13th & 14th August 2022

Fourth
Maldives
Marine
Science
Symposium

MALDIVES MARINE RESEARCH INSTITUTE

Abstract book

Corals & Coral Restoration
Reef Ecology
Marine Mega-fauna
Seagrass and Mangroves
Fisheries & Management
Plastic Pollution

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Abstract Book

Maldives Marine Research Insititute
Ministry of Fisheries, Marine Resources and Agriculture
H. White Waves, Moonlight Hingun
Malé - 20025, Republic of Maldives

Fourth Maldives Marine Science Symposium 2022,
held on 13th & 14th August 2022,
Online via Zoom and at The Maldives National University, Malé, Maldives.

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Note

1. The abstracts in this booklet maybe of preliminary findings, and may be subject to change. None should be cited without prior written permission from the author(s).

2. Abstracts were prepared and submitted well in advance of the symposium, to review by Scientific Committee and to meet the printing deadlines. As a result, some abstracts may have changed or may not have been presented at the symposium. Our apologies for inevitable omissions and errors.

Convener's Remarks

The Maldivian marine environment is home to rich and diverse marine ecosystems, spanning from shallow coral reefs to vast extent of pelagic ecosystem. The marine science and research in the country encompasses a diverse array of topics across a wide spatial distribution. The Maldives Marine Science Symposium (MMSS) provides a platform for sharing dialogue and discussion on extensive marine science topics, with enthusiastic participation from the marine science community in the Maldives. Hence, MMRI is incredibly pleased to continue our biennial MMSS series with our fourth event, and continue providing a platform that brings together researchers and further our overarching goals in both developing marine science and improving accessibility to research based in the Maldives.

The fourth MMSS includes research featuring a broad array of themes including corals and coral restoration, reef ecology, marine megafauna, seagrass and mangroves, fisheries and management, as well as plastic pollution. The diversity of research and approaches allows for those working in marine science in the Maldives to gain different perspectives into the interconnectivity of our ecosystems and ecological processes.

We would like to extend our gratitude to the Scientific Committee for their tireless contribution in reviewing the abstracts, and guidance throughout. We especially recognize and appreciate the contribution by Dr. R. Charles Anderson on the editorial work on abstracts presented in this presentation. This symposia series is made possible by contributions from marine researchers and scientists conducting valuable work across the Maldives. We would like to thank all authors who contributed their work, and the support received for the symposia. We note the dedication and initiative from the Organizing Committee in convening this fourth event of MMSS. Last but not least, we would like to acknowledge the encouragement and support by our Minister Dr. Hussein Rasheed Hassan.

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Corals & Coral Restoration

Monitoring coral reproductive cycles in Laamu Atoll

*Miriam Staiger [1, *], Phillipa Roe [1], Ali Shareef [1], Matthew Drysdale [2] and Jamie Craggs [2]*

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Abstract

Coral reefs around the world are suffering from an ever-increasing array of threats such as climate change, pollution and habitat destruction. Maldivian coral reefs have suffered multiple mass bleaching events as a result of increased water temperatures, highlighting that this nation is at the forefront of climate change. The natural recovery of reefs from such disturbances relies on the successful spawning, fertilization and settlement of larvae produced by surviving coral colonies.

Broadcast spawning, whereby male and female gametes are released into the water by multiple colonies of the same species, often occurs only once a year. Little is known about these events in the Maldives in comparison to other major reef systems. The objective of this research project was to investigate the reproductive patterns of tagged and monitored colonies on the house reef of Six Senses Laamu resort, in order to develop a baseline understanding of coral reproductive cycles in Laamu Atoll.

A total of 24 *Acropora* colonies were monitored for gamete development on a monthly basis, allowing the tracking of reproductive cycles at an individual colony level. Gametes were detected in 17 of the 24 colonies (71%), allowing initial prediction of spawning dates. Development from white to pigmented gametes over time was observed in 14 colonies, giving insights into maturation of these species' gametes. Spawning of 10 (42%) of the monitored colonies was witnessed during 77 hours of survey dives. Spawning months of three other tagged species was recorded through tracking presence and absence of gametes from one month to the next, although not by directly observed spawning. Multiple other colonies of several species (including *Goniastrea* spp, *Asteropora* spp and *Acropora* spp) that were not consistently monitored for gamete development were observed spawning, providing additional information on the variety of spawning cycles for various species and genera.

In 2021, spawning of various species was recorded during the months of April, June, October, November, and December. In 2022 spawning was observed in January, March, and April. This illustrates that, contrary to previous assumptions, coral spawning happens across October to January, and March, April, and June. The majority of coral spawning was recorded from 3 to 6 days after full moon (DAFM), with particular mass spawning of multiple species recorded in January and November. Our observations make up the first consistent monitoring database of the sexual reproduction of corals in Laamu Atoll, highlighting the potential for natural reef replenishment and recovery. Observations will continue with the aim of incorporating additional genera into the study and assessing coral recruitment.

Recovery and regeneration potential of coral in a shallow lagoon experiencing sustained high thermal values

Meral Hafeez [1], Eleanor Claire Butler, Bekki Hull [1] and Tess Moriarty [1]

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Abstract

Marine heat waves caused by global warming and changes in both the frequency and intensity of El Niño-Southern Oscillation (ENSO) events have caused recurring bleaching and mass mortality across significant swaths of the world's tropical coral reef ecosystems. Sustained exposure to higher-than-normal sea surface temperatures (SSTs) for extended periods may prevent or severely reduce the recovery potential of impacted coral reefs, with different species exhibiting varying rates of recovery. The increased frequency and duration of marine heat waves jeopardizes the resilience of coral reefs by breaking down the vital symbiotic relationship between corals and their algal endosymbionts, compromising their ability to recover and increasing the likelihood of coral mortality.

Coral reefs in the Maldives have experienced high coral mortality after the global bleaching events of 1998 and 2016, with mortality rates of over 90% documented after the 1998 bleaching event. Observed recovery following these disturbances to pre-bleaching levels also took a significant length of time. Coral reef ecosystems are integral to the Maldives, both in terms of the protection they provide from rising sea levels and as a source of income and resources. Consequently, efforts to conserve and restore these ecosystems have become a topic of concern in light of the increasing frequency of disturbance events.

Soneva Jani, located on the island of Medhufaru in Noonu Atoll, is surrounded by a large lagoon. An ongoing coral restoration and rehabilitation program at one of the lagoonal reefs frequently experiences high solar radiation levels and high SSTs, with temperatures of 34°C having been logged at the shallow site during the month of April 2022. Surveys to assess the degree of pervasiveness of coral bleaching and mortality at this site were carried out using semi-quantitative rapid visual estimates. The genus and species of each fragment was recorded along with a value on a seven-point scale corresponding to the degree of bleaching observed. The scale also featured an additional two points for partial and complete mortality of the fragments.

Through this study, we aim to continue monitoring the response of coral to these frequent stressors. Understanding the recovery and regeneration potential of different species of coral can help inform restoration efforts through insights into reef dynamics. Additionally, due to the labour and resource intensive nature of coral reef restoration, our study aims to determine the efficacy of restoration efforts in the context of shallow lagoonal reefs and determine the resilience and adaptive potential of reefs being frequently exposed to SSTs above the regional bleaching threshold.

Methodology for the use of coral larvae settlement ex-situ for up-scaling restoration of declining *Acropora* spp

Margaux Monfared [1,], Simon Dixon [1] and Thomas Le Berre [1]*

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Abstract

The accelerating rate at which coral communities have declined in recent years has encouraged the development of ecosystem management through restoration practices that minimize additional coral loss. The most common of these targets the asexual propagation of reef building corals via fragmentation. This is an effective way to increase coral coverage and diversity in an ailing ecosystem. Reef building corals, however, also reproduce sexually (brooding or broadcast) resulting in higher genetic diversity and thus increased resilience. Hermaphroditic broadcast coral species such as the Acroporidae spawn once or twice a year. As corals are extremely fecund, many juvenile corals could be produced if mortality at early life stages of fertilization and settlement are reduced, we could produce a self-sustainable program and share knowledge with local governments and organisations to halt the further decline of Maldivian coral reef ecosystems.

The Reefscapers coral restoration project has been running since 2001. Over half a million fragments from a variety of *Acropora* spp. have been planted out at various locations within the Maldives, where large mature coral colonies now grow. In 2021 we carried out in the Maldives the first collection of coral gametes in-situ, fertilization ex-situ and settlement. The species involved were the near threatened *Acropora secale*, *Acropora humilis* and data deficient *Acropora plantaginea* (as defined by the IUCN red list). In 2022 we continued utilizing this method and have additionally settled *A. millepora* and *A. digitifera*.

We outline trials on a refined technique to optimize the settlement of propagated larvae. Upon observation of mature coral gametes, we placed collection devices in situ and nightly snorkels took place over full and new moon periods from October 2021 to April 2022. Once spawning took place, collection devices were removed and fertilized ex-situ. The dissociated mixture was then placed in an open flow system with a specialized drainage system. Next, embryogenesis was closely tracked and monitored to ensure fertilization success. Once planulae were observed various substrates were added into the tank to identify preference.

Our preliminary results led to the substantial settlement of coral propagules in the thousands from a species-specific spawning event. This technique, coupled with our restoration program in which we out planted almost 20,000 fragments in 2021, would increase coral coverage whilst ensuring genetic diversity. This robust methodology can be shared with organizations within the Maldives to increase the success of restoration practices with the hope of further mitigating ecosystem decline.

Coral gardening in the Maldives: opportunities and challenges of upscaling restoration efforts

Inga Dehnert [1,2,*], Luca Saponari [3], Paolo Galli [1,2], Federica Siena [1,2], Jacopo Gobbato [1,2,] Davide Seveso [1,2] and Simone Montano [1,2]

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Abstract

The low-lying archipelago of the Maldives, a country that depends on healthy coral reefs and the services they provide, is on the forefront of experiencing the adverse effects of climate change. As coral reefs are degrading, the need for coral restoration projects, as part of a broader conservation management strategy, is accelerating. While the Maldives have not yet explored their full coral restoration potential, the unique geographical and socioeconomic situation found here provides ample opportunities for local coral restoration projects. In particular, the luxury tourism industry could be encouraged to engage in restoration projects of scale and to conduct coral frame projects, given that many resorts already employ marine biologists for educational purposes.

This research assesses the application of 'coral gardening' for upscaled coral restoration efforts in the Maldives, by providing the necessary regional validation and useful insights into the various opportunities and challenges of this technique. First, we evaluate the suitability and performance measures of mid-water coral nurseries across different atolls and islands (i.e. resort and local island) and farming habitats (i.e. lagoon and reef environment), using a common monitoring protocol. We report regional benchmark results for *Acropora*, *Pocillopora* and *Porites* fragment survival and growth as well as investigating ecological interactions such as mutualistic fauna and predator associations of farmed and transplanted corals. Out-planting success of nursery-grown corals is reviewed in terms of the wider ecological footprint, indicating significant benefits to the degraded reef environment by increasing fish abundance and diversity along with natural coral cover. Our research further documents some of the challenges of the coral gardening approach, by quantifying the negative impacts of unmitigated coral disease occurrence in coral nurseries. Overall, this work hopes to provide a scientific baseline for future coral gardening projects in the Maldives that can guide restoration practitioners towards efficient and scaled-up coral conservation work.

Corals & Coral Restoration

Corals & Coral Restoration

Launching of a national monitoring protocol for coral reef restoration projects

Federica Siena [1,3,], Hana Amir[2], Paolo Galli [1,3], Inga Dehnert [1,3], Jacopo Gobbato [1], Luca Fallati [1,3], Davide Maggioni [1,3], Davide Seveso [1,3], Enrico Montalbetti [1,3] and Simone Montano [1,3]*

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Abstract

Coral restoration has become a very common activity throughout the world to counter the decline of coral reefs and to kickstart their recovery. In the Maldives, asexual coral restoration is the most commonly practiced method both by the public and the private sector. Sharing successes, failures and challenges of projects is a tool to spread knowledge and thus speed up the recovery process. Despite the numerous efforts, a lot of the data and information currently available for the Maldives is shared via symposiums, grey literature, non-technical reports or Facebook groups, and unfortunately all of these are rarely compiled together, thus potentially slowing down the recovery of reefs.

