/h*net. The number of sharks registered by site was highly variable, with catches of 0 to 39 ind/h*net, but their constant presence throughout the study provides evidence that the four zones studied are areas preferred by this species. The relative abundance of sharks was significantly higher during the warm season than in the cold season (Figure 1a). The differences observed in the size structure of the sharks caught provides evidence of the birth of new individuals in the areas sampled, a situation that can be seen clearly when analyzing the total length (cm) and the presence of an umbilical scar of each shark (Figure 1b and c). During the hot season, the average total length of sharks was ~68 cm, due to a greater number of neonates (recently born sharks with the umbilical scar still open) and young-of-the-year (semi-enclosed scar). The opposite situation was observed in the catches recorded in the cold season, where the average total length was significantly greater (~72.4 cm) due to the dominance of juveniles (with no umbilical scar).

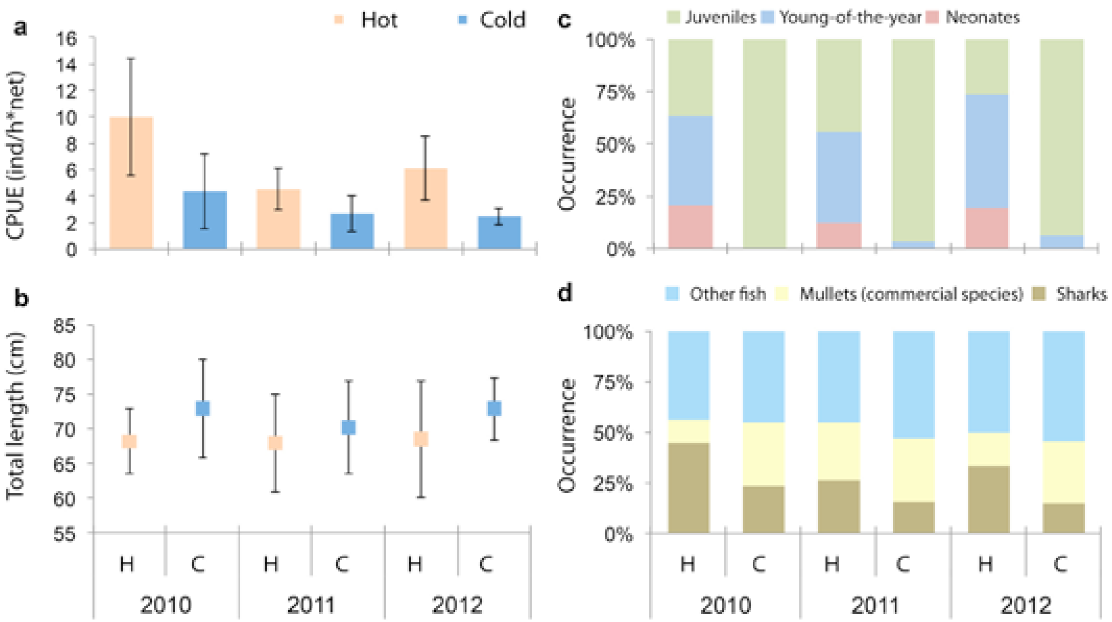

Figure 1. Differences between the hot (H) and cold (C) seasons for the four sites sampled in relation to: a) average relative abundance using CPUE (catch per unit of effort); b) average total length; c) percentage of occurrence of neonate sharks (with open umbilical scar), young-of-the-year (semi-open scar), and juveniles (closed scar), and d) percentage of occurrence of juvenile blacktip sharks, Mugilidae (black- and yellow-tailed mullets), and other boney fish with little or no commercial value.

Observations in this study are similar to those from studies carried out in Hawaii and Florida, where it is suggested that changes in abundance and size may be a product of new births in the warm season and then a high mortality of newborn sharks during their first weeks of life due to predation, malnutrition, or fishing (Heupel & Hueter, 2002; Heupel & Simpfendorfer, 2002; Carlson *et al.,* 2004), and/or from the migration of individuals to other areas of the island following the masses of warm water with the change of season (Heupel, 2007). Causes for inter-annual variations in the relative abundance of this species are unknown. These fluctuations in abundance could be part of normal cyclical processes of reproduction (eg., Lucifora *et al.,* 2002; Meyer *et al.,* 2009), food availability (e.g., Ramirez-Macias *et al.,* 2012), or even a response to changes in oceanographic conditions (e.g., Froeschke *et al.,* 2010).

Juvenile blacktip sharks can be very common in catches using gill nets. Black- and yellow-tailed mullet (higher commercial value species) equaled 10-38% of the catches. However, blacktip sharks can vary between 15-45% in catches, which indicates a higher incidence of the protected species than species with commercial value.

Results of systematic monitoring indicate patterns and trends of the presence and abundance of juvenile sharks that can be compared with other studies (Table 2). While data from the study of Llerena (2009) are restricted to the warm season, the pattern of catches for Puerto Grande, Manglecito, and Tortuga resembles the pattern observed in the systematic monitoring sites. A similar situation was reported for Caleta Tortuga Negra, Venecia, and El Edén in northwestern Santa Cruz, where the greatest relative abundance of sharks with a length under the average were recorded, as well as the presence of neonates during the hot season versus the cold season (Jaenig, 2010). These comparative results of both seasonal and systematic monitoring show that there is a seasonal pattern of use of these areas, which occurs every year.

How long do sharks remain? Do they always use the same areas?

Based on the conventional marking used in the systematic monitoring in Santa Cruz and the continuous monitoring on San Cristóbal, it was determined that certain sites are preferred over adjacent areas (see study sites in Table 1). During the systematic monitoring, a number of marked sharks were re-captured in the same site, and others in bays nearby or adjacent to the initial capture site (Figure 2), similar to that reported by Jaenig (2010). This behavior was observed in greater detail through the acoustic telemetry monitoring (Hirschfeld, 2013). That study showed that the movements of juveniles of this species are concentrated in the inner areas of the mangrove bays, especially neonates, which did not move outside the shallow bays (Figure 3, Table 3). It also showed that the area used is considerably larger than the size of the bay, but that the excursions outside the bay occur primarily at night.

Table 2. Comparison of averages of abundance, length, and composition (N = neonates; YY = young-of-the-year, and J = juvenile) between systematic monitoring and seasonal monitoring in the hot (H) and cold (C) seasons.

Location	Abundance (ind/h*r)		Total length (cm)		Composition (%)						Source
					C			H			
	C	H	C	H	N	YY	J	N	YY	J	
Systematic monitoring											
Santa Cruz – southeast	5.6	3.0	68.3	72.4	32	35	33	0	2	98	This study
Seasonal monitoring											
San Cristóbal – central-northwest	3.3	---	69.5	---	39	0	62	---	---	---	Llerena 2009
Santa Cruz - northwest	8.1	6.1	69.7	84.0	42	47	11	0	0	100	Jaenig 2010

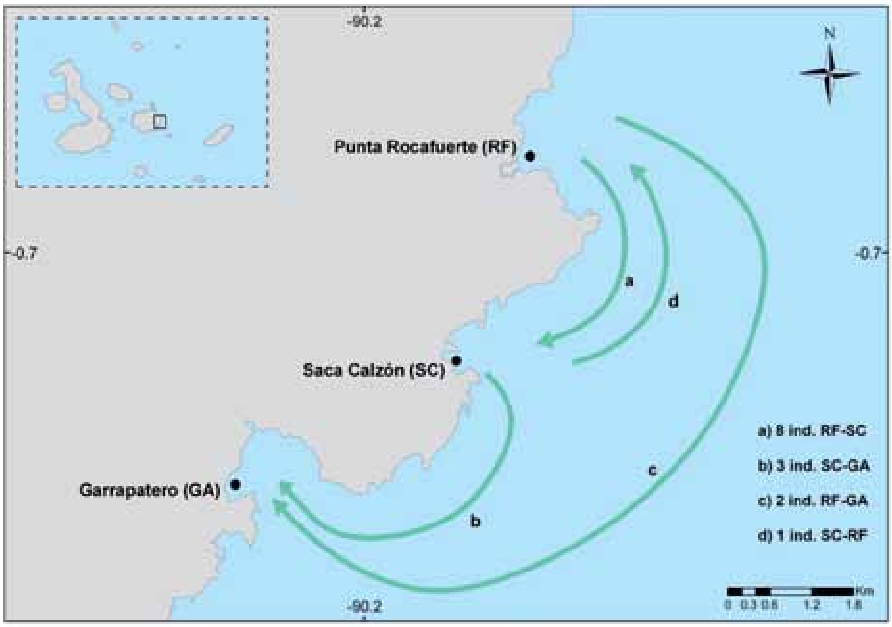

Figure 2. Connectivity map obtained from the conventional marking of juvenile blacktip sharks in the systematic monitoring carried out in southeastern Santa Cruz.

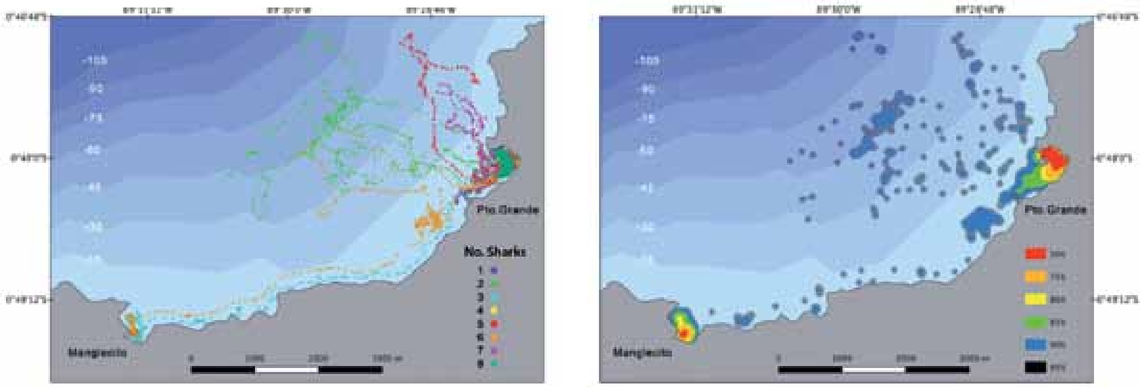

Figure 3. a) Distribution patterns of eight blacktip shark juveniles tracked continuously in Puerto Grande, San Cristóbal. b) Areas used calculated from the concentration of points during monitoring. Red indicates areas where the largest number of sharks was detected.

The results clearly show that the study sites are critical habitats for the early stages of life of blacktip sharks. However, these areas represent only a small fraction of all mangrove-fringed bays in the GMR. For this reason, random surveys were executed in different sites of the Archipelago to identify potential nursery grounds (Table 4, Figure 4). At least one shark was captured at 50% of the 20 sites monitored randomly, so these sites have been categorized as potential nursery areas. However, the remaining sites have been classified as places that should be included in future monitoring, in order to be able to determine if the absence of catches was the product of natural variability.

Table 3. Morphology and movement patterns of eight sharks monitored using acoustic telemetry in Puerto Grande, San Cristóbal, during months in 2012 and 2013 (N = neonate, YY = young of the year).

Shark number	Sex	Age class	Tracking time (h)	Total distance (km)
1	Male	YY	45	38.3
2	Female	YY	35	46.8
3	Female	YY	27	13.6
4	Female	N	42	27.1
5	Female	YY	45	27.1
6	Female	YY	42	27.8
7	Male	YY	40	23.6
8	Male	N	34	20.8

Conclusions and recommendations

Monitoring of 34 coastal sites in the GMR occurred during a period of three years and eight months. Of these sites, 79% were located in subzones of Extractive Use or Fishing (2.3), 12% in the Protection subzone (2.1), and 9% in the No Extractive Use or Tourism subzone (2.2). Based on the criteria of Heupel *et al.,* (2007), this study identified the existence of nine confirmed and 11 potential nursery areas for blacktip sharks. Of these, only 25% are found in Protection or Non-extractive Use subzones, all on Santa Cruz Island.

However, this study and others analyzed here have examined fewer than half of the mangrove bays within the GMR. There are a large number of coastal areas with similar characteristics, such as southeastern Isabela Island, where there are large tracts of mangrove forests that were identified as potential nursery grounds but were not studied due to lack of resources. We recommend that future studies be expanded to include such sites in order to understand the status of all nursery grounds in Galapagos.

The results of this study show the importance of nursery grounds for the birth of blacktip sharks during the hot season, and their subsequent growth within the bay during the cold season. Movement data for this species within, outside, and between bays show the extent of the area used by juvenile blacktip sharks within the bays and the importance of maintaining connectivity between adjacent bays.

Coastal areas surrounded by mangroves have great biological importance not only for sharks but also for many species of commercial interest to the community (Beck *et al.,* 2001). Several of the monitored sites are used by fishermen who use gillnets to catch target species such as mullets. The results show that there is a high chance that approximately a quarter of the catch (~ 25%) is composed of juvenile blacktip sharks, especially if the fishing is carried out during the hot season, which could have an impact on this species over the long term.

We recommend that the results of this study identifying nursery grounds of juvenile sharks be incorporated into the re-evaluation of the current coastal zoning of the GMR, and that these areas be included in the category of Non-Extractive Use or Protection. The protection of these areas will not only ensure that shark populations remain stable, but will also help ensure a healthy marine ecosystem that will benefit other marine species including those of high commercial value (e.g., mullet).

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Table 4. Variation in CPUE (catch per unit effort) by season (Hot = H; Cold = C) registered for each site using bottom-gill nets, and the category assigned (nursery ground = NG; possible nursery ground = PNG; area with insufficient data (ID), and areas not identified as rearing areas (NI). In addition the categories of each site sampled using the current zoning scheme, including Protection sub-zone (2.1), No Extractive Use or Tourism subzone (2.2), and Extractive Use or Fishing subzone (2.3).

Island	Study site	No. of samples	CPUE		Category	Sub-zone	Fig. 4 code
			H	C			
Systematic monitoring							
Santa Cruz	Garrapatero	51	4.7	3.3	NG	2.2	1
	Punta Rocafuerte	50	7.6	3.2	NG	2.3	2
	Saca Calzón	52	6.0	4.0	NG	2.3	3
	Tortuga Bay	26	4.2	1.5	NG	2.2	4
Seasonal monitoring							
San Cristóbal	Cerro Brujo	2	0.0	---	NO	2.3	5
	Manglecito	4	3.9	---	NG	2.3	6
	Puerto Grande	5	4.1	---	NG	2.3	7
	Rosa Blanca	1	0.0	---	ID	2.3	8
	Tortuga	4	2.0	---	PNG	2.3	9
Santa Cruz	Bahía Borrero	1	---	0.0	ID	2.3	10
	Caleta Tortuga Negra	20	4.7	9.5	NG	2.2	11
	Canal (Cerro Dragón)	7	0.0	0.0	NO	2.1	12
	El Edén	14	9.3	2.7	NG	2.1	13
	Venecia	19	10.2	---	NG	2.1	14
Random monitoring							
Baltra	Itabaca Channel	1	0.0	---	ID	2.3	15
	Itabaca Channel north	1	0.0	---	ID	2.3	16
Fernandina	Puerto Copiano	1	0.8	---	PARA	2.3	17
	Punta Mangle	1	0.0	---	ID	2.3	18
Isabela	Elizabeth Bay	1	---	---	ID	2.1	19
	Caleta Negra	1	0.0	---	ID	2.3	20
	Cartago Chico 1	1	32.0	---	PNG	2.3	21
	Cartago Chico 2	1	30.0	---	PNG	2.3	22
	Cartago Chico 3	1	1.9	---	PNG	2.3	23
	Cartago Chico 4	1	0.0	---	ID	2.3	24
	Cartago Chico 5	1	9.4	---	PNG	2.3	25
	Cartago Grande 1	1	---	3.4	PNG	2.3	26
	Cartago Grande 2	1	---	0.0	ID	2.3	27
	Piedra Blanca	1	0.0	---	ID	2.3	28
	Poza de los Tiburones	1	0.0	---	ID	2.3	29
	Puerto Las Tablas	1	22.3	---	PNG	2.3	30
	Punta Albermarle	2	0.7	---	PNG	2.3	31
San Cristóbal	Puerto Grande	2	3.8	3.3	PNG	2.3	7
Santiago	La Bomba	1	0.0	---	ID	2.3	32
	Poza de las Azules	1	1.5	---	PNG	2.3	33
	Santiago noreste	1	0	---	ID	2.3	34

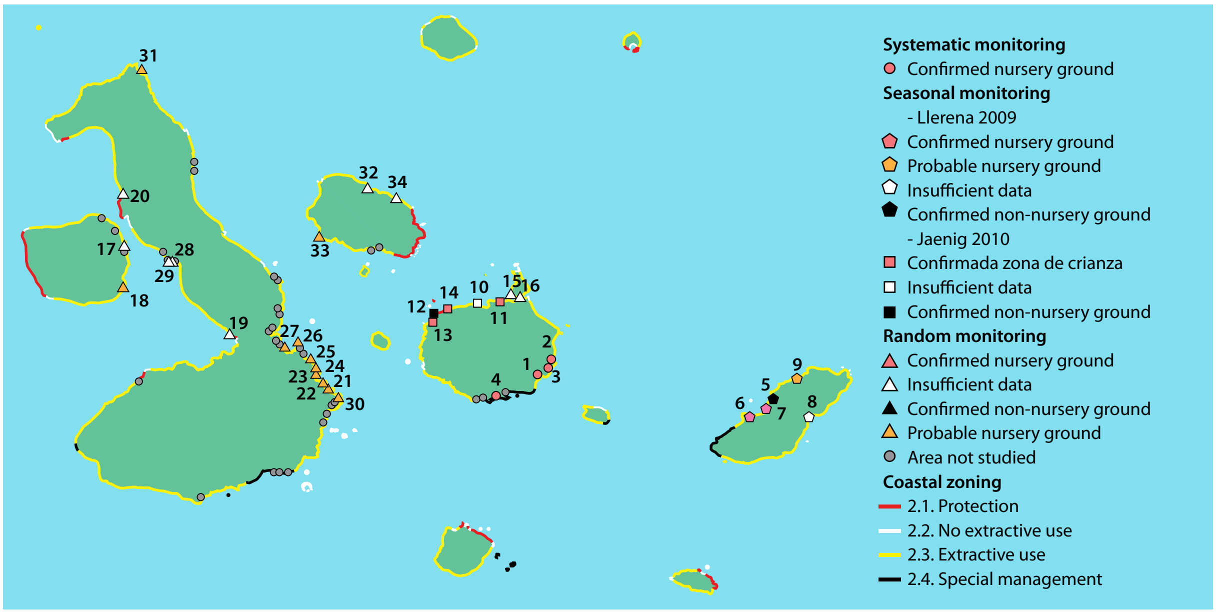

Figure 4. Distribution of mangrove-fringed bays in the GMR evaluated during this study, and the coastal zoning. The category "confirmed nursery ground" is denoted in red, "probable nursery ground" in orange, "area with insufficient data" in white, and "confirmed as non-rearing area" in black. Areas that were not studied are indicated in gray.

