

Final Evaluation Report

Your Details	
Full Name	Maximilian Hirschfeld
Project Title	Population Connectivity of Galápagos Bullhead Sharks and the Identification of Key Habitats for Conservation in the Galápagos Archipelago
Application ID	25628-В
Date of this Report	30 December 2022



1. Indicate the level of achievement of the project's original objectives and include any relevant comments on factors affecting this.

Objective	Not achieve	Partially achieve	Fully achieve	Comments
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I. Generating scientific knowledge				
Geographic distribution				Over 260 sightings of bullhead sharks were recorded throughout the Galápagos archipelago using: (1) SCUBA diving and snorkelling research campaigns, (2) reports through collaborating Galápagos National Park staff, national park guides and scientists, and (3) through the project's citizen science website. The resulting information on the distribution of bullhead sharks was used to inform the latest IUCN Red List review and the IUCN Shark Specialist Group ISRA (important shark and ray areas) project, and was presented in a talk and poster (see item 7) at the IV South American Rufford Small Grant Conference in the Galápagos in 2019 (see Poster presentation in Appendix). Additional information will continue to be collected through the citizen science website and collaborators and the project's field campaigns to generate new knowledge (see item 6).
Life history, demography and demographic connectivity				During this project we developed a unique combination of research techniques, including the use of underwater lasers to non-invasively measure sharks, external examination while diving on SCUBA, and drawing blood samples from the sharks underwater (see Poster in Appendix). On research expeditions we collected 188 blood samples on five different islands and demographic structure of locations on different islands was assessed using photogrammetry (see figure 1, item 3).



		Although, this preliminary information has been useful to report important habitats to the Galápagos National Park, exact size at maturity via plasma hormone analysis has not been determined yet due to several setbacks (see item 2). Further, photo-identification of the unique spot-pattern on bullhead sharks showed that several individuals were present in the same coastal areas after one year. In contrast, no individuals were found to migrate between locations on the same islands or even between islands. This indicates that bullheads are either highly resident or return to the same locations over long time periods supporting the results of genetic analyses (see below).
Genomic connectivity and effective population size		A total of 182 sharks from nine locations on six islands were analysed using 9223 genomic markers (SNPs, or single nucleotide polymorphisms). Galápagos bullhead sharks showed increasing genetic differences with increasing ocean depth, acting as barriers between islands. This resulted in four distinct genetic groups (see figure 2 item 3). The genetically distinct groups had low genetic diversity and groups on smaller islands also had a low population size, making them more vulnerable to extinction. The results were used to identify important habitats for conservation management via the IUCN Shark Specialist Group ISRA (important shark and ray areas) project, were presented at an international conference and are currently in the second stage of review at a high quality international journal called <i>Heredity</i> by the Nature publishing group (see item 7). Tissue samples from this study were also contributed to a recent publication on bullhead sharks, genus <i>Heterodontus</i> and I am co-authoring another publication using our genomic data (see items 7 and 11).
II. Building local capacity		Based on our research funded by the 1st Rufford Small Grant we extended our



		collaborative network with the Galápagos National Park and local NGOs. We were therefore able to increase our impact through the participation in field and lab work and adding to our outreach efforts by including more local organisations and volunteers (see item 5).
III. Conservation education and raising awareness		Together with our local partners our outreach programme was able to reach a large extent of the local population from various age-classes, social sectors and islands. By expanding our network of local collaborators, we were able to extend the planned programme to include additional groups of kids and educational activities. This allowed us to organise Galápagos Shark Day, face-to- face in 2018 and 2022 and virtually in 2020 and 2021. Moreover, we organised the first Shark Conservation Hero campaign, an effort to actively engage youth in hands-on conservation efforts (see item 5).
Citizen Science webpage		During the 2nd Rufford small grant and 1 st Booster Grant we established the project's own citizen science website, to inform the local and international community about our project objectives and outcomes and motivate anyone to participate actively in our research as a citizen scientist. Although we have experienced a few issues with the website over time (see item 2), this tool allowed us to record bullhead sharks from new locations and track the presence of individuals over time.
Outreach & education		Our shark outreach and education programme included working with groups of kids at primary school age in collaboration with the national park and local NGOs. A key element of this effort is the annual Galápagos Shark Day which includes kids of many age classes as well as their parents. This year we were able to provide actual experiences with the marine environment and sharks for participants of the event. Adults were included into the programme through



		workshops and public presentations.
IV. Scientific publication and media coverage (communicating the results)		Although, there have been some delays due to the global pandemic, we believe we have produced a wealth of scientific and popular communication products on the project's progress and results, including conference presentations, workshops, scientific publications, websites, blogs, and more (see item 7).

