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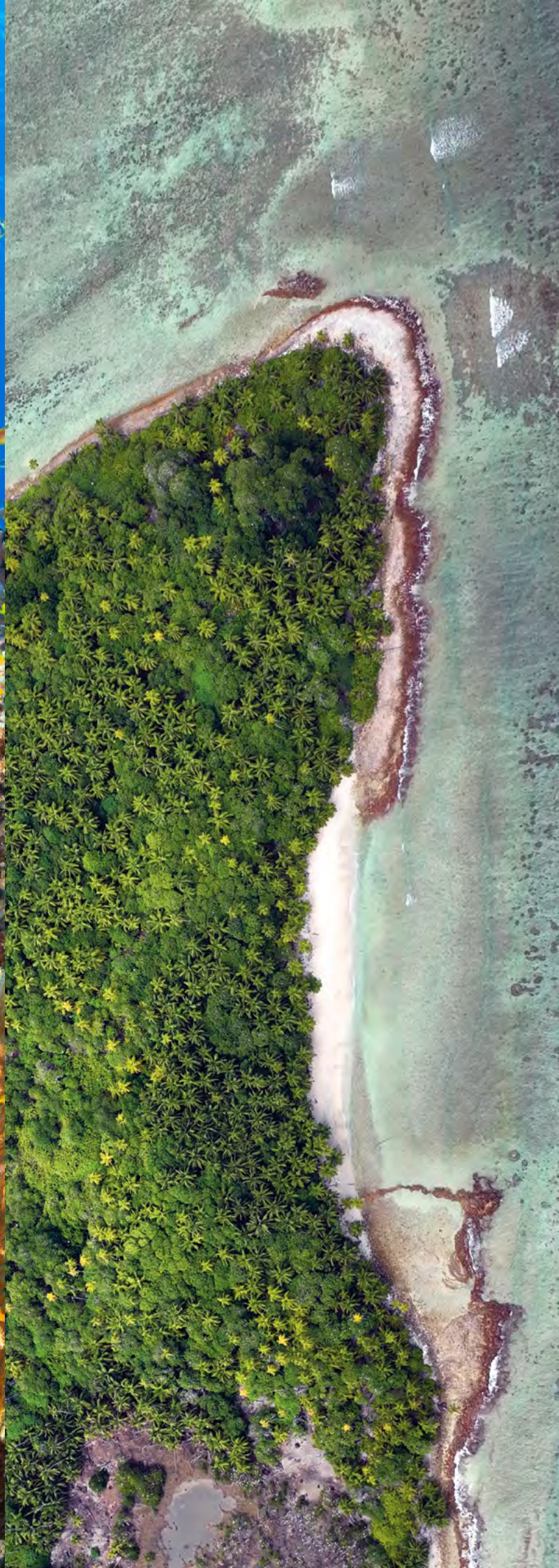
# Marine Science 2022



2021 2030 United Nations Decade of Ocean Science for Sustainable Development

# Contents

# Introduction

Humanity has, since the dawn of civilisation, looked to faraway places with wonder, excitement and curiosity. That yearning for discovery and exploration remains part of the human condition to this day. In the last 70 years we have made great strides in space exploration so that, whilst once we looked to the moon, today we look to Mars and beyond.

That need to explore and understand is very much part of my family's DNA; but instead of looking upward, I am drawn to look closer to home. The ocean is a vital part of the Earth's engine which has, for generations, been overlooked, mistreated and neglected. But my family's foundation is determined to do what we can to correct this.

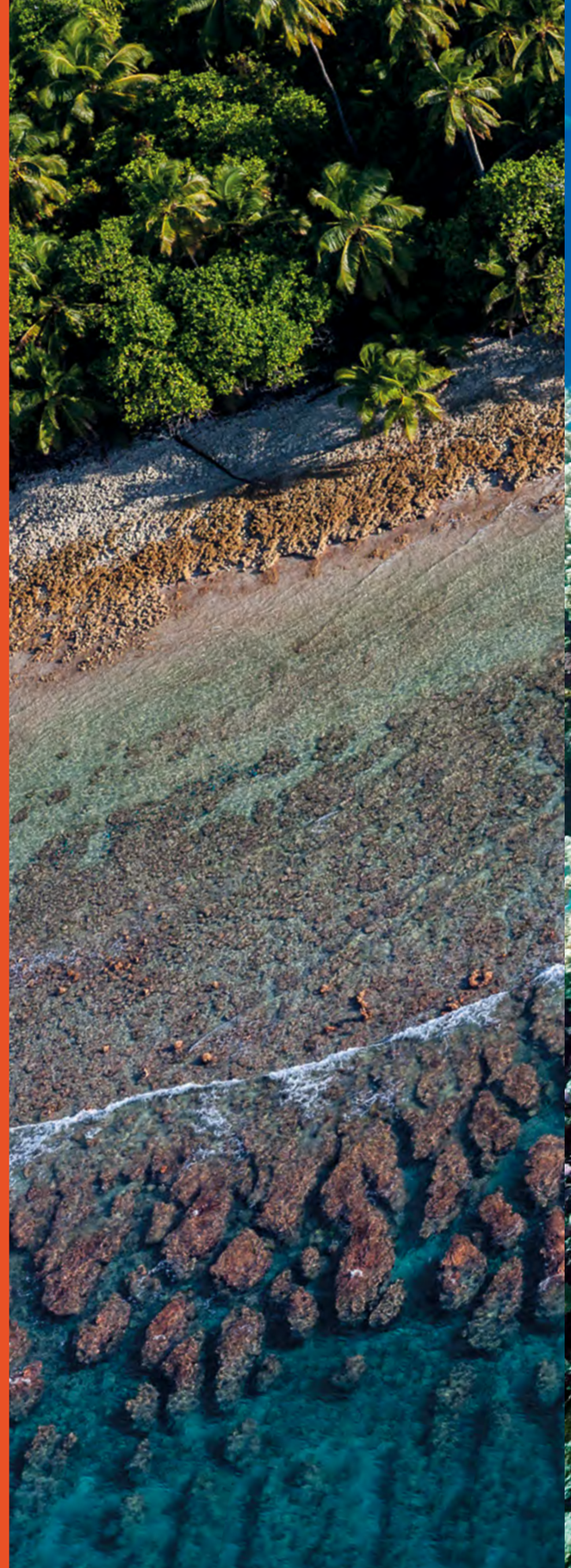
That is why, working with partners around the globe, the Bertarelli Foundation has helped create marine protected areas in some of the most exploited oceans and seas. We have played a part in the protection of over 2,000,000 km$^2$ of ocean in every major basin on the planet.

But if these protections are to be targeted in the places that need them most, and if these areas to be properly managed, then it is vital that the most up-to-date science is available to local communities, policy makers and conservationists.

Recognising that the Indian Ocean is one of the most understudied oceans and that there is less scientific capacity in the region, the Bertarelli Foundation has developed a collaborative and interdisciplinary programme of marine science research. This brings together experts from the world's leading institutions to work together to advance science which can be applied to marine conservation.

Each year, I never fail to be impressed by the work of the programme's growing team of scientists, and this year is no exception. Scientists spent longer in the field than ever before, and using valuable data, published an impressive body of high impact scientific papers. Thanks to the hard work of an incredible team of scientists it is clear that the outcomes of this work will be felt not just in the Indian Ocean, but all around the world.