Launching a national monitoring protocol for coral restoration projects aims at offering a tool to report nation-specific, comparable and science-based data on the performance of the numerous projects.

Recognizing the importance of a holistic approach, the guidelines incorporate a set of ecological indicators, associated with sociocultural and economic indicators, to allow practitioners to perform a comprehensive analysis of their projects and benchmark them against similar ones. The manual is carefully designed for anyone already working on a coral restoration project or attempting to start a new one, using methods of asexual propagation. The protocol is also adaptable to different scenarios whilst providing standard procedures. It is a flexible tool in terms of the quantity a quality of information collected.

The manual provides information and guidance on:

- what to survey
- ecological, sociocultural, and economic indicators and how to measure them
- how to collect data and input them into datasheets and databases
- early detection of problems for a timely implementation of corrective measures
- consistent and complementary collection of information on a national level
- creation of science-based restoration projects which serve as a strategy to increase the resilience of reefs and work on a large-scale
- benchmarking performance against goals and assessing effectiveness
- measuring socio-economic aspects of coral restoration

Evaluating extinction risk: a Maldivian national red list of corals

Hana Amir [1,*], Ahmed Basheer [2], Ilham Atho Mohamed [3], Simone Montano [4,5] and Philippa Roe[6]

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Abstract

To understand the extinction risk of different species found in the Maldives, a Maldives Red List similar to the IUCN Red List is being developed by the Ministry of Environment, Climate Change and Technology. Having global and national significance for their outstanding diversity of over 248 species and 57 genera, coral reefs in the Maldives are exceptionally important for their ecological and socio-economic value. The Coral Working Group of the Maldives Red List Initiative commenced assessments focused on Scleractinian corals in February 2022.

Assessments were carried out using methods developed for IUCN's Red List Assessments. Extinction risk was evaluated based on either impacts to the population in the past or projected impacts on the population in the future. Past impact was inferred from percent cover of hard coral cover data whilst future impact was inferred from onset of Annual Severe Bleaching events and their likely impact on the species relevant to their national distribution and habitat preference. The degree of impact was further qualified by a vulnerability score based on species traits related to bleaching, disease, recovery potential and adaptability, as national level species specific data was limited. The evaluation was compared to IUCN Red List extinction risk thresholds and assigned a category based on a precautionary principle.

A total of 38 species were evaluated from 20 genera: *Acropora, Ctenactis, Diploastrea, Echinopora, Galaxea, Goniopora, Heterocyathus, Hydnophora, Leptastraea, Leptoseris, Monitpora, Pachyseris, Pavona, Physogyra, Plerogyra, Pocillopora, Porites, Stylophora, Tubastrea* and *Turbinaria*. Due to lack of data, only two of the 38 evaluations reached a consensus based on both past impacts and future projection. All other evaluations reached a consensus based on future projections. All species assessed were found to be in unfavorable status with future population decline predicted. Of the species assessed, 22 were found to be Critically Endangered, 9 Endangered and 5 Vulnerable and 2 Near Threatened. Final external review of designations is currently still underway and will be completed by July 2022.

Despite various challenges, the assessment process has shown that it is possible to evaluate the extinction risk of Scleractinia corals on a regional scale within Maldives. The process has also highlighted a number of important data gaps that future assessments or work programs can aim to fulfil. Most importantly, however, the process has shown that climate change and its impacts are the biggest threats to the survival of corals in the Maldives.

Reef Ecology

Reef complexity influences distribution and habitat choice of the corallivorous seastar *Culcita schmideliana* in the Maldives

Enrico Montalbetti [1,], Luca Fallati [1], Jacopo Gobbato [1], Inga Dehnert [1], Marco Casartelli [2], Davide Maggioni [1], Simone Montano [1], Paolo Galli [1] and Davide Seveso [1]*

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Abstract

The cushion seastar *Culcita schmideliana* has gained attention in the last few years because of its selective predation on juvenile corals, as well as its ability to generate large demographic assemblages, causing delays in coral recovery after large mortality events in the Republic of Maldives. However, a lack of data regarding the factors affecting its distribution and habitat selection still persists in this area. Here, we adopted a novel approach in the study of corallivorous seastar habitat selection that combined ecological and digital photogrammetry data. We tested three different parameters as factors potentially influencing seastar habitat choice in the south-east region of Faafu Atoll, Republic of Maldives, namely prey abundance, Linear Rugosity Index (LRI), and Average Slope (AS). The analysis of selectivity coefficient (Ei) of seastars for different habitat types showed a preference for reefs characterized by medium AS values, an LRI between 2 and 2.5, and a juvenile coral density ranging between 10 and 20 colonies m-2. A multiple linear regression analysis showed that different AS and LRI values explained 43.1% and 48.1% of variance in seastars abundance, respectively, while juvenile coral densities did not significantly affect this. These results provide new information on the distribution and behaviour of *C. schmideliana*, an important corallivore of Maldivian reefs.

Reef Ecology

Monitoring changes in benthic communities on coral reefs on Laamu Atoll

Mara Fischer [1,*], Aminath Shaha Hashim [2], Vivienne Evans [3] and Phillipa Roe [4]

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Abstract

Tropical coastal nations such as the Maldives are highly dependent on the ecosystem services that coral reefs provide. These include provision of food, protection from natural hazards and revenue generation from tourism. It is widely recognised that coral reefs are under threat from a multitude of global and local stressors. Unsustainable fishing practices, nutrient enrichment, and physical disturbance, for example from dive tourism, can slowly erode the resilience of the reef, making it more susceptible to the impacts of global climate change such as ocean warming and acidification. The 2016 bleaching event reduced live coral cover across the Maldives and was particularly severe in Laamu Atoll where 75% of corals bleached.

In 2019, Blue Marine Foundation in collaboration with Six Senses Laamu and the University of York undertook a baseline survey of 20 coral reefs around Laamu Atoll to inform management and future protection of reefs in the atoll. The survey showed that live coral cover throughout the atoll was variable, ranging from 7% to 34%, with a mean of 19%. The same sites and an additional ten sites are currently being surveyed by Maldives Resilient Reefs and Blue Marine Foundation in collaboration with Six Senses Laamu and the University of Exeter. Video transects are being collected at two different depths along two 50-meter belt transects to obtain a permanent visual record of the study sites and to assess the benthic community composition. Coral Point Count (CPCe) analysis will be used to measure the percentage cover of different major substrate types within the images extracted from the videos. The substrate categories used in the present analysis are live hard coral (subdivided into *Acropora* sp. and other coral), bleached hard coral (subdivided into bleached *Acropora* sp., other bleached coral, and colourful bleaching), live soft coral, diseased coral, dead standing coral, sponge, corallimorpharian, anemone, algae (subdivided into *Halimeda*, turf and other algae), crustose coralline algae, bare rock, rubble, sand and other life.

The results will be compared to those from 2019 to assess how well Laamu Atoll's coral reefs are recovering from the 2016 bleaching event. There is currently a bleaching alert for coral reefs in the Maldives. Therefore, this research is very timely and may present an opportunity to establish a baseline of live coral cover prior to another bleaching event. Analysis of data from video transects will allow the assessment of changes in benthic substrates and subsequent implications for community composition. In addition, data on reef impacts such as damage by crown-of-thorns starfish will be analyzed to explore possible drivers of these changes in benthic communities. Data collection will be completed by June, and results will be published in August 2022.

Reef Ecology

Hydrozoan research at the MaRHE Centre, Faafu Magoodhoo: an overview

Davide Maggioni [1,], Davide Seveso [1], Enrico Montalbetti [1], Luca Fallati [1], Jacopo Gobbato [1], Inga Dehnert [1], Federica Siena [1], Yohan Didier Louis[1], Paolo Galli [1] and Simone Montano [1]*

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Abstract

Hydrozoans are a class of cnidarians with about 4000 species worldwide. They play fundamental roles in marine environments, both in benthic and pelagic ecosystems. Tropical coral reefs are home to a multitude of hydrozoan species, and Maldivian reefs are no exception. Despite this, the Maldivian hydrozoan fauna has been barely studied in the past. During the last ten years, the MaRHE Centre, located in Magoodhoo, Faafu Atoll, has served as a research station to study multiple aspects of the coral reefs surrounding the island, including hydrozoan diversity, ecology, and evolution. In particular, the research has been carried out using an integrative approach, combining morphological, genetic and ecological techniques to disentangle several questions. Most, but not all, of the research has focused on symbiotic species, living in tight association with scleractinian corals, octocorals, bryozoans and sponges. New species and new genera have been discovered and described, increasing the known diversity of the group in the Maldives. Moreover, the relationships between symbiotic hydrozoans and their hosts have been studied in detail to characterize these poorly known symbioses from multiple points of view including, among the others, host preferences, host modifications and coevolutionary patterns. These relationships have also been ecologically characterized to shed light on their environmental preferences and to investigate the possible outcomes for hosts and symbionts. Overall, the results obtained so far demonstrate that the diversity of Maldivian hydrozoan is high and, in many cases, still unexplored, and also highlight their importance in coral reef ecosystems.

The aim of this presentation is to provide an overview of the scientific achievements of the past years on this topic and to delineate remaining knowledge gaps, in order to develop further hydrozoan research on Maldivian reefs.

Reef Ecology

Bioprospecting of Maldivian soft coral: chemical ecology and cytotoxic activity of their secondary metabolites with a focus on the biochemical investigation of their effect against cancer cell lines

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Abstract

Marine environments, and especially coral reefs, are the source of a wide range of bioactive natural products with structurally unique features. So far, more than 36,000 compounds from marine micro- and macro-organisms have been isolated and more than 1000 new products are discovered every year. Since the 1970s, many natural products with diverse and important biological activities of interest for human health have been isolated and characterized from corals. In particular, soft corals have received specific attention as they produce a greater number of secondary metabolites than hard corals. This is because they do not possess a calcium carbonate exoskeleton and consequently they rely on their chemical defense strategy to survive in competitive environments. There are already more than 5800 secondary metabolites isolated and described from soft corals and these compounds have been frequently investigated in relation to their possible anticancer effects by testing their cytotoxic and anti-proliferative activity against cancer cell lines.

In a recently published review, we focused on the Alcyoniidae, one of the largest octocoral families. 344 cytotoxic compounds were documented, most of which were discovered in the last 20 years, demonstrating that this research field has exploded in recent times. Confirming the potential of this research area, 21 of these secondary metabolites displayed cytotoxic activity comparable to or even higher than the chemotherapy drug used as positive control in studies against specific cancer lines.

The research project we have now started will lead to the identification and chemical characterization of new bioactive compounds extracted from Maldivian soft corals. Among these secondary metabolites we will define the most active ones based on an *in vitro* cytotoxicity test (MTT assay) on different cancer cell lines. At this point we will define the possible mechanism of action of these compounds by study of the cellular target, of the mechanism that reduces cell viability, and of the biochemical pathways activated by these compounds. The ultimate aim is the identification of possible molecules for preclinical studies as potential anticancer therapies.

Soft corals can still considered unexploited since the number of published works is small when compared to the vastness of biodiversity available. Furthermore, no molecule deriving from these organisms has yet reached the stage of pharmaceutical studies, unlike other organisms such as molluscs and sponges. This project and research group aim to be a turning point in this field.

Marine Mega-fauna

Feeding ecology and behaviour of reef manta rays (*Mobula alfredi*) at a key aggregation site in the Maldives

Asia Armstrong [1,2,], Hannah Moloney [3,4], Guy Stevens [4], Kathy Townsend [1,3], Anthony Richardson [2,5], Annie Murray [4], Mike Bennett [2], Julian Uribe Palomino [5], Christine Dudgeon [3], Amelia Armstrong [2] and Phil Hosegood [6]*

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Abstract

Reef manta rays (*Mobula alfredi*) are large planktivorous elasmobranchs and are classified as vulnerable to extinction on the IUCN Red List for Threatened Species, with populations decreasing. They forage in tropical and sub-tropical environments that are generally nutrient-poor. Hanifaru Bay is the largest known aggregation site for feeding reef manta rays in the world with upwards of 250 individuals identified during peak feeding events exploiting ephemeral productivity hotspots. Investigating the zooplankton dynamics that lead to such feeding aggregations remains a key question for understanding their movement ecology.