2. Describe the three most important outcomes of your project.

a). Scientific discovery driving conservation outcomes

At the start of this project, no scientific information existed on Galápagos bullhead sharks. Since then, we have made leaps in the discovery of new information, through our research campaigns in the Galápagos, the contribution of citizen scientists, dive guides, and scientific collaborators in Perú, which is already informing tools for conservation management. We now have a much better understanding of the distribution of the species in the Galápagos, where important habitats are located, how connected distinct populations on different islands are and how this may affect their vulnerability to external factors (see figures 1-2 below and poster presentation in Appendix). In 2019, we supplied the most up-to-date information on this species for a review of its IUCN status. In October 2022, I assisted experts from the Galápagos National Park with delineating key habitats for conservation to be included into the ISRA (important shark and ray areas, https://sharkrayareas.org/) guidelines for the conservation of key shark and ray habitat.



Life history, demography and demographic connectivity

Figure 1. Left panel: demographic distribution of male and female bullhead sharks. Right panel: Male reproductive organs, so called claspers can be used to gauge sexual maturity in male sharks.

Genomic connectivity and effective population size

Genomic analyses have resulted in the identification of at least four genetically distinct units (figure 2) with low migration rates among them. We estimated that these units have low genetic diversity and small population sizes.





Figure 2: Admixture Analysis (top) and Principal component analysis (bottom left) of thousands of genomic markers clearly identify four genetically distinct units: The western archipelago and Santiago Island (West, SAN), Floreana Island (FL), Española Island (ES) and San Cristóbal island (SCY). Genetic effective population size (Ne) for genetically isolated groups were small for geographically isolated islands, Floreana nd Española (sample size of San Cristóbal was insufficient to determine this statistic).



b). Building local knowledge and capacity

Dive guides, volunteers, local and international and research assistants and Galápagos National Park staff were included in research and outreach activities to foster local capacity and knowledge. Participants were able to learn scuba diving research methods to study sharks and participate in laboratory work. Research assistants were also trained in processing samples, managing databases and using specialised computer software for the photographic identification and measuring of sharks. Members of the Galápagos dive guide association were also particularly



involved in learning how to participate as citizen scientists and communicate information to tourists.

Citizen Science Campaigns

To improve local participation in GCT supported citizen science projects we designed and implemented The Galápagos Shark Hero campaign in 2019 (images below). A total of 51 locals participated in the campaign and 11 winners (one first, five second and five third prizes) were publicly announced for their dedication to shark conservation projects and received prices and certificates during the Galápagos Research and Conservation conference in San Cristóbal (June 2019).

Workshops

Together with two colleagues (Javier Oña and Robert Lamb) I organised the Rufford Conference South America - Science for the conservation of the Eastern Tropical Pacific Region including two workshops oriented towards improving collaborative science to study the connectivity of marine species in the Eastern Tropical Pacific and how to translate scientific knowledge into conservation actions. As part of this workshop series, we also organised a round table with researchers from the Galápagos Science Center and Charles Darwin Station, and key Galápagos National Park staff (see photo below).

c). Conservation education and raising awareness

The success of our outreach programme can be attributed to the involvement of many local collaborators and international partners, who were open to new ideas. Next to public presentations and workshops, our local outreach effort focused on the involvement and education of Galápagos school kids. Working with the Galápagos National Park our volunteers participated in the institution's Little Park Rangers programme, which brings the classroom outdoors. During an overnight camp the kids received shark education from our volunteers. One of the most important project components is the annual Galápagos Shark Day, which was first created during the shark conservation project funded by the 1st Rufford Small Grant in 2013. The educational event has gained much support since then and was held for the 9th time in 2022, after two years of online editions. To organise the educational event, we were supported by the Galápagos Science Center, the Municipality of San Cristobal Island, the association of naturalist guides, and the local NGO's Ecociencia and GECO. Both NGOs worked with school kids to prepared educational activities and shows for the shark day event. Further, we worked together with the Casa de la Cultura on San Cristobal Island (as had been suggested by an external reviewer of the application to this grant) to create educational presentations and activities for kids for the Shark Day.