**Ernesto Bertarelli**



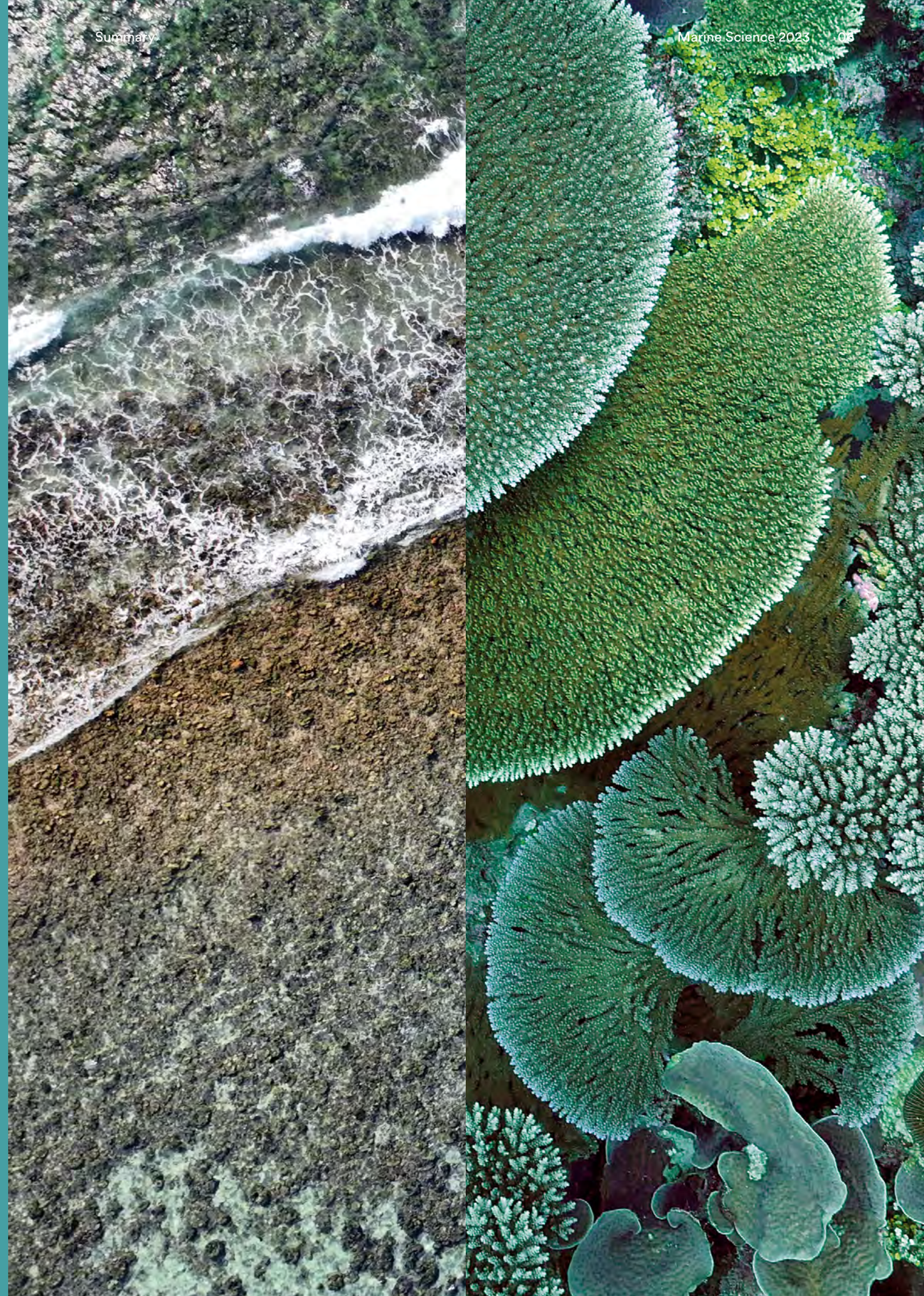


# Summary

## Looking back at our busiest ever year

2022 was the busiest year for the programme since its inception in 2017 with researchers spending more days in field sites across the Indian Ocean than ever before. Thirteen teams spent a total of 2,225 days gathering data. These expeditions included ships at sea deploying diving teams and oceanographic equipment, seabird researchers camped out for weeks on remote islands, and months of work for researchers tracking turtles over an entire nesting season. Notably the programme collaborated with Indian Ocean expeditions led by other philanthropic groups including REV Ocean and Monaco Explorations. Fieldwork was carried out in the Chagos Archipelago, La Réunion, Maldives, Mauritius, New Caledonia, Rodrigues, Seychelles, Sri Lanka, Western Australia and as far afield as Tetiaroa in French Polynesia.

The Bertarelli Foundation's marine science programme continues to publish high quality science in peer-reviewed journals. In 2022, a further 29 scientific papers were published, 21 in journals with good or excellent impact factors, bringing the total number of scientific papers published by the programme to 149.



*© REV Ocean*

Capacity building is core to the programme, and we celebrated two PhD, eight MSc, and six BSc students completing their research with us in 2022. There are 30 students still in training (22 PhD and eight MSc), and it was particularly exciting to see four new PhD students and three Masters students from India, the Seychelles, Sri Lanka, and La Reunion join the programme in 2022. As part of our commitment to increase opportunities for scientists from the Indian Ocean, we equip scientists with broader skills, and this year saw students participate in national and international conferences, including a high-profile event for the next generation of ocean leaders at the UN Ocean Conference in June. This was organised in partnership with the UN Decade of Ocean Science for Sustainable Development which saw some of our early career scientists share the conference stage with established scientists and experts in their field.

The application of scientific research to marine management and policy is another key objective of the programme. We produced two reports in 2022, one summarised the management and policy relevance of our research to the Foreign Commonwealth & Development Office and the second provided recommendations arising



from a stakeholder workshop on Illegal Unreported and Undocumented fishing in the region. Based on the substantial body of research from the programme that demonstrates the importance of rewilding tropical islands in the Indian Ocean, we have been building collaborations to share our expertise and initiate the practical implementation of this priority conservation action.

Our focus on science communication has seen us continue the quarterly webinar series which attracts a global audience and covers a wide range of topics. Ocean Matters, our successful marine science podcast, won the ‘People’s Voice’ podcast award in the environment and sustainability category of The Webby Awards. For the first time, we delivered a successful training workshop for 15 environmental journalists from the Indian Ocean region in the Maldives, increasing media coverage and capacity for ocean stories in the region. Scientists across the programme gained considerable media coverage for their papers and delivered a wealth of conference posters and presentations.

# 2022: The Year in Numbers

**73** researchers from **22** institutions and **11** countries funded

**33** Indian Ocean regional institutions collaborating

**2** PhD, **8** MSc and **6** BSc students completed

**4** Ocean Matters podcast episodes broadcast

**149** scientific papers published by the programme to date

**2,225** people days in the field over 13 expeditions

**15** journalists from **11** countries in the Indian Ocean region trained, generating **19** articles

**30** students currently in training (22 PhD, 8 MSc)

**4** new PhD students, and **3** MSc students from India, the Seychelles, Sri Lanka, and La Reunion

**9** programme scientists in partner expeditions with REV Ocean and Monaco Explorations

**29** scientific papers published in 2022, **6** in journals with Excellent impact factor (>10), and **15** in journals with Good impact factor (>3)

**169** people attended **3** webinars from **22** countries

# Regional Partners


## Non-regional partners

PRIFYSGOL BANGOR UNIVERSITY
DEAKIN UNIVERSITY
UNIVERSITY OF EXETER
Lancaster University
NOVA UNIVERSIDADE NOVA DE LISBOA
UNIVERSITY OF OXFORD
UNIVERSITY OF PLYMOUTH
Stanford University
University of St Andrews
Swansea University Prifysgol Abertawe
VIRGINIA TECH
ZSL Zoological Society of London

# Projects



## Seabird Connectivity

Seabirds are oceanic voyagers – some species can travel thousands of miles over open ocean, further than any other animal. However, they also have strong attachments to particular areas, returning repeatedly to breed and forage in the same place. The question of where they go, and why, remains one of the most enduring mysteries in science. Human activities have negatively impacted seabird populations globally and a loss of breeding colonies has led to population collapse and fragmentation. In the tropical Indian Ocean, the remaining breeding colonies are frequently restricted to remote and undisturbed oceanic islands.

