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A collaboratively derived environmental research agenda for Galápagos

Arturo Izurieta[A], Byron Delgado[A], Nicolas Moity[A], Monica Calvopiña[B], Iván Cedeño[B], Gonzalo Banda-Cruz[A], Eliecer Cruz[B], Milton Aguas[C], Francisco Arroba[D], Iván Astudillo[E], Diana Bazurto[F], Mónica Soria[B], Stuart Banks[G], Steve Bayas[H], Simone Belli[I], Rafael Bermúdez[J], Nicolai Boelling[A], Jimmy Bolaños[B], Mercy Borbor[J], Ma. Lorena Brito[D], Leopoldo Bucheli[H], Karl Campbell[K], David Carranza[D], Jorge Carrión[L], Maria Casafont[M], Xavier Castro[N], Sandra Chamorro[M], Juan Chávez[B], David Chicaiza[O], René Chumbi[P], Paulina Couenberg[Q], David Cousseau[R], Marilyn Cruz[S], Noemí d'Ozouville[A], Cristina de la Guía[T], Giorgio de la Torre[U], Carla Molina Díaz[D], Jessica Duchicela[T], Daniel Endara[H], Vanessa Garcia[B], Cynthia Gellibert[B], James Gibbs[V], Juan Carlos Guzmán[Q], Pippa Heylings[W], Andrés Iglesias[D], Juan Carlos Izurieta[R], Patricia Jaramillo[A], Asleigh Klingman[B], Andrew Laurie[X], Patricia Leon[B], Jaime Medina[E], Edison Mendieta[H], Godfrey Merlen[Y], Carla Montalvo[D], Edwin Naula[B], Diego Páez-Rosas[Z], Manuel Peralta[O], Marcos Peralvo[C], Mario Piu[AA], José Poma[Q], José Pontón[D], Mireya Pozo[J], Daniel Proaño[AA], Mónica Ramos[L], Ana Rousseaud[B], Danny Rueda[L], Pelayo Salinas[A], Gloria Salmoral[AA], Silvia Saraguro[C], Débora Simón-Baile[T], Washington Tapia[V], Byron Teran[AC], Marilú Valverde[AD], Andrea Vargas[B], Josué Vega[D], Wilson Velásquez[C], Alberto Vélez[S], Santiago Verdesoto[D], Hernán G. Villarraga[AB], Fernando Vissioli[T], Cesar Viteri-Mejía[G], Lucía Norris-Crespo[AE], Sophia C. Cooke[AE], M. Veronica Toral-Granda[AF,AG] and William J. Sutherland[AE]

[A]Charles Darwin Foundation (CDF), Puerto Ayora, Santa Cruz, Galápagos, Ecuador.
[B]Consejo de Gobierno del Regimen Especial de Galápagos (CGREG), San Cristóbal, Av. 12 de Febrero, Via Progreso (Cerro Patricio), Galápagos, Ecuador.
[C]Civil Society, Puerto Baquerizo Moreno, San Cristóbal, Galápagos, Ecuador.
[D]Secretaria Nacional de Planificación y Desarrollo (SENPLADES), Juan León Mera Nro. 19-36 y Av. Patria, Quito, Ecuador.
[E]Secretaría de Educación Superior, Ciencia, Tecnología e Innovación (SENESCYT), Whymper E7-37 y Alpallana, Quito, Ecuador.
[F]Ministerio Coordinador de Conocimiento y Talento Humano (MCCTH), Av. Patria S/N y Av.10 de Agosto, Quito, Ecuador.
[G]Conservation International, Catalina Aldaz N34-181 and Portugal, Titanium II Building, Fourth Floor of 402, Quito, Ecuador.
[H]Gobierno Municipal de Santa Cruz (GADMSX), Av. Charles Darwin y 12 de Febrero, Puerto Ayora, Santa Cruz, Galápagos, Ecuador.
[I]Universidad Yachay Tech, San Miguel de Urcuquí, Hacienda San José s/n.
[J]Escuela Politécnica del Litoral (ESPOL), Campus Gustavo Galindo, Guayaquil, Ecuador.
[K]Island Conservation, 2100 Delaware Avenue, Suite 1, Santa Cruz, CA 95060, USA.
[L]Ministerio del Ambiente del Ecuador (MAE), Calle Madrid 1159 y Andalucía Código Postal: 170525, Quito, Ecuador.
[M]WWF, Calle Piqueros S/N y 18 de Febrero, Puerto Ayora, Galápagos, Ecuador.
[N]Secretaría Nacional de Comunicación (SECOM), San Salvador E6-49 y Eloy Alfaro Código Postal: 170518, Quito, Ecuador.
[O]Instituto Ecuatoriano de Pesca (INP), Letamendi 102 y La Ría, Guayaquil, Ecuador.