During the 2018 and 2019 annual Galápagos Shark Day participation exceeded 100 registered participants between the age of 3 to 15 years. In both years 12 overall winners were drawn to participate in an excursion we called the Shark Experience. Professional videos of Shark Day and Shark Experience (click links to view online content).



Putting bullhead sharks on the map

Prior to this project, little was known about Galápagos bullhead sharks in the scientific literature as well as among the local population and managing authorities. Through the support of the 2nd Rufford Small Grant and 1st Booster Grant we were able to put this species on the map (literally and figuratively) at the local and global level. On the local level, we were able to convey knowledge on the location and importance of protecting of key habitats to citizens and managing authorities through outreach and educational events, public talks, online articles, and direct participation in research activities. On an international level, this project accomplished to include new scientific data, including the location and extent of key habitats into international guidelines for conservation management. While these high level international guidelines into the local language and communicate them directly to local authorities in the near future.

3. Explain any unforeseen difficulties that arose during the project and how these were tackled.

Logistical challenges

One of the biggest challenges of this research project is to find and survey Galápagos bullhead sharks in their natural environment. Bullhead sharks are more active at night and tend to hide in caves and crevices during the day, particularly the smaller individuals. Prior to this project, no scientific information was available on the species and we found that the sharks' preferred habitats were often in the most remote areas of the Galápagos, making the field work logistically challenging. To overcome this the project established collaborations with the Galápagos National Park, fishermen, and researchers to increase our time in the field while reducing the costs. Further, we were able to secure additional funding for sequencing samples, making more funds of this grant available for field work in the Galápagos and Perú.

Website technical issues

One challenge was to set up and maintain the photo-identification website, www.bullheads.org. We sought the help of a web designer and programmer to customize the bullhead shark website in 2016. More recently there have been several issues with the website staying online. Since the web designer and programmer initially in charge of the website has left we are in the progress to work with the developers of the wildme.org platform, which forms the base of our website, to come up with a better long-term solution (see items 1 and 9).

Setbacks in reproductive hormone analyses

Blood samples from 188 sharks were collected, processed, and exported to Australia to determine plasma hormones levels. However, during the course of the project the laboratory of the collaborator Cynthia Awruch at the University of Tasmania in Australia was flooded, delaying the lab work. Further, the methods commonly used in sharks have resulted in lower levels of hormones in bullhead sharks. Although, we are working towards refining the hormone detection methods, it will still take some time (all costs and time are covered by C. Awruch) to determine if the resulting hormone levels will be sufficient to determine size of sexual maturity in this species.



Global COVID Pandemic

Since early 2020, conservation projects around the world have been forced to adapt to the challenging circumstances caused by a global pandemic. This included our project on Galápagos Bullhead sharks. After being awarded a Rufford 1st Booster Grant in December 2018 we made great progress during the first half of the funding period, with important scientific findings and exciting new and continuing outreach campaigns. We were also able to secure additional funding from another external grant to cover the costs of DNA sequencing, which is allowing us to analyse additional samples from sharks in Perú and the Galápagos to delineate genetically discrete groups within the Galápagos and between the archipelago and the South American mainland. Unfortunately, Ecuador and Perú have both been substantially affected by the Covid-19 Pandemic, making field work in these countries unfeasible for almost 2 years. Further, the lead of the project (M. Hirschfeld) was based in Australia, where borders had been completely closed for almost 2 years, until late 2021. Therefore, an extension of the project timeline until 30th December 2022 and adjustment to the budget were requested and approved by The Rufford Foundation trustees in early 2022. Our project partner, the Galápagos Conservation Trust, also endorsed the extension of the project timeline. These adjustments as well as additional funding allowed us to work with our collaborators in Perú to collect additional samples from fishing ports.