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Analysis of the perception of population trends for six shark species in the Galapagos Marine Reserve

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The Galapagos Marine Reserve (GMR) has the potential to be a vital element in the conservation of the marine fauna, especially top predators such as sharks. The GMR is the largest of the Eastern Tropical Pacific marine protected areas, and its management framework has provided protection to sharks since the end of the 1980s through the total prohibition of their capture (SRP, 1989), regulation of fishing practices (DPNG, 1998; Murillo *et al.*, 2004), and the implementation of technologies to control and eliminate illegal fishing (DPNG, 2009). It is hoped that the management framework for the GMR will provide the needed protection to positively influence shark populations. Unfortunately, no monitoring system existed prior to the establishment of the GMR to provide an evaluation of the status and trends of shark populations. This absence of empirical data has made it difficult to determine the extent to which the reserve is protecting shark species.

In other protected areas, the knowledge and experience of users regarding a resource have become a valid and useful source of information to understand resource dynamics and optimize management in the absence of other types of empirical data (Murray *et al.,* 2006). Local ecological knowledge, as it is scientifically known, is based on the accumulated experience of resource users who are constantly in touch with the natural environment (Drew, 2005). In Galapagos, dive guides travel regularly to diving sites, and their constant interaction with the marine environment represents a potential source of information on resource status. Moreover, dive tourism activities began in the mid 1980s, which, if analyzed correctly, provides a time scale much beyond that of any continuous monitoring in the GMR.

This study assessed the perception of dive guides regarding trends in shark populations since the start of dive tours in Galapagos. The species evaluated included: the whale shark (*Rhincodon typus*), hammerhead (*Sphyrna lewini*), blacktip (*Carcharhinus limbatus*), silky (*C. falciformis*), Galapagos (*C. galapagensis*), and whitetip reef shark (*Triaenodon obesus*). It is hoped that the results of this study will provide important information to enhance our understanding of historical trends.

Methods

This project was implemented during the knowledge refresher courses for guides offered by the Galapagos National Park Directorate in the second half of 2013. Dive guides received a self-administered survey designed to evaluate: i) their dive experience; ii) qualitative perceptions of population trends of shark species by decade and region; and, iii) the reasons for the observed changes if applicable. To reduce the number of questions and obtain standardized responses the survey was designed as follows:

1. The time scale used was limited to answers that defined the state of change within each decade in which guides dove. Three decades were used (1980s, 1990s, 2000s), as well as years in the 2010s.

2. The spatial scale was defined in four regions of the Archipelago: north (Darwin, Wolf, and Roca Redonda), south (Floreana, Española, seamounts, and surrounding islets), west (western Isabela and Fernandina), and central (Santa Cruz, San Cristóbal, northeast and southeast of Isabela, seamounts, and surrounding islets).

3. Changes in abundance were limited to five categories: major decrease (MD); decrease (D); stable (S); increase (I), and major increase (MI).

4. Each survey respondent was required to provide the percent change in the population for each response (e.g., MD equal to 50% reduction in population size, D 25% reduction, etc.).

The responses were analyzed using simple statistical analyses and a semi-quantitative analysis of virtual population change (VPC) developed for Galapagos based on the work of Burfield *et al.* (2004), Gregory *et al.* (2004), and Moller *et al.* (2004). Given that the actual population size of each species analyzed is unknown, the initial virtual population size (VPS) was assigned the value of 100%. For each following decade, the model estimates the percentage of population remaining based on the categories and percentages of change indicated by each guide. The model is then adjusted using the values of the previous decade and the degree of experience of the guides to avoid the shifting baseline effect (Saenz-Arroyo *et al.* 2005; Bunce *et al.* 2008).

Experience of the interviewees

A total of 27 dive guides were surveyed, of which only two did not provide useful answers. It is estimated that the completed surveys included ~70% of the guides with extensive experience diving in Galapagos. This percentage was estimated based on answers provided by respondents when asked to enumerate other divers who have experience guiding. The answers often mentioned the same people, few of whom we were unable to contact.

All respondents were between 30 and 60 years old, and their dive experience in Galapagos ranged from 5 to 30 years. Three age groups were defined: i) 30-39 years; ii) 40-49 years; and iii) 50-60 years. Of these groups, the second and third (72% of the total) reported having extensive experience diving in the GMR (average of 19 and 17 years, respectively; Table 1). All interviewees dove in the last two decades. The presence of divers during the 1980s and 1990s was, in contrast, variable, with fewer diving in the 1980s. Finally, the experience reported by region showed that 85-100% of the guides dove in the north, south, and central areas. Few guides reported experience in the western region of the Archipelago.

Perception of spatial and temporal trends

Of the guides surveyed, 82% indicated observed changes in the size of shark populations; 7% said that they had observed no changes, and the remaining 11% declined to answer. Of the guides who responded that there were changes, 64% observed declines in shark population sizes, 27% indicated having observed increases, and the remaining 9% indicated that changes varied depending on the species (some increased and some decreased). The guides pointed to fishing as the main factor influencing the decrease in shark populations (70% of responses). It was not clear if they were referring to artisanal, industrial, or illegal fishing, although illegal fishing was noted on several occasions. Climate change, together with strong environmental events such as El Niño, was the second most often mentioned factor influencing the observed decreases (26% of responses).

The apparent agreement on negative trends in shark populations observed in this study is consistent with the study by Hearn *et al.* (2008), who reported that guides expressed concern for the reduction in the abundance of sharks at dive sites. However, this generalized perception does not apply for all species (Figure 1):

Table 1. Description of the experience of dive guides interviewed by age group.

Age group	N	Years of dive experience			Percentage of guides by decade				Percentage of guides by region			
		Ave.	Max.	Mín.	1980	1990	2000	2010	North	South	West	Central
30 - 39	7	10	13	5	--	--	100	100	100	100	43	100
40 - 49	11	19	30	8	18	91	100	100	100	91	73	91
50 - 60	7	17	25	5	29	57	100	100	86	100	71	86

Whale shark. Most guides indicated that the population has been stable (S). With regard to the regions of the Archipelago, there was some consensus of a decrease (D) in the northern region, a stable population in the south and central regions, and interestingly, an increase (I) in the population in the west of the Archipelago.

Hammerhead shark. This is the only species for which most guides consistently agreed on a decline in the population by both decade and region. The categories for a decreasing population (D and MD) dominated the responses for all decades and regions studied. The decade with the greatest decrease was the 1990s, while the areas with the most marked decrease were the south and central regions.

Blacktip shark. Most guides categorized this population as stable (S) during the 1990s. However, for the 2000s and 2010s, guides reported an increase (I and MI) in the population, especially in the northern (45% of responses) and central (56% of responses) regions.

Galapagos shark. Responses related to this species varied, revealing an increase in the categories stable (S) and increase (I) over the last two decades. In regards to regions, the guides observed negative trends in the south (62%), central (67%), and north (40%) regions, while the western region was generally categorized as stable (50%).

Whitetip reef shark. Guides generally agreed that there has been a decrease in the population in the 2000s and 2010s. As for regions, there was a general consensus on the stability of the population in all except the central region, where the categories of decrease (D & MD) dominated the responses.

Silky shark. 60% of guides reported negative trends in the 1980s, while 70% observed a stable population in the 1990s. For the 2000s, 50% responded that the population remained stable and 50% indicated a decline (D and MD). The perception of population trends by region was dominated by the stable category for all regions (50-75%).

Virtual population change model

Unlike previous analyses, the use of this model makes it possible to clearly discern population trends of shark species over the last four decades, showing some interesting patterns in the last two decades (Figure 2).

Whale shark. This is the only species in this study that showed stable conditions during the four decades. The model shows that the variation of the virtual population size (VPS) ranged between 95 and 102% in comparison with the initial population size.

Hammerhead shark. According to the perception of the guides, this species suffered the greatest population decline, with a sustained reduction that reached a VPS of 50% in this decade. This suggests that the population that we see today is approximately half what it was prior to 1980.

Blacktip shark. The model suggests that this is the only species for which guides observed a population recovery. During the 1980s and 1990s, the population declined to 65%, and then rebounded to reach 80% in 2010.

Galapagos shark. For this species guide perceptions also suggests a negative trend. According to the model, the population reached an average VPS of 60% of the initial size in the last three decades.

Whitetip reef shark. In the 1980s and 1990s, this species remained relatively stable, but the perception of the guides suggests a reduction in population size during the 2000s and 2010s with a current VPS of 70% of its initial size.

Silky shark. The model indicated a negative trend similar to that of the Galapagos shark, but its trend curve only reached a VPS of 75%.

The model also suggests that the populations of at least three species have remained stable throughout the last two decades. Hammerhead, Galapagos, and silky sharks have maintained very similar values for their VPS during the 2000s, and so far in the 2010s. There is also a perceived increase in the population of blacktip sharks, while whitetip reef sharks have experienced a major decline in the last decade.

As indicated, there is no empirical information in Galapagos to validate these results for the time-scale studied. However, in the last two decades population trends of several species of sharks in the Cocos and Malpelo Islands corroborate the perceptions on shark trends by guides in Galapagos. Friedlander *et al.* (2012) and Soler *et al.* (2013) reported that the abundance of whitetip reef sharks and hammerhead sharks declined significantly in the 1990s and 2000s in both Cocos and Malpelo, respectively. In addition, Sibaja-Cordero (2008) reported a decline in the occurrence of silky sharks towards the end of the 1990s around Cocos Island, and an increase in the occurrence of blacktip sharks in the 2000s. The perceived increase in the blacktip shark population reported consistently by fishermen and guides was an important result obtained in this study. The growth of this population in Galapagos could be a response to the existence of favorable conditions for reproduction of this species in the Archipelago (Llerena *et al.*, 2014).

A theoretical analysis based on food webs of the pelagic ecosystem of the GMR suggests some degree

Figure 1. Summary of changes in shark populations by decade (left column) and bioregion (right column) for each species as perceived by dive guides. Scales of change: MI = major increase; I = increase; S = stable; D = decline; MD = major decline.

of congruence with the results of this study. Wolff *et al.* (2012) suggested that populations of hammerhead and bentho-pelagic sharks (blacktip, Galapagos, and silky, among others) experienced a substantial increase in the biomass of their populations in the 2000s, while others, such as smaller-sized sharks (like whitetip reef sharks), suffered a population decline. In the case of hammerhead, Galapagos, and silky sharks, the perception of the Galapagos guides and studies in Cocos and Malpelo suggest that their stocks did not change after 2000, but rather stabilized. These differences could result from biological and physiological processes that were not analyzed in detail in the study of Wolff *et al.*, whether related to the nature of the trophic study and/or the clustering of species into functional groups. However, the study by Wolff *et al.* and this report suggest a change from negative trends for all shark populations, to a decline of whitetip reef sharks and an increase in blacktip sharks, after the establishment of the GMR.

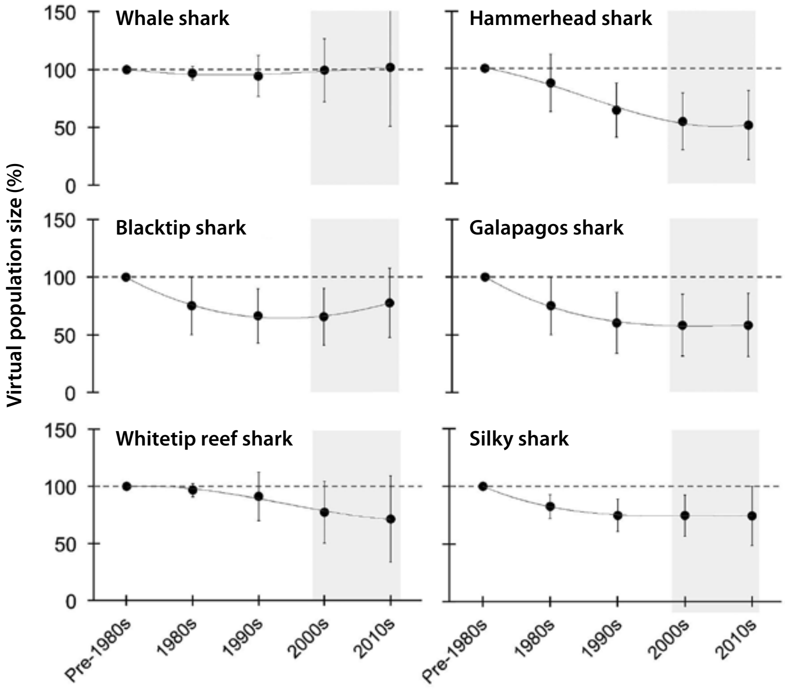

Figure 2. Variation in the virtual population size (VPS) of the six evaluated shark species. Vertical bars show the standard deviation as a measure of variability in responses, and the gray area the decades following the establishment of the GMR.

Discussion and conclusions

While most guides generally agree that all shark species have experienced negative population trends, this study shows that perception varies by species, and that there is an apparent change in trends after 2000. In regards to spatial analysis, the central and southern regions of the Archipelago were categorized as having suffered a significant population decline in the shark species studied. Fishing was identified as the primary cause of the decline of shark populations in the GMR.

It should be noted that this study, as well as any study of perceptions and opinions, carries with it a degree of uncertainty related to the knowledge and belief of each individual (Poizat & Baran, 1997). However, these types of studies are considered valid when the experience of resource users highlights coherent patterns about resource knowledge and status, especially in cases where empirical information is absent or scarce (Berkes *et al.*, 2000; Davis & Wagner, 2003).

The analysis of the collective memory and experience of dive guides examined in this study provides new information on possible population trends of six shark species in the GMR. The three scenarios (stable, decline, and increase) obtained from the ecological knowledge of the guides has identified important population trends, which are supported by studies in Cocos and Malpelo Islands, and partially corroborate results published by Wolff *et al.* (2012). We recommend that additional, more in-depth studies be carried out at the species level to determine what factors are influencing these changes and what role the establishment and management of the GMR have played in providing greater protection for the conservation of these species. In addition, it is hoped that the methodology used in this study will continue to be used by those who manage the GMR to evaluate charismatic species for which little or no information on population trends is available.

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Evaluation of the high seas fishery of pelagic fishes in the Galapagos Marine Reserve

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In the Galapagos Marine Reserve (GMR), there is an artisanal high seas fishery that targets pelagic fish including yellowfin tuna or albacore (*Thunnus albacares*), swordfish (*Xiphias gladius*), wahoo (*Acanthocybium solandri*), escolar (*Lepidocybium flavobrunneum*), blue marlin (*Makaira mazara*), and mahi-mahi (*Coryphaena hippurus*).

High seas fishing began in Galapagos in the 1930s, with foreign industrial fishing boats that employed longlines and purse seines. Subsequently Ecuadorian industrial fishing boats also began fishing in Galapagos (Reck, 1983). Since the creation of the GMR in 1998, only artisanal fishermen are permitted in Galapagos, while industrial fishing is banned (Castrejon, 2011).

Current regulations permit two types of boats for high seas fishing: 1) large fishing boats or artisanal fishing boats up to 18 m in length and 50 tons of gross tonnage; and 2) smaller fishing boats up to 12.5 m long. Permitted fishing gear includes: trolling with handline with lure or bait; fishing rod with or without a reel, and handline. High seas fishing is not regulated by any other management measures, such as total allowable catch, minimum or maximum size of catch, or spatial or temporal closures.

Most studies of fishing of pelagic species are assessments of fishing methods. The use of the longline in the GMR was evaluated in 2001 (Revelo *et al.*, 2005) and 2003 (Murillo *et al.*, 2004). An assessment of the oceanic handline was completed in 2006 (Tejada, 2006) and of fish aggregating devices (FADs; also known as plantados) in 2009 (Castrejon, 2009). More recently, in 2013, the modified oceanic handline method, which is similar to offshore longlining, was evaluated (Reyes *et al.*, 2014). Peñaherrera (2007) analyzed temporal and spatial assemblages of fish in the GMR, including the yellowfin tuna and wahoo. Castrejon (2011) compiled information on yellowfin tuna catches in the GMR from 1997 to 2003.

This assessment of the high seas fishery is intended to initiate regular evaluations of performance indicators established in the Fishing Chapter of the *Management Plan for the Protected Areas of Galapagos for Good Living* (DPNG, 2014).

Methods

We evaluated the following indicators of the high seas fishery in the GMR during 2012 and 2013: catch, fishing effort, catch per unit effort (CPUE), and value of the fishery.

Active fishing effort was measured based on the number of fishermen and vessels active each year. Although the Galapagos National Park Directorate's (GNPD) information system only identifies one fisherman per Monitoring Certificate or fishing trip, we assumed by direct observation that each fishing trip involved two fishermen. Passive fishing effort was obtained as a percentage of fishermen and vessels listed in the fishing register of the GNPD that had no activity in high seas fishing each year.

Catch was calculated in kilograms per species, month, and year. CPUE was defined as the catch in kilograms for each day of a trip and was calculated by species, month, and year. Positive or negative trends in monthly CPUE were detected using linear regression analysis.

Based on prices and volumes of the catch, we estimated the value of each species and the overall high seas fishery. Kruskal-Wallis statistical tests were used to determine differences in prices for 2012 and 2013.

Results

We reviewed 1382 monitoring certificates, 717 in 2012 and 665 in 2013, which indicated that more fishermen and boats participated in the 2012 season (Table 1).

Table 1. Active and registered fishing effort in the GMR in 2012 and 2013.

Year	Active fishermen	Active boats	Registered fishermen	Registered boats	Active fishermen	Active boats
2012	388	124	1084	416	35.8%	29.8%
2013	308	94	1124	416	27.4%	22.6%

The composition of the catch included yellowfin tuna (73.8%), followed by swordfish (15.3%), wahoo (6.5%), and escolar (4.1%), and much smaller numbers of mahi-mahi (0.27%) and sailfish (0.05%; Figure 1). This order of importance remained approximately the same in 2012 and 2013, except that in 2012 more escolar than wahoo were caught. The catch in 2012 was 244 TM and in 2013, 276 TM, giving a total of 520 TM (Table 2).

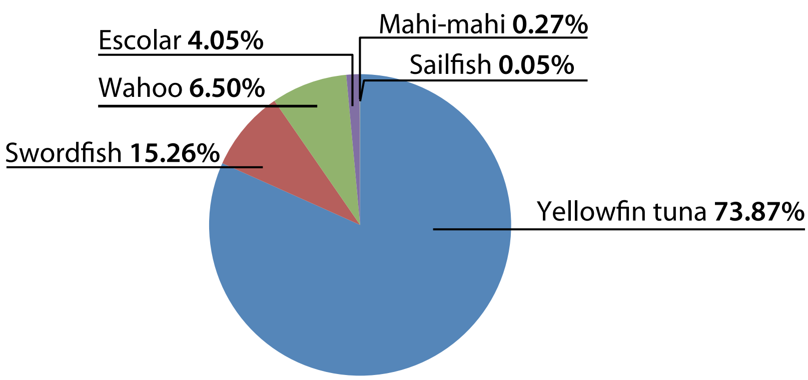

Figure 1. Composition of the high seas fishery catch in the GMR in 2012 and 2013.

Table 2. Volume of catch in metric tons for the high seas fishery in the GMR in 2012 and 2013.

Species	2012	2013	Total
Yellowfin tuna	163.7	220.7	384.4
Swordfish	5.3	21.1	79.4
Wahoo	9.4	24.5	33.8
Escolar	11.7	9.4	21.1
Mahi-mahi	0.9	0.5	1.4
Sailfish	0.0	0.2	0.2
Total	243.9	276.4	520.3

Overall, the average monthly catch was greater in 2013 than in 2012, with a monthly average for the two years of 21.7 MT (Table 3). Sailfish were only caught on one occasion in June 2013 (250 kg). The peak catches of yellowfin tuna were in February, May, and November 2012, and February, April, and November 2013 (Figure 2). Higher catches of swordfish occurred from February to May 2012, of wahoo in April 2013, and of escolar in March 2012.