[P]Ministerio de Electricidad y Energía Renovable (MEER), José Tamayo E-1025 y Lizardo García (Esquina), Quito, Ecuador.
[Q]Ministerio de Agricultura, Ganadería, Acuacultura y Pesca (MAGAP), Av. Amazonas y Av. Eloy Alfaro Código Postal: 170516, Quito, Ecuador.
[R]Ministerio de Turismo del Ecuador (MINTUR), Av. Gran Colombia N11-165 y Gral. Pedro Briceño Edificio 'La Licuadora', Quito, Ecuador.
[S]Agencia de Regulación y Control de la Bioseguridad y Cuarentena para Galápagos (ABG), Av. Baltra, Puerto Ayora, Galápagos, Ecuador.
[T]Universidad de las Fuerzas Armadas (ESPE), Sangolquí, 171-5-231B Pichincha, Ecuador.
[U]Instituto Oceanográfico de la Armada (INOCAR), Av. 25 de Julio Vía Puerto Marítimo, Base Naval Sur, Guayaquil, Ecuador.
[V]Galapagos Conservancy, 11150 Fairfax Blvd, Suite 408, Fairfax, VA 22030, USA.
[W]Talking Transformation Ltd 13, Burrough Field, Impington, Cambridge, CB24 9NW, UK.
[X]Amblyrhynchus, 64 Richmond Road, Cambridge, CB4 3PT, UK.
[Y]Sea Shepherd, Av. Charles Darwin s/n and Piqueros, Apartment 2[a], Puerto Ayora, Galápagos, Ecuador.
[Z]Universidad San Francisco de Quito (USFQ), Galapagos Science Center, Av. Alsacio Northía, Isla San Cristóbal, Galápagos, Ecuador.
[AA]Universidad Regional Amazónica (IKIAM), Kilómetro 7 Vía Muyuna, Napo, Ecuador.
[AB]Instituto de Altos Estudios Nacionales (IAEN), Av. Amazonas N37-271 y Villalengua, Quito, Ecuador.
[AC]Estación de Investigaciones Marinas y Ayudas a la Navegación de Galápagos – Instituto Oceanográfico de la Armada (EIMAGA-INOCAR).
[AD]Instituto Nacional de Investigaciones Agropecuarias de Ecuador (INIAP), Av. Eloy Alfaro N30-350 y Amazonas, Quito, Ecuador.
[AE]Department of Zoology, University of Cambridge, The David Attenborough Building, Cambridge, CB2 3QZ, UK.
[AF]Research Institute for the Environment and Livelihoods, Charles Darwin University, Casuarina, NT 0909, Australia.
[AG]Corresponding author. Email: veronica.toral-granda@cdu.edu.au

Abstract. Galápagos is one of the most pristine archipelagos in the world and its conservation relies upon research and sensible management. In recent decades both the interest in, and the needs of, the islands have increased, yet the funds and capacity for necessary research have remained limited. It has become, therefore, increasingly important to identify areas of priority research to assist decision-making in Galápagos conservation.This study identified 50 questions considered priorities for future research and management. The exercise involved the collaboration of policy makers, practitioners and researchers from more than 30 different organisations. Initially, 360 people were consulted to generate 781 questions. An established process of preworkshop voting and three rounds to reduce and reword the questions, followed by a two-day workshop, was used to produce the final 50 questions. The most common issues raised by this list of questions were human population growth, climate change and the impact of invasive alien species. These results have already been used by a range of organisations and politicians and are expected to provide the basis for future research on the islands so that its sustainability may be enhanced.

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Introduction

Galápagos, a province of Ecuador, is one of the most iconic sites for biodiversity and conservation globally. The islands were colonised by humans only relatively recently, allowing Galápagos to remain one of the most pristine oceanic archipelagos in the world (González *et al.* 2008). It is situated ~1000 km off the coast of mainland Ecuador and this geographic isolation has allowed the evolution of a large number of endemic species – 100% of terrestrial reptiles, 32% of vascular plants, 71% of coral fans, 40% of cup corals and over 50% of invertebrates are found nowhere else in the world (Tye *et al.* 2002). In addition, the archipelago's location at a confluence of southerly cold, nutrient-rich currents and warm, northerly currents, combined with strong, persistent, equatorial upwelling has given rise to a wide range of marine species with a very high level of endemism (Edgar *et al.* 2010).