4. Describe the involvement of local communities and how they have benefitted from the project.

Raising awareness and building local capacity have been a central goal of this project. To achieve this, the local community has been actively involved in research activities and has been the main audience as well as the main supporter of our project's outreach programme.

Local and Ecuadorian volunteers and students, national park staff, fishermen, and Ecuadorian research assistants have been actively involved in planning and running field research, laboratory analyses (including DNA extraction, blood hormone extraction, and using photogrammetry software) and educational activities of the funded shark conservation projects. Many participants were able developed substantial skills and knowledge in shark conservation research and some of them have moved on to lead their own projects.

Many local organisations, including the Galápagos National Park Services, the municipality of San Cristóbal Island, local collaborating NGOs (also see item 12) and from the tourism industry have participated in the project's education and outreach efforts (see item 3). The involvement of both individuals and local organisations in our project aims to provide an opportunity to become actively engaged in research and conservation of sharks and develop new skills and ideas, thus empowering the local community to guide the Galápagos into a more sustainable future. On the ground conservation needs a strong foundation and support from both the local managing authorities and even more importantly the local population.



5. Are there any plans to continue this work?

Yes, this project was laid out as a long-term endeavour and the support received through the 2nd Rufford Small Grant and 1st Booster Grant, and the Galápagos Conservation Trust has catalysed the project's progress. After a period of slower progress caused by the global pandemic, the next milestones are under way and the project will continue to grow and produce important scientific knowledge and management outcomes. Moreover, the collection of citizen science data to study bullhead shark distribution, movements and population size will continue providing new insights over the next years, highlighting the strength of the long-term duration of this project.

More specifically, some of the most important next steps we plan for the years 2023-2024 include the following:

• Island-mainland connectivity and conservation units

DNA sequencing of the samples we were able to collect through the 1st Booster Grant funding is underway. We will compare genetic (mitochondrial DNA) and genomic (single nucleotide polymorphisms) to distinguish populations of Galápagos bullhead sharks (*Heterodontus quoyi*) from the Galápagos Islands and the coast of Perú. These data will also be compared to a congeneric species (*Heterodontus mexicanus*), provided from our collaborator Sean Canfield (see item 12). This will allow us to identify how different populations of *H. quoyi* are and if they are isolated populations that should be considered as individual conservation and management units.

• Vulnerability of population units

After identifying distinct units of *H. quoyi* populations we will assess genetic diversity and population size, similar to our results for the Galápagos Islands (see item 3). This will allow us to gauge the vulnerability of individual units to external pressures, including fishing, habitat destruction, and climate change.

Geographic distribution

During the booster grant funding phase, we gained much knowledge on the where Galápagos bullheads harks occur, where they may lay their eggs and where their offspring find shelter. So far, the results have been shared in presentations, posters and reports. In the next phase of the project, we aim to engage at least two local students from the Galápagos or mainland Ecuador to support the ongoing data collection as part of thesis projects and to (co-author) scientific publications.

6. How do you plan to share the results of your work with others?

The findings of this project and their value for conservation has been and will be shared through a range of scientific and popular media.

Scientific publications

The project supported by the 1st Booster Grant also led to several publications, where funding by the Rufford Foundation was acknowledged:



Hirschfeld, M., Dudgeon C., Sheaves, M., & Barnett A. (2021). Barriers in a sea of elasmobranchs: From fishing for populations to testing hypotheses in population genetics. Global Ecology and Biogeography, 00, 1–17. https://doi.org/10.1111/geb.13379. Summary of the in English and Spanish available on the Galápagos Science Center website and a graphical abstract of the findings in the Appendix at the end of this document.

Hirschfeld, M., Barnett A., Sheaves, M., & C. Dudgeon. What Darwin couldn't see: Island formation and historical sea levels shape genetic divergence and island biogeography in a coastal marine species. Heredity - Second Revision (manuscript ID HDY-22-A0148).