This study investigated the feeding environment of reef manta rays in Hanifaru Bay. It specific aims include relating changes in zooplankton biomass to *M. alfredi* behaviour; establishing the critical prey density threshold for feeding at this site; and determining whether prey density influences the type of feeding strategy *M. alfredi* employs to exploit their prey. Further, we aimed to compare the relationships between zooplankton dynamics, environmental variables, and how they influence *M. alfredi* abundance, demographics and foraging behaviour.

In combination with physical environmental and oceanographic data, this study used plankton tows (hand-towed) to sample over the tidal cycle, lunar phase and temporally during the southwest monsoon (*hulhangu*) in Hanifaru Bay Marine Protected Area and core zone within a UNESESCO Biosphere Reserve. Preliminary results from August 2017 were presented by Armstrong et al. (2021, PeerJ 9:e11992), with the work leading from this being conducted over the southwest monsoon (August-November) 2021 and 2022.

Zooplankton biomass changed rapidly throughout the tidal cycle and *M. alfredi* feeding events were significantly related to high zooplankton biomass during these daytime surface feeding events in Hanifaru Bay. The feeding threshold for *M. alfredi* was found to be more than double the theoretical levels estimated to meet metabolic requirements. Zooplankton community composition was different when *M. alfredi* was feeding compared to present but not feeding, with *Undinula vulgarius* being the dominant species of zooplankton during feeding events. This is a large-bodied calanoid copepod that blooms in oceanic waters, suggesting offshore influence at this site.

A hitchhiker guide to manta rays: patterns of association between *Mobula alfredi*, *M. birostris*, their symbionts, and other fishes in the Maldives

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Abstract

Despite being among the largest and most charismatic marine species, considerable gaps remain in our understanding of the behavioural ecology of manta rays (*Mobula alfredi, M. birostris*). Manta rays are often sighted in association with an array of smaller hitchhiker fish species, which utilise their hosts as a sanctuary for shelter, protection, and the sustenance they provide. Species interactions, rather than the species at the individual level, determine the ecological processes that drive community dynamics, supporting biodiversity and ecosystem health. Thus, understanding the associations within marine communities is critical to implementing effective conservation and management. However, the underlying patterns between manta rays, their symbionts, and other hitchhiker species have been unknown.

This study aimed to improve our ecological understanding of interactions between manta rays and their hitchhikers by highlighting how these associations are structured, and what the drivers of the associations might be. We explored the spatial and temporal variation in hitchhiker presence with *M. alfredi* and *M. birostris* throughout the Maldives and investigated the factors which may influence association using generalised linear mixed effects models (GLMM).

For the first time, associations between *M. alfredi* and *M. birostris* with hitchhiker species other than those belonging to the family Echeneidae were described. Differences in the species of hitchhiker associated with *M. alfredi* and *M. birostris* were identified, with sharksucker remora (*Echeneis naucrates*) and giant remora (*Remora remora*) being the most common, respectively. Spatiotemporal variation in the presence of manta rays was identified as a driver for the occurrence of ephemeral hitchhiker associations. Near-term pregnant female *M. alfredi*, and *M. alfredi* at cleaning stations, had the highest likelihood of an association with adult *E. naucrates*. Juvenile *E. naucrates* were more likely to be associated with juvenile *M. alfredi*, and a seasonal trend in *E. naucrates* host association was identified. *Remora* were most likely to be present with female *M. birostris*, and a mean number of 1.5 ± 0.5 *R. remora* were observed per *M. birostris*.

Given the rapid pace at which anthropogenic activities are altering oceans worldwide, significant effort should be aimed at understanding these associations. Further research of hitchhikers in different manta ray populations is warranted to evaluate whether the associations and structures found within the Maldives apply to other geographic locations, as well as understanding the drivers of the association more holistically.

Marine Mega-fauna

Sublethal injuries and physical abnormalities in Maldives manta rays, *Mobula alfredi* and *Mobula birostris*

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Abstract

Manta ray populations worldwide are vulnerable to sublethal injuries resulting from human activities, e.g. entanglement in fishing line and boat strikes, which have the potential to impact an individual's health, fitness and behaviour. Sublethal injuries and physical abnormalities also occur naturally from predation events, deformity, parasites and disease. This is the first time a study has attempted to identify and categorize all sublethal injuries and physical abnormalities (collectively called injury events here) exhibited by both manta ray species, *Mobula alfredi* and *M. birostris*.

To investigate the origin, type, and frequency of injury events observed in the two manta ray species in the Maldives, the study examined data from the Manta Trust's Maldivian Manta Ray Project (MMRP) database, which contains 73,638 photographic-identification sightings of the two species from 1987 to 2019. The likely origin of each injury event was determined based on visual assessment of the photo-ID images. Generalized linear mixed models (GLMM) were used to investigate the relationship between the occurrence of injury events and the explanatory variables sex and maturity status for both species, with the additional variable site function for *M. alfredi*. Spatial and temporal variations in *M. alfredi* injury events, and their origin and type, were investigated by calculating the percentage of injury events per sighted individual in each Maldivian atoll, and per re-sighted individual in each year from 2005 to 2019.

For both species, injury events were predominantly of natural origin with predatory bites being the most frequent type. The most common anthropogenic injury type was entanglement in fishing line. Injuries to *M. alfredi* were significantly more likely to be observed on juveniles than adults, males than females, and at cleaning stations as opposed to feeding or cruising sites. Neither sex nor maturity status were significant explanatory variables for the occurrence of injuries to *M. birostris*. Highest percentages of anthropogenic injuries per sighted *M. alfredi* were recorded in North Malé, South Malé, Baa, Addu and Laamu Atolls, where boat traffic, fishing and tourism activities are concentrated.

Although manta rays in the Maldives are protected nationally, the continued increase in marine traffic, tourism and fishing activities will likely lead to more frequent injuries, which could have implications for the health and fitness of these populations. By improving understanding of the relative impact of the different types of threats to manta rays in the Maldives, this study highlights conservation management actions required to better protect these threatened species throughout their range.

Marine Mega-fauna

The importance of a key aggregation site for juvenile reef manta rays (*Mobula alfredi*) in the Maldives

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Abstract

Reef manta rays (*Mobula alfredi*) are slow-growing cartilaginous fishes, and their late maturity and low fecundity leave them highly vulnerable to overexploitation. They are classed as 'Vulnerable to Extinction' on the IUCN Red List of Threatened Species, being particularly susceptible to by-catch and targeted fisheries.

Elasmobranch nursery areas have been widely reported and are considered an important aspect of elasmobranch ecology, with likely benefits including reduced predation risk and/or good provision of food. Data collected and reported by the Manta Trust indicate that Maamunagau, in southern Raa Atoll, is an important nursery habitat for juvenile reef manta rays.

This study identified the first manta ray nursery habitat recorded in the Maldives Archipelago. For an area to qualify as an elasmobranch nursery ground it must have: (1) higher juvenile density within the area compared to elsewhere; (2) individuals must be present for extended periods; and (3) the area must be repeatedly used by juveniles over time (Heupel et al., 2007, MEPS 337: 287).

Manta ray sightings were documented by photographing the unique spot patterns on their ventral surface, allowing for identification of individuals. In addition, photogrammetry was used to accurately measure manta rays.

Using photogrammetry, it was found that most of the manta rays measured at the Maamunagau aggregation site were smaller than 2.4m wide, with some individuals measuring less than 2m, indicating a high presence of juveniles in the area. Maamunagau also meets the criteria for a nursery site: (1) Of the 4,276 recorded sightings of reef manta rays in Raa Atoll, 53% (n=2,283) of these sightings were of immature individuals, and 64% (n=1,466) of these sightings were recorded in the Maamunagau. (2) Thirty-three juvenile individuals were repeatedly recorded across all three survey years within the Maamunagau region with the same individuals also recorded across consecutive months. (3) Of the 176 immature manta rays recorded in Maamunagau, 56% (n=98) were recorded more than once, 23% (n=41) more than 10 times, and 8% (n=14) more than 30 times.

Juvenile reef manta rays are likely utilizing Maamunagau due to its large, sheltered lagoon, which offers these smaller individuals greater protection from predation and ample foraging opportunities. To ensure that these juvenile reef manta rays are not impacted by the increasing pressures within the region, a Marine Protected Area (MPA) proposal has been submitted to the Environmental Protection Agency (EPA).

Marine Mega-fauna

A social-ecological systems assessment of anthropogenic pressure on whale sharks in South Ari Atoll

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Abstract

Whale shark (*Rhincodon typus*) tourism has been estimated to generate a global annual revenue of about US$ 42 million, with tourist numbers expected to increase. These giants form a key part of marine wildlife tourism in the Maldives, where they are vulnerable to anthropogenic pressure through boat strikes, pollution, overcrowding and disruption of their natural behaviour. Little research has focused on quantifying the impact of tourism and human disturbance on whale sharks. Furthermore, a significant gap in research on the socio-cultural dimensions of human-whale shark interactions in the Maldives remains.

The objective of this research was to conduct the first social-ecological systems assessment of anthropogenic pressure on whale sharks in the South Ari Atoll Marine Protected Area (SAMPA), and to provide recommendations for effective conservation management that benefit both whale sharks and local livelihoods.

This study was split into three distinct sections: (1) Through a literature review and 15 interviews, this study first qualitatively examined the social and economic processes that are co-producing multi-species relations through shark-based tourism in SAMPA. (2) A quantitative analysis of nine years (2011-2019) of MWSRP whale shark encounter, vessel traffic and photo ID data on the impacts of increased tourism on whale sharks in SAMPA. Using linear regression models, injury rates, abundance of whale sharks and behavioral changes were assessed. (3) Employing a social-ecological systems framework to combine the findings from the previous two sections, this study develops a Drivers-Pressure-State-Impact-Response Model (DPSIR) to show systemic interdependencies between tourism, local livelihoods and the health of whale shark populations in SAMPA.

The number of whale sharks recorded with anthropogenic injuries increased from 40% in 2011 to 76% in 2019. The number of individuals displaying evasive behavior also increased, from 11.9% in 2013 to 63.6% in 2019. A decline in whale shark encounters was detected, from 652 total whale shark encounters logged in 2015, to 310 total encounters in 2019. This suggests that anthropogenic pressure may be altering whale shark behaviour and displacing sharks.

Tourism, local livelihoods and the health of whale shark populations in the SAMPA are inextricably linked through multiple feedback loops. SAMPAs whale sharks may have reached a 'carrying capacity' for tourism. The impacts of whale shark tourism not only affect these animals negatively, but also reduce the economic sustainability of the industry through a decline in the very species responsible for attracting tourists, hence also affecting local development. Successful whale shark tourism thus needs to simultaneously protect wildlife and their habitats while balancing associated social and economic values.

Assessing the socio-economic value of sea turtles to the Maldives' tourism industry in 2019 (pre-pandemic)

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Abstract

Tourism in the Maldives provided significant revenue to the country in 2019 with 1.7 million visitors, many of whom came to experience marine life through snorkeling and/or diving. Sea turtles are some of the megafauna attracting visitors, due to the high possibility and frequency of in-water encounters, as well as encounters on land during nesting or hatching events. Sea turtles have been described as the ocean's sentinels: susceptible to changes in their environment, from the warming and acidification of waters to human threats such as encroachment on nesting beaches, marine pollutants, such as plastic and by-products from increased fishing pressures, notably abandoned, lost and discarded fishing nets.

A total of five sea turtle species can be found in the Maldives, all of which are listed on the International Union for Conservation of Nature (IUCN) red list of threatened species. Hawksbill and green turtles are the most commonly found in Maldivian waters, and therefore have the most interactions with tourists. Turtle trade and consumption has been banned in the Maldives since 2016 under the Environmental Protection and Preservation Act (Number 4/93) Section (A). Turtle tourism may present an attractive economic alternative to the illegal exploitation of these species.

This study is the first estimate of the potential socioeconomic value of sea turtle tourism in the Maldives. Dive and snorkel operators were interviewed on the sea turtle trip sites they visit, the amount in US$ spent directly on advertised sea turtle trips in 2019, and it examines the perceived value of turtles to operators, and to what extent guests request to see turtles.