Galápagos was one of the first sites on UNESCO's World Heritage List (listed in 1978) and has been identified as one of the 137 'most irreplaceable protected areas' in the world (Le Saout *et al.* 2013), as well as a 'flagship' area for conservation (González *et al.* 2008) and a Priority Ecoregion for Global Conservation (Olson and Dinerstein 2002). The uniqueness of the islands led the Ecuadorian Government to create the Galápagos National Park in 1959. The marine resources were granted protection by law in 1986, and in 1998 the Galápagos Marine Reserve was created with an overall area of 138 000 km^2, one-third of which was designated as a no-take sanctuary zone in 2016. Approximately 97% of the total land area is national park and, overall, only 0.03% of the entire archipelago is open for human activities (DPNG 2014).

Galápagos has played a key role in biological sciences since Charles Darwin visited in 1835 (Valle 2013). Darwin's observations led to the development of his theory of evolution by natural selection and drew the world's attention to this then largely unheard-of group of islands. Over the next century, many explorers and leading scientists from Europe and North America visited Galápagos for research, which included mapping the archipelago and collecting specimens (Quiroga 2009).

The Charles Darwin Research Station opened in 1964 (Corley Smith 1990) and supported numerous scientists undertaking research in Galápagos, making the archipelago one of 'most studied places on earth' (Valle 2013). Santander *et al.* (2009) noted that research had been largely in the biophysical sciences with particular focus on certain taxa, especially birds and reptiles, while Watkins (2008) recommended more social science research to provide the information required to manage the impacts of human activities. Overall, research in Galápagos has traditionally been guided by either issues of urgency or the interest of donors, funding agencies and research institutions.

The current Galápagos Protected Areas Management Plan (DPNG 2014) states the importance of considering the needs of humans alongside those of wild species and the integrity of ecological processes in policy formulation. As with many other island systems, Galápagos faces many serious environmental challenges including invasive species (Causton *et al.* 2006; Trueman *et al.* 2010; Toral-Granda *et al.* 2017), managing El Niño–Southern Oscillation variability and long-term climate change, tourism (Viteri-Mejía and Brandt 2015), overfishing (Hearn 2008; Toral-Granda 2008), and land-use changes (Trueman *et al.* 2014).

In 2007, Galápagos was included in the List of World Heritage in Danger. Poor governance (leading to inadequate regional planning), unsustainable tourism development, overfishing and unregulated sport fishing were cited as contributing factors. In 2010, a follow-up inspection mission reported that the Government of Ecuador had taken important steps towards addressing these issues. The islands were taken off the List of World Heritage in Danger, noting that continued efforts were required to address ongoing threats to the integrity of the islands.

Research is a vital tool for adequate decision-making for the conservation of Galápagos, yet limited capacity and funds, combined with political compromise mean that not all desired research can be undertaken in the immediate future. Prioritisation of research areas and questions is important therefore, in order for resources to be used most efficiently. This participatory research identifies the priority questions which, if answered, will have the greatest benefit on the conservation of species and ecosystems of Galápagos and the sustainability of its human livelihoods.

Methods

This project was initiated by the Government Council for the Galápagos Special Regime with the aim of identifying the priority research questions for the islands, as stated in the Special Law enacted in 2015. It was undertaken in collaboration with the Ministerio Coordinador del Conocimiento y Talento Humano (Ministry for Coordination of Knowledge and Human Talent) and the Secretaría de Educación Superior, Ciencia, Tecnología e Innovación (Ecuadorian National Secretary of Higher Education, Science, Technology and Innovation) along with other government entities, universities and non-government organisations. Technical advice and support was provided by the Charles Darwin Foundation for the Galápagos Islands.

To identify the research questions we used the Priority Setting Exercise method established by Sutherland *et al.* (2006), described in Sutherland *et al.* (2011) and modified by Sutherland *et al.* (2013). This brought together a working group of participants in a transparent, collaborative and democratic manner, to reduce an initial, long and unfiltered list of candidate questions through a multistage participatory process to a final, short and democratically agreed list.

A broad range of institutions with interest and experience in the Galápagos environment were identified and asked to participate. Invitations were also sent to key individuals, including community leaders, government employees and both national and international researchers with relevant experience concerning Galápagos.

All participants were invited to submit research questions that could be answered through the following criteria:

- able to be answered through a realistic research design,
- able to be answered factually rather than through individual judgment,
- able to be answered within a realistic time.