Table 3. Monthly catch in metric tons by species for the high seas fishery in the GMR in 2012 and 2013.

Species	Average	Maximum	Minimum	Standard deviation
2012				
Yellowfin tuna	13.6	20.3	5.2	5.1
Swordfish	4.9	13.9	0.02	5.1
Wahoo	0.78	2.8	0.09	0.73
Escolar	1.0	4.4	0.0	1.6
Mahi-mahi	0.07	0.74	0.0	0.21
Total	**20.3**	**35.0**	**8.7**	**8.3**
2013				
Yellowfin tuna	18.4	31.1	10.6	5.6
Swordfish	1.8	6.1	0.30	1.8
Wahoo	2.0	11.3	0.09	3.2
Escolar	0.78	2.8	0.0	1.0
Mahi-mahi	0.04	0.11	0.0	0.04
Total	**23.0**	**37.2**	**15.5**	**7.4**
2012-2013				
Yellowfin tuna	16.0	31.1	5.2	5.8
Swordfish	3.3	13.9	0.02	4.0
Wahoo	1.4	11.3	0.09	2.4
Escolar	0.88	4.4	0.0	1.3
Mahi-mahi	0.06	0.74	0.0	0.15
Total	**21.7**	**37.2**	**8.7**	**7.8**

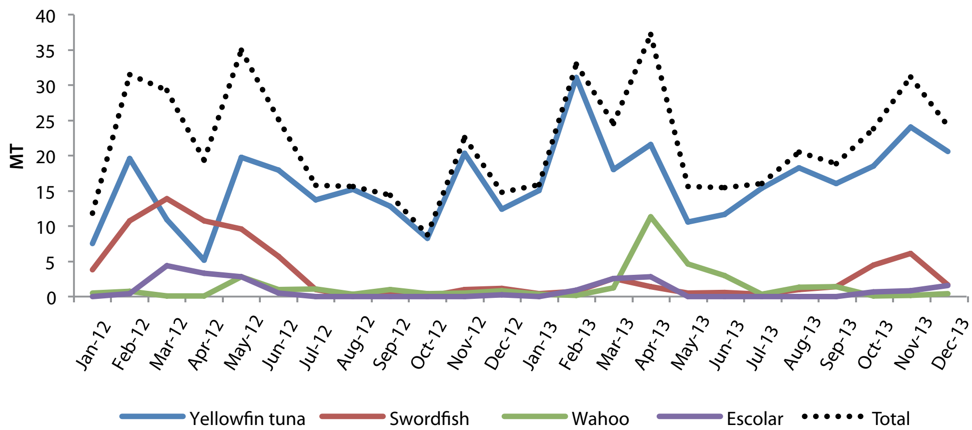

Figure 2. Monthly catch in metric tons for the main species in the high sea fishery in the GMR in 2012 and 2013.

A total of 1382 fishing days were recorded, 717 in 2012 and 665 in 2013. Total average CPUE was 170.5 kg per day of fishing (Table 4). The order of importance of the monthly average CPUE by species was the same as the catch composition. Linear regressions indicated a positive trend of monthly CPUE for yellowfin tuna and a negative trend for swordfish (Figure 3).

When completing the CPUE analysis, 44 monitoring certificates for yellowfin tuna, swordfish, and mahi-mahi, and one certificate for wahoo and escolar were not included as they did not have departure and arrival dates. The sailfish was not considered for the analysis by species as there was only a single catch.

Table 4. CPUE (kg/day fishing trip) of species in the high seas fishery in the GMR in 2012 and 2013.

Species	2012	2013	Average 2012-13
Yellowfin tuna	3.9	4.4	4.1
Swordfish	4.0	4.9	4.6
Wahoo	4.5	3.9	4.3
Escolar			1.8
Mahi-mahi			0.9
Sailfish			1.1

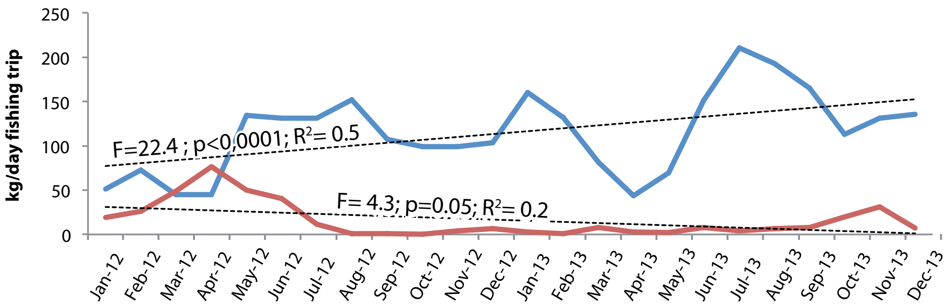

Figure 3. CPUE (kg/day fishing trip) and monthly trend for yellowfin tuna and swordfish in 2012 and 2013. The statistical results of each regression are shown..

Although there were price fluctuations for the main species (Figure 4), swordfish had the highest average price, followed by wahoo, yellowfin tuna, escolar, mahi-mahi, and sailfish (Table 5). There was no statistical difference between the average prices in 2012 and 2013 for yellowfin tuna, swordfish, and wahoo.

Table 5. Average prices in US$/kg of the species caught in the high seas fishery in the GMR in 2012 and 2013.

Species	2012	2013	Average 2012-13
Yellowfin tuna*	$ 3.9	$ 4.4	$ 4.1
Swordfish*	$ 4.0	$ 4.9	$ 4.6
Wahoo*	$ 4.5	$ 3.9	$ 4.3
Escolar*			$ 1.8
Mahi-mahi**			$ 0.9
Sailfish**			$ 1.1

* Average prices in COPROPAG (Artisanal Fisheries Production Cooperative of Galapagos). Escolar had very few data per year; only the total average price is shown.
** Reference prices at the dock in Puerto Ayora during 2013.

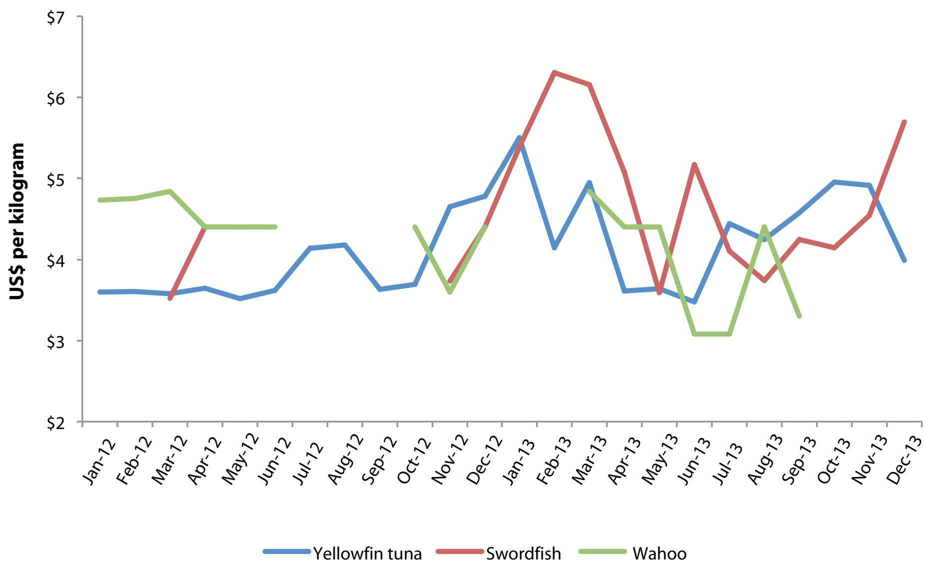

Figure 4. Average monthly prices for the main species of the high seas fishery in the GMR in 2012 and 2013.

Estimated gross income of the high seas fishery was US$958,419 for 2012 and US$1,180,320 for 2013 (Table 6). In 2013, there was an increase in income for yellowfin tuna and swordfish compared to 2012 (Figure 5).

Table 6. Estimated gross income (US$) from the high seas fishery in the GMR in 2012 and 2013.

Species	2012	2013	Total
Yellowfin tuna	636,375.1	964,483.8	1,600,858.9
Swordfish	233,231.8	102,421.7	335,653.5
Wahoo	42,130.3	96,123.2	138,253.5
Escolar	45,876.8	16,543.2	62,420.0
Mahi-mahi	804.9	462.8	1,267.7
Sailfish	0.0	285.0	285.0
Total	**958,418.8**	**1,180,319.7**	**2,138,738.5**

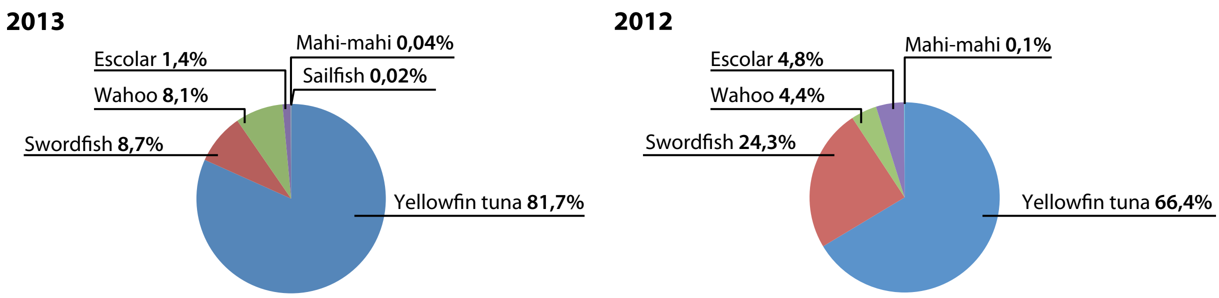

Figure 5. Distribution of gross income by species in the high sea fishery in the GMR in 2012 and 2013.

Discussion

This is the first long-term assessment of all species of economic importance in the high seas fishery in the GMR and includes performance indicators outlined in the Fishery Chapter. Indicators included: fishing effort, catch, CPUE, price, and economic value. However, more information is needed on other important indicators, such as: average size, sex ratio, and distribution of gross income. Having data on all of these indicators would permit a better analysis of whether production changes in this fishery are due to population, fishing, and/or environmental changes.

The percentage of active effort in the high seas fishery in the GMR is low in relation to registered fishermen and boats. This is the same for the lobster fishery, where the percentage of active effort is approximately 40% (Ramírez *et al.*, 2013). This indicator reinforces the recommendation made on several occasions to update the GNPD fishing registry to include only those who are actively fishing (Ramírez *et al.*, 2013; Castrejon, 2011).

Catch volume and value are likely underestimated. There is an unknown level of landed catch that is not monitored by the GNPD, especially catch that is sold at local fishing docks, establishments, or markets. This unregistered volume remains unknown for all three ports.

Results indicate that yellowfin tuna is increasingly important for fishermen in the GMR. From 1997 to 2003, the maximum production of yellowfin tuna was a little more than 40 MT (Castrejon, 2011). The current catch is five times higher than during that period. Peñaherrera (2007) shows that in catches from 1998 to 2006, wahoo was equal to or more important than yellowfin tuna. Currently the yellowfin tuna catch far exceeds that of wahoo.

This analysis reveals a change in the dynamics of the high seas fishery in the GMR. In 2010, a new technique was documented to catch pelagic fish called the modified oceanic handline (MOHL). The MOHL was developed by combining several oceanic handlines, giving rise to a fishing method with features similar to mid-deep longlines (Reyes *et al.*, 2014). Unfortunately it was impossible to know which fishing method fishermen used, since it was often commented that many fishermen reported using one method when completing the Monitoring Certificate, when in reality they used another. However, it is likely that the use of MOHL is the reason for the change in species composition in the high seas fishery catch in the GMR. The MOHL is being evaluated through a pilot project carried out jointly by the Artisanal Fisheries Production Cooperative of Galapagos (COPROPAG – Spanish acronym) and the GNPD. The final decision regarding use of the MOHL, based on the results of the pilot project, has not yet been taken.

According to CIAT (2013), yellowfin tuna is fully exploited and swordfish under exploited in the Eastern Pacific. This suggests that trends in monthly CPUE of yellowfin tuna and swordfish are due more to fishing method utilized, than to resource abundance. Data from the MOHL pilot project also show a positive trend in CPUE of yellowfin tuna. For swordfish the trend was unclear as there were few records (GNPD data). However we must also consider the impact of the MOHL on the ecosystem, especially given that longlines have proven to have a negative impact on some of the most protected species on a global scale, such as sharks, sea turtles, and sea lions (Reyes *et al.*, 2014).

Despite no statistical differences in the prices of the main species of high seas fishing between 2012 and 2013, it is worth noting that since November 2012, prices have increased. This increase was due to COPROPAG taking control of marketing these resources in continental Ecuador. Prices fluctuated due to quality and size (for yellowfin tuna and swordfish), changes in the COPROPAG customer base, and changes in international price (Kléber López, manager of COPROPAG, pers. com.).

The economic value of the high seas fishery in 2012 was slightly less than that of the spiny lobster fishery, which was estimated to be US$1,086,408 (GNPD data) for the same year. If the catch and price of pelagic fish continue to increase, in a few years the high seas fishery will be the most important in the GMR.

Recommendations

Based on this evaluation of the high seas fishery in the GMR, we recommend that more information be collected, and existing information and management of fishing effort and marketing be improved. To do this, the following actions are recommended:

- Evaluate all performance indicators of the high seas fishery referred to in the Fishery Chapter. For this purpose it is suggested to:

  Update the GNPD fisheries information system to provide greater and easier access to information, such as mobilization of the fishery product, fishing methods, costs, etc.

  Obtain biological information of species caught onboard or at the docks.

- Update the GNPD Fishing Register based on active fishing effort and the exploitation status of each resource.
- Monitor 100% of landings, or failing that, estimate the volume of fish not registered by the GNPD.
- Continue to strengthen the marketing of quality products through fishing cooperatives. Marketing by the cooperatives was observed to increase the price of the products and, it is assumed, results in a more equitable distribution of income.
- Conduct periodical assessments of the high seas fishery, as is done with sea cucumbers and spiny lobsters.

Acknowledgements

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Settlement habitat and seasonal relative abundance of spiny lobster *Panulirus sp.* larvae and accompanying fauna in the Galapagos Marine Reserve

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Introduction

Spiny lobster and sea cucumber fisheries are of major economic importance for the artisanal fishing sector of the Galapagos Archipelago. In Galapagos two species of lobster belonging to the Palinuridae family are commercially exploited: red lobster (*Panulirus penicillatus*) and the green or blue lobster (*Panulirus gracilis*). Until 2006, both fishing and population indicators showed that the lobster resource had declined (Hearn *et al.*, 2006); however since then fishery indicators (catch per unit effort or CPUE and total catches) have shown a recovery of the resource (DPNG, 2014).

Larval dispersal and the recruitment index are determining factors in the life cycle and the relationship between larval, juvenile, and adult lobsters. Until a few years ago, however, this information was unknown for lobsters in the Galapagos Marine Reserve (GMR) (Hearn *et al.*, 2005). This lack of knowledge increases the uncertainty when implementing suitable management strategies (Cruz, 1999).

Understanding the natural contribution of ecosystems to lobster populations will help ensure population abundance of these species. The present study aims to obtain information about the distribution of the larval stages of lobster in order to help determine the life cycle of lobster species in Galapagos and the rate of recruitment in relation to population size.

The results are based on the Larval Monitoring Program initiated in 2006, under the framework of the GMR conservation project funded by the Japan International Cooperation Agency (JICA). The Galapagos National Park Directorate (GNPD) continues this work to this day.

Methodology

During the initial phase of the project, larval collectors used in various parts of the world were tested and one was eventually designed specifically for Galapagos. The Galapagos collector resembles a mass of artificial algae. It was developed using synthetic material (plastic straw, plastic straps, and plastic mesh) formed into a sphere measuring approximately 80 cm in diameter, tied to a 70-kg concrete anchor (Figure 1). Buoys were located inside the collectors to keep them suspended.

Figure 1. Checking a larva collector installed in Itabaca Channel.

Initially, a total of 18 larva collectors were distributed at nine sites (Table 1). However not all sites could be monitored regularly and larvae were only found in places with similar characteristics (shallow bays surrounded by mangrove). Therefore, the study turned its primary attention to Santa Cruz Island (Itabaca Channel and Tortuga Bay). Each time a collector was examined, it was raised out of the water and shaken 30 times to remove any larvae before being returned to its original position.

Table 1. Distribution of collectors by site and geographic position. Monitoring categories were: a) collectors monitored at least once, but no lobster larvae found; b) collectors with regular monitoring where lobster larvae were continuously found; and c) collectors monitored at least once with settlement of lobster larvae.

Island	Site	Number of collectors installed	Monitoring category	Latitude	Longitude
Isabela	El Finado	1	a	01º02'490"S	91º09'350"W
	Barahona	1	a	00º58'638"S	91º00'201"W
	Bolívar Channel	1	a	00º18'300"S	91º21'215"W
	Cartago Bay	2	a	00º43'148"S	90º48'340"W
Santa Cruz	Itabaca Channel	5	b	00º29'198"S	90º16'211"W
	Punta Estrada	1	b	00º45'664"S	90º18'218"W
	Tortuga Bay	4	b	00º46'072"S	90º21'091"W
	Las Palmitas	2	c	00º40'310"S	90º32'227"W
Fernandina	Across from Caseta Bolívar	1	a	00º18'253"S	91º23'587"W

Based on work with *Panulirus argus* (Cruz *et al.*, 1991; Cruz, 1999), larval specimens collected were divided into four stages of development (Figure 2):

1. ***Philosoma:*** pelagic phase with transparent cuticle, depressed body;
2. ***Puerulus:*** ability to swim, developed pleopods, migrate to the coast, 4-6 mm long;
3. ***Post-puerulus:*** algal phase, 6-15 mm long, occurs after metamorphosis during settlement;
4. **Juvenil:** phase with differentiation of sexes, which occurs when they reach 16-20 mm.