The connection of different seabird populations in the Western Indian Ocean, and their genetic relatedness, is key to seabird conservation. Isolated populations are less resilient than inter-connected ones, and the amount of movement between sites will influence the recolonisation of islands which have been restored. Identifying sites where seabirds and their prey interact in the vast open ocean helps inform how areas are protected and managed.

This multi-team project is working to understand connectivity among seabird communities at the scale of the Western Indian Ocean, and also more locally within the Chagos Archipelago.

## Western Indian Ocean

**Lead investigators: Dr. Malcolm Nicoll,** *Zoological Society of London,*
**Dr. Matthieu le Corre,** *Université de la Réunion*

The Western Indian Ocean supports in the region of 19 million seabirds of 30 species across 54 individual sites, and is one of the most important aggregations of tropical seabirds in the world. Different seabird colonies are connected through the movements of individual birds between sometimes remote oceanic islands. This project assesses how breeding colonies of six, ecologically contrasting seabird species are connected within the Western Indian Ocean by establishing the rate of gene flow between colonies. This will identify discrete 'conservation or management units' which are themselves made up of one or more connected colonies.

The team are also exploring what encourages the birds to move to other islands. It is doing this by tracking bird movements using satellite tags and identifying areas that are foraging hotspots for breeding red-footed boobies (Sula sula) and wedge-tailed shearwaters (*Ardenna pacifica*). From these data the researchers can propose what the underlying environmental drivers are that are helping to create these hotspots. This then guides how, and where, seabirds can be protected in the region.

## Chagos Archipelago

**Lead investigator: Dr. Steve Votier,** *Heriot Watt University*

The Chagos Archipelago is the most isolated seabird breeding community in the Indian Ocean with approximately 700,000 seabirds of 18 different species. However, we currently know nothing about the connectivity among seabird colonies within the archipelago, nor if, and how, they link with the wider Western Indian Ocean.

This multidisciplinary research project focusses on red-footed boobies (*Sula sula*) and wedge-tailed shearwaters (*Ardenna pacifica*). It combines observations of seabird movement and ecology together with data obtained from echosounders of the birds' fish prey, oceanography and terrestrial habitat maps to determine what drives the movement of these seabird species on land and at sea. Importantly, it seeks to determine whether immature seabirds have a role in connecting colonies.

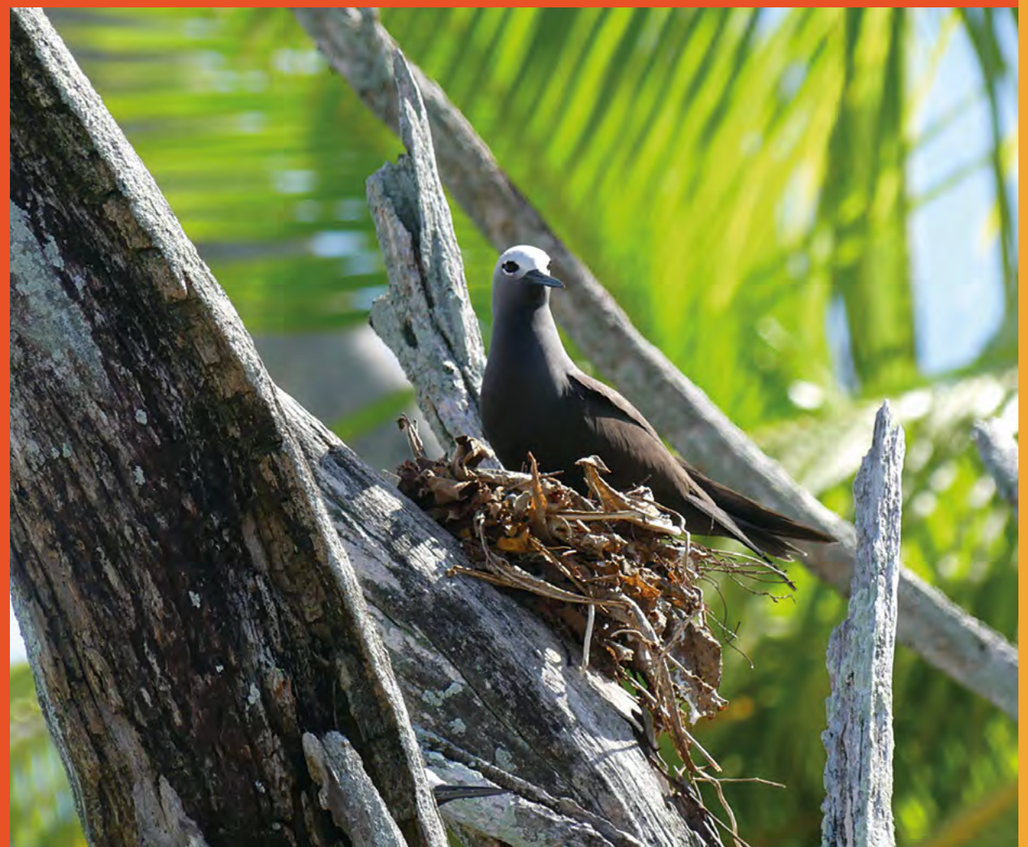
Researchers are using the Chagos Archipelago as a model system to answer questions about fine-scale movement and dispersal of seabirds, which can then be applied to other seabirds around the Indian Ocean region.

# Island Reef Connections

**Lead investigator: Prof. Nick Graham,**
*Lancaster University*

When seabirds forage at sea, they deliver large quantities of nutrients back onto the islands on which they roost and breed. The introduction of the invasive black rat (*Rattus rattus*) has caused the decimation of seabird populations on the islands it had invaded. With seabirds gone, the precious nutrient subsidies from their guano no longer percolates through the islands to fertilise adjacent reefs and support the fish and other animals that live amongst them. The loss of these supplementary nutrients affects the resilience and recovery rate of reef communities in the face of other human anthropogenic factors, such as climate change.

Seabird guano boosts nutrient cycles and affects island ecosystems, coral reef ecology, and how coral reefs form and change over time. As expected, these important nutrients can increase plant biomass on land and the abundance of land invertebrates. Research by this team has also shown how seabird guano can enhance coral reef productivity, biodiversity, and how they work. The team are conducting this research in the Chagos Archipelago, Seychelles, and French Polynesia, incorporating into their study sites, islands with and without rats, and those with ongoing rat eradication programmes. The research will help inform tropical island conservation and restoration efforts all around the world.





# Multi-scale Oceanographic Modelling

**Lead investigator: Dr. Phil Hosegood,**
*University of Plymouth*

Animals use ocean currents and changes in water properties to move and feed. Particles, including larvae, microplastics and contaminants, are suspended in the water and drift at the mercy of these currents. The ocean is a tremendously complex environment, with currents arising from a myriad of mechanisms such as tides, wind, sea surface elevation and internal density differences that each evolve at different timescales. Added complexity arises because of natural global climate patterns or when these currents meet seamounts and islands, and also because of anthropogenic change. The truly effective management of the marine environment therefore requires an understanding of how animals throughout the food web exploit, and respond to, changes in water properties and currents.