In total, 781 initial questions were received from 360 participants. Those that did not meet the established criteria were eliminated, along with duplicates and those that had already been answered by previous research. The remaining 415 questions were grouped into nine themes and returned to the participants. Each person was given 100 votes to distribute among the 415 questions (or fewer if only reviewing some themes) and asked to assess the priority of each question in the themes of which they had sufficient knowledge. The questions in each theme were then ranked using the number of votes and reclassified under 12 thematic groups (Fig. 1).

Sixty-five people, selected for their expertise and ability to be representative of the main organisations and their interests, were then selected to attend a two-day workshop. This workshop was held in Galápagos and run by Sutherland and Heylings, with the aim of identifying the 50 highest-priority research questions. The whole process, including the wording of questions, was in Spanish, and the results were translated into English. All attendees are included on the author list of this paper. Each session of

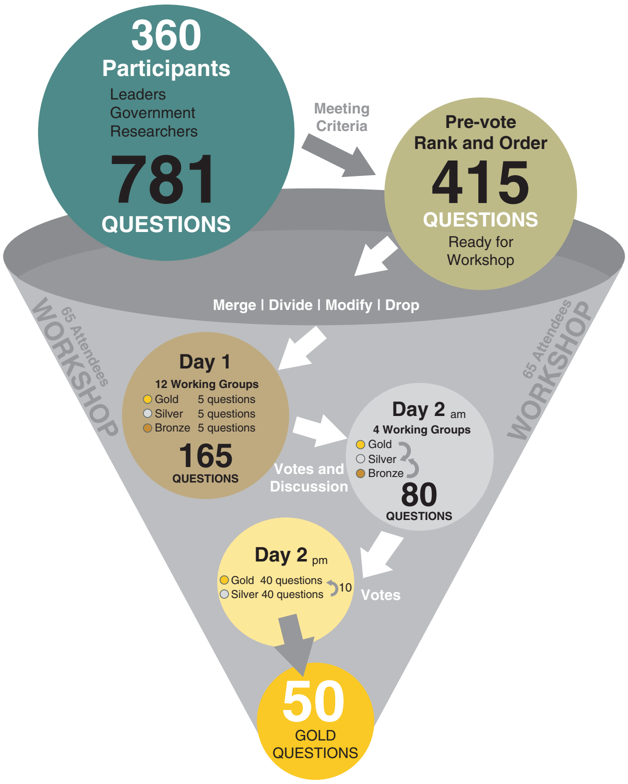

Fig. 1. Schematic representation of the Priority Setting Exercise method established by Sutherland *et al.* (2006), described in Sutherland *et al.* (2011) and modified by Sutherland *et al.* (2013) followed for the generation of the research questions and the prioritisation process to obtain the 50 priority environmental research questions for Galápagos.

the workshop was facilitated by a conservation scientist with experience in Galápagos and an assistant. Each attendee was given a printout of the questions under discussion during that session. The questions were also collated and projected onto a screen so that participants could always see the latest version.

The first day of the workshop started with a description and discussion of the process, followed by three sessions, each with four parallel working groups, in which each group reviewed and discussed the questions listed under one of 12 themes. Participants were free to join whichever group they preferred but some were encouraged to move if groups became too imbalanced numerically. Some questions were dropped by majority vote and some were modified, merged or divided. The main filter used for evaluating each question was the following: Is this question one of the 50 that, if answered, will have the greatest benefit for the conservation of Galápagos' diversity? At the end of each session, participants were asked to vote on the questions in each theme. The highest-scoring five were then classified as gold, the next five as silver and the next five as bronze, with the remainder no longer being included in the process. Ties were resolved by further voting.

On the second day, the questions were grouped into four broader themes, each combining three of the themes from the previous day. In two sessions, each with two parallel working groups, attendees were first asked to identify gold questions that might be removed or demoted to silver, then bronze questions that could be raised to silver and then finally to vote amongst the silver questions to decide which of those would go through to the next stage. Through a series of votes and discussions as before, each of the four working groups identified 10 gold and 10 silver questions, resulting in 40 gold questions and 40 silver questions for the final plenary session.

For the final plenary session, all attendees worked together. The 40 gold questions identified in the previous session were completed with 10 questions from the silver group. The silver questions were voted on by the attendees and the 10 questions ranked the highest were promoted to gold, to produce the final 50 questions. These were then grouped into nine themes for the manuscript.

Finally, the text of the manuscript was circulated amongst all workshop attendees for editing of content and final agreement on the wording of each question.

Results

The final 50 questions are listed below, grouped by theme but not ranked.

