Final Evaluation Report

Your Details	
Full Name	Josué Jacob Martínez Noguez
Project Title	Landscape genomics to define conservation units and impact of the climatic change in the Cirio (*Fouquieria columnaris* (Kellogg) Kellogg ex Curran)
Application ID	32109-1
Date of this Report	November 28, 2022

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

Objective	Not achieved	Partially achieved	Fully achieved	Comments
Tissue sampling for DNA				We managed to collect samples from practically the entire distribution of *Fouquieria columnaris*; only the insular locality of Ángel de la Guarda could not be sampled, since it is an area of difficult access that mainly involves risk in navigation, and unfortunately we had bad weather on both visits to make the trip by sea, although there were periods of good weather during our stay in Bahía de los Ángeles, but they were insufficient, since the time to reach the area where the trees are located takes approximately whole day at foot. Therefore, the deputy director of the protected natural area "Zona Marina Bahía de los Ángeles, Canales de Ballenas y de Salsipuedes" Dr. Rosalía Ávalos-Téllez (who can be consulted at the email: rosalia.avalos@conanp.gob.mx), with whom we coordinated the entrance to the island, she recommended us not to access the site for our safety and that of his team, since in October 2021 and July 2022 the environmental wind conditions we found were insufficient to go to the island and return safely.
Soil Sampling				Only the locality of Ángel de la Guarda Island could not be sampled for the reasons described in the previous point.
DNA extraction				DNA extractions were successfully performed.
Characterization of the landscape				It was achieved successfully characterise the landscape as planned.
Bioinformatic analysis				It was achieved successfully bioinformatic analysis as planned.

Products				I achieved all the products raised in my original project proposal. I generated useful information that describes the structure and biological and environmental dynamics of one of the components of biodiversity in *Fouquieria columnaris*, the genetic biodiversity, which will allow managing and conserving the species with data that supports decision-making. I published the results of my project; I produced a scientific article and a social divulgation article that are currently under review. In addition, the development of this project will allow me to obtain the PhD degree in Management, Use and Conservation of Natural Resources from CIBNOR in February 2023. As additional activities to the proposals, I disclosed my data as divulgation talk, making two oral expositions, one at the high school level and another for society in general.

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

1. I achieved quantify the genetic diversity of the species *Fouquieria columnaris* in practically the entire range of its distribution, except for Ángel de la Guarda Island. In general, the diversity values of the species were low, which tells us that it has gone through events of historical demographic decline, exercising negative pressure against the populations, possibly due to events of historical changes. I also managed to structure four different genetic groups (population of Sonora, population of the Tres Vírgenes volcano, and population of the north and central Peninsula), which I propose to function as Management Units (MUs) for the different natural protected areas where it is distributed. In addition, it was found that the population of Sonora have the greatest genetic diversity and that naturally provides diversity to the northern peninsular region (see results in the next point) is an area that is under none type of special protection (Figure 1).