Our preliminary results suggest that sea turtle tourism is not seasonal and occurs throughout the year, with some notable hotspots such as Lhaviyani and Laamu Atolls. Sea turtles were perceived to be important to the operators' business with the majority of operators advertising sea turtle viewing excursions to attract guests. According to operators, guests ranked sea turtles in their top 4 marine species to view, alongside manta rays, whale sharks and sharks. Most operators received requests to see sea turtles several times per week, with some operators receiving daily requests.

These preliminary results suggest sea turtles have a high socioeconomic value for the country. We also expect our results to elucidate areas of less well known turtle aggregations, which will also benefit our population estimates for the country. From the survey results we may find turtle tourism pressure on certain areas which may require stricter protection measures.

Marine Mega-fauna

Entanglement of sea turtles: risk factors, health impacts and influences on successful conservation outcomes in the Maldives

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Abstract

Five out of seven sea turtle species can be found in the Maldives: hawksbill (*Eretmochelys imbricata*), green (*Chelonia mydas*), olive ridley (*Lepidochelys olivacea*), loggerhead (*Caretta caretta*), and leatherback (*Dermochelys coriacea*). All are listed on the International Union for Conservation of Nature (IUCN) red list of threatened species, as vulnerable to critically endangered. Globally, sea turtles face a range of threats, including climate change, habitat degradation, pollution, poaching and entanglement in marine debris. Entanglement occurs when marine animals become entangled in anthropogenic material, most commonly abandoned, lost or discarded fishing gear (ALDFG) also known as 'ghost gear'.

Entanglement can have a range of negative effects which can cause prolonged suffering, resulting from restricting movement, wounding and drowning. Between 2016 and 2020, among rescued sea turtles recorded by the Olive Ridley Project (ORP), 86.8% has injuries due to entanglement, ranging from lacerations to limb amputations. A number of turtle patients with the ORP had buoyancy syndrome; further research is needed to establish any cause and effect relationship between entanglement and this syndrome.

The aim of this project is to identify factors influencing the risk of entanglement, and the health implications of entanglement and buoyancy syndrome, as well as to investigate their effects at a population level. The results should be used to develop conservation strategies to improve sea turtle health in an ecological context, to manage and/or mitigate risk factors and to improve animal welfare on many levels from individual turtles to populations.

We carried out retrospective analysis on four years of patient record data from the Olive Ridley Project Marine Turtle Rescue Centre in Baa Atoll. Quantitative statistical data analyses were carried out using R studio software.

Preliminary results suggest entanglements vary throughout the year, with peak admissions occurring during the northeast monsoon, although this finding was non-significant. Buoyancy at admission also was more frequently reported during this season. Of the various reasons for admission to the ORP, entanglement was the most common with ghost nets involved in the majority of these cases. Entanglement was significantly associated with flipper injury, and has a high association with the requirement for amputation surgery. Most entanglement cases were successfully released following rescue and rehabilitation. Buoyancy syndrome continues to occur and further research is required to establish possible causes.

Data analysis for this project is currently ongoing and will be completed by August 2022. However, these initial results highlight the importance of eliminating entanglement risks at source.

Marine Mega-fauna

Where the baby turtles come from: summary of nesting from 2018-2021

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Abstract

Sea turtles are an important part of the marine ecosystem in the Maldives. While five species have been recorded in the country, only two can be found in relevant numbers, the hawksbill turtle and the green turtle. Historically, both species have been recorded to nest throughout the country, but consistent long-term nesting data are not available.

In this study we present cumulative data from four years of nest monitoring, including ad hoc reports from citizen scientists and marine biologists, as well as targeted monitoring initiatives, with the aim of providing a comprehensive long-term dataset on sea turtle nesting activity in the Maldives.

During targeted monitoring, nests and false crawls were recorded with GPS location, species, track width, and - if possible - ID photographs of the nesting female. Nests were monitored until hatching and excavated afterwards to document hatching success, developmental status and potential reasons for egg failure.

We recorded nesting information from both species, but the majority of reports are of green sea turtle nests. Nesting in the Maldives occurs throughout the year, with a peak in overall nesting during the south-west monsoon. However, nesting seasonality varies between atolls.

Consistent data from selected islands in Lhaviyani and Laamu Atolls are available, including temporal and spatial distribution of nesting activity, incubation times, and hatching success rates. Between 2018 and 2021, 239 nests and 121 false crawls were recorded from these atolls. Overall median hatching success rate was 88.1% (SD = 23.1) and incubation lasted between 46 and 70 days (median: 58 days, SD = 4.09).

Marine Mega-fauna

Endangered and critically endangered: summary of the first marine national red list assessments for green and hawksbill turtles

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Abstract

The Republic of Maldives is home to diverse fauna and flora, including five species of sea turtles. Over the past decades, anthropogenic pressures have greatly altered the populations of different species all across the globe. Illegal wildlife trade is the fifth largest crime in the world. Habitat destruction, climate change, over-exploitation, pollution and invasive alien species are listed as the five major drivers of biodiversity loss by IPBES in its first Global Assessment on Biodiversity and Ecosystem Services.

To understand the status of different species found in the Maldives, a Maldives Red List similar to the IUCN Red List is being developed by the Ministry of Environment, Climate Change and Technology. All the five species of sea turtles found in the Maldives were assessed under the Maldives Red List Initiative with the help of conservation experts working in the country. Three of these turtle species, olive ridley sea turtle, loggerhead sea turtle, and leatherback sea turtle, were categorised as Data Deficient. Based on the nesting data, population size and trends, threats as well as conservation and research actions and needs, green sea turtle and hawksbill sea turtle have been assessed and categorised as "endangered" and "critically endangered" respectively.

Despite the limited data available for both species, a first baseline assessment was conducted for both, including historical and recently published literature as well as unpublished data from ongoing research efforts.

For green turtles, specific observations from an index nesting beach indicated a decline in nesting activity and therefore population size of 70-78% since at least the 1980s. The species is suspected to be threatened by marine and terrestrial habitat loss, climate change and unsustainable illegal take.

Documented cases of hawksbill nests have decline severely by over 95% since at least the 1980s, making the species critically endangered. Current population models do not show a clear trend for recovery and the threats hawksbills face such as habitat loss, illegal take and pollution are not projected to cease or decline significantly in the near future.

The recently published assessments provide a basis for conservation action and education campaigns, and highlight important knowledge gaps in sea turtle biology in the Maldives.

Marine Mega-fauna

Congenital malformations in green turtle (*Chelonia mydas*) embryos in Lhaviyani Atoll

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Abstract

Teratogenesis is a prenatal deformation characterized by structural or functional defects in the developing embryo. Depending on severity, the embryo may die or be born with congenital malformations. These malformations may be caused by genetic factors, environmental factors or a combination of both. Over the past few decades, studies have shown various abnormalities in turtle embryos and hatchlings in different nesting locations the across the world. The green turtle (*Chelonia mydas*), is the most predominant turtle to nest in the Maldives, yet there have been few published studies on the congenital malformations in green turtles of the Maldives.

From July-December 2021, daily sunrise patrols were undertaken on the islands of Kanuhura, Jehunuhura and Masleggihuraa in the Lhaviyani Atoll, to look for turtle tracks and locate turtle nests. These turtle nests were then monitored for signs of hatching and emergence. With relevant permits from the Environmental Protection Agency of Maldives, exhumation was carried out 48 hours after hatchling emergence, to determine the hatching success rate and to identify the developmental stages of the unhatched eggs.

During these exhumations, many abnormalities were observed in turtle embryos including: facial anomalies such as undeveloped eyes (anophthalmia) and cross over jaw (laterognathia); scute anomalies such as supernumerary and asymmetric staggering; flipper anomalies such as unequal fore flipper length and deformed flippers; and pigmentation anomalies such as albinism. One particular embryo, highlighted in this poster, showed multiple forms of congenital malformations including albinism, laterognathia, as well as supernumerary and asymmetric staggering of the vertebral scutes.

During six months of monitoring, we found a number of abnormalities in *Chelonia mydas* embryos, including the aforementioned albino specimen that we believe is the first record for the Maldives with these specific multiple malformations. Regular monitoring and post-hatching exhumation of sea turtle nesting sites in the Maldives will assists in recording congenital mutations, and recognizing if there are any patterns in these abnormalities and whether they can be correlated with local anthropogenic activity.

Marine Mega-fauna

Environmental DNA as a tool for assessing cetacean occurrence: preliminary data from the Maldives, an open-air lab for marine mammal biodiversity

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Abstract

The detection of genetic material left by organisms in the environment (environmental DNA, eDNA) has rapidly grown as a tool for monitoring aquatic animal communities. The possibility to simultaneously identify multiple taxa within a single seawater sample (metabarcoding), allows both to detect the presence of cetaceans and to study the biological communities associated with them. This approach, applied to the marine vertebrate fauna, can be extremely informative for assessing the health of marine ecosystems, by evaluating the species composition of the highest levels of the marine food chain (fish, marine reptiles and mammals).

In this study we coupled the use of universal vertebrate primers (12S-rRNA and 16S-rRNA regions) to that of two novel primers sets specific for marine mammals and targeting the same two mitogenome regions. The method tested here is a multi-primer approach with two primer sets employed, for each targeted barcode, in a single high-throughput sequencing run, rather than requiring multiple runs, making it versatile and cost-effective.

The test was performed on 39 marine eDNA samples collected in 2020 and 2021 over a wide area of the Maldivian archipelago covering different habitat types: atolls' internal waters, kandu-oli (passages connecting the outer ocean with the waters inside the atoll) and channels between atolls. The Maldivian marine district provides the ideal scenario for validating the new assay considering its diversity in cetofauna, with 23 cetacean species recorded (Anderson et al., 2012, J. Cet. Res. Manage., 12: 219).

Across the 39 environmental samples, we identified over 250 molecular barcode signatures. Cetacean species were detected both when sample collections were simultaneous to cetacean sightings and when no cetaceans were spotted at the time of sampling. The two most commonly detected cetacean species (*Stenella longirostris* and *Tursiops truncatus*) confirm the most frequently observed in the archipelago. When the identified species were classified on the basis of their trophic level (which varies from 2 for herbivores to 5.5 for apex predators), we could appreciate that, as expected, low trophic-level species were predominant within the atoll, while in pelagic waters predators were prevalent, confirming the reliability of the eDNA to resolve local communities at sampled sites.

In conclusion, the newly developed markers seem promising in increasing cetaceans' detection and combining multiple primers pairs within the same run (multiplex) provide a more cost-effective approach for the simultaneous detection of fish and marine mammals.

Maldives northern atolls cetacean survey

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Abstract

Whales and dolphins (cetaceans) are protected within Maldivian waters, but subject to high levels of anthropogenic mortality in adjacent areas, particularly as a result of bycatch in gillnet fisheries. Even within the Maldives cetaceans may be impacted by increasing noise pollution, plastic pollution, direct human disturbance, and also potentially by climate change. In order to assess the status of regional populations, quantitative time series of cetacean abundance estimates are required.

A boat-based survey of cetaceans around the northern atolls was carried out from 6 to 23 April 2022, repeating surveys carried out in April 1998 and April 2013.

A total of 148 cetacean sightings of 14 species was recorded. Acoustic recordings and eDNA samples were collected from the vicinity of all 14 species. There was an average of 8.7 sightings per day in April 2022, compared with 8.6 in 2013 and 12.7 in 1998. Sightings per km surveyed declined more clearly from 1998 to 2013 to 2022.

These data suggest a possible decline in abundance of cetaceans in the Maldives over the past 24 years. Cetaceans are protected locally not only by law but also by the lack of cetacean bycatch in the dominant pole-and-line and handline fisheries. It therefore seems likely that any decline, if confirmed, may be primarily due to fisheries activities in surrounding waters. However, the role of oceanographic conditions has also to be taken into account: 1998 was an El Niño / positive Indian Ocean Dipole year, while 2022 is a La Niña / negative Indian Ocean Dipole year, both of which have profound effects on Maldivian pelagic ecosystems.

A more detailed analysis is being undertaken, using the line-transect distance-sampling data collected, and taking account of inter-annual changes in weather and oceanographic conditions.