Larvae in the *philosoma* phase were captured during nocturnal samplings conducted by boat, traveling at 2-5 knots, far from the coast. This method sampled both

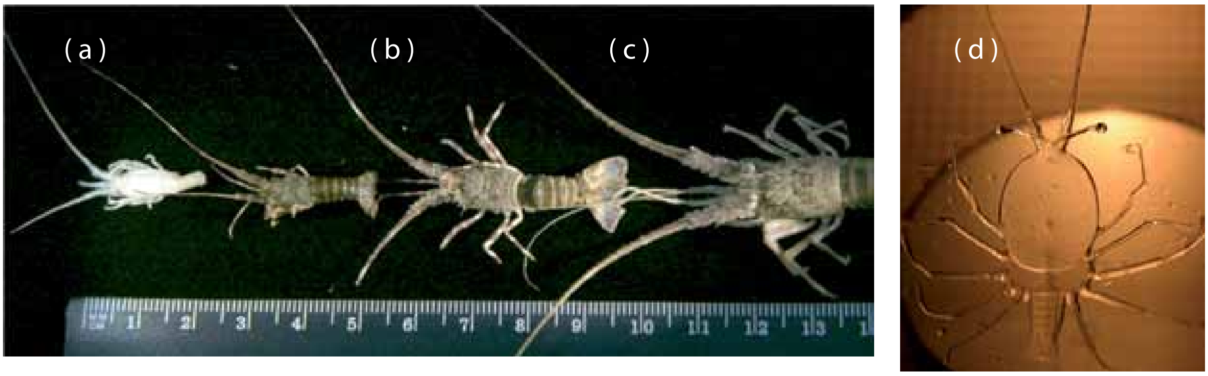

Figure 2. Different larval stages of the spiny lobster: a) *Puerulus*, b) *Post-puerulus*, c) Juvenil, d) *Philosoma.*

meso- and macrozooplankton. Two approaches were used. The first involved an oblique tow with a conical net of 335 microns (μ) being towed for approximately 15 minutes, raising it from a depth of 100 m to the surface. The second involved an hour-long surface tow of a conical net of 0.5 mm pore mesh. Alcohol (75%) was used to preserve post-*puerulus* and *philosoma* phases, and any additional fauna.

Results

The pilot phase of the project involved the design of the first working lobster larval collector for the GMR. Lobster larvae were captured in a systematic fashion, primarily in the collectors installed at three coastal sites on Santa Cruz Island (Itabaca Channel, Tortuga Bay, and Las Palmitas). Based on logistical considerations (some sites were difficult to monitor regularly) and preliminary results (larvae were found only in shallow bays surrounded by mangroves), from 2008 on, monitoring was concentrated at two sites (Itabaca Channel and Tortuga Bay).

In 2006 and 2007, six lobster larvae were collected in Itabaca Channel (Table 2). In 2008 the number captured increased to 29. The larval settlements at this site represent 67.2% of the total three-year catch for all sites. At Tortuga Bay, on the other hand, captures only occurred in 2007 and 2008, representing 29.5% of the total. At Las Palmitas, only two lobster larvae, or 3.3% of the total, were collected in 2007. Most of the larvae collected during the study were in the post *puerulus* phase.

The presence of larvae in the Itabaca Channel varied over time, peaking in March and May 2008 (Figure 4). In Tortuga Bay two peaks occurred, between February and March 2007. Itabaca Channel had fewer settlements in

Table 2. Number of lobster larvae (*Panulirus* sp.) captured by year and sampling site.

Site	Year			Percent of catch
	2006	2007	2008	
Itabaca Channel	6	6	29	67.2
Las Palmitas	0	2	0	3.3
Tortuga Bay	0	8*	10	29.5
Total	**6**	**16**	**39**	**100**

*This group includes one lobster that was observed and captured in its natural habitat.

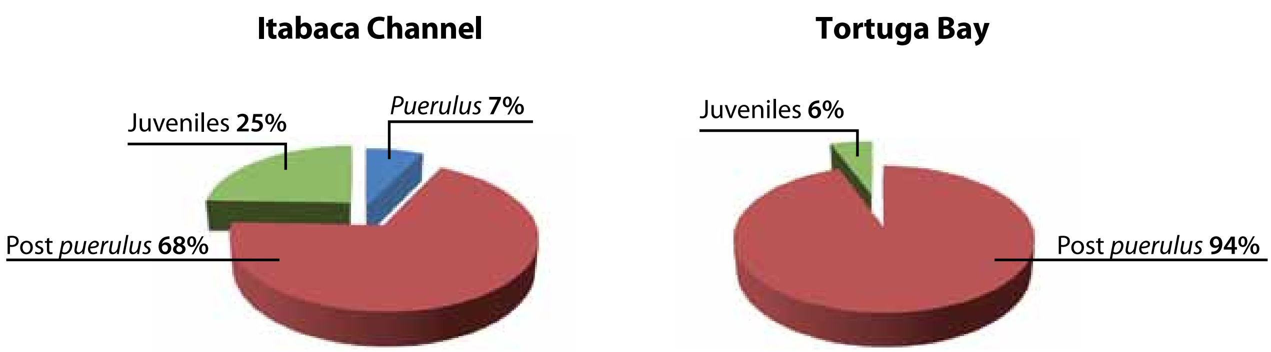

Figure 3. Percentage distribution of the larval stages found in Itabaca Channel and Tortuga Bay.

January, April, May, July, October, and November, with two individuals captured per month. Tortuga Bay had only one settlement in January, April, May, June and August.

Captures of *philosomas* of the genus *Panulirus* were carried out during three collection trips between 2006 and 2007, with a total of 18 individuals collected.

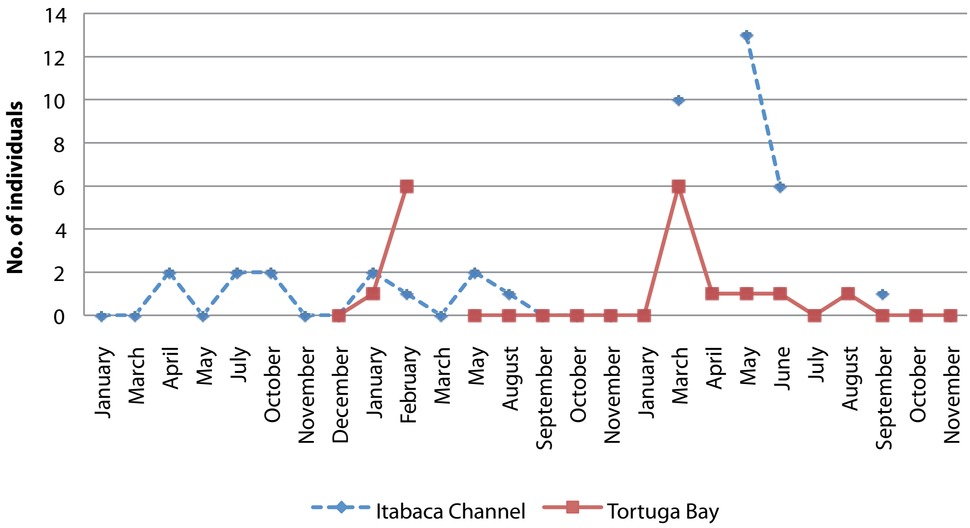

Figure 4. Number of lobster larvae (*Panulirus* sp.) captured during the monthly monitoring.

Conclusion and discussion

During this study we established that there are lobster recruitment sites in geographical areas with similar characteristics, such as mangrove-fringed bays with backwater currents and continuous water circulation.

The need to design a larval collector different from those used elsewhere suggests that the ecology of the settlement of spiny lobsters in Galapagos and their geographical and ecological characteristics are distinctive.

Between Tortuga Bay and Itabaca Channel on Santa Cruz Island, the greater presence of lobster larvae was found in collectors located in Itabaca Canal, possibly due to oceanographic conditions as the system of currents converging in the area generates high productivity, while Tortuga Bay is more confined and more exposed to continuous wave action.

Settlements of *puerulus*, post *puerulus,* and juvenile larvae in warm months (December to May) coincide with the reproductive peaks for both red and blue lobster described by Reck (1983).

In 2008, 23 more lobster larvae were collected than in 2007, probably due to increased reproduction or the action of currents and climatic conditions that favored the presence of a larger number of recruits. This suggests that this indicator would be directly related to fishery indicators for 2012-13, when an increase in the catch volume and CPUE of spiny lobster was observed.

Juvenile green lobsters have also been observed in the collectors. This should be confirmed with parallel studies (genetic testing) since red lobsters have a greater abundance and distribution in Galapagos.

Despite the fact that the monitoring did not demonstrate large scale recruitment, the results suggest that the levels of recruitment have some degree of seasonality and show patterns related to different oceanographic factors, such as sea temperature and potentially others that still need to be studied.

Given that spiny lobsters are one of the major fisheries of Galapagos, we recommend that this study be continued and strengthened with parallel monitoring of oceanographic variations, such as currents and circulation systems, and examining relationships with other organisms that colonize the same locations. Finally, the impact of environmental events on crustaceans is unknown and should be researched (Booth & Phillips, 1994).

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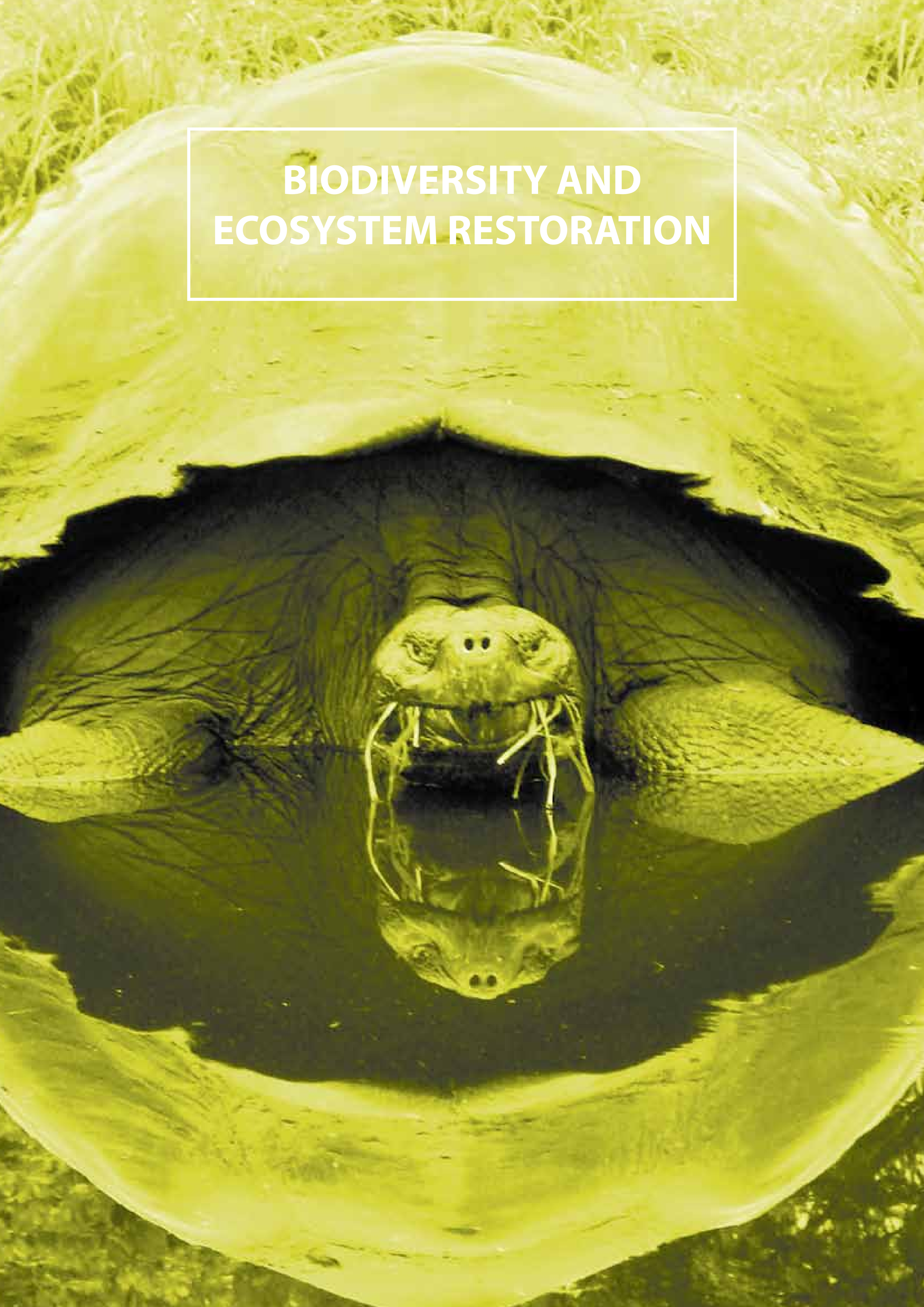
BIODIVERSITY AND
ECOSYSTEM RESTORATION

Photo: © Galápagos Verde 2050

Galapagos Verde 2050: An opportunity to restore degraded ecosystems and promote sustainable agriculture in the Archipelago

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Invasive species constitute the greatest threat to terrestrial biodiversity in Galapagos (Gardener *et al.*, 2010a, 2010b). Currently, there are about 900 species of introduced plants of which at least 131 are already invading natural areas of the Archipelago (Guezou & Trueman, 2009; Jaramillo *et al.*, 2013). The humid zones of inhabited islands have the most degraded ecosystems, largely due to invasive species and agriculture (Gardener *et al.*, 2010a; Renteria & Buddenhagen, 2006).

Conservation and/or restoration of the integrity and resilience of ecosystems represent the most effective strategies for ensuring that Galapagos ecosystems continue to generate environmental services for society (DPNG, 2014). The Galapagos Verde 2050 project, a model of applied science on a regional scale, was designed with these conceptual principles in mind. It seeks to transform an altered socioecological system into a healthy and functional system.

Galapagos Verde 2050 is a multi-institutional, interdisciplinary initiative that seeks to contribute to the sustainability of the Archipelago through ecological restoration and sustainable agriculture, while providing an example of effective sustainable development for the rest of the world (Jaramillo *et al.*, 2014). The objectives of the project are:

1. Contribute to the restoration of degraded ecosystems in order to restore and/or maintain their capacity to generate services for humans;

2. Control and/or eradicate invasive introduced species in areas of high ecological value;

3. Accelerate the recovery process for native and endemic plant species that have slow natural growth;

4. Reduce the risk of introduction of exotic species through sustainable agriculture, which would also contribute to local self-sufficiency;

5. Contribute to economic growth through year-round sustainable agriculture.

All project objectives contribute to the well-being of the human population of Galapagos and their natural environment and are thus aligned with the *Management Plan of the Protected Areas of Galapagos* (DPNG, 2014) and the

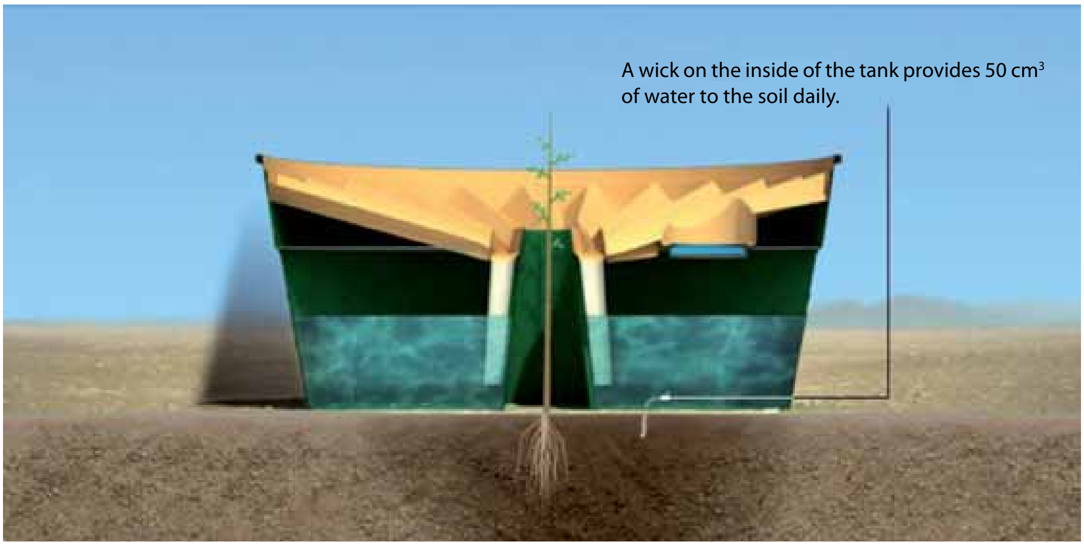

Figure 1. Structure and model of the Groasis Technology, from a vertical cut (taken from www.groasis.com/es).

National Plan of Good Living (SENPLADES, 2013); as well as with the United Nations Millennium Development Goals.

A new technology for water conservation and to enhance plant growth

The Groasis Technology (GT) waterboxx, invented by Mr. Pieter Hoff of the Netherlands and designed by Groasis, is an innovative tool to optimize water use in propagating and cultivating plants (Figure 1). It reduces normal water consumption by 90%, a much greater reduction that seen in other techniques such as drip irrigation. It has been used successfully in more than 30 countries around the world, primarily in arid and desert areas, such as the Sahara Desert (Hoff, 2013). GT has proven effective in increasing survival of seedlings in a variety of environments, including highly eroded land.

The GT waterboxx is designed to provide a permanent supply of water to plant roots through a wick, allowing the roots to grow deeper and more vertically, which ensures the vitality of the plants even after the box is removed. Its use in Galapagos can contribute to restoring ecosystems through the recovery of emblematic native and endemic plant species and to establishing year-round sustainable agriculture.

This article describes the results of a pilot project to test the functionality of GT in Galapagos. These findings were used to develop Galapagos Verde 2050, which from 2014 to 2050 will contribute to the conservation of vulnerable ecosystems, primarily in the humid zones (DPNG, 2014; Jager *et al.*, 2007; Renteria *et al.*, 2006; Trusty *et al.*, 2012; Tye *et al.*, 2001; Jaramillo *et al.*, 2014) and to the development of sustainable agriculture. Sustainable agriculture in Galapagos can help to reduce imports of plant products from mainland Ecuador, thus reducing the threat of introduction of invasive species (FEIG, 2007; Martinez & Causton, 2007; Trueman *et al.*, 2010; Trueman & d'Ozouville, 2010). Sustainable agriculture also contributes to food security for the human population, which is a stated goal of the *National Plan for Good Living* (SENPLADES, 2013).

Methods

The pilot project was based on an agreement between the Fundación Fuente de Vida (FFV) of Ecuador, representing Groasis (a Dutch company), and the Charles Darwin Foundation (CDF), and close collaboration with the Galapagos National Park Directorate (GNPD). The project also involved the Decentralized Autonomous Government of Floreana, the Provincial Directorate of the Ministry of Agriculture, Livestock, Aquaculture, and Fisheries (MAGAP – Spanish acronym), the Galapagos Ecological Airport (ECOGAL – Spanish acronym), and the port captaincy of Puerto Ayora.

Ecological restoration

GT was used for restoration work on Floreana, Baltra, and Santa Cruz. In Floreana 300 waterboxxes were used at a model farm located in the humid zone. In Baltra 19 waterboxxes were located in a highly degraded area located in the abandoned garbage dump to grow six native and endemic species. In Santa Cruz, five waterboxxes were used with three endemic species in a small area at Los Gemelos, a visitor site in the highlands. In addition, invasive introduced plants were eliminated from the facilities of the Puerto Ayora port captaincy and were replaced with endemic species using GT to promote the use of native and endemic plants in urban areas. Several waterboxxes with endemic plants were also located within the premises of the GNPD and CDF to showcase the technology.

Sustainable agriculture

Experiments in sustainable agriculture were carried out on Floreana and Santa Cruz, with community support. Waterboxxes were used in 21 family vegetable gardens (18 on Floreana and three on Santa Cruz) in both the humid and the arid zones. At the Safari Camp resort in Santa Cruz, this technology was tested with cacao, tomato, and cucumber plants.

Plant species used

The pilot project involved 52 species (native, endemic, introduced, and cultivated plants) of which 60% were intended for ecological restoration and 40% for sustainable agriculture in vegetable gardens and farms (Table 1). The selection of species for ecological restoration was based on the IUCN Red List (Jaramillo *et al.*, 2013), focusing primarily on emblematic and threatened species from each island. In the case of sustainable agriculture, most species were fruit trees. Several ornamental and endemic species were also tested at the request of community members in Floreana.