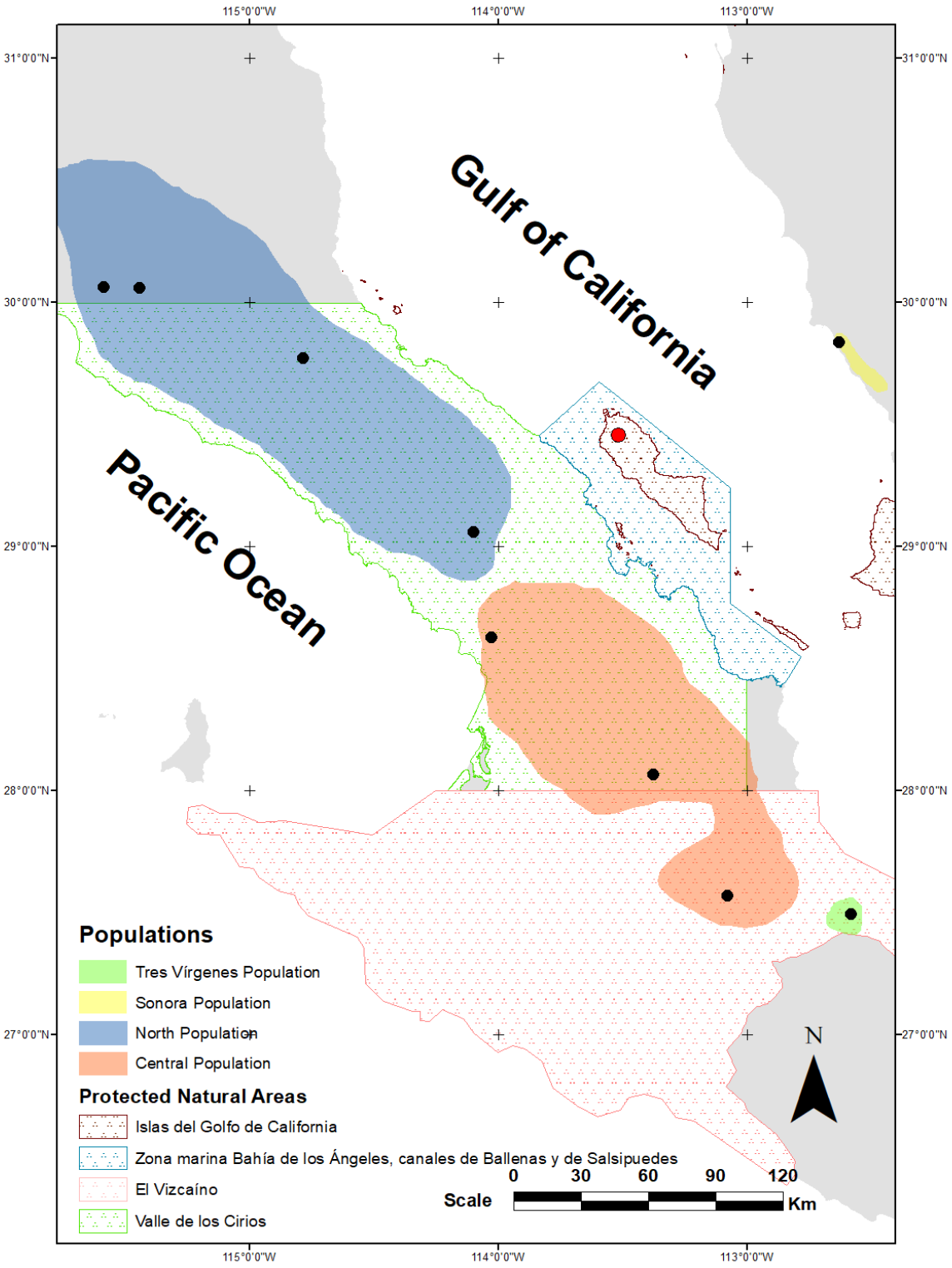

Figure 1. Distribution of *Fouquieria columnaris*, differentiated into four distinct populations. The protected natural areas of the region are also shown. Black dots

are the sampled localities in the project, the red dot is the locality of Ángel de la Guardia Island, which could not be sampled.

2. Using genetic data, we found that surprisingly there is unidirectional gene flow through the Gulf of California, which goes from the continental massif to the northern population of the peninsula. Where the population of Sonora is a natural stock that contributes variability and genetic diversity to the peninsular area, this probably through pollinators that travel through the sea, possibly hummingbirds on their migratory routes (Figure 2).