This complex project combines oceanographers, physicists, and biologists to better understand how ocean currents influence the distribution and behaviour of threatened species such as manta rays in the Indian Ocean. The development of oceanographic numerical models that simulate conditions throughout the Western Indian Ocean helps understand which factors create biodiversity hotspots that require the highest levels of protection.

*Bertarelli Foundation*

## Sea Turtle Conservation

**Lead Investigator: Prof. Graeme Hays,**
*Deakin University*

Sea turtles typically undertake long migrations from their nesting sites to their foraging areas and are increasingly threatened by fishing, shipping, plastic pollution, and climate change. This long term sea turtle research programme is investigating sea turtle biology and behaviour, and how they can be used as indicators of where their habitats, such as seagrass meadows, might be located. This includes addressing long-standing ecological questions, such as how sea turtles navigate during ocean migrations and how the size and location of their foraging sites shape their fine-scale movements.

Satellite tracking of adult nesting female sea turtles identified the importance of the Chagos Archipelago for green (*Chelonia mydas*) and hawksbill (*Eretmochelys imbricata*) turtles in the Indian Ocean. These tracking data are being used to identify where the turtles go after nesting, for example to the Seychelles or other countries in the region. While all sea turtles nest on sandy beaches, at the end of the breeding season each species then travels to its preferred habitat – seagrass beds for green turtles, and reef habitat for hawksbill turtles. Therefore, as well as identifying key areas for conservation, the tracking of sea turtles' movement shows where these habitats are distributed across the Indian Ocean. Tags using the latest technologies are also being used to assess the movements of juvenile turtles and how they travel up and down the water column. Data suggest that both adult green and hawksbill turtles are foraging in deeper water than previously thought, changing current thinking on their foraging ecology. This research is helping to inform regional policies relating to sea turtle management and conservation.



## Cetacean Refuges

**Lead investigator: Dr. Clare Embling,**
*University of Plymouth*

Cetaceans (whales, dolphins and porpoises) are charismatic yet vulnerable marine animals that play a vital ecological role in our ocean. Many whale populations are still recovering from historic whaling and cetaceans worldwide are threatened by fishery bycatch, ship strikes and increasing noise pollution. Cetaceans are highly mobile and tend to travel huge distances. Their movements are often determined by changing oceanography, the distribution and concentration of their prey, and by the life cycle such as seasonal breeding migrations. Successful management, particularly in the face of impacts such as bycatch, is dependent on a proper biological understanding.

The central Indian Ocean may be one of the last tropical refuges where cetaceans remain protected from human impacts, yet unfortunately we know very little of their diversity, distribution, and abundance. This project is surveying cetaceans in this poorly-studied region, with a focus on the Chagos Archipelago, using sightings and acoustic surveys and closely linked with regional capacity building.

# Shark Genomics Seascapes

**Lead Investigator: Prof. Barbara Block,**
*Stanford University*

Illegal fishing in the Indian Ocean has drastically decreased reef shark populations and severely impacted ocean ecosystems. The loss of these important species leads to an imbalance in the oceanic food web, leading to a decline in coral reef health and the loss of other marine organisms that depend on healthy reef environments. Limited surveillance capacity, and insufficient cataloguing of current shark populations, has made it difficult to prioritise areas for conservation or measure success of existing conservation efforts.

Advanced DNA sequencing presents an opportunity to identify sub-populations of reef sharks across the entire Indian Ocean region. This study is working to create a Genomic Seascape, or comprehensive DNA catalogue, of reef shark populations within the Indian Ocean which will enable enhanced tracking of shark populations. By matching genetic signatures of illegally fished sharks with those of catalogued populations, the location of areas that are being targeted by illegal fisheries can be identified. These Genomic Seascapes can then be used as a management tool once lower cost, portable sequencing technology and genetic testing capacity is introduced at key fishing ports in the Indian Ocean.



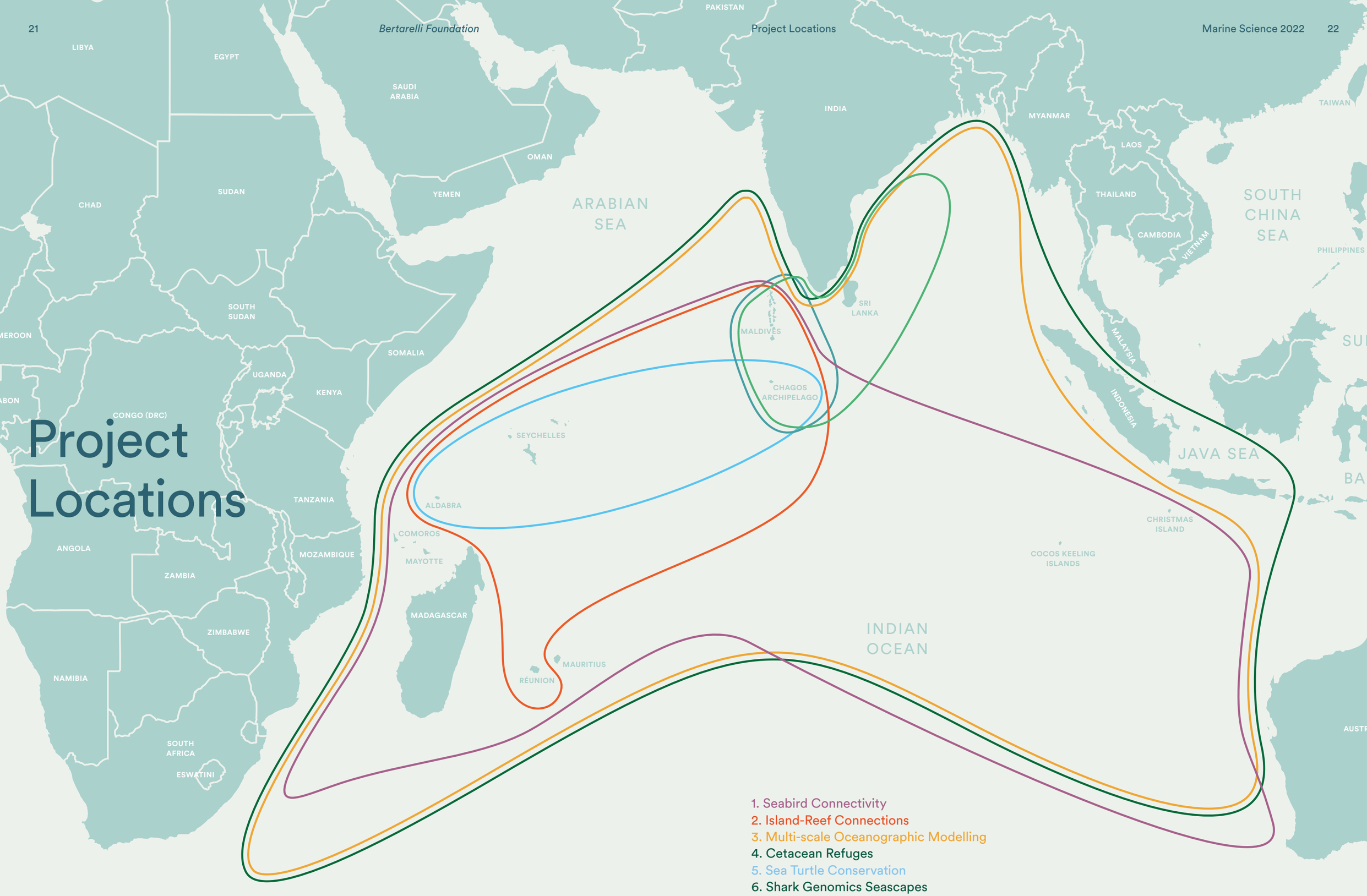
# Human Dimensions of Illegal, Unregulated and Unreported Fishing

**Lead Investigators: Dr. Ana Nuno,** *Nova University*,
**Dr. Asha de Vos,** *Oceanswell*

Illegal, Unreported and Unregulated (IUU) fishing is a global issue that threatens fish populations, marine habitats, and the livelihoods and food security of vulnerable communities. This type of fishing often targets healthy fish populations in marine protected areas and undermines their effectiveness.