Marine Mega-fauna

Responsible dolphin watching: case study from the southern channel of Laamu Atoll

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Abstract

Cetaceans were some of the first nationally protected marine species in Maldives. As a key species for the economy, they also have a historical, cultural and ecological value. Globally, much research has been conducted into the impacts and regulations surrounding tourist cetacean watching experiences. In Maldives, although individual tourism operators have established their own guidelines, no national regulations have been implemented. Six Senses Laamu has been recording data on guest 'Sunset Dolphin Cruises' since 2017, with revised methods since 2019.

This study aimed to record species behavioral and migratory patterns to facilitate the development of sustainable guidelines. Evening excursions target the daily migration of spinner dolphins (*Stenella longirostris*) from the inside to the outside of the atoll at the southernmost channel. The search pattern of the cruise and location of any encounters were recorded with a handheld GPS. During an encounter the species, pod size, number of calves, speed and direction of travel, level of surface activity and any avoidance behavior was noted, in addition to whether the boat adhered to the resort's dolphin watching code of conduct (CoC).

From January 2019 to December 2021, a total of 504 encounters were recorded. Cruises took place between 16:00 and 18:16, with a mean duration of 69 minutes. Spinner dolphins accounted for 90.8% (n=455), bottlenose dolphins (*Tursiops* sp.) 9% (n= 48), and false killer whales (*Pseudorca crassidens*) 0.2% (n=1) of encounters. Spinner dolphins were found mostly exiting the atoll, close to the reef corner on the west of the channel. 47 spinner dolphin encounters consisted of more than 100 individuals, and 4 with more than 200 individuals. 293 encounters included calves. The majority (n=27) of bottlenose dolphin encounters consisted of less than 20 individuals, and 64% of encounters included a calf. The CoC was successfully followed on 93.7% of all bottlenose dolphin encounters, and 90.3% of spinner dolphin encounters. Of these, 19.9% of bottlenose and 12.7% of spinner dolphin encounters displayed avoidance behavior. Avoidance behavior was displayed in 100% of all spinner dolphin encounters where the CoC was not followed. It is concluded that spinner dolphins regularly use the southern channel of Laamu Atoll, particularly the western corner, as a migration route. Although the CoC is effective, avoidance behavior is still demonstrated on occasions. Presently, only one resort targets this migratory route for a guest experience. However, with pending further development in the atoll, it is important to identify and minimize disturbances that may cause long-term changes in habitat use of these animals. This method provides low-cost, consistent data on cetacean sightings.

Seagrass and Mangroves

Seagrass and Mangroves

Seagrass meadows as valuable sources of reef island building sediments

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Abstract

Coral reef islands are often regarded among the world's most vulnerable environments to climate change since they are low-lying (typically <3 m above mean sea level) and formed entirely of sediment produced by organisms in the adjacent reef communities. Understanding the links between reef ecology and reef island building is therefore crucial for assessing future island resilience. While the rates of sediment production on coral reefs are becoming increasingly well constrained, the role of seagrass meadows as a potential source of island-building sediments has been largely overlooked.

Here, we present detailed analyses of sediment production within a seagrass meadow surrounding Faathihutta island, Huvadhoo Atoll, Maldives. Using field surveys, laboratory analyses and Unmanned Aerial Vehicle (UAV) orthophotography, our objectives were to quantify: (1) the rates and types of sediment production associated with a seagrass bed; and (2) the proportion of this sediment production which is of a suitable grade to contribute to reef island-building.

Seagrass sediment production rates ranged from 0.07 kg m^{-2} yr^{-1} to 0.77 kg m^{-2} yr^{-1}. Estimated annual sediment production by seagrass epibionts was 849 t yr^{-1} across an area of 1.1 km^2. Of this material, 78% (662 t yr^{-1}) was found to be of an appropriate grade (i.e. sand-sized) to contribute to reef island building. Such volumes of sediment are sufficient to produce the volume of Faathihutta island over a ~10 year period. We thus highlight the role of seagrass meadows as hotspots for the production of island-building sediments. Moreover, this role of seagrass as a reef island builder may become increasingly important as coral health in the region has declined under the recent global bleaching event. Results are discussed in the context of seagrass conservation, which is particularly pertinent in the Maldives as seagrass removal by the tourist industry is a routine practice.

Seagrass and Mangroves

Generating a national-scale seagrass map and quantifying seagrass fish diversity and value

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Abstract

Healthy seagrass habitats support a high diversity of marine taxa, with considerable societal value to conservation, food security, livelihoods and tourism. Additionally, seagrass beds themselves aid the resilience of small island nations to climate change by protecting shorelines from wave energy, storing atmospheric CO_2, producing island-building sediments, and improving water quality for adjacent coral reefs. Despite their high value, seagrass habitats are in global decline due to multiple stressors such as poor water quality, coastal development, extreme weather events and active removal (e.g. by the tourism industry in the Maldives). Mitigating these stressors is important to retain the benefits provided by seagrass beds in the future. However, seagrass conservation in the Maldives is difficult due to the absence of an accurate baseline understanding of seagrass habitat presence, areal extent and distribution. Here, we aim to produce an accurate national-scale seagrass habitat map of the Maldives Archipelago. In addition, to support the case for seagrass conservation, we characterize fish assemblages associated with seagrass zones adjacent to two reef islands. Satellite data were used to train a habitat classification algorithm to generate high resolution (10 m) freely available contemporary and historical seagrass habitat maps for the Maldives. Additionally, fish assemblages across different seagrass habitat zones were surveyed using video and small net sampling on inhabited (L. Hithadhoo) and uninhabited (L. Gaadhoo) islands. Fish density data will then be combined with economic valuations of species present in the seagrass habitats. All aspects of this work are ongoing, and as such preliminary results will be presented. Preliminary results from the mapping work highlight the presence of extensive beds across atoll rims nationally. Results from the fish surveys indicate a high abundance and diversity of seagrass-associated fish species across different zones. Notably, the analysis shows the presence of commercially-important groups. The findings of this work will contribute to a baseline understanding of Maldivian seagrass habitat area against which future changes can be monitored. Both the seagrass map and quantification of seagrass fish assemblages can provide scientific and economic evidence to support seagrass bed protection and management.

Seagrass and Mangroves

A multidisciplinary investigation into mangrove health in the Maldives using remote sensing and geochemical techniques

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Abstract

Mangroves forests are crucial ecosystems, providing many ecological and economic ecosystem services for coastal communities such as nutrient cycling, fisheries production and carbon storage. In addition, mangrove forests play a critical role in providing shoreline protection for coastal areas, a service which is highly significant for low lying nations such as the Maldives. Yet, despite their ecological and social significance, mangrove forests in the Maldives have experienced deforestation and deterioration over recent years. In 2020, reports of mangroves die-offs were documented across at least 11 islands and, thus far, the extent and cause of mangrove loss is unknown.

The aim of this study was to investigate mangrove health decline across seven islands in the Maldives (H.A. Kelaa, H.Dh. Keylakunu, H.Dh. Vaikaradhoo, H.Dh. Neykurendhoo, Sh. Feydhoo, Sh. Goidhoo and G.Dh Hoadedhdhoo) and to understand what factors are driving such changes. Specific research objectives were (1) to Identify and quantify any temporal trends in mangrove health from approx. 1972 to 2021 using remote sensing and assess the relationship between mangrove health and various climate and geomorphological variables such as sea level, precipitation and elevation. (2) To undertake a geochemical investigation into mangrove health decline from field-based research on G.Dh Hoadedhdhoo. (3) To provide estimates for carbon loss due to mangrove mortality.

This multidisciplinary research utilized a broad range of methodologies to enable a comprehensive understanding into the recent mangrove loss in the Maldives. Methods included: (1) Mangrove forests on seven islands were mapped from approx. 1972 to 2021 at 30m resolution to capture changes in mangrove health using Landsat satellite images. Moreover, the relationship between mean normalized difference vegetation index (NDVI) and sea level, precipitation and elevation was assessed by linear regression analysis for each island. (2) Comparisons of mangrove wood, leaf and sediment cores from living and dead zones enabled insights into mangrove geochemistry in each zone. (3) Carbon stocks were estimated and compared for living and dead mangrove zones. While this research is ongoing, our preliminary results indicate that since December 2020, mangrove health has significantly decreased across all seven islands. For the next stage in our analysis, investigations into the drivers of mangrove health decline will be examined using remotely sensed data and geochemical techniques.

Fisheries & Management

Preliminary findings on tuna association at AFADs in the Maldives through tagging and echosounder data

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Abstract

Anchored fish aggregating devices (AFADs) have been widely used in the Maldives tuna fishery since there deployment began in the early 1980s. At present 55 AFADs are deployed throughout the Maldives. The associative behavioral patterns of tuna have not yet been studied on a large scale at AFADs in the Maldives. This research project studied the behavior of two commercially important species of tuna (skipjack, *Katsuwonus pelamis* and yellowfin, *Thunnus albacares*) in the Maldivian AFADs array.

An subset of 21 AFADs was selected in the south of the Maldives. Echosounder buoys were attached to each AFAD to study the associated biomass. Acoustic and conventional tagging was conducted to investigate the movement of tuna between the AFADs and between other types of schools, namely drifting FADs (DFADs), log schools and free-swimming schools.

Preliminary findings from tagging data indicate that there is no apparent movement of tuna between AFADs in the Maldives, but there is some movement of tuna between different types of schools. Investigation of echosounder buoy data suggests that biomass at neighboring AFADs can vary in size and that there is no clear east to west gradient in biomass across the Maldives. The combination of echosounder buoy and acoustic tagging data suggest that there is a continuous turnover of fish at AFADs. In the Maldives array, the inter-AFAD distances are much greater than in several other AFAD arrays, and this could be the reason why the Maldivian do not act as a network.

Tuna behaviour at anchored FADs inferred from local ecological knowledge (LEK) of pole-and-line tuna fishers in the Maldives

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Abstract

The Maldives tuna fishery landings in 2018 was 148,000t and accounted for nearly a quarter of the global pole-and-line tuna catch. This fishery partly relies on a network of 55 anchored fish aggregating devices (AFADs) deployed across the archipelago. Although the AFAD fishery has existed for 35 years and about 1/3 of the total tuna catches is harvested from AFAD schools, knowledge on the behaviour of tuna in this low-density AFAD array is still poor, precluding development of evidence-based fishery management. In this study, local ecological knowledge (LEK) of fishers was used to improve the understanding on tuna behaviour in the Maldives, through personal interviews with 54 pole-and-line fishers from different parts of the archipelago.

The responses were subjected to a Principal Component Analysis on covariance matrix (centred PCA) in order to obtain an overview of the seasonality of tuna abundance, in relation to the species and type of school as well as with the origin and the location of the fishers. Interview results suggest that during the northeast monsoon there are more tuna on the east, while in the southwest monsoon there are more tuna on the west of the Maldives. Most fishers believed that tuna tend to stay at the AFADs for 3 to 6 days and remain associated within 2 miles of the AFADs. Strong currents are the main factor for tuna departure from AFADs, though high sea surface temperatures and stormy conditions were also thought to contribute to departures. Slight currents helped tuna to aggregate at the AFADs while suitable temperature, prey and attractants enhance this aggregation. There are multiple schools segregated according to size and species present at AFADs. Catchability is higher at dawn and in the late afternoon when the tuna surface. This study is an important step towards engaging the Maldivian tuna fishers in science-based fishery management.

Fisheries & Management

Assessing the biomass of commercially important fish being removed from the coral reefs of Laamu Atoll

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Abstract

Coral reef fisheries support over six million fishers worldwide. Commercial reef fisheries in the Maldives are a relatively recent phenomenon, with the national sector previously dominated by pelagic tuna fisheries. New and weakly regulated coral reef fisheries in the Maldives have been driven by increasing tourist demand, with the tourism sector demonstrating pre-pandemic annual growth of 7% since 1970.

Laamu Atoll's marine and coastal environment supports a community of 18,000 residents, providing them with jobs and food through fisheries and tourism as well as numerous other ecosystem services. Approximately 20% of the local population is engaged with fishing directly, with a larger percentage benefitting indirectly and several hundred people being employed by the tourism industry. Six new protected areas were declared in Laamu Atoll in December 2021. Blue Marine Foundation and Maldives Resilient Reefs are supporting the national and local governments to effectively protect these areas and to ensure that the remaining areas are managed. Understanding the scale and distribution of exploitative activities around the atoll is critical to develop effective marine conservation and management initiatives that ensure resources are not overexploited and continue to support the communities that rely on them.