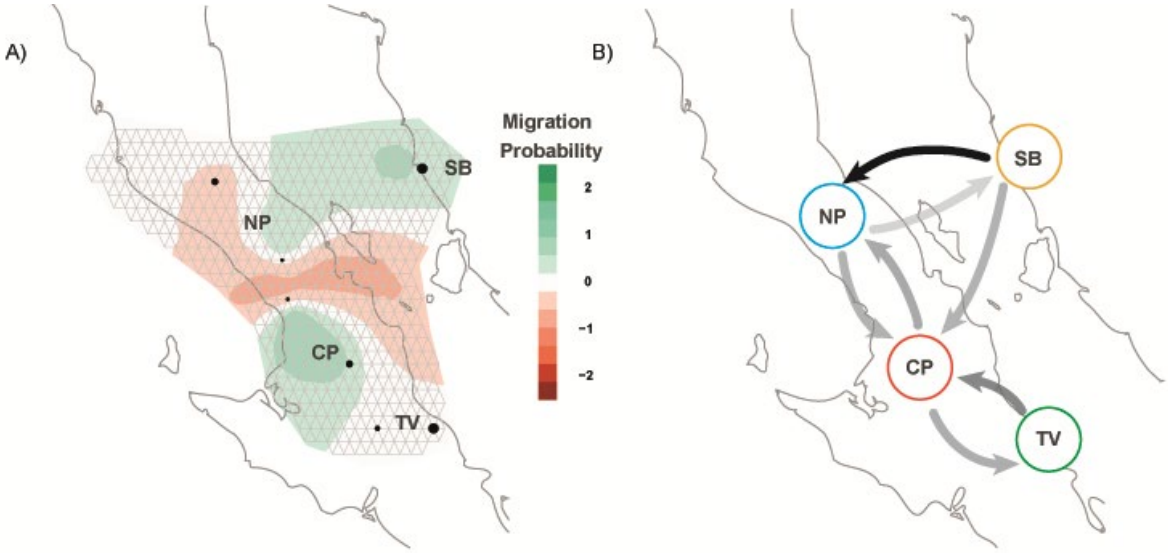

Figure 2. Predictive migration models for *Fouquieria columnaris* populations based on genetic data. A) This model is based on algorithms that estimate the effective surface of migration, in an intense green color we can see the area that estimates the highest probability of migration and while this area tends to a hot color it shows a lower probability of migration. B) In this diagram we see the four genetic populations identified, the arrows indicate possible gene flow by migration, the intensity of the solid color of the arrow tells us how likely it is that there is migration.

3. Finally, when characterising the landscape, I found that *F. columnaris* is a species sensitive to climatic conditions, responding to winter rainfall and maximum temperatures in summer as the main variables that limit its distribution.

   Although I did not find significant differences in the soil variables chosen, I found differences in climatic variability in the different populations. Where the population of the north and central Peninsula have a very similar niche, where we obtained a niche similarity value Schoener's D = 0.59, (where the value of 0 is completely different and the value of 1 shows total similarity). On the other hand, the population of the Tres Vírgenes volcano and of Sonora, showed niches with values of D = 0, showing that they are populations that have been locally adapting to different and climatic conditions due to their isolation. This shows the ability of the species to cope with climatic variation, but also shows populations pre-adapted to specific climatic conditions that

could be used for reforestation programmes in the face of sudden future environmental conditions. In addition, through niche modeling based on 380 points of presence and 686 points of absence, we project the potential distribution of *F. columnaris* to future climates of the year 2061-2080, where we find that climate predictions are not favorable for the four populations, the which will considerably reduce their area of distribution.

Therefore, these three findings together provide information that will allow decision makers to base strategies for management and conservation, allowing them to propose and prioritise efforts for the protection of the *F. columnaris* populations. Mainly for the populations of Tres Vírgenes and Sonora. In addition, the last of these according to my results contributes naturally to the intrinsic genetic diversity of the species, also this population of Sonora sustain a unique ecosystem in the continental massif, where it coexists with species of great importance for conservation such as the puma (*Puma concolor*) , the wild cat (*Lynx rufus*), the desert tortoise (*Gopherus morafkai*), the real eagle (*Aquila chrysaetos*), and plants such as the biznaga (*Ferocactus emoryi*), the sahuaro (*Carnegiea gigantea*) and the ironwood (*Olneya tesota*). In addition, *F. columnaris* represents a great value for the ethnic groups in Sonora, for the indigenous group of the Seris it manifests itself as an ancestor of their people, which is why among them they respect these trees and are prohibited felling or damaging them, something that the Mexican Government should also consider, not only for the value of the biodiversity of the species and regional biodiversity, as well as for the value in the worldview of the indigenous communities of Sonora.

Figure 3. Specimen of *Fouquieria columnaris* in the volcano of la Virgen, in the localities of Tres Virgenes.

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

1. Undoubtedly the biggest challenge that my project presented was the health emergency caused by SARS-CoV-2 that caused the COVID-19 disease. For Mexico, there was great tension, where important restrictions had to be lifted at the national level. CIBNOR, the institution to which I belong, joined the strategies to mitigate infections by COVID-19, limiting field trips and the use of laboratories depending on the number of infections that were reported monthly. Where all activity was totally restricted in the periods of July-September 2021 and January-March 2022.

2. A second problem occurred with tissue from two sampled locations, since the trees of those localities did not have leaves, and tissue for DNA samples had to be taken from the trunk and branches. This forced me to standardize a new method that would allow us to have high molecular weight DNA for those two locations, but finally it was achieved by obtaining a kit for DNA purification.