The species selected for both ecological restoration and sustainable agriculture were distributed in eight different substrate types and four vegetation zones (Table 2). For each species, two controls (no GT) were established. Due to the extreme shortage of water in Floreana and Baltra, the amount of water used for the operation of the boxes was decreased to 70% and 50% of the normal volume of water required.

Table 1. Classification of the species used in the pilot project on the three islands.

Island	Objective	Family	Species	Common name	Origin*
Baltra	Ecological restoration	Mimosaceae	*Acacia macracantha* Humb. & Bonpl. ex Willd.	Acacia	N
		Burseraceae	*Bursera malacophylla* B.L. Rob.	Incense tree	E
		Simaroubaceae	*Castela galapageia* Hook. f.	Castela	E
		Cactaceae	*Opuntia echios* var. *echios* Howell	Prickly pear cactus	E
		Caesalpinaceae	*Parkinsonia aculeata* L.	Jerusalem thorn	N
		Asteraceae	*Scalesia crockeri* Howell	Crocker's scalesia	E
Santa Cruz	Ecological restoration	Amaranthaceae	*Alternanthera echinocephala* (Hook. f.) Christoph.	Spiny-headed chaff flower	N
		Amaranthaceae	*Alternanthera filifolia* (Hook. f.) Howell	Thread-leafed chaff flower	N
		Verbenaceae	*Clerodendrum molle* Kunth	Glorybower	N
		Combretaceae	*Conocarpus erectus* L.	Button mangrove	N
		Malvaceae	*Gossypium darwinii* G. Watt	Darwin's cotton	E
		Convolvulaceae	*Ipomoea pes-caprae* (L.) R. Br.	Beach morning-glory	N
		Celastraceae	*Maytenus octogona* (L'Hér.) DC.	Maytenus	N
		Melastomata-ceae	*Miconia robinsoniana Cogn.*	Galapagos miconia	E
		Cactaceae	*Opuntia echios* var. *gigantea* Howell	Prickly pear cactus	E
		Fabaceae	*Piscidia carthagenensis* Jacq.	Piscidia	N
		Rubiaceae	*Psychotria rufipes* Hook. f.	White wild coffee	N
		Asteraceae	*Scalesia affinis* Hook. f.	Radiate-headed scalesia	E
		Asteraceae	*Scalesia helleri* ssp. *santacruziana* Harling	Heller's scalesia	E
		Asteraceae	*Scalesia pedunculata* Hook. f.	Tree scalesia	E
	Sustainable agriculture	Cucurbitaceae	*Cucumis sativus* L.	Cucumber	C
		Solanaceae	*Solanum lycopersicum* L.	Tomato	C
		Sterculiaceae	*Theobroma cacao* L.	Cacao	C

Floreana	Ecological restoration	Amaranthaceae	*Alternanthera filifolia* (Hook. f.) Howell	Thread-leafed chaff flower	N
		Burseraceae	*Bursera graveolens* (Kunth) Triana & Planch.	Incense tree	E
		Verbenaceae	*Clerodendrum molle* Kunth	Glorybower	N
		Boraginaceae	*Cordia lutea* Lam.	Yellow cordia	N
		Asteraceae	*Darwiniothamnus tenuifolius* (Hook. f.) Harling	Lance-leafed Darwin's shrub	E
		Asteraceae	*Lecocarpus pinnatifidus* Decne	Wing-fruited lecocarpus	E
		Verbenaceae	*Lippia salicifolia* Andersson	Narrow-leafed lippia	E
		Plumbaginaceae	*Plumbago zeylanica* L.	Ceylon leadwort	N
		Rubiaceae	*Psychotria angustata* Andersson	Pink wild coffee	N
		Asteraceae	*Scalesia affinis* Hook. f.	Radiate-headed scalesia	E
		Asteraceae	*Scalesia pedunculata* Hook. f.	Tree scalesia	E
		Aizoaceae	*Sesuvium portulacastrum* (L.) L.	Sea purslane	N
		Solanaceae	*Solanum quitoense* Lam.	Purple solanum	I
		Sterculiaceae	*Waltheria ovata* Cav.	Waltheria	N
		Rutaceae	*Zanthoxylum fagara* (L.) Sarg.	Cat's claw	E
	Sustainable agriculture	Anacardiaceae	*Mangifera indica* L.	Mango	
		Apocynaceae	*Nerium oleander* L.	Oleander	
		Lamiaceae	*Ocimum campechianum* Mill.	Wild sweet basil	
		Lauraceae	*Persea americana* Mill.	Avocado	
		Alliaceae	*Allium fistulosum* L.	Welsh onion	
		Annonaceae	*Annona cherimola* Mill.	Cherimoya	
		Cannaceae	*Canna indica* L.	Indian shot	
		Solanaceae	*Capsicum annuum* L.	Cayenne pepper	
		Caricaceae	*Carica papaya* L.	Papaya	
		Cucurbitaceae	*Citrullus lanatus* (Thunb.) Matsun. & Nakai	Watermelon	
		Rutaceae	*Citrus reticulata* Blanco	Mandarin orange	C
		Rutaceae	*Citrus x limetta* Risso	Sweet lemon	C
		Rutaceae	*Citrus x limon* (L.) Osbeck	Lemon	C
		Rutaceae	*Citrus x sinensis* (L.) Osbeck	Orange	C
		Solanaceae	*Solanum lycopersicum* L.	Tomato	C
		Euphorbiaceae	*Jatropha curcas* L.	Barbados nut	C
		Arecaceae	*Cocos nucifera* L.	Coconut	C
		Cucurbitaceae	*Cucumis melo* L.	Muskmelon	C
		Fabaceae	*Phaseolus lunatus* L.	Lima bean	C

* N = native; E = endemic; I = introduced; C = cultivated.

Table 2. Vegetation zones, soil types, and the origin of the plant species used in the pilot project on Baltra, Santa Cruz, and Floreana (N = native, E = endemic, C = cultivated).

				Species origin			
Island	**Project**	**Zone**	**Substrate**	**N**	**E**	**C**	**Total Species**
Baltra	Ecological restoration	Arid	Clay	2	4	0	6
		Littoral	Clay	0	1	0	1
Floreana	Sustainable agriculture	Arid	Clay	0	0	13	13
			Humus	0	0	6	6
			Humus-clay	0	0	15	15
			Humus-rocky	0	0	8	8
			Rocky	0	0	3	3
			Rocky-clay	0	0	6	6
		Humid	Clay	0	0	1	1
			Humus	0	0	6	6
	Ecological restoration	Arid	Clay	5	4	0	9
		Humid	Humus	0	1	0	1
			Humus-clay	1	1	0	2
			Humus-rocky	2	4	0	6
			Rocky-clay	0	1	0	1
			Humus	3	5	0	8
			Humus-rocky	2	4	0	6
		Littoral	Clay	2	1	0	3
			Rocky-clay	2	2	0	4
Santa Cruz	Sustainable agriculture	Transition	Clay	0	0	2	2
			Humus	0	0	1	1
			Humus-rocky	0	0	1	1
	Ecological restoration	Humid	Humus	0	4	0	4
		Littoral	Clay	3	0	0	3
			Sandy	3	4	0	7
			Humus	2	1	0	3
			Rocky	2	1	0	3
			Rocky-sandy	2	1	0	3

Results

Ecological restoration

Preliminary results for the arid zone in Baltra indicated that the growth rate of seedlings planted using GT was significantly greater than those without GT, and that the growth rate of certain species, especially *Opuntia echios* var. *echios*, was particularly rapid. The same results were seen in Floreana and Santa Cruz (Figure 2). *Opuntia* species normally grow an average of 2 cm per year (Colonel, 2002; Hicks & Mauchamp, 2000; Estupiñan & Mauchamp, 1995), in contrast with the registered monthly growth of 1.5 cm with this new technology, which could result in an annual growth of more than 10 cm (Figure 3).

However, the growth and survival of seedlings in Baltra were affected by the physical characteristics of the soil (high levels of clay), evidenced by the stress of the control seedlings, and soil compaction caused by anthropological activities (airport, transport of heavy equipment, etc.). Signs of herbivory by land iguanas were also noted, as some species included in the project are part of the iguanas' natural diet. This observation demonstrates the importance of the project to restore the natural dynamics of degraded ecosystems in order to ensure food sources for native fauna.

In Floreana as in Baltra, positive results were obtained in three vegetation zones (literal, arid, and humid), using 14 native and endemic species. The greatest success was observed in the humid zone.

Sustained growth was also observed for the majority of the 14 native and endemic species used in Santa Cruz.

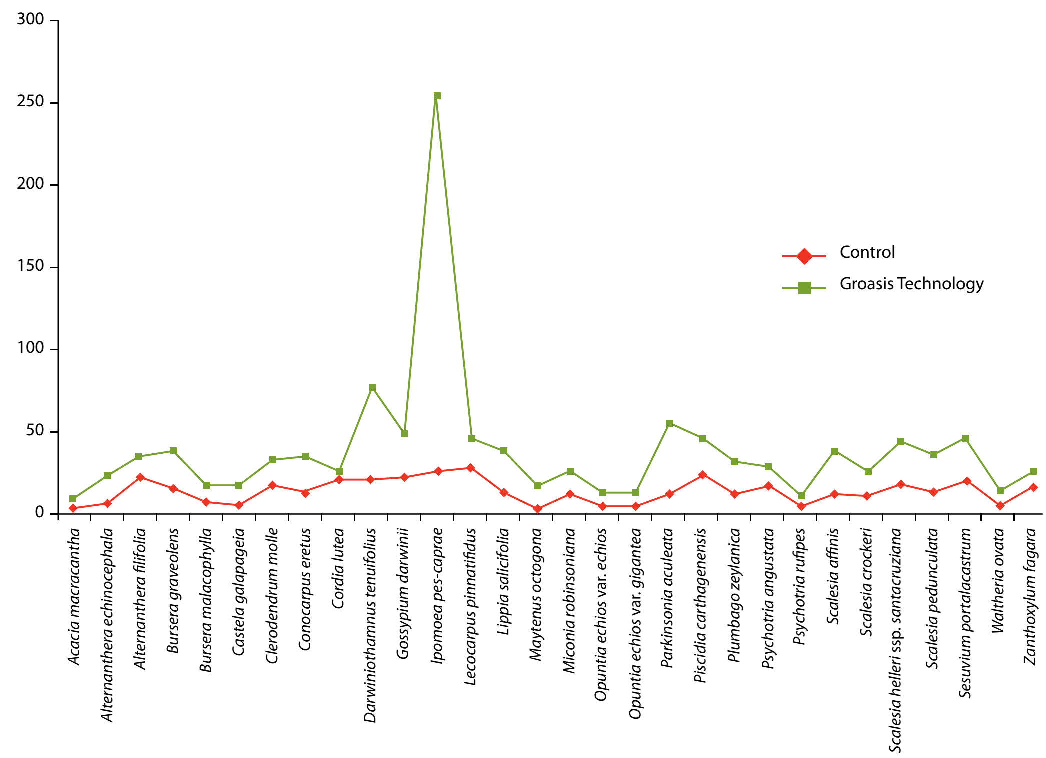

Figure 2. Average growth rate of the 30 species used in the pilot project for ecological restoration (using GT and control without GT) on Baltra, Floreana, and Santa Cruz Islands.

Figure 3. a) *Opuntia echios* var. *echios* near the Baltra airport, July 29, 2013; **b)** the same plant, November 17, 2013, after almost four months of monitoring, and **c)** the same plant without the box after 6 months, January 27, 2014.

An exceptional case was the high growth rate of *Scalesia pedunculata*, in both Floreana and Santa Cruz (at Los Gemelos), much like *Opuntia echios* var. *echios* in Baltra (Figure 4).

Sustainable agriculture

Preliminary results in sustainable agriculture in both Floreana and Santa Cruz were positive for the 22 cultivated species included in the experiment. However, in the case of tomatoes (*Solanum lycopersicum*) and watermelon (*Citrulus lanatus*), growth rates were more rapid than was observed for the other species (Figure 5).

Galapagos Verde 2050: Steps towards the future

Results of the pilot project in both restoration and sustainable agriculture indicate that GT works in Galapagos under different climatic and ecological conditions. Based on these results, Galapagos Verde 2050 was launched. This three-phase project began in January 2014 and will end in 2050.

Figure 4. *Scalesia pedunculata* in Floreana Island ready to grow naturally; Aníbal Altamirano, GNPD ranger, and Adrián Cueva, CDF field assistant, demonstrate how the box is extracted without causing damage to the plant.

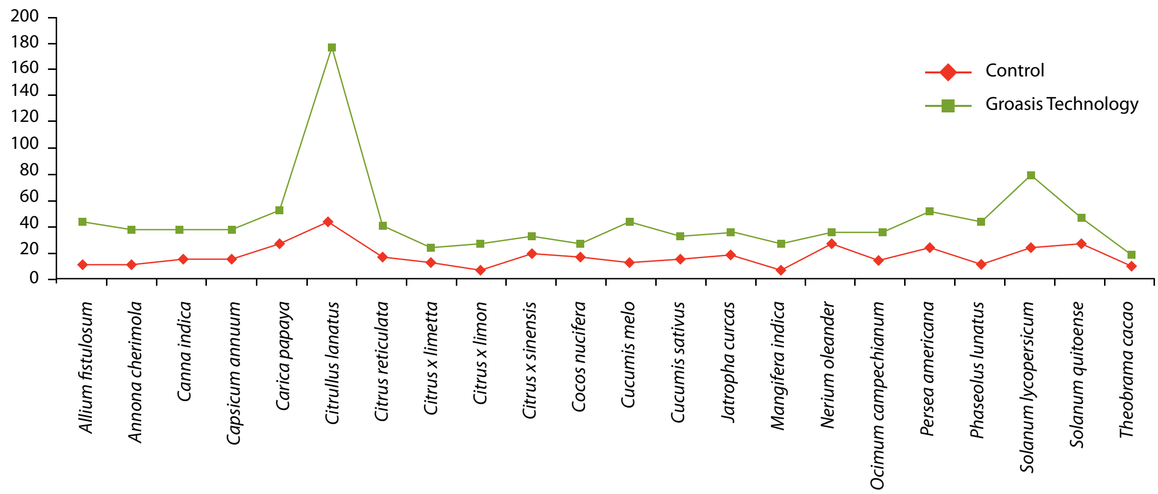

Figure 5. Average growth rate of 22 species used for sustainable agriculture (with GT and control without GT) in Floreana and Santa Cruz Islands.

Phase 1 (January 2014 to December 2016). Phase I includes ecological restoration on Baltra, Santa Cruz, South Plaza, and Floreana Islands. On Baltra the project focuses on land iguana nesting areas. On Santa Cruz, two small populations (1 ha) of *Scalesia affinis*, an endangered species, will be restored in the areas of El Mirador and Garrapatero (Figure 7). On South Plaza the work will focus on the restoration of the *Opuntia echios* var. *echios* population throughout the island (13 ha). On Floreana the efforts will focus on the restoration of a degraded area in the Black Gravel mine and supporting MAGAP's efforts to achieve adoption of sustainable agricultural practices on 25% of the farms. It is expected that some agricultural areas on Floreana will be designated for agro-ecological production according to MAGAP's Bioagriculture Plan for Galapagos, which promotes integrated production systems (Elisens, 1992).

Phase 2 (January 2017 to December 2018). During Phase 2, ecological restoration will occur in degraded ecosystems on Floreana that have been defined as priority areas by the GNPD. Work will be conducted on Española Island to achieve the repopulation of at least 20% of the area where *Opuntia megasperma* var. *orientalis* existed historically. In terms of sustainable agriculture, according to plans established by MAGAP, this phase of the project will strive to involve 100% of farms on Floreana in agro-ecological production.

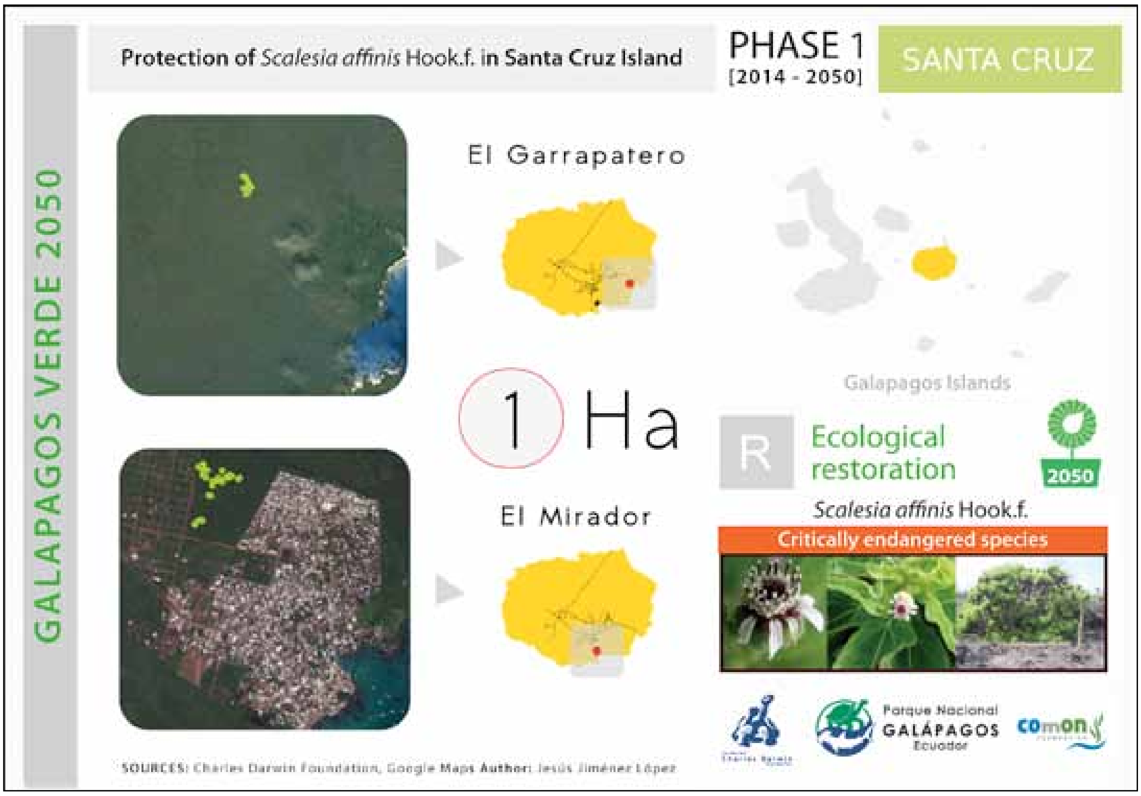

Figure 6. Fenced areas in El Mirador and Garrapatero to protect the last remnants of Scalesia affinis, a critically endangered species on Santa Cruz Island.

Phase 3 (January 2019 to December 2050). During this extended period the use of GT will be expanded to restore priority ecosystems and species identified in the GNPD's *Management Plan for the Protected Areas of Galapagos*. This work will take place on populated islands as well as on Santiago, where invasive plant and animal species have caused degradation, and on Española Island, where the goal is complete recovery of the cactus population (*O. megasperma* var. *orientalis*), based on available information regarding its historical distribution. In terms of sustainable agriculture, GT will be used to help achieve the goals of MAGAP regarding the implementation of the new model of agricultural production in the Islands.