While there has been considerable progress on new technology and enforcement practices to tackle IUU fishing, there have been limited studies to date that focus on understanding why people do it. Working with communities in Sri Lanka and India that fish across the north and central parts of the Indian Ocean, the project is investigating what motivates people to fish illegally. With a research team that includes social scientists and management and policy experts, the findings of the project will be used to understand what determines whether people comply or not with legislation, and what deterrents are likely to be most effective. Combined with enforcement, these strategies can then be applied across the entire Indian Ocean region to reduce levels of illegal fishing, particularly in marine protected areas.

# Project Locations




1. Seabird Connectivity
2. Island-Reef Connections
3. Multi-scale Oceanographic Modelling
4. Cetacean Refuges
5. Sea Turtle Conservation
6. Shark Genomics Seascapes
7. Human Dimensions of Illegal, Unregulated and Unreported Fishing

# Scientist Spotlight

Marine scientists are at the heart of science innovation and are key to translating scientific conclusions into improved management practices. Increasingly, they are also playing a vital role in the move towards sustainable development of the ocean. Through the collaborative and interdisciplinary approach of the Bertarelli Foundation's Indian Ocean marine science programme, there has been a real focus on providing academic training through undergraduate and postgraduate programmes.

Since the programme began in 2017, we have trained a total of 90 students. In 2022, two PhD (Dr. Mike Williamson and Dr. Nick Dunn), eight MSc and six BSc students graduated after contributing towards projects delivered within the programme, and there are a further 30 in the programme at the start of 2023 (22 PhD and eight MSc students). As part of our commitment to regional capacity building, four new PhD students and three Masters students from India, the Seychelles, Sri Lanka, and La Réunion joined the programme in 2022.

Students were lead authors of six of the scientific papers published this year, presented at many national and international workshops and conferences, as well as participating in fieldwork.

# Principal Investigators

## Prof. Barb Block

*Charles and Elizabeth Prothro Professor of Marine Sciences, Professor of Oceans and Senior Fellow at the Woods Institute for the Environment, Stanford University, USA*

**Lead: Shark Genomics Seascapes**

**"Human technology has made it to Mars. We are transmitting gorgeous pictures from it. Yet we have not explored our own planet. Two-thirds of it is covered with oceans that are still mysterious places."**

Barb's research aims to monitor the Indian Ocean region's sentinel species using tagging technology. Using a range of techniques, including genomics and biologging, she focuses on how large pelagic fish use the open ocean.

Barb and her team have pioneered the development and deployment of electronic tags on tunas, billfishes, and sharks around the world. Her research has led to an increase in our understanding of movement patterns, population structure, physiology and behaviours of pelagic fish and sharks, enabling us to better inform conservation. Barb and her team also study bluefin and yellowfin tunas from a whole organism to genome perspective with interests in the physiology of migrations, thermogenesis, cardiac biology, energetics, and reproduction.

## Dr. Matthieu le Corre

*Director of the Laboratory of Ecology and Marine Research, Université de La Réunion*

**Co-lead: Seabird Connectivity**

**"Seabirds can travel for thousands of kilometres in the high seas but many species return to their place of birth for breeding. This ability to travel far but with very strong philopatry are the two components of the *seabird paradox*. In a world that is changing rapidly, this may also make these species particularly vulnerable to human impacts."**

Matthieu's research is focused on the foraging and migratory behaviour of seabirds in the Indian Ocean and the identification of marine biodiversity hotspots in the region. Seabirds are powerful indicators of ocean health because they often feed on prey that tuna and other species drive to the ocean's surface, so revealing the location of highly productive areas where prey species are concentrated. Matthieu is collaborating with population genetics experts to investigate the level of connectivity between seabird colonies of the Indian Ocean and beyond to the Pacific Ocean which will inform conservation plans and island restoration strategies.

## Prof. Nick Graham

*Royal Society University Research Fellow and a Chair in Marine Ecology at Lancaster University, UK*

**Programme Lead: Island-Reef Connections**

**"Eradicating invasive rats and restoring habitat on tropical islands will help increase seabird populations, and the nutrients they provide influence both island and coral reef structure and ecology."**

Since 2004 Nick has been working on the ecology and management of coral reefs in the Indian Ocean and since 2015 he has been studying the role of seabirds in influencing coral reef ecology. He tackles large-scale ecological coral reef issues under the overarching themes of climate change, human use, and resilience. Nick and his team have assessed the impacts of climate induced coral bleaching on coral reef fish, fisheries, and ecosystem stability. He has studied the patterns and processes by which degraded coral reefs recover, and how this can be influenced by management. He has worked extensively on the ecological ramifications of fishing and closed area management. Increasingly he works with social scientists linking social- ecological systems for natural resource assessment and management.

## Dr. Asha de Vos

*Director, Oceanswell, Sri Lanka, Adjunct Research Fellow at the Oceans Institute of the University of Western Australia*

**Co-Lead: Human Dimensions of Illegal, Unregulated and Unreported Fishing**

**"Every coastline needs a local hero."**

Asha is a marine biologist, ocean educator, and pioneer of long-term blue whale research within the Northern Indian Ocean. Asha is the first and the only Sri Lankan to have a PhD in marine mammal research and established Sri Lanka's first marine conservation research and education organisation Oceanswell in 2017. Asha continues to research blue whales and other cetaceans, and also addresses other conservation issues such as the social drivers of illegal fishing and the impacts of marine disasters.

Asha passionately believes that the health and future of coastlines depends on local people and is working to build more equitable involvement in marine science in the Global South.

## Dr. Nick Dunn

*PhD Student (Graduated in 2022), Imperial College London and Zoological Society of London, UK*

**Student: Marine Predators and Fisheries (2017–2021)**

**"The ability to detect species from single water samples has the potential to revolutionise marine monitoring, particularly for rare and elusive species like sharks and rays. Nick's work is helping to conserve these incredible species that are so important for the health of our oceans."**

Nick's PhD research used environmental DNA (eDNA) to monitor biodiversity in marine ecosystems and developed eDNA methods for the detection and monitoring of marine animals. Because of the non-invasive nature of this technology, species do not need to be observed or captured for their presence to be recorded, making the technique ideal for the study of elusive and cryptic species such as sharks and rays. Nick's research assessed the applicability of eDNA methods for monitoring reef sharks in the central Indian Ocean, and compared results against more established monitoring methods such as diver surveys and telemetry.

# Early Career

## Lasuni Gule-Godage

*MPhil student, Ocean University of Sri Lanka*

**Student: Human Dimensions of Illegal, Unregulated and Unreported Fishing**

**"Ocean conservation can only be successful if we consider the needs of those most dependent on it. That's why it's vital to understand the human dimensions of illegal fishing and integrate that understanding into marine policy management."**

Lasuni's research project began in 2022 and focuses on the human dimensions of illegal fishing, including ascertaining socioeconomic reasons for non- compliance and evaluating the deterrence effect of conservation management and policy. Her research interests relate to sustainability in marine ecosystems and socio-ecological aspects of conservation and marine policy management.