This study aimed to quantify the fish biomass being removed from the coral reefs of Laamu Atoll by local communities. Data were collected by trained fisheries officers from seven islands in Laamu Atoll over three months between November 2021 and February 2022. During this period, the fisheries officers collected data from all fish and invertebrate landings which arrived on the island harbour for five days a week (Monday-Tuesday and Thursday-Saturday) and for five hours each day during peak times (7-9 am and 8-11 pm). Semi-structured interview questionnaires were then carried out surrounding the target species (i.e. reef fish, lobster, sea cucumber, octopus and other invertebrates) and included information about species, number of fish caught and fish length. Spatial questions were also asked to determine the location of fishing effort.

Measurements of 3,924 fish were recorded, and the biomass calculated for all 93 species landed. Size frequency distributions were created to determine the ratio of adults to juveniles being caught for each fishing gear used. Using the biomass and duration of each trip, the catch per unit effort (CPUE) was calculated. The spatial distribution of the CPUE and frequency of fishing trips will be mapped using GIS. The association between time of month and spawning aggregations will be determined. Data will be analyzed and recommendations made in July 2022.

Ensuring sustainable resort coral reef fisheries in Laamu Atoll

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Abstract

Despite being historically characterized by tuna fisheries, over the last 50 years, the Maldivian economy has become dominated by tourism. Rapid tourism development has resulted in an increased demand for coral reef fish, with weak enforcement of national fisheries management policies leaving coral reef environments vulnerable to overexploitation. The extent and impact of both commercial and recreational coral reef fisheries exploitation in the Maldives is not fully understood, with a lack of baseline data and governance structures making scientifically informed fisheries management a challenge. This study documents the work of Blue Marine Foundation (Blue Marine) and Maldives Resilient Reefs (MRR) in building sustainable coral reef resort fisheries through the development of (1) the *Laamaseelu Masveriya* (LM) programme as the Maldives's first sustainable resort reef fisheries model; and (2) a baseline understanding of tourist recreational fishing activity.

Based in Laamu Atoll in partnership with the five-star resort Six Senses Laamu (SSLM), Blue Marine and MRR established the LM programme in February 2020 to ensure that SSLM sources sustainably caught local seafood. Working closely with local fisher communities, the LM programme promotes reef fishing practices which have a minimal ecological impact upon marine ecosystems. A socio-ecological assessment of the LM programme in February 2022 found that the model had been successful in preventing the sourcing of protected reef species by SSLM. However, issues were identified around the traceability and sustainability of programme reef fishery activity, with 41% of landed reef fish identified to species-level regarded as biologically immature. Programme managers are addressing these issues through multiple management streams, which include the development of innovative fisher educational materials, transparent seafood sourcing processes, and precautionary landing size limits.

Analysis of SSLM recreational fishing activity has been able, for the first time, to characterize the extent of resort recreational fisheries in Laamu Atoll. Baseline data collection has identified the size and frequency at which reef fish species are landed, in addition to uncovering where fish are being caught around the atoll. Data collection and analysis will continue throughout 2022 and inform the development of resort recreational reef fishery management. Combining assessments of both commercial and recreational resort fishing activities is allowing Blue Marine and MRR to gain a holistic perspective of the impacts and extent of tourism-driven fisheries exploitation in Laamu Atoll. This work carries national significance for resorts across the Maldives and will help develop science-based fisheries management frameworks to ensure that the resort reef fisheries sector does not undermine coral reef resilience to future climatic change.

Fisheries & Management

Addressing post-harvest mortality in the livebait fishery in the Maldives

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Abstract

The Maldivian pole-and-line tuna fishery depends on livebait. Small shoaling fishes are thrown alive into the water behind the fishing vessel. This elicits a feeding response in the tuna and encourages them to attack the lure on the line at the end of the pole whereupon they are flicked into the fishing vessel. These small fish are collected within the atolls using rectangular lift nets, often employing lights at night to lure them to the water's surface. This baitfishing is carried out prior to each tuna fishing trip in the open ocean, with the bait being kept alive on the fishing vessel in tanks in the vessel's hold.

The pole-and-line tuna fishery was accredited by the Marine Stewardship Council as being sustainable in 2012, but with eight conditions. One of these was concerned with the quantity of livebait being harvested, while another questioned interactions of endangered, threatened and protected species (ETP) with the livebait fishery.

Analysis of livebait catch data reported through logbooks showed great variability in quantities of livebait between region, year and month. Statistical comparison of catches between years was impaired in many cases by lack of data, but several species showed either no significant difference in catches between years or a decrease from 2011 to 2014, depending on region. Importantly, any differences between years were not consistent by species or region and therefore changes in catches may be related to local depletion or inter-annual variability in abundance of these short-lived species rather than population-level effects of the bait fishery.

During field work conducted between 2011 and 2015 (130 trips), it was observed that post-harvest mortality of livebait was high. There is a need to address this issue to reduce pressure on existing livebait stocks. Further investigations revealed that this high mortality was linked to methods used for catching, transfer of livebait to the vessel and conditions inside the bait tank. Hence efforts were made to reduce post-harvest mortality in livebait through introduction of a wet-scoop and modification of livebait hold/tank on the vessel. These changes were shared with fishers and have helped to reduce the post-harvest mortality of livebait and to increase the stocking of livebait in the bait hold/tank.

Assessing the effectiveness of Marine Protected Area management in the Maldives: a summary of three case studies

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Abstract

The Maldives has a rich marine environment that is integral to the food security, income and recreational wellbeing of its inhabitants. Recognizing the value of the marine environment, the Maldives government has established a network of Marine Protected Areas (MPAs) to protect this environment. These MPAs are supported by many forms of national and international legislation and must be well-managed to ensure their success. This can be measured through Protected Area Management Effectiveness (PAME) assessments. PAME assessments help to measure the impact of management actions on the MPA's values and track progress towards achievement of the MPA's goals and objectives.

The Ministry of Environment, Climate Change and Technology has been working in partnership with technical specialists from the Ocean Country Partnership Programme (OCPP) to undertake a pilot study conducting PAME assessments for three MPAs in the Maldives: Hanifaru Bay MPA, Angsana Velavaru house reef and Kudahuvadhoo Kanduolhi grouper aggregation site. The completed PAME assessments combined extensive literature reviews and expert advice, with both virtual and face-to-face engagement of all relevant stakeholders, to synthesise information on protected area characteristics, resources, human pressures, monitoring, management and enforcement. The results of these assessments provide a holistic view of management effectiveness and are used to highlight priority elements where further action is needed. In partnership with the Maldives Government, OCPP will use the results of these assessments to plan the future work and priorities for this partnership in the Maldives for the coming year.

This presentation will include a summary of the key findings from the PAME assessments for the three MPAs, discussing the intersections between conservation goals, stakeholder opinions and management actions, and will provide an overview of the key recommendations from the assessments. It will also highlight key lessons learnt from undertaking the assessment for three different types of MPAs in the Maldives, providing recommendations on factors that could be considered not only in the management of MPAs, but also when assessing management effectiveness in the future.

The OCPP was established by the UK Government to deliver technical assistance to Official Development Assistance eligible partner countries worldwide, addressing three key marine conservation themes: biodiversity, seafood sustainability and pollution. In 2021, the Maldives Government partnered with the UK Government. Further information is available at https://jncc.gov.uk/our-work/maldives/

Plastic Pollution

Preliminary investigation of microplastic distribution and concentration in beach sediments in Greater Malé: a pilot study

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Abstract

Centrally located in the Indian Ocean, there is potential for Maldivian ecosystems to become a sink for both local and global microplastic pollution. Microplastics (< 5mm) are taken up by marine organisms and this exposure may result in adverse effects on both individual and ecosystem functioning. Despite this threat, the scale and magnitude of microplastic pollution in the Maldives has yet to be properly qualified or quantified. What is known is dependent on a handful of studies that have collected samples during a single season from single or limited locations, providing a poor national description and understanding of the situation at present.

This pilot study aimed to establish a baseline of the current concentration, composition and distribution of microplastics associated with beaches in the Greater Malé region. The resulting data will contribute to the development of a national (micro)plastic monitoring program (embedded within the National Coral Reef Monitoring Framework). 120 beach sediment samples were collected in 2020, from three stations within Malé, Hulhumalé, Villimalé and Thilafushi in the Greater Malé region. At each station, a 20m transect line was laid along the high tide line on the beach and a 50cm x 50cm quadrat was placed every 0, 1, 2, 10 and 20m to collect samples. Five 100ml subsamples were taken from each quadrat to obtain a 500ml sample per quadrat. Additionally, 5 control samples were collected per station for each sample, making a total of 120 samples. Collected samples were sent for analysis to Centre for Environment Fisheries and Aquaculture Science, UK, where microplastics were extracted from dried sediments and analyzed using Focal Plane array (FPA) detector-based micro-Fourier-transform infrared imaging. Particle size analysis was also performed to determine whether microplastic hotspots aligned with specific sediment compositions.

Analysis is ongoing, but the preliminary findings indicate microplastic concentrations ranged from 0 to 600 particles per kg (dry weight sediment). Over 80% of the microplastics were attributed to polypropylenes, with the rest characterized as polyurethanes, acrylates and rubber, among others. These preliminary findings give an insight into potential sources of microplastics in the Greater Malé region. Additionally, this pilot study highlights the need for additional and more widespread studies of microplastics in the Maldives.

The first multiuse water-landing fixed-wing drone trials in the Maldives

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Abstract

Annually, 4.8 to 12.7 million of tons of plastic are released into the seas. Much plastic floats on the ocean's surface, often for years before degrading to microplastics. The Republic of the Maldives, with 1129 km of coastline and its geographical position in the middle of the Indian Ocean, receives significant plastic debris, much of which has travelled many miles from its source.

In April 2022, Oceans Unmanned donated a water-landing fixed-wing drone (the first time this system is being used in the Maldives) to the MaRHE Centre Maldives, to augment an ongoing collaborative project, around methodologies for plastics detections using drones.

To help fill the gap of understanding plastic aggregations in the Maldives, we are developing simple methodologies and operational guidelines for resorts and local islands, to use drones as citizen scientists. The guidelines will help drone operators build a viable plan for image gathering, which takes into consideration context dependent variables, allowing for tailored operations for any site.

This project incorporates drone engineering, method development and remote sensing objectives. The fixed-wing drone, DJI Phantom 4 and DJI Mavic Enterprise were compared for usability and image output. The study site was Magoodhoo island, Faafu Atoll. Six fixed-wing flights were flown, with flight times <55 minutes, at 80m and 100m altitude. Sixteen quadcopter flights were flown, lasting 15-25 minutes, at altitudes of 100m, 50m, 25m and 10m. The fixed wing was equipped with a Sony RX0 15mp camera and piloted using Mission Planner software. An overlap of 80% and side lap of 50% produced the best orthomosaics to area ratio. Image geotags were assigned to the EXIF files in postprocessing using the GNSS coordinates from the flight controller. Orthomosaics were made using Agisoft Metashape software.

Preliminary interrogation of the images was carried out in Agisoft Metashape and MATLAB, where images were viewed in different colour bands. Orthomosaics from geotagged fixed-wing images had an average ground resolution of 1.56cm/pixel, which is comparable to quadcopters. The average fixed-wing flight was 45 minutes long, traveling 32km total distance, covering up to 1km2. The fixed wing has 10km range and if the objective of the flight is surveying beaches and reefs only (no grid survey) total area could be increased to ~12km^2 per flight with an 80% overlap and no side lap. The system tolerates gusts greater than 30km/hr.

Water-landing fixed-wing drones can cover large areas quickly, but system operation may be off-putting for new users (a smaller version may be more suitable). Technology acceptance assessment is needed to understand how this system and associated methods will work in Maldives. The water-landing feature works well on open ocean and lagoonal areas. There is clear application in habitat mapping and land-use change monitoring.