Each phase of the project will involve establishing a timeline for completing specific goals for each island or species, as in the example of *Scalesia affinis* on Santa Cruz Island (Figure 7).

Conclusions and recommendations

The Groasis Technology (GT) pilot project in Galapagos resulted in the following conclusions:

- The use of GT is viable in Galapagos for both large-scale ecological restoration and sustainable agriculture.
- Some transplanted control plants (cultivated without GT) did not survive the stress from transplanting, while those that used GT not only survived but demonstrated accelerated growth. This indicates that GT offers protection for endemic Galapagos plants and minimizes the stress of transplanting, ensuring and increasing their survival rate.
- Despite certain externalities, such as herbivory and damage caused by domestic animals and humans, it is clear that GT stimulates growth and is effective with agricultural species.
- Growth acceleration occurred in restoration activities and sustainable agriculture, even in very arid zones where it was necessary to significantly reduce the normal amount of water required by the Groasis waterboxx. This result indicates that GT is an effective technology, even in extreme drought conditions.

The following recommendations are based on the conclusions of the pilot study:

- Expand the use of GT for ecological restoration on additional islands.
- Expand the use of GT in agriculture to increase production in Galapagos.

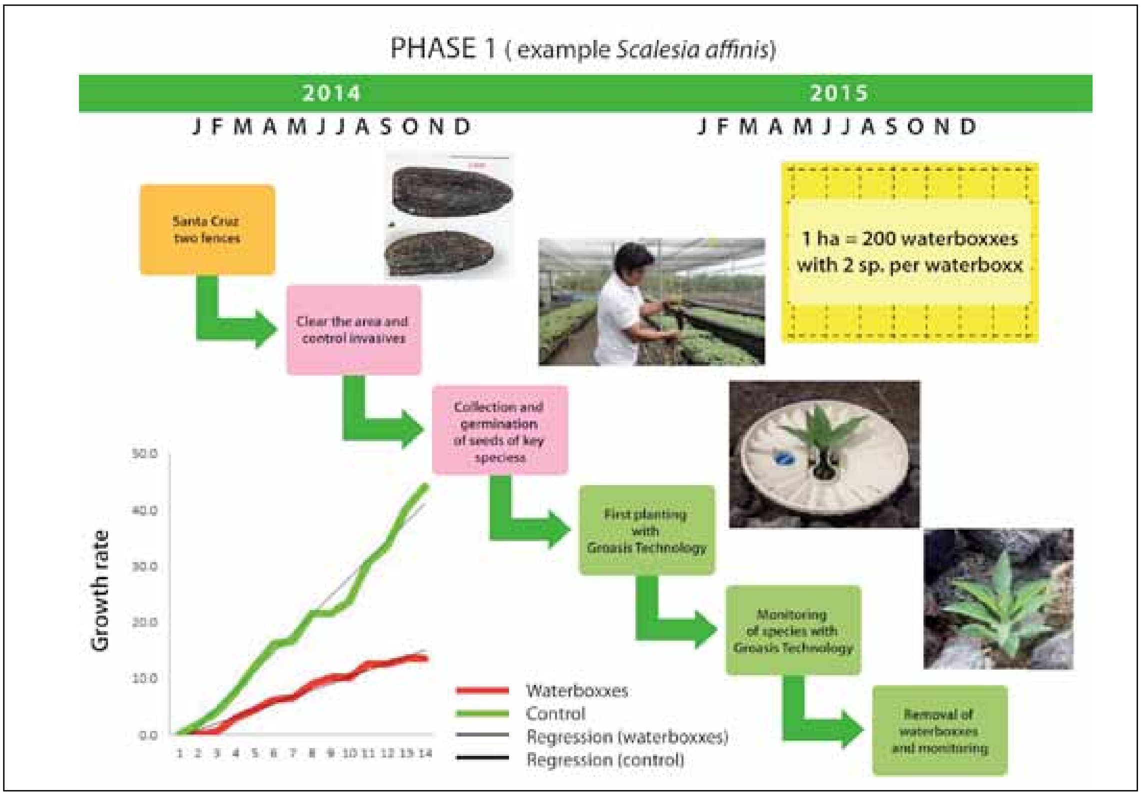

Figure 7. Example of work with Scalesia affinis to restore 1 ha in two areas on Santa Cruz Island during Phase I of the project.

- Expand inter-institutional coordination of restoration and agriculture projects to ensure project success and to incorporate new eco-friendly technologies, such as GT.

The ability of GT to overcome water constraints makes it an important tool for restoring threatened ecosystems and species and improving agricultural production. By 2050, it is expected that this project, implemented through coordinated and cooperative efforts of Galapagos stakeholders, will result in significant contributions to ecosystem restoration, sustainable agriculture, and a more sustainable archipelago.

Information about the Galápagos Verde 2050 Project is available at: www.darwinfoundation.org/es/ciencia-e-investigacion/galapagos-verde-2050/.

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Migration by Galapagos giant tortoises requires landscape-scale conservation efforts

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Galapagos tortoises (*Chelonoidis spp.*) are among the most iconic animals on Earth, inspiring wonder at the natural world among people everywhere. Ecologically, they play an important role in the ecosystem through seed dispersal, herbivory, trampling, and trail construction (Blake *et al.*, 2013; Gibbs *et al.*, 2008; Gibbs *et al.*, 2010). They are also a major attraction for tourists to the Galapagos Islands, making them a cornerstone of the local economy (Watkins & Oxford, 2009). Effective conservation of these animals is therefore important on many levels for the sustainability of Galapagos.

Galapagos tortoises on Santa Cruz Island undergo long distance seasonal migration (Blake *et al.*, 2013), during which individuals may travel many kilometers between the coast and upland farmland. Around the world, long-distance migrations are disappearing rapidly (Berger, 2004; Wilcove & Wikelski, 2008) because of overhunting and habitat loss due to agriculture expansion, fencing, and other barriers (Harris *et al.*, 2009). The disruption of migration can be catastrophic to migratory species, which often display little behavioral and ecological flexibility with which to cope with changing landscape dynamics (Holdo *et al.*, 2011a; Shuter *et al.*, 2012).

Conserving migratory species in the face of human impacts is often more difficult than for sedentary species due to the scale of their geographic requirements and their evident lack of behavioral flexibility to adapt to change (Milner-Gulland *et al.*, 2011). Disruption of migration can have catastrophic consequences for migratory species and ecosystems (Holdo *et al.*, 2011b; Wilcove & Wikelski, 2008). Most Galapagos tortoise populations are no longer threatened by overhunting (Márquez *et al.*, 2007), but tortoise persistence on the major islands will depend on maintaining connectivity for tortoise migration as intensification of land use in Galapagos moves forward. Here we briefly describe the salient features of the Galapagos tortoise migration on Santa Cruz Island and provide practical management recommendations that can be implemented immediately. We anticipate management and science evolving together closely over the next decade as we continue to gather better information on the geography, ecology. and extent of tortoise migration, and the corresponding impacts of human activity.

Methodology

To understand tortoise migration patterns, we fitted GPS tags (Figure 1) to 25 adult tortoises from two populations on Santa Cruz Island (*Chelonoidis porteri*). The largest population occurs in the Tortoise Reserve (La Reserva) to the southwest, while a second, smaller population, which is likely a different species, is found near Cerro Fatal on the eastern flank of the Island (Figure 2). Twelve tracking tags (made by e-obs GmbH, Munich, Germany) were deployed in Cerro Fatal (seven females and five males) and 13 in La Reserva (six females and seven males). The tags record a tortoise's location every hour. Results presented here are from tortoises with over one year of data.

Tortoises from both populations displayed long-distance seasonal migration up and down the flanks of the island. In La Reserva, tortoises migrated over an elevation range between sea level and 400 m, whereas in Cerro Fatal they ranged between 63-429 m. Nineteen (76%) tagged tortoises completed altitudinal migrations of over 150 m in elevation (Figure 2). The migrations in La Reserva were longer, up to >10 km, and more linear that those at Cerro Fatal. Six individuals (24%) were sedentary, occupying consistent elevations year round, five in the lowlands and one in the highlands.

The pattern of migration is largely driven by forage quality (Figure 3). During the dry or garúa season, the highlands

Figure 1. An adult male Galapagos tortoise from the La Reserva population on Santa Cruz Island, fitted with a GPS tag made by e-obs GmbH, Munich, Germany.

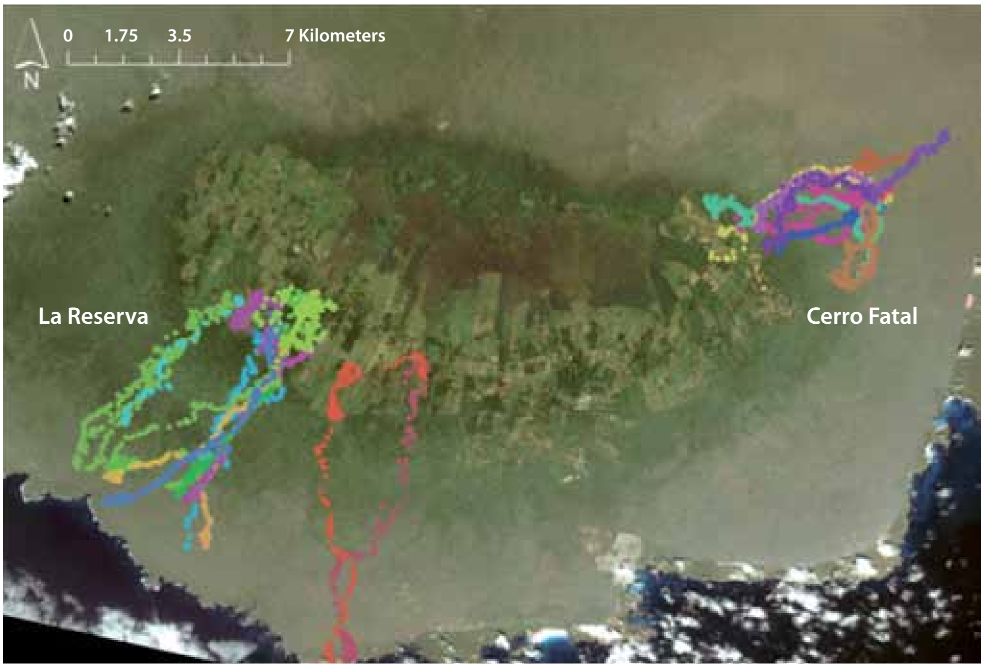

Figure 2. Movement tracks of giant tortoises on Santa Cruz Island.

remain humid due to prolonged periods of fine mist (garúa), while the arid lowlands become progressively drier. Therefore, vegetation productivity is relatively consistent year round in the highlands, compared to the highly variable lowlands. During the garúa season, tortoises occur predominantly in the highlands where they take advantage of abundant vegetation. As rainfall increases in January, the lowlands "green up" [as measured by a NASA satellite in the form of Normalized Difference Vegetation Index (NDVI), a measure of greenness and a proxy for vegetation productivity]. Tortoises then migrate downslope as lowland productivity peaks, and remain in the lowlands until productivity declines to low levels whereupon they migrate back to the highlands. Tortoises are likely drawn to lowland vegetation during the wet season because the rapid new plant growth means that food quantity is higher and more easily digestible than older growth upland vegetation.

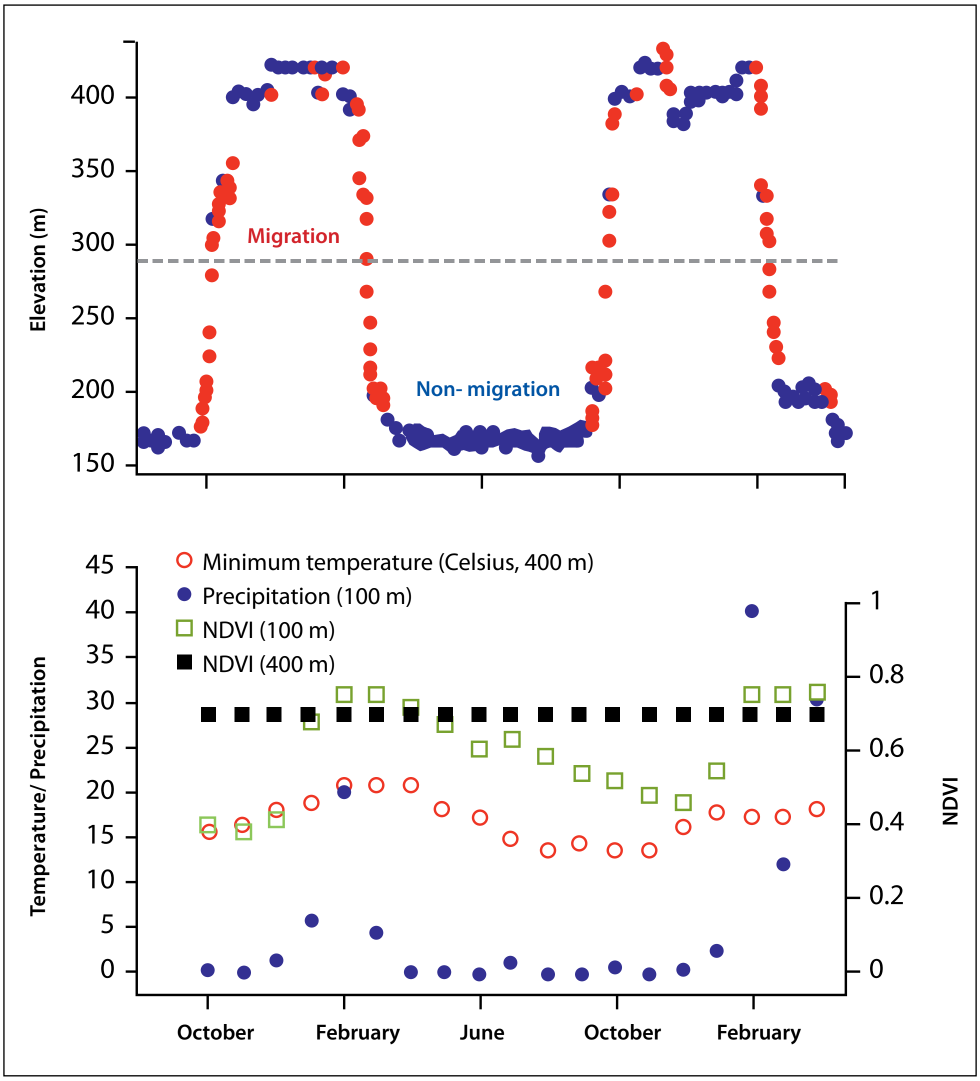

Figure 3. An example of the migration (using the tortoise Helber's tracks) in relation to environmental variables, including elevation, precipitation, temperature, and vegetation productivity (NDVI, the Normalized Difference Vegetation Index, derived from satellite data).

That food quantity and quality alone drive tortoise migration is certainly an over-simplification of what is happening and more work is needed. For example, reproduction is critical to population dynamics, and female tortoises nest only in the arid lowlands, which may help explain the timing of migration and sedentary behavior.

Tortoise migration and landscape management

Tortoise migration links important seasonal habitats for these animals: feeding/nesting grounds in the lowlands and foraging areas in the highlands. Tortoise migration patterns evolved over millennia, long before humans arrived on Galapagos and transformed natural highland habitats into farmland filled with introduced and invasive species, traversed by roads and fences, and dotted with habitations. The natural migration patterns result in many tortoises moving high into the agriculture zone of Santa Cruz. Tagged tortoises in La Reserva spend 33% of their total time in the agriculture zone, where they feed overwhelmingly on leaves and fruits of introduced species (Figure 4). Preliminary data indicate that tortoises do well on this diet based on body condition indices calculated in late 2013, using a formula modified from Flint *et al.* (2009). Condition index was calculated as weight ÷ length^2.89; Flint *et al.* (2009) used an exponent of 3, whereas our exponent of 2.89 is based on the slope of the relationship between log-curved carapace length vs log-mass, calculated from a sample of 100 Santa Cruz tortoises. Red blood cell counts and total protein content of blood were all higher for tortoises in the highlands than in the lowlands. Large areas of the agriculture zone

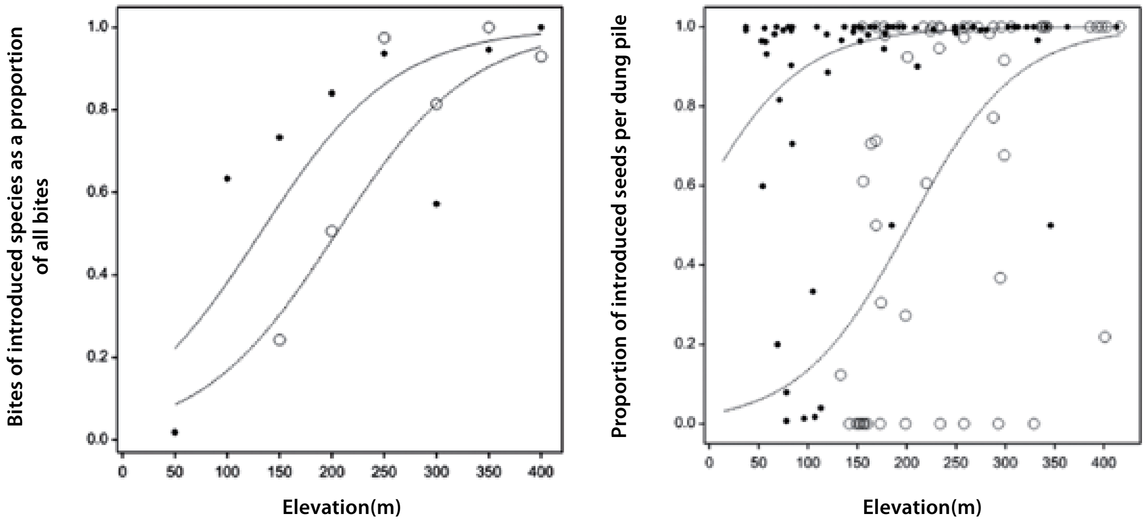

Figure 4. The effect of elevation on giant tortoise diets in terms of (a) the proportion of bites on invasive species and (b) the proportion of seeds of invasive fruit species in tortoise scat (open circles represent data from Cerro Fatal and closed circles from La Reserva).

contain species that were introduced specifically for their high nutritional value for livestock, such as the grass *Paspalum conjugatum*, and for human consumption, such as *Psidium guajava* and *Passiflora edulis*, the fruits of which are attractive to tortoises.

A serious problem facing Santa Cruz tortoises lies in maintaining access to and the quality of their critical seasonal habitats in the face of the increasing expansion of invasive species and infrastructure development. Two particularly aggressive introduced plant species, *Rubus niveus* (blackberry) and *Pennisetum purpureum* (elephant grass), grow in extensive, dense thickets in which they out-compete and eliminate tortoise food species, inhibit tortoise movements, and block migration routes.