## Jyodee Sannassy Pilly

*PhD student, Bangor University, UK*

**Student: Reef health (2017–2023)**

**"My research is helping us to better understand remote reefs and how they compare to the degraded reefs in many other areas in the Indian Ocean to help improve their management."**

Jyodee started her PhD in 2018 and is due to graduate in 2023. Her research is on the growth, cover and populations of bottom dwelling invertebrates, such as corals, sea fans and sponges, of remote reefs in the central Indian Ocean. These reefs have been monitored since 1978 and assessing the changes in coral reef benthic communities has proved to be vital in understanding the future condition and trajectory of the marine environment in the present warming world. Jyodee's research use isolated reefs as an ocean observatory, as remoteness from direct human impacts provides a benchmark against which other reefs can be assessed.

## Holly Stokes

*PhD student, Swansea University, UK*

**Student: Sea Turtle Conservation**

**"The Chagos Archipelago supports all life stages of two turtle species and provides a great opportunity to study immature turtles – a currently understudied life stage. Our research in the coves of Diego Garcia shows the highest densities of immature hawksbill turtles in the world."**

Holly began her PhD in 2020, and is using a range of technologies, including remote cameras and drone surveys, to conduct research on sea turtle ecology in the Chagos Archipelago. Estimating the total number of individuals of a population, along with breeding success, is vital to understanding the ecosystem role of the two species (green and hawksbill) and their population dynamics. Holly has conducted long-term field research to observe nesting behaviour and hatchling emergence and investigate how variations in beach zone, seasonality, beach vegetation, predation and temperature influence their success. She has also been exploring how sea level rise may affect turtle nesting beaches and how rising temperatures may impact nesting conditions.

# Our Impacts in 2022



# Science Impacts

This year saw a further 28 scientific papers and one book chapter published by scientists in the marine science programme, bringing the total number of published papers to 149 since 2018. Of the 28 papers published in 2022, six were published in journals with an “excellent” impact factor (>10) and a further 14 in journals with a “good” impact factor (>3).

## Diving into the vertical dimension of elasmobranch movement ecology

**Andrzejaczek, S.**, plus 182 co-authors including programme scientists **Jacoby, D., Chapple, T. K., Ferretti, F., Gollock, M., Llewellyn, F., Schallert, R., Tickler, D., Block, B., Curnick D.** (2022) *‘Diving into the vertical dimension of elasmobranch movement ecology’* – **Science Advances** *https://doi.org/10.1126/sciadv.abo1754*

Knowledge of the three-dimensional movement patterns of elasmobranchs (sharks, rays and chimeras) is vital to understand their ecological roles and their exposure to human pressures. To date, comparative studies among species at global scales have mostly focused on horizontal movements, however, threats to elasmobranchs vary with depth, as do the techniques used to monitor them. This study compiles the first global synthesis of vertical habitat use by elasmobranchs from data obtained by deployment of 989 biotelemetry tags on 38 elasmobranch species.

Elasmobranchs displayed high variability within and between species in their vertical movement patterns. For example, the oceanic whitetip shark (*Carcharhinus longimanus*) spent most of its time in the surface 50m, reef manta rays (*Mobula alfredi*) showed different diving patterns in different regions whilst whale sharks (*Rhincodon typus*) were the deepest diving species at 1,896 m. Substantial vertical overlap was observed for many elasmobranchs living in the upper open ocean (defined as sea depths down to 200m). This increases the likelihood these species will overlap spatially, biologically interact, and share similar risk to threats that vary on a vertical gradient.

This study shows the importance of incorporating vertical as well as horizontal movement into global management and monitoring strategies for elasmobranchs. This includes fisheries management and bycatch mitigation considering how these fishes move vertically. Monitoring programmes need to develop more affordable tags, increase geographic coverage of studies to include developing nations, and of under-represented species.

## Travel routes to remote ocean targets reveal the map sense resolution for a marine migrant

**Hays, G.C., Atchison-Balmond, N., Cerritelli, G., Laloë, J.O., Luschi, P., Mortimer, J.A., Rattray, A.,** and **Esteban, N.,** *'Travel routes to remote ocean targets reveal the map sense resolution for a marine migrant'* – **Journal of the Royal Society Interface**
*https://doi.org/10.1098/rsif.2021.0859*

In 1873, Charles Darwin marvelled at the ability of sea turtles to find isolated island breeding sites, but the details of how sea turtles and other animals navigate during these migrations remains perplexing. To help solve this long-standing enigma, this study tracked 22 critically endangered hawksbill turtles (*Eretmochelys imbricata*) after they had finished nesting in the Chagos Archipelago all the way to their foraging grounds in other parts of the Indian Ocean. The team considered the likely resolution of any mapping sense used in migration, based on the navigational performance across different scales (tens to thousands of kilometres).

The studies found that these turtles often followed circuitous paths when migrating short distances. For example, one turtle travelled 1,306.2 km, seven times the beeline distance to the target foraging ground of only 176.4 km. When off the beeline to their target, turtles sometimes corrected their course both in the open ocean and when encountering shallow water. The results provide compelling evidence that hawksbill turtles only have a relatively crude map sense in the open ocean, almost certainly using a geomagnetic map that only corrects them when they are a long way off route. The existence of widespread foraging and breeding areas on isolated oceanic sites points to target searching being common in sea turtles in the final stages of migration.

Hawksbill turtles typically migrate much shorter distances than green turtles, around 150 km compared to up to 5,000 km. An earlier paper about tagged green turtles in 2020 by the authors provided some of the best evidence to date for the ability of turtles to reorient in the open ocean, but similarly only at a crude level. Sea turtles therefore locate isolated targets through a roughly target-oriented ocean crossing, open ocean course corrections and then localised search closer to the target. Sea turtle navigational abilities are therefore far from perfect but may simply be as good as possible within the constraints of their sensory ability.



## Monitoring shallow coral reef exposure to environmental stressors using satellite earth observation: the reef environmental stress exposure toolbox

**Williamson, M.J., Tebbs, E.J., Dawson, T.P., Thompson, H.J., Head, C.E.I., Jacoby, D.M.P.** (2022) *'Monitoring shallow coral reef exposure to environmental stressors using satellite earth observation: the reef environmental stress exposure toolbox (RESET)'*
– **Remote Sensing Ecology and Conservation**
*https://doi.org/10.1002/rse2.286*

This paper is led by one of the programme's PhD students and uses satellite technology to monitor some of the world's most remote and vulnerable coral reefs and, for the first time, observe multiple climate change related stressors from open-source data. The team created a Reef Environmental Stress Exposure Toolbox (RESET) from the readily available Google Earth Engine geospatial processing platform.

Using the satellite data to collate nine environmental variables (cloud cover, current, depth, salinity, wind, and four sea surface temperature-based metrics), they were able to map out combinations of environmental stressors caused by climate change and monitor the reefs all-year-round.

Data were used from 3,157 coral reef locations around the globe, including twelve major ocean ecosystem regions. These included the Chagos Archipelago, coral reefs off the coast of the Gilbert Islands in the South Pacific and in the Red Sea. To test the capabilities of RESET, occurrences of El Niño were used to test the toolkit's ability to capture variability during these extreme climatic events which are well known for damaging reefs by coral bleaching. By comparing coral reefs at times when El Niño occurred with 'usual' conditions the study found that depth, degree heating weeks, and sea surface temperature anomalies were the potential drivers of inter- and intra-region variation in environmental stress exposure.