Plastic Pollution

Abstracts of

Poster Presentations

Corals & Coral Restoration

An observational insight into coral spawning patterns on two Maldivian reef ecosystems

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Abstract

Coral spawning is a well-known phenomenon, with much information from across the Indo-Pacific collated in the Coral Spawning Database. However, little about the extent of spawning synchronicity has been documented from the Maldives, one of the world's most renowned coral reef ecosystems here in the Maldives. This in turn limits our understanding of coral reproductive biology at a regional scale and limits our ability to assess shifts in reproductive phenology over time.

Reefscapers have compiled a spawning database dating back to 2013, however, in 2020 we began to hone our in-situ observations and to formally track species specific coral spawning events. Research surveys took place on two Maldivian reef ecosystems across three islands, one in Baa Atoll and two in North Malé Atoll. To identify coral reproductive maturity, we conducted in-water surveys to locate the presence of gametes, prior to known spawning months. Once identified, colonies were tagged, tracked, measured and photographed via snorkeling or SCUBA. Upon observation of mature gametes, nightly snorkels/dives took place between 1900 – 2300h around the Full and New Moons from October 2020 to April 2022. This was to identify exact 'bundling' and spawning times. In addition, environmental cues, including lunar stage, tidal state, wind, precipitation and temperature were monitored.

To date we have tracked 19 species spawning across three sites over 22 events. This includes 18 species of Acroporidae and one species of *Goniastrea*. Observational data reveal that spawning dates are atoll- and species-specific. Two spawning cycles occur, one asynchronous towards the end of the year and a mass spawning event early in the year. Evidently, there are correlations with spawning patterns and environmental cues. Results suggest that Baa Atoll species spawn earlier than those in Malé Atoll.

This information will help to understand ecosystem recovery and connectivity of Maldivian reefs on both local and regional scales, and to improve our knowledge on species-specific synchrony and timing of spawning in connection with environmental cues.

Effect of the COVID-19 lockdowns on the management of Maldivian coral restoration projects

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Abstract

Coral restoration initiatives are gaining momentum in a global effort to enhance the recovery of degraded coral reefs and to protect the ecosystem services they provide from anthropogenic and climate threats. After the first investment to build the nursery, maintenance and monitoring are fundamental for the success of such projects. However, the implementation and upkeep of coral nurseries are particularly demanding in term of time and workforce involved. Therefore unforeseen breaks in maintenance might jeopardize well-established projects.

In the last two years, the COVID-19 pandemic has resulted in the temporary yet prolonged abandonment of several coral gardening infrastructures worldwide. Here we provide a first assessment of the potential impacts of monitoring and maintenance breakdown on different coral restoration projects based on floating rope nurseries in the Maldives, and comparison with similar projects in Colombia and Seychelles. The study included nine nurseries from six locations, hosting a total of 3,554 fragments belonging to three coral genera (*Acropora, Pocillopora* and *Porites*), that were left unsupervised for a period spanning from 29 to 61 weeks. Floating nursery structures experienced various levels of damage, and total fragment survival ranged from 40% to 95% among projects, with *Pocillopora* showing the highest survival rate in all locations studied. Overall, the study shows that, under certain conditions, abandoned coral nurseries can remain functional for several months without suffering critical failure from biofouling and hydrodynamism. However, even where gardening infrastructures were only marginally affected, the sudden unavoidable interruptions in data collection have slowed ongoing project progress, diminished previous investments, and reduced future funding opportunities. These results highlight the need to increase the resilience and self-sufficiency of coral restoration projects, so that a possible future global lockdown or casualty will not further shrink such efforts to prevent coral reefs from disappearing.

Paradise under threat

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Abstract

The vulnerability of the Republic of the Maldives to current climate change has been highlighted for over three decades. Geographical, ecological and oceanographic dynamics all play a role in the low-island nation's susceptibility to water inundation, increased sea temperature, coral mortality and ecosystem phase shifts. For example, the Maldives has reported mass coral bleaching and concurrent mass mortality as a direct result of increased water temperatures, losing up to 90 % of coral cover.

Due to these recent unprecedented losses of coral cover, and in order to safeguard the longevity and biodiversity of the coral reef systems and the nation's tourism sector, numerous NGOs, resorts, guesthouses and dive centres have implemented small scale coral restoration projects. However, many of these projects have not been reported or published and so it can be difficult to assess best restoration practices specific to the Maldives. Here we attempt to synthesize the extent of restoration projects throughout the Maldives and their success. Having this knowledge will assist all coral restoration efforts in the Maldives and move the field forward.

Assessing the impacts of nitrogen pollution on coral reef ecosystems in the Maldives: preliminary insights from Laamu Atoll

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Abstract

Although the negative effects of elevated nitrogen on corals are widely assumed, the direct effects of nitrogen enrichment on corals are complex, affecting both the coral host and their symbiotic dinoflagellates. Under optimal conditions, natural levels of nitrogen equate to the needs of the coral holobiont. Excessive amounts of inorganic nitrogen from anthropogenic activity disrupt this equilibrium by stimulating overgrowth of the symbionts to the detriment of coral host metabolism and calcification; by encouraging algal phase shifts and coral diseases; by decreasing coral reproduction and survivorship;, and importantly, by increasing coral susceptibility to temperature-induced bleaching. For the Maldives, an island nation dependent on healthy resilient reefs, understanding what factors both mitigate and exacerbate the prevalence and intensity of bleaching events is crucial.

The aim of this study was to improve understanding of the relationship between Maldivian corals and elevated nitrogen concentrations, with a focus on the susceptibility of these corals to bleaching. To address this question, we created a 6-month nitrogen enrichment experiment on an oligotrophic patch reef located within Laamu Atoll, a time period that has included at least one moderate thermal stress event. To enrich local concentrations of nitrogen, Osmocote slow-release fertilisers were placed into 'nutrient diffusers', constituting a mesh bag placed inside a PVC pipe, with 15 ~ 1cm holes drilled into it. 30 *Pocillopora* coral colonies were identified within a depth range to 3 to 8m, tagged, and then assigned one of three treatments: control (n=10); high nitrogen (150g 18-9-10 N:P:K, n=10) ; or a balanced nitrogen : phosphorous (150g 13-13-13, N:P:K, n=10), with fertilisers replenished every 6-8 weeks. Every 2 weeks at the beginning and conclusion of experiment, water samples were collected for DIN, ammonium and phosphate analysis, with bleaching surveys taking place every 2-3 weeks. Each month, coral nubbin samples (5-10cm) were collected for nitrogen isotopic composition analyses ($\partial15N$) of both the coral tissue and algal symbionts to help identify nitrogen sources and provide insights into heterotrophic vs. autotrophic feeding preferences. HOBO loggers recorded temperature every 15 minutes.

This experiment is still on-going (concluding June 2022), but preliminary findings suggest that 20% corals treated with high N and 30% of corals treated with N+P have experienced mild bleaching, whilst 80% of untreated colonies have experienced mild to moderate bleaching. Although more lab work is required to supplement in-depth analyses on the impacts on coral-algae feeding preferences, these initial findings suggest that enriched nitrogen may positively influence Maldivian corals, although tipping points may still exist, perhaps on longer timescales.

Reef Ecology

Exploration of linkages between coral reef complexity and soft coral growth in coastal environments

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Abstract

Various factors such as water depth and movement, temperature variations, tidal range, salinity and water mixing, among others influence the growth of corals in coastal areas. Research over the past six decades shows multiple measures of complexity to be primary drivers of biodiversity in these ecosystems. Complex reef formations such as reef cracks, collapsed sections, crevices, passageways and similar structural formations have been observed to display abundant and unique marine life in comparison to other areas of the reef. Field observations, in the Maldives, by the research team show similar abundance, especially of soft corals, in complex reef formations.

This study, focusing on the Banana Reef, in North Malé Atoll in the Maldives will be a preliminary attempt to verify if there are significant differences in growth of soft corals in areas with varying degrees of reef complexity. Reef complexity will be measured using a 20m floating transect line. Large scale measurements are made by measuring the distance from the reef bed to the line every 0.5 m using a laser 'yardstick device'. Coral abundance will be measured using a line intercept transect. Based on visual observations, soft coral growth is expected to be more abundant in more complex reef areas with cavities and crevices. Based on the findings of this study, it is proposed to expand this research to include more sites comparing similar complex habitat areas with control sites to understand what factors contribute to the abundance of soft corals in these structurally complex areas. While many researchers and divers may have made similar observations, there has been little scientific study of these areas in the Maldives.

The use of local ecological knowledge (LEK) in manta ray conservation, Maldives

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Abstract

Since 2005, the Maldivian Manta Ray Project (MMRP), the founding project of the Manta Trust, has contributed to advances in knowledge about the Maldives manta ray population. However, most of the data collected has been sourced from more populated atolls with many operators submitting sightings data. Little is known about the presence, distribution, and population demographics of the manta rays in the less developed atolls. Thus, knowledge gaps remain, hindering the development of efficient conservation management.

Local ecological knowledge (LEK) acts as a cumulative body of information from local communities through direct observation, interaction, and experience. Due to the financial and logistical challenges of researching the marine world across numerous islands and atolls, long term and complete observational studies are difficult to attain. However, local communities, particularly fishers, have more frequent access to such locations. Targeted community interviews can, therefore, provide a cost-effective method for obtaining data on the distribution of, and recognizing changes in, megafauna populations.

The primary aim of this study was to gain LEK from the Laamu Atoll local community and fishers, via semi-structured interviews. Specific aims included determining the community's understanding of manta rays, and their awareness of and attitude towards conservation regulations, as well as determining if any anthropogenic impacts are threatening such species in order to identify how management might aid their conservation.

By conducting social science surveys, the MMRP will be able to set a baseline understanding of manta ray presence, distribution, and status in Laamu Atoll where data are currently lacking. The survey aims to discover new manta aggregation areas which are currently active or were active many years ago. By questioning fishers on threats that manta rays face, the MMRP will gauge whether any specific fishing gear is more susceptible to manta ray entanglement and determine an effective management approach to reduce pressures and subsequent risk of entanglement. Finally, the MMRP aims to increase the awareness of the Manta Trust's research and presence in Laamu Atoll.

The Laamu Atoll MMRP team, an Exeter University Marine Environmental Management MSc student, and a representative from the EPA, will visit every inhabited island in Laamu, during April and May 2022, to conduct interviews with fishers, boat captains, and seafarers. The questionnaire will include questions regarding historical manta ray abundance perspectives, perceived threats, and opinions on local conservation measures. The student will provide an 8000-word report, with supervision from Exeter University and the Manta Trust. Surveys will finish in May 2022, with results and conclusions completed by August 2022.

Seagrass colonization in recently disturbed areas

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Abstract

Seagrass meadows are one of the most important marine ecosystems, for the multiple services they provide. For example, they act as carbon sinks, nursery grounds for multiple fish species and foraging grounds for species such as the endangered green sea turtle. However, approximately 15% of seagrass species are considered threatened because of several natural and anthropogenic threats, such as climate change and habitat fragmentation.

In the Maldives many seagrass meadows are removed for aesthetic purposes. Of the resorts which have seagrass meadows 46% actively remove seagrass. In this research project we document seagrass recolonization in areas which have recently been cleared, in order to better understand the regrowth of seagrass and to find out if the methods used to remove seagrass are effective.

By placing three 1m x 1m quadrats in the area where the seagrass meadows have been removed or disturbed, we look at both the rate of seagrass recolonization and the species which recolonize the area.

This study is still ongoing, but initial observations suggest that some methods of seagrass removal (e.g. digging out with heavy machinery and hand removing) will leave fragments of leaves and rhizomes, which help in the recolonization and expansion of the meadows, rather than controlling their growth. The aim is to find out how effective these methods are, so that we can control the growth of seagrass in certain areas rather than removing the whole meadow. This research is important for the understanding of the effectiveness of seagrass extraction practices.

The protection of sharks in the Maldives : a case study

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Abstract

Sharks play a vital role in coral reef ecosystems. As apex predators, they maintain the structure and health of marine ecosystems. The Maldives is a country that relies on healthy coral reef ecosystems for its sustainability. Consequently, maintaining healthy shark populations is a significant concern.