In other cases, farmers construct dense fences of tightly spaced trees spanned by barbed wire to keep tortoises off their cattle pastures (Figure 5). Small fenced areas that protect vegetables and fruit may not be detrimental for tortoises, but if large areas of upland habitat are blocked by fences, the tortoises' ability to find food and maintain good body condition in their upland phase will be compromised. In 2011, a tortoise called Sebastian (Figure 5), who had migrated in the previous year, entered a fenced farm. Sebastian remained in the farm for most of the following year and did not migrate. Eventually Sebastian found a way out of the farm in time to migrate as he had previously. While we cannot be sure that Sebastian was unable to find his way out of the farm, there are very few gaps in the fence, and we surmise he was accidentally held captive by fencing.

Similarly, there is little doubt that the main road from Puerto Ayora to Baltra is a formidable barrier to tortoise movement (Figure 6a). By contrast, dirt tracks are used frequently by tortoises, though they often have barriers along much of their length, which prevent tortoises from moving off the road into surrounding vegetation (Figure 6b).

Conclusions and recommendations

Effective management of tortoises requires better knowledge of their seasonal distribution and abundance, the identification of migration corridors, a quantitative

Figure 5. An adult male tortoise called Sebastian, who was apparently trapped inside an upland farm for a year by nearly impregnable fencing and was thus unable to complete his seasonal migration to the lowlands.

Figure 6. Contrasting impacts of roads on tortoises: (a) the main road bisecting Santa Cruz is likely a formidable barrier for tortoises, (b) small tracks can be conduits for movement.

assessment of the geography and severity of current threats, and an analysis of likely future problems and opportunities. An important step forward on Santa Cruz would be a quantitative census and mapping exercise across the range of tortoises to: (a) provide accurate estimates of tortoise abundance, which are currently unavailable; (b) identify the seasonal distribution of tortoises by habitat type including natural versus farmed areas and proximity to infrastructure, and (c) map harmful invasive species and assess their effectiveness as barriers. In addition, tortoise researchers and managers should work with land use planning departments to determine likely development scenarios and their potential impacts on tortoises in order to plan mitigation measures.

Pending the results of such an assessment and more detailed analysis of tortoise movements on Santa Cruz, Alcedo, and Española currently underway, the following actions are recommended:

1. Removal and/or reduction of barriers to migration

Cattle farmers who attempt to protect their farms from tortoises should be encouraged to make their pasture lands available to tortoises, which have relied on such areas for millennia. This can be achieved by maintaining multiple openings within otherwise dense fences through which tortoises can pass, but which are too small to allow the passage of cattle.

No successful methods exist for the eradication of either blackberry or elephant grass, which represent two significant barriers to tortoise movement that are also catastrophic to native species. In lieu of effective eradication, pathways should be made through extensive thickets of these species in known tortoise migration areas.

2. **Mitigation of impacts due to roads.**

   We are unaware of current plans for road development in the Santa Cruz highlands, but as the economy continues to grow infrastructure development becomes more likely. Ideally, further road construction should be avoided due to the myriad negative ecological impacts (Trombulak & Frissell, 2000), not just on tortoise migrations. If road developments occur, planning should include mitigation measures for tortoises focusing on: (a) highland to lowland orientation; (b) ensuring that roadside vegetation is permeable to tortoises; (c) developing and enforcing strict rules on minimal urbanization in areas of tortoise use; (d) controlling traffic, and (e) considering the establishment of tortoise overpasses or underpasses at critical intersections where major roads cross tortoise migration routes.

3. **Maintenance of high quality habitat at both ends of the migration**

   Tortoises may be incompatible with production of low stature vegetable and fruit crops, given that failure to protect these crops in areas with large numbers of tortoises will lead to damage and economic losses. However, these crops tend to require small areas with high degrees of input for which fencing should not represent a major additional cost. Fruit and nut trees are compatible with tortoises as long as understory plants are maintained. Applied research is necessary to explore production options compatible with tortoise conservation, potentially involving a matrix of pasture and native/semi-native open woodland. Other crops such as coffee, the production of which is expanding rapidly on Santa Cruz, may require protection in the establishment phase, so careful consideration of how to protect large areas under cultivation without creating major barriers to tortoise movement is needed.

In summary, the tortoises of Santa Cruz are of enormous ecological, cultural, and socioeconomic benefit to Galapagos. The fact that tortoises migrate render them vulnerable to habitat modification at the landscape scale. Failure to maintain critical habitats and connectivity for migration could result in serious negative consequences for both tortoise populations on Santa Cruz. Careful land use planning, refinement of our recommendations through discussions among farmers, citizens, professionals, and scientists, and implementation in the short term of simple, effective ways to help tortoises continue to do what they have done for millennia, are solid, practical, and compassionate first steps.

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Photo: © Juan Carlos Ávila

Conserving the critically endangered mangrove finch: Head-starting to increase population size

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The critically endangered mangrove finch (*Camarhynchus heliobates*: BirdLife International, 2013) is one of the most range-restricted birds in the world (Dvorak *et al.*, 2004; Fessl *et al.*, 2010a,b). An estimated 80 individuals (F Cunninghame, pers. obs., 2013) consisting of fewer than 20 breeding pairs are found in 30 ha of mangrove forest at Playa Tortuga Negra (PTN) and Caleta Black (CB) on the northwestern coast of Isabela Island in the Galapagos Archipelago (Fessl *et al.*, 2010a,b). Past research has identified introduced black rats (*Rattus rattus*) and the introduced parasitic fly *Philornis downsi* as the main threats faced by the species (Fessl *et al.*, 2010a,b; Cunninghame *et al.*, 2011; Young *et al.*, 2013). Conservation management has included successful rat control and trial translocation in an attempt to increase the species' range (Fessl *et al.*, 2010a,b; Cunninghame *et al.*, 2011). While these measures produced encouraging results they have not significantly increased the population size or range of the mangrove finch (Young *et al.*, 2013). Parasitism by *P. downsi*, for which no control method yet exists to protect mangrove finches (Causton *et al.*, 2013), coupled with the tendency of translocated birds to return to the source population (Cunninghame *et al.*, 2011), required a more intensive approach to conservation management, using a method called head-starting.

Head-starting to increase population size

Head-starting applies artificial propagation techniques to enhance recruitment of juveniles into a wild population. This strategy has been used to augment populations of critically endangered birds throughout the world (e.g., Cristinacce *et al.*, 2008). The process involves collection of wild eggs or young, followed by artificial incubation and hand-rearing, ending with release of juveniles back into the wild. Certain birds will nest again if a clutch/brood is removed, thereby increasing fecundity, further enhancing ability of conservation programs to maximize juvenile recruitment (Colbourne *et al.*, 2005; Jones & Merton, 2012). To improve survival and establishment chances of reintroduced head-started individuals, the soft-release technique, where supplementary food is provided following their release, has been used internationally in several reintroduction programs of threatened species (Clarke & Schedvin, 1997; Armstrong *et al.*, 2002; Wanless *et al.*, 2002).

Mangrove finch field research has shown that nesting success early in the breeding season is exceptionally low (5% between December to mid-April in 2013) due to egg abandonment and parasitism of nestlings by *P. downsi* resulting in complete brood loss (Fessl *et al.*, 2010b; Cunninghame *et al.*, 2013; Young *et al.*, 2013). Late nests have higher success as evident in 2013 when 70% of nests fledged chicks from eggs laid after mid-April (F Cunninghame, pers obs). Upon nest failure, mangrove finches readily re-nest; females can lay up to five clutches with an average clutch size of 2.1 (Fessl *et al.*, 2010b).

The availability of eggs from early nests that have little chance of survival to fledging, combined with the likelihood of multiple nesting cycles, made head-starting a promising option as a conservation strategy for the mangrove finch. This would involve the collection of eggs from early clutches leaving wild pairs to rear their own young from later clutches that have higher anticipated levels of survivability. However, the head-starting approach had never been conducted on any bird species within Galapagos; furthermore there have been few attempts to artificially rear any species of Darwin´s finch (Good *et al.*, 2009) and none with the mangrove finch. Consequently, this first attempt was conducted as a trial, collecting from a small number (10) of nests to see whether it presented a viable management technique for increasing the population size.

Mangrove finch head-starting

Project planning, involving Mangrove Finch Project partners Charles Darwin Foundation (CDF), Galapagos National Park Directorate (GNPD), and San Diego Zoo Global (SDZG) as the lead organizations, began in September 2013. The remote location and limited infrastructure in northwestern Isabela meant that artificial incubation and hand-rearing would need to take place in Puerto Ayora, Santa Cruz. An insect-proof rearing room with airlocks and a double-door system was established at the Charles Darwin Research Station (CDRS) to prevent exposure to disease, principally mosquito-vectored avian pox virus that occurs in Puerto Ayora but which is not currently present at PTN. Pre-release aviaries were built and installed in the mangrove forest at PTN in December 2013, following strict quarantine procedures.

Nest collection

Mangrove finch nest collection at PTN occurred over four weeks beginning in late January 2014. Nesting behavior of wild pairs was monitored to identify when nests were suitable for collection. Tree climbers collected nests by hand, placed them in padded bags, and then lowered them by rope to team members on the ground. To avoid embryo damage or death due to cooling, the eggs were immediately placed into cotton wool cups inside a warm thermos. Two people relayed the thermos out of the forest to the camp where the eggs were transferred to a portable incubator (Figure 1). Some nests also contained chicks, which were transported in an open thermos and once in the portable incubator were fed with abdomen contents of moths every 60 minutes. Nest harvests took place on three separate occasions. Eggs and chicks were transported inside portable incubators by helicopter or onboard the GNPD's boat, the Guadalupe River, with the transfer to CDRS taking 8-16 hours. In total 10 nests from eight wild pairs were collected, including 21 eggs and three recently hatched chicks, and taken to the captive rearing facility.

Figure 1. Mangrove finch eggs in cotton wool in nest cups inside portable incubator at Playa Tortuga Negra ready for transfer to CDRS. Photo: © Beate Wedelin

Artificial incubation and hand-rearing

Upon arrival, eggs were installed in cradle incubators (Brinsea Octagon) at 37.8°C, with automated turning mechanisms with additional 180° hand-turns three times per day. Eggs were weighed daily and humidity altered accordingly to control appropriate water-loss from each egg over the incubation period. The eggs were candled daily to evaluate fertility and embryonic development. Of the 21 eggs collected, 19 were viable for incubation (90.5% viability). Seventeen of the eggs were fertile (89.5% fertility) and 15 hatched (88.2% hatchability), representing eight wild pairs (Figure 2).

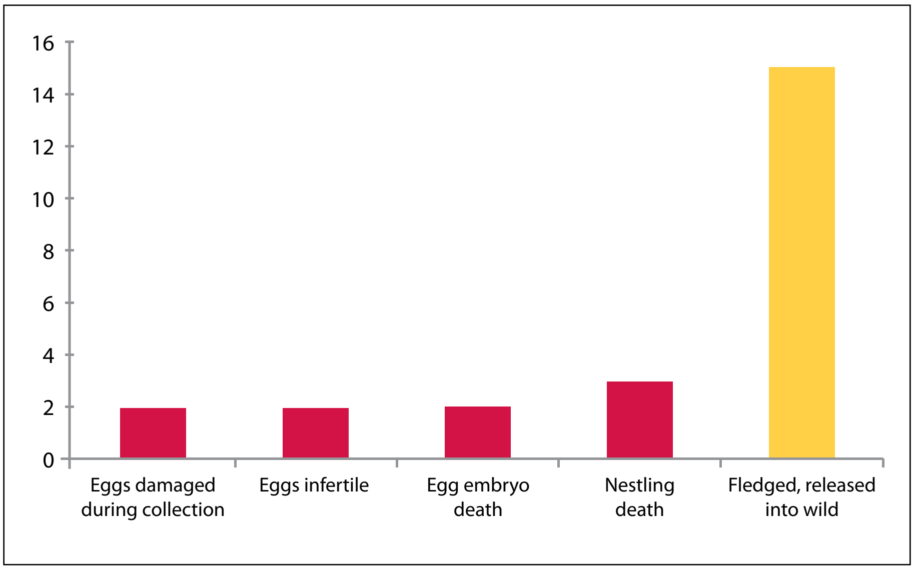

Figure 2. Outcome of 24 mangrove finches collected as eggs (21) or nestlings (3) for head-starting, 2 February – 6 May 2014.

The three wild-hatched chicks were all infested with *P. downsi* larvae in nasal and/or ear cavities. These were removed with a layer of Vaseline preventing larvae from breathing. One of these chicks arrived severely dehydrated and anemic due to parasites and died a few hours later. Two other chicks, which hatched from artificially-incubated eggs, died at six days old with symptoms suggesting omphallitis (yolk sack infections) (Figure 2).

Newly hatched chicks were kept in individual nest cups in brooders (initially modified Brinsea Octagons, then Lyon Animal Intensive Care Units). Prior to fledging, chicks were kept in communal nest cups to facilitate the development of correct species identity. Upon fledging (at 14-18 days), birds were transferred to wire cages, still inside the hand-rearing room under quarantine conditions (Figures 3a-3c).

Figure 3a. Mangrove finch nestlings inside Brinsea Octagon Incubator modified as a brooder (Photo: © Juan C Ávila). **3b.** Mangrove finch nestling in individual nest cup (Photo: © Juan C Ávila). **3c.** Mangrove finch fledglings inside holding cage inside quarantine captive rearing room prior to transfer to Playa Tortuga Negra (Photo: © Francesca Cunninghame).

Chicks were fed on a captive diet, appropriate for insectivorous passerines, according to protocols established by SDZG. For the first 14 days, chicks were fed hourly 15 times a day from 06h00 until 20h00. After 15 days, feeding was reduced to every two hours and after 19-20 days to every three hours. To encourage the fledglings to feed for themselves, dishes of prepared food were put in their cages once they reached 18-28 days old. A total of 15 chicks were successfully raised to independence (83.3% chick survivability) (Figure 2).

All birds were ringed with unique color combinations to enable identification, and blood samples were taken for sexing and genetic analysis.

Recordings of wild mangrove finch calls were played daily in the hand-rearing room to encourage the development of appropriate vocalizations. Quarantine regulations meant it was not possible to use natural substrates to encourage foraging, so cardboard tubes and shredded newspaper were offered. Once the fledglings had been feeding independently for at least seven days, they were transported back to PTN overnight in mosquito-proof boxes onboard the GNPD boat, the Guadalupe River, in two groups, seven on 13 March and eight on 28 March.

Pre-release aviary care at Playa Tortuga Negra

Soft-release principles were used. Fledglings were housed for four to six weeks in specially made aviaries (7.2 x 3.6 x 2.4 m) situated in a clearing within the mangrove forest at PTN (Figure 4). These aviaries enabled fledglings to adapt to their natural habitat before release to the wild. Natural foraging material (Fessl *et al.*, 2011) was placed throughout the aviaries. While prepared food dishes were provided twice daily, emphasis was placed on encouraging the birds to forage. Lepidopteran larvae found in fallen black mangrove (*Avicennia germinans*) seeds on the forest floor are an important food source at certain times of year for wild mangrove finches. These were collected along with adult moths and fed to the captive birds daily. Behavioral observations showed that individuals spent an average of 45% of their time foraging on natural substrates (P Medranda & A Carrión, pers. obs.). Wild mangrove finches approaching the aviaries interacted non-aggressively with captive fledglings; captive fledglings displayed interest only in mangrove finches.

Figure 4. Mangrove finch fledglings on a natural black mangrove perch inside the pre-release aviaries within the mangrove forest at Playa Tortuga Negra. Photo: © Paul Medranda

Post-release monitoring

The release of the15 fledglings was conducted to coincide with the end of the breeding season of wild mangrove finches to reduce intra-specific territorial aggression. Releases took place on 20 and 25 April and 6 May. The aviaries were left open, and food and water provided twice daily inside the aviaries until 10 May. Four days prior to closing the aviaries, fresh food was replenished just once a day. The aviaries were closed on the evening of 14 May, two days before the field team left the site.

Birds were fitted with 0.35-g radio transmitters (Holohil, Canada) two days prior to release (Figure 5). Upon opening, aviaries were observed daily from 06h00 until 18h00 to monitor supplementary feeding visits of each bird. All but two birds returned regularly to feed.

Figure 5a. VHF transmitter (0.35 g) mounted on the underside of the tail on a head-started mangrove finch fledgling prior to release. Photo: © Paul Medranda. **5b.** Released head-started mangrove finch with VHF transmitter antennae showing. Photo: © Francesca Cunninghame

Additional survival and dispersal results were gathered through telemetry monitoring. Birds were radio-tracked for a maximum of 19 days following release, as determined by transmitter battery life. However, 11 transmitters stopped functioning prematurely due to becoming unattached or technical problems. While released fledglings were found predominantly within mangroves at PTN, five were also located outside of the forest, up to 3 km away. The monitored birds were observed foraging for invertebrates on six tree and shrub species, and feeding on the fruits of *Bursera graveolens* and *Castela galapageia*. Two individuals regularly spent the early morning feeding on *B. graveolens* fruits in the arid zone, alone or with wild birds. This is the first record of mangrove finches in arid zone vegetation. Captive-reared fledglings were seen following unrelated wild adult males with fledglings, a behavior that has been observed with wild fledglings.

Two individuals never returned for supplementary feeding. One was found in a small patch of mangrove forest 1 km to the north of PTN where it was observed foraging each day. The other was not located and its transmitter was found 14 days later, 2 km south in arid zone vegetation. On 15 May, the last day the field-team conducted monitoring, the whereabouts of only eight fledglings were known suggesting that seven were no longer in the vicinity of PTN, or their transmitters had ceased working. No mortalities were confirmed.

Fledging success in the wild population

From 18 nests not collected for head-starting that were monitored at PTN (16) and CB (2), 27.7% were successful, with only five pairs of wild mangrove finches rearing a total of six fledglings (Table 1, Figure 6). Nests failed due

Table 1. Comparative number of nestlings fledged and nesting success of head-started and wild mangrove finch nests during the 2014 breeding season (25 January – 6 May 2014). Total is number of confirmed eggs or nestlings found in early stage of development. Wild total is lower than actual due to failed nests with unknown contents not being included. Consequently, actual fledging success and nesting success for wild nests is almost certainly lower than indicated.

	Total eggs or nestlings	Total chicks fledged	% Fledging success*	Total nests	Nests fledged^	% Nesting success
Head-started	24	15	62.5	10	9	90
Wild	28	6	21.4	18	5	27.8

* Incorporates assessments of fertility, hatchability, and chick survivability, since this data is not available for the wild nests.
^ Nests that fledged at least one young.