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

a) As I mentioned before, our data add arguments and solid data that will provide value for the conservation of the population of Sonora, since it represents a population with great relevance for conserving the genetic biodiversity of the species. This locality is close to the territory of the indigenous group of the Seri people, for whom this tree has a sacred value, since it is considered a predecessor of their people who according to their myths, were giants who ended up turning into trees, since they climbed to the mountains to blow against the waters of the sea trying to make them recede during a flood, for which the Seri people respect and care for them. This mountainous area has been reported as an area where poaching, clearing and illegal extraction of restricted distribution plants, specifically *F. columnaris*, have affected. Therefore, our data support the protection of this area, both to maintain the genetic biodiversity of the species, the biodiversity of species that it sustains in the ecosystem that it forms, as well as the ethnic value that it represents for the indigenous peoples of the region.

b) The population of the Tres Vírgenes Volcano, the southernmost population on the peninsula, is in the common land of Bonfíl, a rural community that supported us as guides in the volcano and which is part of the protected natural area Biosphere Reserve of Vizcaino. The residents have provided services to the reserve for sports hunting activities for bighorn sheep and taking tourists to visit the various cave paintings found in the region. In our visits and time with them, we wanted to convey the importance and value of the ecosystem that *F. columnaris* is based on, and how unique this plant is in the world and how valuable its conservation would be. For this reason, we proposed the opportunity to establish and propose guided hiking tours aimed at visiting places of the Tres Vírgenes population, which would allow a monetary income for the community, as an additional alternative to hunting and

visiting cave paintings and, in turn, would provide environmental education to the visitors.

Figure 4. Josué Martínez-Noguez collecting leaf samples.

5. Are there any plans to continue this work?

Of course, I would like to continue with the project trying to generate useful information that allows monitoring the populations that could be at greater risk in the face of climate change events. In addition, with the knowledge acquired from my field trips during this project, I have seen that the *F. columnaris* is a key species within desert ecosystems and its conservation not only involves the protection of an iconic plant but also allows the conservation of a large number of organisms (many of them at risk), in addition to the fact that it is a species with an important cultural value within the worldview of the indigenous groups that inhabit the area, for which I would like to continue delivering my work for the study and conservation of this beautiful tree of the Mexican desert, protecting an environmental and cultural heritage of my country.

In addition, I plan to be able to make the most of the data obtained, I hope to submit a second scientific article at the beginning of next year, on my niche modeling results and the response of populations to climate change. And I would like to analyse the data differently to assemble the chloroplast genome, which will make it easier to carry out work like mine in the future, and not only in the same species but in any of the Fouquieriaceae botanical family (Any product obtained in the future will take thanks to The Rufford Foundation, ID Grant: 32109-1).

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

With the intention of sharing my results I have carried out the following activities:

a) On June 20, 2022, I submitted the scientific article entitled: "Genome-wide diversity and population structure to define management units in the cirio (*Fouquieria columnaris*), an emblematic tree of the Sonoran Desert", in the journal "Biodiversity and Conservation" by the Springer publishing group, which is currently under review (last status review 24 Nov 22, Figure 5). In this work I make accessible to the scientific community the results and the data obtained on the diversity, structure and gene flow of the cirio, where I propose four Management Units defining priority populations for conservation.

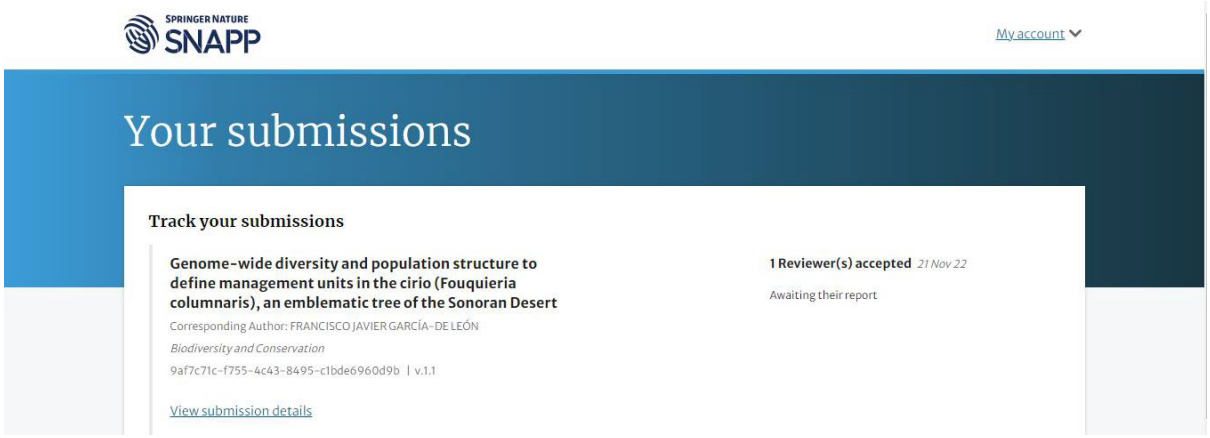

Figure 5. Screenshot of the Biodiversity and Conservation journal page, where it is shown that it is still under review, date of last access: November 24, 2022.