Devloo-Delva, F., Burridge, C. P., Armstrong, A., Davenport, D., Dudgeon, C., Green, M., Hirschfeld, M., Junge, C., Kyne, P., Manuzzi, A., Ovenden, J., Pazmiño, D., Portnoy, D., Maes, G., Feutry, P., Sex chromosomes in Chondrichthyes: Evolutionary stability of the sex-chromosome systems of 21 shark and ray species through sex-linked markers. Under Review at Molecular Biology and Evolution.

Scientific Presentations

Hirschfeld, M., Adam Barnett, Christine Dudgeon, Marcus Sheaves: Sharks, volcanoes and coral reefs (Genomic signatures of geographic isolation in shallow-water demersal sharks). Oceania Chondrichthyan Society virtual conference, November 2020.

Hirschfeld M., Adam Barnett, Christine Dudgeon, Juan García, Marcus Sheaves: The Galápagos Bullhead Shark Project – Balancing scientific discovery and conservation of an elusive marine species. Rufford Conference Science for the conservation of the Eastern Tropical Pacific Region in January/February 2019 (poster presentation attached).

Hirschfeld, M., Adam Barnett, Christine Dudgeon, Marcus Sheaves: Island treasure hunt: The search for Galápagos bullhead sharks. Oral presentation at Sharks International, June 2018, Joao Pessoa, Brazil.

Hirschfeld, M., Barnett, A., Dudgeon, C., Sheaves, M., From global to local scale: Physical barriers to population connectivity of demersal sharks. Oceania Chondrichthyan Society conference, February 2018, Moreton Bay Research Station, The University of Queensland, Dunwich, Qld, Australia.

Online

One of the most important platforms for communicating the research aims and progress will be the project's website, www.bullheads.org. News and updates are published through the project website, the Galápagos Science Center (2nd Galápagos Conservation and Research Symposium video report) and the Galápagos Conservation Trust as well as social media profiles (Twitter and Facebook).

New knowledge about Galápagos Bullhead sharks is constantly integrated in games and activities of outreach and educational events and campaigns. See some of our



professional videos of Shark Day and Shark Experience (click links to view online content).

Public talks

In June 2019 I presented about sharks and conservation issues in the Galápagos at a public event of the global Pint of Science movement (https://pintofscience.com/):

 Galapagos: trouble in paradise?

 Maximilian Hirschfeld (PhD candidate, James Cook University)

 Image: Comparison of the calapagos state of the depicted as a pristine paradise. This photographic journey celebrates the beauty of the Galapagos but also explores human-made threats and the conservation actions that may preserve this paradise. Don't miss it!

 Maximilian is a PhD candidate at James Cook University and an Associate Researcher at the Galapagos Science Centre. He has participated in a number of documentaries, including BBC's Galapagos (UK), Das Meerechsen-Rätsel (Germany), and My family and the Galapagos (UK).

TV documentaries

In 2016, some of the work funded by the 1st Rufford Small Grant tracking juvenile blacktip sharks to provide spatial data for management has been featured in the BBC's Mission Galápagos. The Galápagos bullhead shark project funded by the 2nd Rufford Small Grant and the 1st Booster Grant were filmed by SeaDog Productions UK, for a three-episode documentary featuring Monty Hall.

Children's book

Together with a team of science communicators at the University of San Francisco de Quito we created an educational story about the Galápagos Bullhead shark as part of a children's book about animals and conversation in the Galápagos, published in Spanish in 2020.



7. Looking ahead, what do you feel are the important next steps?

Vulnerability assessment

Although an IUCN review of coastal shark species in South America was undertaken in early 2019, the scientific data available is insufficient for solid evaluation of IUCN Red List status in many cases, including for Galápagos bullhead sharks. Our results to date (see item 3) and upcoming results from genetic analysis comparing the



Galápagos Island populations with the continental coast of South America will allow us to delineate important units for conservation, assess their vulnerability to threats and inform IUCN status.

Conservation advocacy

Next to publishing scientific results and contributing to international conservation guidelines there is a need to engage with local authorities and decision makers to successfully integrate the conservation of Galápagos bullhead sharks and key habitats into management strategies. In June/July 2023 we plan to deliver key results and their relevance to marine protected area management in talks and workshops with the Galápagos community and the Galápagos National Parks Services. Moreover, following the promising result of the Rufford Conference South America - Science for the conservation of the Eastern Tropical Pacific Region, my colleagues (also Rufford grantees) and I plan another conference, likely in early 2024, where results from this study can be integrated with conservation strategies for the Eastern Tropical Pacific Region.