Tourism

The local economy of Galápagos is now almost entirely reliant on nature-based tourism (Oleas 2008; Taylor *et al.* 2009). Tourism in Galápagos grew at an annual rate of 9% between 1995 and 2011 (Pizzitutti *et al.* 2014). This increase has led to growth in local resident populations and cargo imports (Causton *et al.* 2008; Toral-Granda *et al.* 2017).While tourism generates some financial support for conservation, there is evidence that high levels are responsible for deleterious impacts on species and ecosystems (Burger and Gochfeld 1993; Romero and Wikelski 2002). It is difficult to disentangle the specific (and cumulative) impacts of different types of tourist visits (e.g. yacht based versus land-based) from the wider impacts of a growing resident population on the islands. At visitor sites on uninhabited islands the direct impacts of increased numbers of tourists and residents have been fairly well managed by the Directorate of the Galápagos National Park, but indirect impacts in the inhabited portions of the archipelago have been much more pronounced. Increased numbers of tourists and residents has resulted in a rapid growth in physical infrastructure (not always subjected to adequate environmental assessment), ever-increasing demands for public services, and a continuous growth of the risk of alien species introductions (Viteri-Mejía and Brandt 2015, 2017; Toral-Granda *et al.* 2017). It is generally agreed that, to reduce environmental impacts and risks, improvements in tourist management are required, along with a reduction in the dependence on labour and fresh food coming from the mainland.

1. What is the multiplier effect of tourism?
2. What low-impact and small-scale alternatives are most effective in achieving a community tourism model?
3. How can the uptake of environmental measures be encouraged to reduce the environmental impact of tourism?

Development

Estimates vary for the current human population size. The last national census was in 2010 when the population was recorded as 25 124, almost 20 times that of 1950 (1346). Population growth has been relatively constant since the beginning of organised tourism in the 1970s, although it has decreased from 6.4% per annum to 1.8% per annum in the last 15 years (INEC 2016). Most inhabitants live in the four main towns: Puerto Ayora on Santa Cruz, Puerto Baquerizo Moreno on San Cristobal, Puerto Villamil on Isabela and Puerto Velasco Ibarra on Floreana (listed in decreasing order of population size). About 4600 people live in small tourist/agricultural communities in the highlands of the four inhabited islands (INEC 2016).

A haphazard approach to urban and rural planning policy and its implementation (see below under *Planning*), has resulted in the construction of many houses, hotels and other buildings without any construction codes (Tullis 2016). This has led to the increase of impervious surface, with an average annual growth of urban areas of 3.3% between 1992 and 2017 (Benítez *et al.* 2018). Although there has been some improvement in governance, failure to enforce regulations has led to over-development of urban seafronts and encroachment of infrastructure into natural ecosystems, while some building lots have been left abandoned in urban centres. Provision of health services is poor and faces difficulties in facilities and recruitment of medical staff, particularly under the current immigration control regime. Innovative waste-management systems and notably recycling centres have been established but the challenges in exporting most waste to the mainland are considerable. Public transport for both residents and tourists is limited (Zander *et al.* 2016), creating a heavy and environmentally unfriendly reliance on taxis and private vehicles. There are obvious links between this theme and the others: important policy questions arise when considering how to reconcile the food, water and raw material needs of a growing population on islands that are fundamentally inhospitable to human life, with the conservation of the islands' biodiversity.

4. How is the labour market likely to respond to different models of sustainable development?
5. What are the likely trajectories of future population growth in the archipelago and how could various actions modify these?
6. What measures would be most effective in reducing urban sprawl?
7. What measures would most increase the sustainability of the transport system?
8. What methods would be most effective in reducing the impact of extracting or processing building materials?

Planning

The large number of people now present on the islands (see above under *Development*) fuels an ever-increasing need for improved planning and management (Quiroga 2017). Issues of land-use change, lack of services, insufficient public transport facilities, and alien species introductions, among others, are typical of human settlements, and Galápagos is no exception. In Puerto Villamil on Isabela Island, Walsh *et al.* (2010) demonstrated how lack of adequate design and engineering in urban and rural planning has had implications for the health of residents as well as for the fauna and flora of the archipelago.

A holistic cross-sectoral approach is required: government departments in all sectors should coordinate policy and action; the Galápagos National Park Directorate and the Charles Darwin Foundation should work together more closely to reduce duplication of efforts (for example, in research and monitoring), and there should be better use of scientific information in governmental planning, decision-making and action.