b) On August 17, 2022, I submitted the disclosure article entitled "La historia del cirio, lo que cuenta el ser humano y lo que cuenta su ADN " ("The history of the cirio, what the human being tells and what his DNA tells") in the Science communication magazine "SaberMás" of the Universidad Michoacana de San Nicolás de Hidalgo, México. This article is intended for the non-specialised sector of the population seeking to inform the findings of my work and making known the problems and the value of the biodiversity of the species from our genetic perspective in an accessible language, in addition to talking about the historical value it has the species and the importance of the plant to the indigenous worldview.

Figure 6. Screenshot of page where the article was submitted. The submission is still under review, date of last access: November 24, 2022.

c) I presented my work at the forum of Postgraduate Fair XXI event in Baja California Sur, Mexico, where I made known the scientific work that is being done in favor of the conservation of *Fouquieria columnaris*. The presentation was titled: " Variación genómica a través del paisaje geográfico e impacto de los eventos de cambio climático en *Fouquieria columnaris* " ("Genomic variation through the geographic and impact of climate change events on *Fouquieria columnaris*").

XXI Semana de Posgrado
Del 25 al 29 de abril de 2022
Ciencia, Tecnología y Sociedad: Una mirada desde el Posgrado

El Comité Organizador de la
XXI Semana de Posgrado en Baja California Sur
Otorga la presente

Constancia

A:

Josué Jacob Martínez Noguez

Por su participación en la modalidad de Ponencia oral intitulada:

Variación genómica a través del paisaje geográfico e impacto de los eventos de cambio climático en Fouquieria columnaris

La Paz, Baja California Sur, a 29 de abril de 2022

Dra. Gracia Alicia Gómez Anduro
Directora de Estudios de Posgrado y Formación de Recursos Humanos Centro de Investigaciones Biológicas del Noroeste S.C.

Dr. Silverio López López
Subdirector Académico y de Investigación Centro Interdisciplinario de Ciencias Marinas-IPN

Dr. Mario Cortés Larrinaga
Director del Instituto Tecnológico de La Paz

Dr. E. Alejandro Gómez Gallardo Unzueta
Director de Investigación Interdisciplinaria y Posgrado Universidad Autónoma de Baja California Sur

Figure 7. Proof of the science communication talk.

d) I gave a science communication talk in the College of scientific and technological studies of the state of Baja California to high school students from the Bahia de los Angeles community, one of the most remote and limited access of scientific information towns in the state of Baja California, where I titled the topic: "Diversidad y estructura genética del cirio para la conservación" ("Diversity and genetic structure of the cirio for the conservation").

BAJA CALIFORNIA
CECyTE Baja California

EL COLEGIO DE ESTUDIOS CIENTÍFICOS Y TECNOLÓGICOS DEL ESTADO DE BAJA CALIFORNIA
otorga el presente:

RECONOCIMIENTO

A: M.C. JOSUE JACOB MARTÍNEZ NOGEL

POR SU BRILLANTE PARTICIPACIÓN AL HABER IMPARTIDO LA CONFERENCIA
"DIVERSIDAD Y ESTRUCTURA GENÉTICA DEL CIRIO PARA LA CONSERVACIÓN"
POR PARTE DEL CIBNOR REALIZADAS EN EL PLANTEL GRUPOS BAHIA DE LOS ANGELES EL DIA 29 DE ABRIL DEL 2022

S.E.P.

ING. Julio Cesar Moreno Prado
Jefe de oficina

Figure 8. Proof of the scientific dissemination talk.

e) I made a freely accessible video on the YouTube platform, where I let you know my progress and main problems of my project as of December 16, 2021. Link: https://www.youtube.com/watch?v=POLFwLPpo88

Activities to do:

f) As I mentioned in my application, the financing would serve to support my doctoral thesis, so the results and activities carried out will be published in my doctoral thesis in Sciences on the Use, Management and Preservation of the Natural Resources of the CIBNOR, period 01-2019 to 01-2023, La Paz, Baja California Sur.

g) As I mentioned in the previous point, I seek to publish a second scientific article that involves my results on niche modeling and the possible response that populations will have to global climate change. This is based on the characterisation of the landscape that I made for the different populations. In addition to that I will try to take full advantage of the massive sequencing data that we used for this project, with which I can re-analyse the data in an alternative way to use it to assemble a reference genome of the *F. columnaris* chloroplast, which can be published as an additional scientific article. Having this assembled genome will allow us to have a genome template that will allow us to generate similar works like the one I did and not only for the *F. columnaris*, but for the entire botanical family Fouquieriaceae.