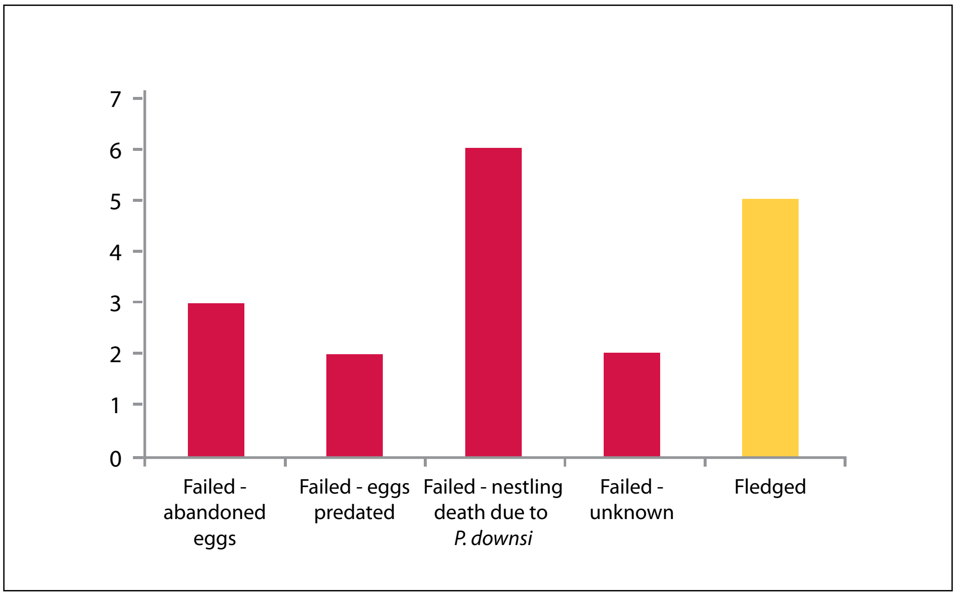

Figure 6. Outcome of 18 wild mangrove finch nests at Playa Tortuga Negra and Caleta Black 25 January – 03 April 2014. Nests with at least one chick fledged are represented as fledged; only those nests where the entire brood was lost to *P. downsi* parasitism are represented in the "Failed – nestling death due to *P. downsi*" column.

Figure 7. Released head-started mangrove fledgling foraging in mangrove forest at Playa Tortuga Negra. Photo: © Francesca Cunninghame

to: death of nestlings from *P. downsi* parasitism (33.3%), egg abandonment (16.7%), egg predation (11.1%), and undetermined causes (11.1%) (Figure 6).

Conclusion and recommendations

The collection, artificial incubation, hand-rearing, and release of 15 fledgling mangrove finches back into their native habitat represent an important step for the conservation of this Critically Endangered species (Figure 7).

At least one fledgling was successfully reared from nine of the 10 nests collected (35.7% total season's nests). Based on the assumption that nests collected for head-starting were destined to fail, head-starting increased both nesting success and the number of chicks fledged by over 200% in one season. Given that this first year was a trial, the number of head-started fledglings produced was low. However, there is potential to further increase fledgling productivity through the collection of more nests. Project planning is underway to determine the best use of head-starting in conjunction with continued management to control threats in the wild and to meet the long-term goals of mangrove finch conservation to increase population size and range of the species.

Continual conservation management is needed for several years to improve the status of the mangrove finch due to its extremely small population size and restricted range. Head-starting, with complementary wild population management, will be needed and the following recommendations should be considered.

- Evaluate this year´s progress in consultation with stakeholders to improve efficiencies and develop a plan for intensive species management over the next five years.

- Use head-starting for a minimum of three to four years to increase population size.
- Use genetic data and studbook-keeping when harvesting eggs to ensure maintenance of genetic variation in the population.
- Use captive-reared fledglings to repopulate other mangrove forests within historic range of the species.

- Continue introduced rat control and increase cat control in all areas inhabited by mangrove finches.

- Carry out trial of rat-specific, multi-kill canister traps (GoodNature NZ) at PTN with the goal of replacing bait stations (and brodifacoum) with non-toxic control.

- Trial methods of *P. downsi* control in wild nests in collaboration with the *Philornis* Project (CDF).

- Continue to build capacity within local institutions and in the local community through training GNPD personnel, local and mainland Ecuadorian staff, students, and volunteers in captive rearing and field techniques (tree climbing, bird monitoring, and telemetry).

- Continue with activities that raise awareness of the mangrove finch within the local community at Puerto Villamil on Isabela.

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Chronic lack of breeding by Galapagos blue-footed boobies and associated population decline

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Introduction

The abundance of seabirds across the vast Pacific Ocean basin is thought to have declined by at least 99% over the past 3000 years, coincident with the spread of Polynesian humans (Steadman, 2006). Human settlements on islands lead to habitat loss, hunting, and indirect effects of predatory and other invasive animals accompanying humans (Szabo *et al.*, 2012), and these effects are thought to explain the local extinction of most seabird species on colonized islands (Steadman, 2006). The seabird populations of the Galapagos Islands, in the far east of the basin and distant from source populations of Polynesians, depart from this pattern. Paleontological data give no evidence of permanent human habitation before approximately 200 years ago (Latorre, 1997), and also no evidence of local extinction of seabird species (Steadman, 1986; Jiménez-Uzcátegui *et al.*, 2006). However, some species show clear evidence of recent anthropogenic effects that reduced population size (Vargas *et al.*, 2005; Jiménez-Uzcátegui *et al.*, 2006; Anderson *et al.*, 2008), while other species are too poorly studied to allow similar evaluations. Evaluation of possible anthropogenic effects on observed population declines must be a conservation priority.

Blue-footed boobies (*Sula nebouxii*) breed on Galapagos and on islands and headlands on the west coast of South and Central America, and Mexico. The demography and population biology of the Galapagos subspecies (*S. n. excisa*) is poorly known. However, serial data from two former breeding sites in Galapagos (Daphne Major and Punta Cevallos [Española]) indicate that an abrupt change in breeding activity occurred in approximately 1997, from irregular but frequent breeding to essentially none (Figure 1). This pattern is consistent with anecdotal observations in recent years of long-term scientists and tour guides that adult birds are seen less frequently and breeding sites are seldom occupied (DJ Anderson, unpub. data). If chronically poor breeding affects the entire subspecies, then it should be reflected in a reduced population size. Population size has been estimated only once, by Nelson in the 1960s. He concluded that "the total Galapagos population must exceed 10,000 pairs and could be substantially more" (Nelson, 1978).

The goals of this study were: 1) evaluate if the poor breeding observed since 1997 at two colonies is archipelago-wide; 2) determine the cause, and 3) estimate

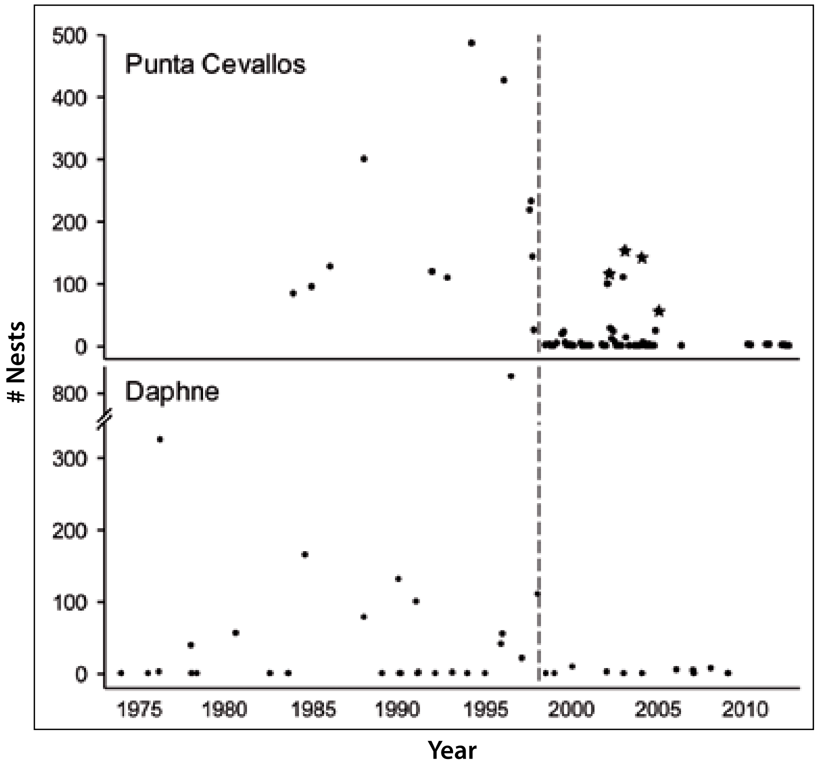

Figure 1. Numbers of active nests of blue-footed boobies at Punta Cevallos, Española (D. J. Anderson, unpub. data) and Daphne Major (P. R. Grant and B. R. Grant, unpub. data). Vertical line indicates March 1, 1997, middle of the 1997-98 ENSO event, and roughly the timing of declining sardine abundance in the Peruvian upwelling. Stars indicate the peak of a rapid increase in number of nests followed by a mass breeding failure in the subsequent 4 weeks.

the current size of the Galapagos blue-footed booby population. This paper presents the principal results of the study; for complete details, see Anchundia *et al.* (2014).

Methods

From May 2011 to June 2013, we monitored breeding at three- to five-month intervals at four of the six historically largest breeding colonies of blue-footed boobies (Daphne Major, Cabo Douglas [Fernandina], Punta Vicente Roca [Isabela], and North Seymour), and one additional recently established colony (Playa de los Perros [Santa Cruz]). A sixth regularly large and active colony, Punta Suárez (Española), and two others (Punta Pitt [San Cristobal] and Punta Cormorant [Floreana]; Figure 2) were visited less frequently (three or four times each) than were focal colonies. A seventh historically large colony, at Punta Cevallos (Española), was known to be essentially unattended through our group's other research activities there. An additional, apparently newly established, non-focal colony on Baltra was discovered in 2012 and thereafter was included as a non-focal colony. Diet was documented from regurgitation samples during visits to breeding colonies.

To estimate population size we made two surveys of the entire coastline of the islands south of the equator, including all of Isabela (1100 km of coastline of 14 islands and 20 islets), which encompasses virtually all of the historical (Nelson, 1978; Harris, 1982) and current (DJ Anderson, pers. obs.) breeding activity of the species. In the first survey, we made daytime counts in piecemeal fashion, covering the entire survey range in a boat at 1 m/s between June 3 and August 7, 2011, with a single observer using a binocular 20-100 m from the coast. In the second survey, 1-3 June 2012, five separate pairs of observers used a dependent double observer protocol (Nichols *et al.*, 2000). Over the three-day period the entire survey range was covered, one observer pair per each section of coastline.

Results

Breeding

Breeding activity was consistently low. All monitored colonies contained <15% of the historical maximum of breeding pairs on most visits. Summing across all monitored sites, the largest number of simultaneous nests observed (349) represents 698 breeding birds, only 10.9% of the population size estimate of 6423 adults (see below). Three previously unknown breeding sites were identified during the study: on Baltra with approximately 49 nesting pairs in 2012 and 94 nesting pairs in 2013; on the south coast of Fernandina west of Punta Mangle, with approximately 75 adults present and an unknown number of nests; and on the south coast of Isabela (Los Tuneles) with nine nesting pairs in 2013. The formerly large colony at Punta Cevallos (489 nests in 1994; Townsend *et al.*, 2002) was not monitored as part of this study, but was checked frequently as part of our ongoing research there; we never observed more than three nests there during this study.

Most clutches failed without producing a nestling. On visits after one in which nests with eggs were recorded, few or no nestlings or fledglings (either living or dead) were found, although incubating adults were sometimes present. In the focal colonies in 2011, a total of 26 fledglings were observed; in 2012, 59 offspring fledged. December and January were the only months in the three-year study in which we observed large nestlings and fledglings, with the exception of the newly established Baltra colony, in which 24 fledglings were present in August 2012.

Population size

In the 2011 coastal survey, 7379 blue-footed boobies were counted, of which two (0.03% of the total) were in juvenile plumage. That survey was conducted over an 11 week period by a single observer, with significant potential for missing or double-counting individuals. In the 2012 coastal survey, detection probabilities were high but varied by island and stretch of coastline. Model selection analysis yielded an estimate of 6423 birds (95% confidence interval = 6420-6431) for the population size of the entire Archipelago. These estimates apply to the portion of the population visible during daylight from boats within 100 m of the coast, and exclude birds away from the coast. Four lines of evidence indicate that few birds were outside the visual range of observers on the survey boats: 1) birds with GPS tags spent most of their foraging time within 200 m of an island's coast, well within visual range; 2) during boat travel between islands during the 2012 survey blue-footed boobies were sighted at a rate of only 2 birds/30 min compared to an average of 48 birds/30 min on the coast; 3) ~85% of birds sighted during the 2012 survey were resting on land and not on the move; and 4) >90% of the birds seen flying during the 2012 survey were moving parallel to the coast, rather than to or from the open ocean.

Diet

Sardines and herrings (Family Clupeidae) were the most common item in the samples, representing 80.2% of all items and 50.4% of the total weight. The fork length of the fish ranged from 3-35 cm, with a mean of 6.8 cm (SD = 3.2).

The blue-footed booby colonies visited fell into three clusters based on oceanographic habitat: the western colonies of Fernandina and Punta Vicente Roca, adjacent to the productive upwelling of the Equatorial Countercurrent with much lower sea surface temperature (SST) than elsewhere in the archipelago (Ruiz & Wolf, 2011); the central colonies of Daphne Major, North Seymour, Baltra, and Santa Cruz, adjacent to a complex merging of currents and a mosaic of SST and productivity (Witman *et al.*, 2010); and the southeastern colonies on San Cristóbal, Española, and Floreana, with less complex and less productive marine habitat. The diet composition in these regions varied, with sardines/herrings much more common and occurring more regularly in the central cluster, particularly in 2012. Sardines and herrings were 68% of the prey items in the central colonies, but 28 and 29% of those in the western and southeastern colonies, respectively.

Predicting breeding attempts

Model selection analysis indicated that breeding activity by blue-footed boobies varied by month (breeding was rare in December) and by the probability of regurgitating during diet sampling (breeding attempts were associated with more birds having food during diet sampling). Variation between years was unimportant in our modelling.

Discussion

Our results indicate that Galapagos blue-footed boobies attempted to breed very little between August 2011 and June 2013. During this period no more than 10.9% of the adult population had an active nest at any one time, and only 134 fledglings were noted. During two comprehensive coastal surveys we recorded only 77 birds in juvenile plumage (maintained until age 2-3 years; Nelson, 1978) compared to an adult population estimated as 6423 birds. We sighted only two juveniles across the Archipelago between May and August 2011, indicating that essentially no successful breeding occurred in the previous two years. We discount the possibility of temporary emigration of juveniles, based on the distribution of juveniles at sea (Anchundia *et al.*, 2014) and the abundance of juveniles in both coastal areas and between islands before 1998 (DJ Anderson, pers. obs.). The simplest interpretation of these results is chronic poor breeding from 2009 to 2012. Noting the similar situation on Española and Daphne since 1997, this chronic breeding failure may span a total of 16 years. A comparison of the 1960s estimate with our new estimate indicates a trend of a population decline, with the current population approximately 33% of Nelson's (1978) estimate for the 1960s. Acknowledging significant uncertainty in the actual values, especially for the 1960s estimate, we conclude that the population has declined in size by at least 50% since the 1960s, and probably by more than 50%.

Poor breeding has contributed to the fall in blue-footed booby population size during our study, and data from Daphne and Española suggest that breeding has been poor and that adult deaths have exceeded recruitment after birth since 1997. A simple model of population shrinkage is broadly in agreement. Assuming constant annual adult mortality of 0.10 (Oro *et al.*, 2010), an initial adult population size of 20,000, and a continuous series of years ending in 2012 with no successful breeding, the hypothetical chronic breeding failure would have begun in 2001, 11 years earlier (20,000 * 0.9011 = 6276); a larger starting population (as Nelson (1978) alluded to) would bring this date even closer to 1997, when we suggest that the breeding failure began. Since 1997 the formerly large and regularly active blue-footed booby colony at Punta Cevallos has been virtually vacant, and on Daphne Major few adults are found only in a small part of the main crater, while in the past both the main and side craters sometimes held up to 1600 blue-footed boobies. Now vegetation covers much of the past breeding site. Neither island has an introduced predator, and no evidence of disease has been noted among breeders or non-breeders at either site. Although these two colonies are in separate oceanographic habitat regions of the Archipelago, they exhibit similar breeding histories, suggesting the possibility that poor breeding has been archipelago-wide since 1997, in spite of spatial habitat variation. If so, then the age structure of the current population must be strongly biased toward elderly individuals; if the death rate of blue-footed boobies increases with age, as in Nazca boobies (Anderson & Apanius, 2003), and their reproduction declines as they age (Velando *et al.*, 2006), then the birth and death processes leading to smaller population size can be expected to accelerate in the future.

Two lines of evidence implicate diet in the low rate of birth. Considering long-term data from Punta Cevallos, blue-footed boobies foraged mostly on sardines, similar to Nazca boobies (Anderson, 1989). After 1997, sardines disappeared from the Nazca booby diet, but Nazca boobies continued breeding by switching to other prey (Anderson *et al.*, unpub. data). In contrast, blue-footed boobies abandoned this colony. Data from Galapagos sea lions (*Zalophus wollebaeki*) also suggest that sardines have become less available throughout the Archipelago; sea lions foraged mostly on sardines during the 1980s (Dellinger & Trillmich, 1999), but more recently (2008-09), sardines were completely absent from their diet (Páez-Rosas & Aurioles-Gamboa, 2010).

Diet samples from blue-footed boobies, taken during our study, suggest that the central archipelago currently has a more regular availability of sardines and their close relatives Galapagos herrings than the other regions; relatively more current breeding attempts have been observed within this region. This suggests that declines in both initiation and success of breeding may be tied to sardine/herring availability (Anchundia *et al.*, 2014).

In conclusion, our data indicate chronic poor breeding and a decline in population size of Galapagos blue-footed boobies, with circumstantial evidence implicating low availability of preferred prey since approximately 1997. Since 1997 the food base has been sufficient for adults to exist but not to reproduce.

If breeding has been poor since the late 1990s, as we suspect, the age structure of Galapagos blue-footed boobies is probably biased strongly toward older individuals. Reduced survival and reproduction with aging in blue-footed boobies (Velando *et al.*, 2006; Torres *et al.*, 2011) can be expected to accelerate this iconic and genetically distinct population's decline via poor breeding ability and lower annual survival associated with old age, with important implications for biodiversity and local ecotourism.

Recommendations

Based on the findings of this study, we recommend the following:

1. Continue the archipelago-wide counts, using the same methods (Anchundia *et al.*, 2014), no less frequently than every two years. The population size has probably declined to ~30% of its size in the 1970s and documenting the continuing population trend is critical.

2. Formal studies of the population biology of clupeid fish in Galapagos are urgently needed, including any potential anthropogenic effects. These fish, especially the sardine *Sardinops sagax*, are important elements of the diet of blue-footed and Nazca boobies, sea lions, and possibly other predators in Galapagos. Our results indicate that clupeids have declined dramatically in availability since 1997, possibly from natural causes (Anchundia *et al.*, 2014).

3. Continue carrying out surveys at the 10 breeding colonies, for as long as breeding continues to be poor. We visited each colony four times per year. These visits of only several hours each provide critical information about a principal population process that influences population size, and provide the opportunity to leg-band nestlings to estimate juvenile survival. During the two years, very little successful breeding occurred, and probably has not occurred for many years, which probably accounts for the decline in population size.

4. Conduct a formal study of health, and especially of disease, in blue-footed boobies. We did not evaluate formally the possibility that diseases contribute to the population decline except by casual observations.

5. Estimate annual adult survival in the blue-footed booby population. Logistical considerations limited our ability to estimate annual adult survival: adults simply did not attend the colonies frequently enough to use appropriate mark-resight methods. With significant effort, this parameter could be estimated even under the current attendance regime, using

small radio-transmitters on adults and detection from aircraft (either Galapagos National Park patrol plane or UAVs).

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