9. What management systems and policies implemented in other protected areas could be adapted to Galápagos to improve local participation in its conservation?
10. What is the effectiveness of different tools for monitoring and managing the various uses of protected areas?
11. What is the most effective governance model for protected areas to ensure long-term conservation?
12. What is the effectiveness of different instruments of adaptation and mitigation of the effects of climate change for the Galápagos ecosystems?
13. How do the health needs of the island's inhabitants interact with sustainable use?
14. What are the consequences of the possible options and locations for expanding renewable energy?
15. What are the various possible disaster risk scenarios?
16. What are the priority areas for restoration of degraded ecosystems?
17. What are the effective strategies to enhance native biodiversity in urban areas?
18. How can the ability to predict the impact of the El Niño Southern Oscillation and climate change on Galápagos be improved?

Education

The 1998 Galápagos Special Law identified the need to develop and establish a formal education system for Galápagos, which would take into account the needs and challenges of the islands and its inhabitants. However, this education reform never took place despite important steps taken by both private and public stakeholders (e.g. the Charles Darwin Foundation together with staff from the Ministry of Education). The lack of implementation was one of the triggering points leading UNESCO to include Galápagos in its List of World Heritage in Danger. Stepath (2009) observed that neither the unique nature and biological importance of the archipelago, nor the vital importance of following lifestyles appropriate for such a place were well taught to those living on the islands, and that there was no pervasive culture of collaboration and sustainable practice. Mendieta and Falconi (2008) reported that over 200 students graduated from high school annually with limited access to university education. In addition, Galápagos had the lowest performance in the country at high school graduation. Many children in Galápagos spend most of their time in the towns and do not experience the islands as tourists do. Travelling to the uninhabited islands or going on snorkelling trips to prime sites is expensive and something that most local children do not experience, although it is possible to walk to nearby beaches and to visit highland sites by bus and on foot. There is a dual problem here: too many young people are growing up without a sense of either the importance or the fragility of their local environment, and also without having achieved an academic profile appropriate for employment in key professional governmental and non-governmental roles in the islands (despite existing labour law preferences in place for Galápagos residents). Again, this is linked to population size and the pressure that this exerts on the social framework and ecosystems of the archipelago.

19. How can school and college education be designed to increase environmental awareness and influence more sustainable behaviour?
20. What are the professional and university training gaps most needed to achieve environmental sustainability?

Agriculture

Agriculture began in Galápagos when the first settlers arrived in the early 20th century and for many decades was a common way of life. Despite difficult circumstances, farmers were able to produce a wide variety of products for their own consumption and for the initially small local market through developing production practices appropriate to the Galápagos environment. Since the 1990s, increasing opportunities in the tourism sector, both better paid and more attractive, led people to move from agriculture into tourism. Some land was left uncultivated, and this led to the proliferation of invasive species on abandoned farms (Guzman and Poma 2015). As permanent and temporary resident populations and tourist numbers have increased, the amount of food required has surpassed the capacity of local farms. There is heavy reliance on goods transported on cargo ships from the mainland, which cause problems such as boats running aground, oil spills and introductions of alien species (Toral-Granda *et al.* 2017).

Agricultural productivity on the islands is limited by a lack of workers, alien invasive species and challenging climate. Droughts and floods frequently cause crops to fail and may be increasing because of global climate change. In addition, productivity and delivery to market are limited by lack of adequate transport and machinery and the margins earned by commercial intermediaries erode farmer profits. Finally, attempts to control invasive species, in both agricultural and National Park areas, use large amounts of herbicides and insecticides, and chemical contamination of the environment is a serious issue (Alava *et al.* 2013).

Coordination between sectors is required to develop appropriate land-use patterns, considering the inherent suitability of each area for cultivation, and to increase the availability and use of locally sourced agricultural goods.

21. What is the extent of agrochemical contamination in the environment and in people?
22. What are the expected effects of climate change on the functioning and profitability of production processes?
23. What is the current status of agricultural pests present in urban and rural areas?
24. How can local production activities (including agroforestry) be made more ecologically and economically sustainable while contributing to food and nutritional security?
25. What socio-environmental strategies would help the main actors in the agricultural area to support the control of introduced species?
26. How can value chains in productive activities be made more sustainable?
27. How could beneficial organisms, such as predators, parasitoids, pollinators, antagonists or mutualists, be enhanced in agricultural landscapes?
28. Which new species in Galápagos are the most suitable for sustainable cultivation considering biosecurity processes?
29. How does soil type vary across the islands and where are alternative practices, such as organic farming, most likely to be feasible?