RESET provides an open access, easily interpretable set of tools and associated indices for monitoring environmental stress exposure on coral reefs and is designed to inform conservation and management decisions. As such, RESET has broad potential to assist in the monitoring of imperilled coral ecosystems, in particular, those that are remote or inaccessible.

# Management Impacts



The Marine Science programme prioritises conducting science that has direct applications for management. Here we provide an example to demonstrate how our research is relevant and used for improved marine management.

## Important bird and biodiversity areas

Seabirds are declining globally and are one of the most threatened group of birds. The western Indian Ocean supports ~19 million breeding seabirds of 30 species, making it one of the most significant tropical seabird assemblages in the world. The Important Bird and Biodiversity Area (IBA) programme is a method of identifying the most important places for birds based on globally agreed standardised criteria and thresholds.

The Chagos Archipelago has around 280,000 pairs of breeding seabirds from 18 species per year. Four species breed in IBA qualifying numbers: tropical shearwater, red-footed booby, sooty tern (*Onychoprion fuscatus*) and lesser noddy (*Anous tenuirostris*). Data from 1975 and 1996 were used to designate 10 islands as terrestrial IBAs. In 2020, based on more recent data, programme scientists (Carr *et al.*, 2020) redefined the IBAs into four island clusters: Eastern Diego Garcia island group, eastern Peros Banhos island group, Nelson Island, and Western Great Chagos Bank island group (figure 1). They recommended that IBA monitoring should be done every four years, with two breeding seabird censuses of all islands undertaken six months apart, one in January/February and the other in July/August.



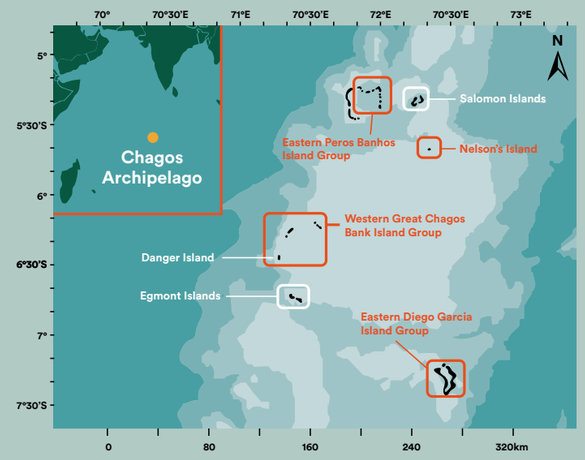



*Figure 1. The Chagos Archipelago in an Indian Ocean context showing the four terrestrial Important Bird and Biodiversity Areas (in red) within the five atolls of Peros Banhos, Salomon Islands, Great Chagos Bank (includes Nelson's Island), Egmont Islands and Diego Garcia. The black circular border in the inset box shows the boundary of the marine protected area.*

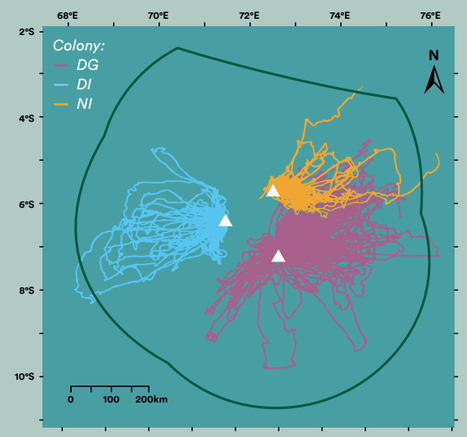



*Figure 2. The 511 foraging trips conducted by 194 Red-footed Booby from the three largest breeding colonies in the Chagos Archipelago. Tracking took place during 2016, 2018 and 2019 in both monsoon seasons. White triangles denote breeding colonies. DG = Diego Garcia, DI = Danger Island, NI = Nelson's Island. Grey circular line indicates the marine protected area boundary. Inset, Red-footed Booby.*

This year, the seabird team investigated two previously proposed marine IBAs, based on seaward extensions to breeding colonies, and assessed the potential for open ocean marine IBAs for the first time (Carr *et al.*, 2022). The study used up-to-date seabird status and distribution information and global positioning system tracking from red-footed booby – one of the most widely distributed breeding seabirds on the archipelago – to identify any open ocean marine IBAs (figure 2). Due to overlapping boundaries of the seaward extension to breeding colonies and pelagic areas of importance, there is a single marine IBA in the central Indian Ocean that lays entirely within the Chagos Archipelago Marine Protected Area (figure 3). Covering 62,379 km2 it constitutes ~10% of the MPA and if designated, would become the 11th largest marine IBA in the world and fourth largest in the Indian Ocean. The paper recommends that BirdLife International assess the proposed Chagos Archipelago marine IBA and confirm if appropriate.

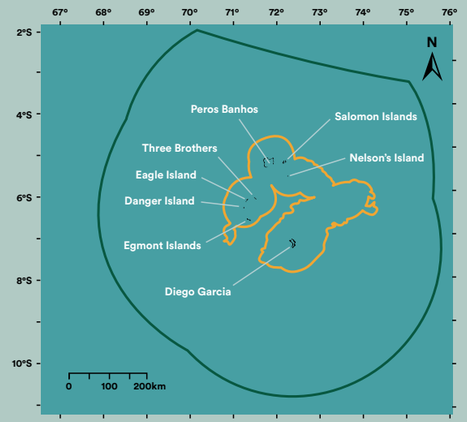



*Figure 3. The proposed Chagos Archipelago marine Important Bird and Biodiversity Area (62,379 km²).*

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# Conservation Impacts

## Research on nutrient pathways leads to plans underway for Indian Ocean

Researchers in the Marine Science programme have pioneered understanding into how seabirds provide important nutrients across tropical islands and coral reefs. Most of these nutrients are in the form of guano (excrement) which help drive nitrogen and phosphorous cycles. The importance of these nutrients has been demonstrated by measuring the differences between coral reefs off islands with healthy seabird populations and those with invasive rats. Reef fish biomass is 48% higher off rat-free islands and rates of two critical ecosystem functions, grazing and bioerosion, over three times higher adjacent to rat-free islands. Parrotfish around rat-free islands grow 35% faster and their overall mean body size is 16% larger. While seabird nutrients do not enhance resistance to coral bleaching, they may promote reef recovery due to their positive influence on calcareous algae and herbivorous fishes. This year, the team's latest paper (Benkwitt *et al.*, 2022) shows that seabird biomass is particularly important for providing terrestrial and near-shore nutrients, while seabird diversity is important for offshore nutrients.



Collectively, these results reveal how rat introductions disrupt nutrient flows among pelagic, island and coral reef ecosystems. Removing invasive rats will therefore recover seabird populations and all the benefits they provide for islands and reefs. Research on existing eradication projects show that seabird nutrients return to islands and coral reefs within 16 years of rat removal. However, de-ratting needs to be combined with the restoration of native island vegetation. Models from the seabird team show that restoring just 1 km2 of abandoned coconut plantation to native forest and savannah could more than double the number of breeding pairs of seabirds in the Chagos Archipelago.