Next generation conservationists

This project has grown over the years with many collaborators, participating students and volunteers. However, in the future we aim to focus on providing Ecuadorian and/or Galápagos student the opportunity to lead their own research within the project. In this way we hope to foster knowledge and support students to become independent in undertaking conservation projects in the Galápagos.

8. Did you use The Rufford Foundation logo in any materials produced in relation to this project? Did the Foundation receive any publicity during the course of your work?

The Rufford Foundation logo was used in all scientific and public presentations, print material, the project website, and mentioned in the scientific publications listed above (see item 7). Moreover, we have acknowledged The Rufford Foundation and used the logo on our educational print material used in outreach events and online publications, including high quality video productions.

9. Provide a full list of all the members of your team and their role in the project.

Institutions: James Cook University (JCU), Galápagos Science Center (GSC), Universidad San Francisco de Quito (USFQ), University of Queensland (UQ), University of Tasmania, Australia (UTAS), University of California Davies (UC Davis), Galápagos National Park Services (GNPS), Galápagos Conservation Trust (GCT).

Adam Barnet, Ph.D. and Marcus Sheaves, Ph.D., supervisors at JCU, will provide expertise in project management, study design, data analysis and scientific publication.

Christine Dudgeon, Ph.D., specialist in shark population assessment and population genetics (UQ).



Cynthia Awruch, **Ph.D.**, specialist in shark reproduction using non-invasive blood hormone analysis (UTAS).

Jaime Chavez, Ph.D., collaborator on genetics based in Ecuador (USFQ and GSC).

Alex Hearn, Ph.D., shark scientist at USFQ and GSC will participate in the Shark Conservation Hero campaign and co-supervise Ecuadorian undergraduate students.

Diana Pazmiño, Ph.D., shark geneticist and Galápagos resident is supporting the analysis of mitochondrial DNA together with local students as part of the ongoing Barcoding Galápagos project.

Mayurie Yepez, GNPS, is head of marine investigations. All fieldwork and permitting processes, workshops and participation of National Park rangers will be coordinated through her.

Jen Jones, project coordinator at GCT, will be our contact for outreach and educational campaigns supported through the organization.

Roberto Vera, Galápagos resident, is president of the local NGO GECO and has experience working with the community, the municipality and local schools.

Leidy Apollo, communications/education manager at the GSC has been supporting the Shark Day and Shark Hero outreach campaigns.

Manolo Yepez, Galápagos resident, director of Galápagos SharkSky Travel & Conservation will continue to support the Galápagos Shark Day event and provide logistics for educational campaigns.

Joselo Ballesteros, Galápagos resident, owner at Galápagos Blue Evolution dive agency, San Cristóbal Island.

Joanna Alfaro is the main collaborator from the Peruvian marine conservation organization ProDelphinus Perú (www.prodelphinusperu.com).

Sean Canfield, Ph.D. (UC Davis), has been a collaborator on the project and is providing tissue samples from Heterodontus mexicanus, from the coast of California.

10. Any other comments?

I appreciate the continued support given by The Rufford Foundation, which made it possible for this long-term conservation project to generate important contributions to scientific knowledge and conservation of important shark habitats in the Galápagos. I will continue the Galápagos bullhead shark project as a long-term project and I aim to apply for further support through The Rufford Foundation to support field research and to engage Ecuadorian students to run their own research projects in co-supervision with collaborators from the Galápagos Science Center and Universidad San Francisco de Quito.



Appendix

Graphical abstract:

Hirschfeld, M., Dudgeon C., Sheaves, M., & Barnett A. (2021). Barriers in a sea of elasmobranchs: From fishing for populations to testing hypotheses in population genetics. Global Ecology and Biogeography, 00, 1–17. https://doi.org/10.1111/geb.13379.





Poster presentation presented at the 2nd Rufford Conference South America -Science for the conservation of the Eastern Tropical Pacific Region.