Hydrology

Availability of fresh water has always been limited in Galápagos (d'Ozouville and Merlen 2007) and San Cristóbal is the only inhabited island with a permanent freshwater source (Liu and d'Ozouville 2013). It has been suggested that a better delivery system of water to populated areas is required (d'Ozouville 2007). Both Santa Cruz and Isabela have to extract their water from basal aquifers, which are contaminated with both organic (Liu and d'Ozouville 2013) and inorganic (Lopez and Rueda 2010) matter. Floreana depends on small-outflow springs for its water, which have become depleted (d'Ozouville 2007). Irrigation water is in short supply for farmers on the islands (d'Ozouville 2007) and current wastewater treatment systems are considered environmentally hazardous (Ragazzi *et al.* 2016). Predicted increases in water use and pollution by humans are also likely to have implications on the wildlife and ecosystems present on the islands.

30. What is the hydrogeological potential of the highlands of the populated islands?
31. What is the current and future demand for water for both the household and commercial sector?
32. To what extent may different ecosystem capacities (e.g. the availability of fresh water) constrain socioeconomic development?
33. What is the effectiveness of different means of implementing prevention and mitigation strategies for wastewater pollution of water bodies?
34. What is the effectiveness of different strategies for the sustainable use of water in agricultural activities?

Invasive species

As with many other island systems, alien invasive species are considered one of the greatest threats to native Galápagos flora and fauna (Trueman *et al.* 2010; Valle 2013). Currently, 1579 introduced species – including historical records, eradicated and intercepted species – have been recorded in Galápagos, of which 1476 have become established in the islands (Toral-Granda *et al.* 2017). Among these, some are considered to be amongst the world's worst invaders (Lowe *et al.* 2000). Some invasive species in Galápagos have already been shown to be severely detrimental to native and endemic species, including the parasitic fly *Philornis downsi* (Kleindorfer and Dudaniec 2016), the black rat (*Rattus rattus*) (Phillips *et al.* 2012), the feral cat (*Felis catus*) (Levy *et al.* 2008), and the blackberry (*Rubus niveus*) (Renteria *et al.* 2012). Their impact mechanisms include parasitism, direct predation, spread of disease

(Causton *et al.* 2006; Bataille *et al.* 2009; Deem *et al.* 2012) and competition (Trueman *et al.* 2010).

Management of marine invasives (Keith *et al.* 2016) is challenging due to the intrinsic properties of marine ecosystems (Bax *et al.* 2003). Although important steps have been taken to manage the issue of alien species in Galápagos, the number of possible pathways to the islands for new arrivals is still high and continues to increase (Toral-Granda *et al.* 2017). This is mainly due to the growing number of tourists (Viteri-Mejía and Brandt 2017) and the ever-increasing number of goods and services arriving on the islands (Toral-Granda *et al.* 2017).

The mechanisms, invasion pathways and impacts of many alien species are not well known (Hulme *et al.* 2008) and suitable methods of control have not been developed. New introductions are therefore expected unless further and sustained action is taken and policies concerning pathway management, quarantine and biosecurity procedures are implemented consistently (Toral-Granda *et al.* 2017).

The contribution and commitment of both scientists and quarantine officers to their work in limiting the risk posed by alien species is substantial. It is not for lack of effort that the threats remain high. Rather, what is needed are better links between government departments so that development and operation of quarantine measures and facilities can be properly coordinated.

35. Which, if any, biological control agents are most suitable for consideration for reducing the impact of the main invasive species?
36. What are the dispersal pathways of priority invasive species?
37. How is climate change likely to affect the distribution and prevalence of introduced species and diseases?
38. What are the most suitable strategies for managing the introduced species that represent the greatest threat to agriculture?
39. What are the most effective prevention and biosafety systems to prevent the introduction of species to the archipelago and between the islands?

Marine

The Galápagos Marine Reserve is a multiuser protected area that allows for artisanal fishing, tourism and conservation (Edgar *et al.* 2008). Its zoning scheme has been recently reviewed and updated to include larger no-take zones. It consists of a mix of temperate, upwelling and tropical environments yielding a diverse assemblage of marine species with endemism ranging from 8 to 67% (Bustamante *et al.* 2000; Hickman 2009) in five distinctive bioregions (Edgar *et al.* 2004). Both introduced species and fishing activities pose threats to the overall health of the reserve and increased maritime traffic may lead to further introductions (Campbell *et al.* 2015; Keith *et al.* 2016). Galápagos is also prone to intense El Niño events, which often cause high levels of mortality in some marine species. Until recently, populations have generally recovered well before the next strong El Niño event (e.g. Laurie 1990), but it is probable that damaging and unsustainable fishing activities, and the effects of global climate change are increasing the vulnerability of the Galápagos marine environment to these events (Edgar *et al.* 2010).