This body of science has informed and motivated plans for re-wilding tropical islands, as a vital conservation action to restore biodiversity and build resilience for vulnerable ecosystems in a rapidly changing climate. The research was central to a white paper produced by Re:wild that was subsequently published as a peer-reviewed paper (Sandin *et al.*, 2022). In March, the Island-Ocean Connection Challenge was launched at the Our Ocean summit in Palau that aims to restore 40 globally significant island-ocean ecosystems from ridge to reef by 2030 to benefit people, wildlife and our planet. In July, the islands and reef team collected data alongside the eradication of invasive rats on Tetiaroa Atoll in French Polynesia. In October, the team and collaborators ran a workshop to consider priorities for re-wilding across Indian Ocean islands at the WIOMSA conference in South Africa. At the same time, programme scientists collaborated with the Seychelles Islands Foundation as part of the Monaco Explorations expedition to Aldabra, where knowledge exchange is underway to inform their re-wilding efforts. In the Chagos Archipelago, the Chagos Conservation Trust progressed their 'Healthy Islands, Healthy Reefs' programme with research into interactions between land crabs and rat bait. In collaboration with Marine Science programme scientists, this programme is working to complete the detailed rat eradication plan and progress the vegetation management plan that are the foundational for re-wilding the Chagos Archipelago.

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# Communication Impacts

One goal of the programme is to use accessible ways of explaining marine science. A measure of success was when Series 1 of the Ocean Matters podcast won the 'People's Voice' podcast award in the environment and sustainability category of The Webby Awards in April. These awards for excellence on the Internet are presented annually by the International Academy of Digital Arts and Sciences.

With an increasing focus on the Indian Ocean region, we were finally able to deliver a partnership with the Earth Journalist Network in September in the Maldives after COVID-19 delays. Following a competitive judging and selection process of 123 applicants, we invited 15 journalists from across the Indian Ocean region to attend a marine science training workshop. The journalists came from 11 countries across the region (South Africa, Kenya, Tanzania, Somalia, Madagascar, Mauritius, Maldives, Mozambique, Sri Lanka, India, Indonesia) with a training team that included journalist trainers (US and India) and scientists from the Marine Science Programme (Asha de Vos from Sri Lanka and Joanna Harris, Heather Koldewey





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from the UK). Other scientists from the programme and collaborators also participated in remote interviews as subject experts. Prior to the workshop, the journalists generally reported limited confidence or knowledge on reporting on ocean issues, with marine pollution the topic which had the highest confidence. After the training, the journalists had significantly increased their confidence in reporting on a wide range of ocean topics.

A highlight of the training was for the journalists to experience the ocean. While all came from coastal countries, most had limited experience of swimming and snorkelling. The science team provided intensive in-water training to allow the journalists to first snorkel on coral reefs and then have the incredible experience of swimming with mantas in the Baa Atoll UNESCO World Biosphere Reserve. This proved transformational for the journalists, influencing their storytelling and enthusiasm to report on ocean issues. As a result, 19 ocean stories have already been published by the journalists in a variety of media. The network remains very active and we plan to continue this training initiative into 2023.

# Collaboration Showcase

Collaboration is core to the Marine Science programme. This applies within the programme and with external partners, illustrated by three notable collaborations that took place in 2022.




## UN Decade of Ocean Science for Sustainable Development 2021–2030

Our Indian Ocean Marine Science programme is an endorsed action of the UN Decade. In 2022, we participated in the Foundations Dialogue meeting in Morocco, and ran joint events at the UN Ocean Conference in Portugal in June and at the West Indian Ocean Marine Science Association conference in South Africa in October. We also built links with other endorsed Actions, including the Early Careers Ocean Professionals.

## REV Ocean expedition

In October 2022, REV Ocean and OCEEF organised the first dedicated mesophotic and deep sea expedition to the Chagos Archipelago on the R.V. Odyssey. Five scientists participated from the Marine Science programme from Bangor, Plymouth, and Oxford universities. Submersibles were able to conduct transects from 60 m to 500 m at two locations in the archipelago. Common seafloor organisms and seaweeds were collected for taxonomic work. Further sampling was done to examine shallow-to-deep connectivity of coral populations and environmental DNA to genetically fingerprint biodiversity. Snorkel surveys were also carried out to sample the world's rarest coral, *Ctenella chagius*, for genome sequencing.

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## Monaco Explorations expedition

The Marine Science programme collaborated with Monaco Explorations for their 'Indian Ocean Expedition' from October to December 2022. The expedition sailed from Mauritius to La Reunion to Aldabra and Mahe (Seychelles), then from Seychelles to Saya del Malha bank and Mauritius. There were more than 150 participants from around 20 nationalities onboard the S.A. Agulhas II, including scientists, early career researchers and students, filmmakers and photographers, artists, communicators, and the ship's crew. As part of the expedition, HSH Prince Albert II of Monaco conducted an official visit to Aldabra and to the ship. Guided by an Advisory Committee of fourteen international experts (including Heather Koldewey), the scientific programme focused on the four main themes of Monaco Explorations: coral protection, megafauna protection, marine protected areas and new exploration techniques.

Our team from Oxford University and ZSL continued our ongoing collaboration with the Seychelles Islands Foundation. We focused on collecting samples and data linked to population structure, connectivity and resilience of corals and other invertebrates in the central and western Indian Ocean, including *Ctenella chagius*. We were able to organise opportunistic sampling to 700 metres around Aldabra using a remotely operated vehicle using the standard transect and depth methodology being applied by the REV Ocean expedition at the same time. This research was led by regional scientists. Unfortunately, due to equipment failure, one of our team had to be medivaced from the expedition back to the UK via Nairobi for medical attention and recovery. This highlighted the risks involved in conducting research in such remote regions.

Monaco Explorations is endorsed by the United Nations Decade of Ocean Sciences for Sustainable Development 2021–2030 and the Expedition itself was endorsed by the 2nd International Indian Ocean Expedition.

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# 2022 Published Papers

*We had another very productive year for scientific papers, with the publication of 29 papers and five papers from other projects by researchers working within the programme. There are an additional 14 papers in review.*

Citations
(*Programme authors in bold*)


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## 2022 Papers by marine science researchers on other projects

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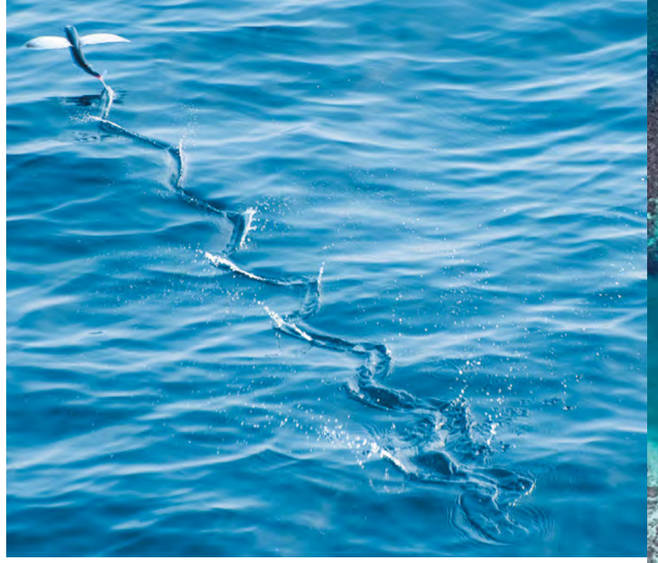

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**Bertarelli Foundation**
The marine science programme is funded by the Foundation, which has supported science and conservation in the Indian Ocean region for over a decade. The Bertarelli Foundation was founded in 1998 in memory of Fabio Bertarelli, the father of Ernesto and Dona. Today, the Foundation is active in those fields that have an historic significance to the family, such as life sciences, marine science and conservation, education and sport. The foundation's cutting edge marine science programme supports vital research in the Indian Ocean.
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