Figure 9. Landscape of Tres Virgenes, Baja California Sur.

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

I consider three important activities to take from my work. They are the following:

1. With my work, four different populations of *F. columnaris* were found that can be used as Management Units for its conservation, also with our data we found that it is a climatically sensitive species that responds mainly to climatic seasonality and maximum temperatures during summer. Previous studies have seen demographic changes in historical photographs at 77 sites, photographs that were taken in the area that I defined as the north and central population, where they found that in the last 100 years there has been an increase in the mortality of the species and a low recruitment of new individuals. However, there are no demographic records for the populations of Tres Vírgenes and Sonora, sites that would be interesting to evaluate demographically in order to monitor the status of the species in the future, especially since in my results they are shown as the areas with greater genetic diversity and the results of niche modeling show that these two populations would be the area's most strongly impacted by climate change scenarios for the year 2041-2061. For what I would propose for a new project, taking aerial photographs through the use of drones in these populations and from the images to be able to carry out bioinformatic analyses that allow the counting of individuals, estimating sizes and ages of the trees, in addition to describing the precise distribution throughout the area and those uncertainties in the images resolved by visiting the sites, which could also identify the recruitment of seedlings in the rainy season or juvenile plants that could not be seen in the photographs. This work would provide a starting point to evaluate changes and the health of populations in the future.

2. I would also propose creating a list of all existing information on the three elements of regional biodiversity, both in species, ecosystem and genetic richness that exists from scientific works for the Sierra Bacha region, Sonora and compare the biodiversity of this region with the one that exists in protected natural areas in the northwest of México. I believe, the diversity of the Sonora Mountain range will be greater, so this information would allow us to propose it again as a priority region for conservation to the Mexican Government.

3. Finally, I would propose an environmental education programme for society in general, mainly in northwestern Mexico, and make known the biodiversity found in desert ecosystems that are often underestimated. Make known the ways of life that inhabit these areas, the particularity of their ways and habits of life, the cultural value they possess and the perspective of indigenous peoples towards them, not only about *F. columnaris* but also to present it as what it is, an ecosystem. This will allow the creation of environmental education and awareness in society in general, which I believe could help conserve not only the biodiversity of *F. columnaris*, but also the ecosystems it supports.

Figure 10. Landscape of Sierra Bacha, Sonora

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?

- I used the logo and thanked The Rufford Foundation in the slides used in the science communication talks described above.

- I also used the logo and thanked The Rufford Foundation in the informative video of my progress that I published on YouTube.

- In addition, both publications that I have in review status have a special section where they thank The Rufford Foundation for the funding granted.

- Finally, I would like to inform you that the rest of the products that are planned to be carried out will take their respective thanks to the foundation.

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

Dr. Francisco Javier García de León. As a conservation genetics expert, he assisted and supervised my performance in genetics-oriented bioinformatics analysis and laboratory work. In addition to helping me in all the work that involved the field trips.
Dr. José Luis León de la Luz. Being an expert in the regional flora, he gave me his support to interpret my results and to be able to explain the processes that the species could be going through.

Dr. Rafael Hernández Guzmán. He helped me process the environmental data and carry out the projections and modeling of the species niche, both present and future scenarios.

10. Any other comments?

I want to use this space to thank all the support provided for The Rufford Foundation and apologise for the delay in the completion of the project, there were several events that ended up delaying my goals, but I appreciate that they always had an understanding attitude in the face of my adverse circumstances. I hope to continue working with you in the future and I hope you are happy with the results achieved. I also want to thank the people who supported me during this project, the Biol. Víctor Gelasio Sanches, director of the protected natural area "Valle de los Cirios", the Deputy Director Dr. Rosalía Ávalos of the "Bahia de los Ángeles, Canales de Ballenas and Salsipuedes" Reserve, for their comments and support during the project. Also, to Dr. Alberto Arnaud Franco, Dr. Alejandro Carbajal Saucedo, M. at C. Alexsandre Gutiérrez, M. at C. Anayeli Márquez and the guides Oscar Castañeda and Martín Salgado for their support during the field trips.

Figure 11. Landscape of Sierra de San Francisco, Baja California Sur.