40. What marine-coastal zoning system would be most effective for the Galápagos Marine Reserve?
41. How would changing the area for no-take zones affect the ecological sustainability of the Galápagos Marine Reserve?
42. What are the impacts and priorities for the management of existing marine invasive species?
43. What is the likely effect of increasing ocean acidification on ecosystem processes?
44. What is the importance of the Galápagos Marine Reserve for highly migratory fish stocks?
45. What are the social and economic consequences of different fisheries management strategies?
46. How does the El Niño Southern Oscillation influence trophic chains in marine and terrestrial communities?

Conservation

Galápagos is a globally important site for biodiversity, which was long isolated from human activities. Although humans began to hunt certain species, such as the Galápagos tortoises, in the 19th century, the islands were settled only in the mid-20th century, and then only lightly. More recent rapid human population growth has led to great pressure on the biodiversity and natural ecological processes of the archipelago (see above). It is important, therefore, for conservation policy to consider the needs of the resident human population and their livelihoods in combination with those of endemic and native species.

The establishment of the Galápagos National Park and the Charles Darwin Foundation in 1959 mandated the Ecuadorian government to preserve this unique archipelago with tools based on scientific advice. Much important research has been undertaken since the creation of the Charles Darwin Research Station, which has influenced and aided management practices across the islands. The establishment of other scientific education organisations and non-governmental organisations in the last 15 years reflects the understanding that increased efforts in conservation are needed (Reck 2017) and there is currently considerable interest in restoration (e.g. Atkinson *et al.* 2010). As the populations of local residents and tourists continue to increase, further research is vital to protect the environment of Galápagos and ensure that anthropogenic activities do not begin, or continue, to endanger the islands and their unique fauna, flora and ecosystems. A balance is necessary to fulfil the needs of the human inhabitants without exceeding environmental limits.

47. What are the major threats faced by endemic species and what do we need to do to minimise these?
48. What are the major factors influencing the change in status of the key and emblematic species?
49. How effective are current strategies for integrating scientific knowledge into policies and how can they be improved?
50. What are the levels of heavy metals, polychlorinated biphenyls (PCBs) and emerging pollutants in coastal and terrestrial ecosystems?

Discussion

Globalisation is engulfing most island ecosystems around the world and Galápagos is no exception. A wide range of issues, largely of human origin, are causing increased stress on its natural environment (e.g. Causton *et al.* 2006; Toral-Granda 2008; Benitez-Capistros *et al.* 2014; Viteri-Mejía and Brandt 2015) and threatening its future as one of the most pristine archipelagos in the world.

Scientific research and conservation in Galápagos has typically been focused on urgent issues or those of most interest to donors or external research institutions. Furthermore, issues on the islands often vary in the way they are viewed by its inhabitants (Lu *et al.* 2013), leading to confusion about which issues to prioritise. This paper provides much-needed foci for scientific research in Galápagos, using a well established methodology that enabled important collaboration between key scientists and government officials.

Many of the research questions produced in this paper related to issues with common causes, of which three in particular featured frequently: human population growth (of permanent residents, temporary residents and tourists), climate change, and the impact of invasive alien species. A large number of questions also related to socioeconomic aspects, reflecting the need to find ways of reconciling the long-term sustainability of human activities and livelihoods with the conservation of Galápagos' species and natural ecosystems.

The challenge now is to implement the research needed to respond to these questions, collaboratively and cooperatively. While some have already received initial attention, and can perhaps be answered relatively quickly, others will require long-term funding and collaboration between key organisations. Improved coordination between the Charles Darwin Foundation, the Galápagos National Park Directorate and other government institutions such as the Galápagos Biosecurity Agency and the Provincial Direction of Agriculture will be necessary to avoid overlap in research and monitoring efforts. The use of data in planning and decision-making needs to be improved and consistent application of scientific method and statistical protocols by all organisations should be ever-present features in efforts to answer these questions.

High-level authorities and decision-makers, including the Minister and President of the Galápagos Government Council, have already taken the results of this work to other organisations, including the Supraministry of Human Talent and Ministry of Higher Education, Science and Technology, who will be holding a science forum to discuss the produced research questions. The Ecuadorian Government (through the Galápagos Governance Council), the Ecuadorian academia and the Charles Darwin Foundation have already started to use the outputs of this exercise to formalise joint ventures to deliver directed information to work towards a well managed and conserved Galápagos for future generations. Continued use of these questions to focus scientific research on Galápagos will improve the chances of this unique ecosystem maintaining its pristineness in an ever-changing, human-impacted world.

This exercise just considered questions that had importance for policy makers and practitioners, yet the Galápagos is famous for many pure research fields. It would be interesting, therefore, if a parallel exercise for fundamental research questions were undertaken.

Conflicts of interest

The authors declare no conflicts of interest.

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