Sharks grow slowly, mature late and give birth to a small number of pups. As a result, shark populations are very susceptible to overfishing. Once overfished, different species may take years, or even decades, to recover. Worldwide, shark populations have declined 77% over the past fifty years as a result of overexploitation in fisheries. Despite an increase in protection measures for sharks over the last 20 years, there continues to be a downward trajectory in many shark species' populations.

The Maldives is one of seventeen countries to have committed to protecting sharks and ban shark fishing, with complete protection commencing twelve years ago. Before assessing the current population status of sharks in the Maldives, we aim to gain a better understanding of the perceptions surrounding sharks from local communities, both before and after protections were introduced.

After initial interviews with local fisherman in Noonu Atoll, it appears that the population of sharks has exponentially increased since the protection of sharks in 2010. Maldivian fishermen are reporting increased numbers of sharks in all fishing locations within the atoll and a loss of catch due to interference from sharks (i.e. through direct capture of their fish or disruption of fishing activities), resulting in losses of income.

We aim to look at the shark fishing ban in Maldives and produce a case study of its achievements for the community of Maldives. We expect that there has been an increase in shark populations since the protection came into place in 2010. We aim to understand, through interviews with individuals in the community, if this increase in shark population has influenced fish catch numbers for the fisherman in Noonu Atoll and thus has had a negative impact on the local community.

This case study is ongoing, and collection of data is underway. It seeks to give a broad overview of the overall results of the shark ban from the perspective of local fishermen, both environmentally and socio-economically. We anticipated that the overall protection of sharks will have multiple positive impacts, not just environmental. Healthy shark populations should lead to improved reef ecosystem health, healthy fish stocks and a positive impact on the dive-tourism industry.

Fisheries & Management

An atoll level mapping of resource use to inform improved marine resources management

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Abstract

Laamu Atoll is extremely biodiverse, and its natural resources support many industries and user groups. However, their activities are not well understood or quantified. Understanding the levels and spatial extent of resource use activities is essential to ensure that ecosystems and the resources they provide can maintain their capacity to support the people who depend on them. This study provides the first baseline for marine resource use in Laamu Atoll and is important to monitor future change in resource use.

Between December 2020 and June 2021, we carried out surveys with 240 fishers, 11 local councils, 25 local fish export companies, 41 NGOs, two tourism operators and one fish factory in Laamu Atoll. Interviews were conducted by Maldives Resilient Reefs and Blue Marine Foundation staff and trained interns from the Maldives National University and were carried out using the Survey123 mobile data collection application provided by ArcGIS.

Results showed that tuna and reef fisheries are the most popular fisheries in Laamu Atoll. Reef areas (<2.5km from land) are extremely important in supporting several commercial fisheries including the reef fish, billfish, bait fish, sea cucumber and lobster fisheries. Inner areas of the atoll (>2.5km from land) do not appear to be very important areas for fisheries. Areas further away from the atoll are important for the tuna fishery, although the bait fishery is heavily concentrated inside the northern areas of the atoll.

Fishers reported seasonality for billfish and sea cucumber fishing which are mainly conducted during the southwest monsoon and for lobster which is mainly conducted during the northeast monsoon. Both the reef fishery and invertebrate collection are mainly conducted during full moon and new moon periods.

The lobster fishery was reported to be the most valuable in terms of income per month. Typically, fishers rated the status of fisheries they were involved in as being very good, however, in each fishery responses ranged from very good to very bad. The exception was tuna where most fishers rated this fishery to be in the worst shape possible. Several unsustainable practices were identified by fishers including the use of powerful lights to catch tuna baitfish, nets for reef fishing, SCUBA gear for sea cucumber collection and chemicals for the octopus collection. Fisheries resource use activities were also assessed in respect to the new Marine Protected Areas (MPAs) around Laamu. There was a high level of commercial and non-commercial reef fishing and billfish fishing activities within these areas. Therefore, these user groups should be actively engaged when designing management interventions.

Calculating the biomass of commercially and ecologically important fish families on the coral reefs of Laamu Atoll

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Abstract

In 2019, research was conducted by Blue Marine Foundation in collaboration with Six Senses Laamu and the University of York which provided a baseline assessment of coral reefs around Laamu Atoll. Like other reefs across the Maldives, and globally, coral reefs in Laamu Atoll are under threat from a combination of anthropogenic activities and climate change. The Maldives is dependent on its coral reefs for both tourism and fishing, the two most important economic activities for the country. It is therefore imperative that a baseline of reef health is established, and reefs are continually monitored to enable both proactive and reactive protection of coral reefs.

The 2019 study, which assessed 20 coral reefs, concluded that reef fish populations of Laamu Atoll were relatively diverse with a mean of Simpson index value of 0.91, with the index value ranging between 0.46 to 0.96 between sites. Lutjanidae (snapper) was the most abundant family among the commercially important fish species and Chaetodontidae (butterflyfish) was the most abundant family among ecologically important fish species. Due to the high abundance of coral dependent species, it was suggested that the reefs on Laamu Atoll appeared to be experiencing ongoing recovery from the 2016 bleaching event with varying success.

Now, Maldives Resilient Reefs and Blue Marine Foundation, in collaboration with Six Senses Laamu and the University of Exeter are building on this baseline survey. Data on fish and invertebrate abundance and biomass, and coral cover are being collected at all 20 of the original survey sites and an additional 10 sites. Data is collected at two different depths along two 50-meter belt transects. The present study will include size estimates of fish to calculate the biomass of commercially and ecologically important fish species and provide a new assessment of fish and invertebrate assemblages on the reefs of Laamu Atoll. This study will also allow comparisons to be drawn between 2019 and present day. Data collection will be completed by June 2022 and analyzed immediately after.

Fisheries & Management

Fisheries & Management

Determining the current catch per unit effort of the gleaning fishery in seagrasses in selected locations on Laamu Atoll

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Abstract

The practice of gathering or collecting marine life from the shallow coastal waters during low tide is known as gleaning. Gleaning is practiced across the world, in a variety of different forms, and in many cases is an important food source for fishing families. Due to a lack of research, it is often overlooked as a fishery and underappreciated in fisheries science. Both men and women glean but it is usually the women and children who are involved in this fishery in most countries where gleaning is practiced.

The residents of Maldives have always relied on fishing for sustenance and livelihoods. A range of gears and techniques are used across the country for the capture of a variety of pelagic, reef and benthic organisms. The most widespread fishery in the Maldives is the pelagic tuna fishery. The reef fishery is expanding, mainly catering to the domestic tourism markets. Additionally, there are established fisheries for grouper, billfish, sea cucumber, lobster, marine aquarium fish and diamond back squid. Fishing for invertebrates along the shoreline appears to be widely practiced in the Maldives but is poorly understood and hence the fishery is currently not managed.

Resource use surveys conducted by Maldives Resilient Reefs and Blue Marine Foundation across all eleven inhabited islands in Laamu Atoll in 2020 showed that invertebrate gleaning is practiced by at least 55 fishers in the atoll within seagrass meadows. However, many fishers reported that this fishery is in poor state. Fishers typically conduct gleaning activities in the evenings (5pm - 10pm) at low tide, particularly during new and full moon periods and target a range of species such as sea cucumbers, octopus, crabs and shells. The products of gleaning are either sold for additional income or used as food.

Maldives Resilient Reefs in partnership with Blue Marine Foundation and University of Exeter are currently conducting interviews with gleaners and observing their fishing trips across three islands on Laamu Atoll. The information gathered will help us determine the dynamics of this fishery and determine the catch per unit effort in order to establish a baseline from which future changes in catches can be measured. Data collection will be completed by June, and results will available immediately after.

Management and research on the livebait fishery of the Maldives

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Abstract

Monitoring and research on fisheries are critical for successful management. The International Pole-and-Line Foundation (IPNLF-Maldives), together with the Maldives Marine Research Institute, has been fortunate to have been running a Catch and Bycatch Sampling Program in the Maldives since 2012. So far, the data acquired have been used to evidence levels of bycatch, ETP interactions and fuel-use-intensity of the Maldives one-by-one pole-and-line and handline tuna fisheries.

However, the livebait fishery, which is essential for the tuna fisheries, has received limited research focus until now. Preliminary analyses of livebait data have shown changes taking place in the fishery in terms of methods of harvesting, levels of catch and species composition. In tuna fisheries, issues with livebait are often considered to be an impediment to the success of fishing trips. As a result, IPNLF-Maldives and MMRI have initiated a series of activities to improve conservation and management of livebait resources.

With support from GEF-SGP/UNDP one project is demonstrating a suite of best practices on transfer, holding and reducing post-harvest mortality of livebait. Under the Maldives National University, a resource mapping exercise is being conducted that will help to identify key bait fishing areas, and thus assist in minimizing conflict and addressing fishers' needs during spatial and development planning. Under the Darwin Initiative (UK) an ambitious research project is underway to explore the efficacy of several external stimuli to attract surface-swimming tuna schools to pole-and-line gear with minimal or no use of livebait.

These activities are important in several respects: promoting rational utilization of the limited livebait resources; alleviating the pressure on the resource; understanding the spatio-temporal aspects of the fishery; promoting fishers' contributions towards spatial and development planning; reducing dependency on livebait resources for tuna fishing; and reducing negative effects of livebait fishing. Ultimately, these projects should contribute towards improved conservation and management of livebait fishery, which is critical for maintaining a sustainable one-by-one tuna fisheries in the Maldives. IPNLF-Maldives works in close collaboration with the Ministry of Fisheries, Marine Resources and Agriculture, and especially the Maldives Marine Research Institute in delivering the science. All data and findings from the research activities of IPNLF-Maldives are provided to the collaborators.

Plastic Pollution

Microplastics in sewage: from monitoring challenges to mitigation technologies

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Abstract

The presence of microplastics (MPs) in water and in sewage has been variously reported in the scientific literature, as have the possible implications for human health and marine organisms. Water and wastewater treatment plants (WWTPs) may still release large quantities of MPs in effluents even if their efficiency in removal may reach 99%. Moreover, MPs travelling to WWTPs may degrade into smaller nano-plastics due to mechanical stress, and they may also clog the filtration unit. Microplastics can cause cellular damage, through oxidative stress, inflammatory and immune reactions. Moreover, microplastics can also act as carriers of toxic pollutants and pathogens, especially the nano-sized fraction that is more effective at crossing biological membranes and, due to its increased surface area, can display higher chemical reactivity. The main concerns are related to the contamination of freshwater and therefore to the use of contaminated water for drinking, agriculture, and aquaculture. In addition, sewage may carry microplastics (e.g. from cosmetics and agriculture) and synthetic microfibres (e.g. from textile washing) to the marine environment.

At the present time the lack of standard methods for sampling, extraction and identification of microplastics prevent the ready comparison of data collected from different studies and therefore the definition of exposure and discharge limits. More specifically, the choice of analytical instrumentation results in pronounced differences in the data format. For example, micro-spectroscopy techniques provide particles counts that may be affected by severe size limitation due to the physical limitation of the radiation wavelength used, while mass spectrometry of polymers requires thermo-degradation and is affected by matrix interference. Applying sample pre-treatment may help to limit these drawbacks, but extensive sample manipulation may cause increase of background contamination issues.

Finally, for mitigation of the impacts, implementation of new filtration technology and application of dedicated processes (e.g. density separation, coagulation and biodegradation) may limit the impacts of MPs. At the same time, replacement of single-use plastic with more sustainable materials is needed.

Plastic Pollution

First detection of microplastics in reef-building corals from a Maldivian atoll

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Abstract

The presence of microplastics in the world's oceans and their effects on marine habitats are highly concerning. As suspension-feeders, corals are very exposed to microplastics, compromising the health of coral reef ecosystems. In this study we surveyed for the first time the presence of microplastics in Maldivian reef-building corals. The aim was to determine the influence of exposure and depth on microplastic distribution. Analyses were carried out on 38 individuals belonging to three different species. 58% of the investigated colonies were contaminated with particles within the 25-150 µm size range. The maximum concentration was encountered in one *Pocillopora verrucosa* colony sampled from a shallow inner reef (8.9 particles/g of coral). No significant differences in microplastic concentration were observed between different depths, exposures, sites and species. Overall, this study confirmed microplastic presence in coral reefs of the Maldivian archipelago including foundation species.