Egypt Marine Expedition 2025 Report

Funded By

The British Sub-Aqua Jubilee Trust

Lord's Mayor 800th Grant

Gilchrist Educational Trust

The Chancellor's Fund

Turing Fund

Report Outline

The following document aims to provide a report of the 2025 Egypt Expedition, organised by University of Glasgow students in association with the Exploration Society, and the work conducted.

The University of Glasgow Exploration Society has been running geographical and zoological research expeditions since the 1920s. The society, and therefore this expedition was affiliated with the University of Glasgow, Scottish Charity Number SC004401.

Cover Photo: Whitespotted Puffer taken by the 2025 Egypt Expedition Team

Contact Information

Email: Egyptexpedition23@gmail.com
Facebook: @ University of Glasgow Egypt Marine Expedition
Instagram: @uofgmarineegypt

Leo Yokota
28 Ochiltree Drive
Hamilton, ML3 9NH
yokotakoyo614@gmail.com
+447478914831

Catherine Mou
Unit 404, Scotway House
165 Castlebank Street
Glasgow, G11 6EU
catherine.momijie@gmail.com
+447399127304

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1. Introduction

The 2025 Marine Egypt Expedition ran from the 9th of June to the 6th of July 2025 in El Quseir, a coastal town situated on the coast of the Red Sea in Egypt. The expedition was able to be carried out according to plan thanks to our incredible team members' fundraising efforts, personal contributions, and the exceedingly generous support and funds supplied by our grant funders. Two proposed SCUBA based research projects were run, altered slightly from the original Marine Egypt Expedition Prospectus.

Overall, the 2025 Marine Egypt Expedition was incredibly successful. This report will go forth to document the expedition, break down our income and expenditure, outline the expedition aims, how they were achieved and the findings from our projects.

Above: 2025 Egypt Expedition team with local supervisor, Guy Henderson and a volunteer prior to a research dive in El Quseir. Egypt Expedition 2025

2. Income and Expenditure

The expedition was funded through a mix of team member personal contributions; fundraising, including team run events, GoFundMe, and grant funding. We would like to acknowledge the Turing Fund, The British Sub-Aqua Jubilee Trust, Gilchrist Educational Trust, Lord's Mayor 800th Grant, Glasgow Natural History Society (Blodwen Lloyd Binns Bequest Fund), University of Glasgow Chancellor's Fund without whom this expedition would not have been possible.

Below is a clear visual breakdown of this income and expenditure and the expedition's full budget is available upon request.

2.1 Income

Source	Notes	Amount
Personal Contribution	£700 per person	£4,900.00
Fundraising	Fundraising Events	£1,028.50
Grants	Turing fund	£2,110.39
	The British Sub-Aqua Jubilee Trust	£2,000.00
	Gilchrist Educational Trust	£2,000.00
	Lord's Mayor 800th Grant	£1,400.00
	Glasgow Natural History Society	£1,000.00
	University of Glasgow Chancellor's Fund	£700.00
Project funds	Masters Student Fund	£130.00
	Honours Student Fund	£270.00
	Total	**£15,538.89**

2.2 Expenditure

Source	Notes	Amount
Flights	£444.04 per person (return)	£3,108.28
Transfer Bus		£310.00
Accommodation	£145/week/per person	£3,895.00
Food & Water	£160.00/week/per person	£4,300.00
Research Licence Fee	£16/per person	£112.00
Dive Costs	£160.00/week/per person	£2,233.00
Dry Lab Access	£4/day/per person (7days/4weeks)	£720.00
Equipment		£860.61
	Total	**£15,538.89**

3. Expedition Aims

3.1 Collaboration

This expedition marked the 3rd consecutive year returning to El Quseir after COVID-19 and the eighth expedition in Egypt overall. We stayed at ROOTS Red Sea which is a resort aimed for divers and is owned by Steve and Clare Rattle. All food and drinks were provided by ROOTS Red Sea, and we were assisted by their staff members during day-to-day activities. For the duration of our stay, we worked with Open Ocean Science Centre (OOSC) which is an organisation aimed to conduct scientific research on the reefs and was founded as part of ROOTS Red Sea. The diving was supported by Pharoah Dive Club which is the dive centre operating out of ROOTS Red Sea.

We are immensely grateful to the staff members, dive professionals and volunteers working at ROOTS Red Sea as they were incredibly helpful with the running of the projects, helping us overcome issues we encountered during pilot studies, data input, and subsequent statistical analysis. The overall environment ROOTS Red Sea created for us was incredibly welcoming and enjoyable.

During our days off in El Quseir, we volunteered with some staff members and other volunteers from ROOTS Red Sea to conduct some beach cleans. Two beach cleans were held at Hamrawein with the local children, accompanied by some games and a match of football afterwards. Another beach clean was organised at the mangroves which was accompanied by an educational tour by Guy Henderson to show us the incredible ecology of mangrove forests.

Above: (left) Team members exploring the mangroves. (right) Team members conducting a beach clean with local children.

Prior to the team's departure to Egypt, team members without the required SCUBA certifications underwent SCUBA diving training in Scotland through Blue Hippo Diving (a Glasgow based dive organisation). The 2023 Marine Egypt Expedition also carried out their dive training through Blue Hippo. This sets up the hope that the expedition can develop a long-term working relationship with Blue Hippo.


Above: (left) Team members from the 2025 Egypt Expedition, 2025 Thailand Expedition with Instructors from Blue Hippo. (right) Team members from the 2025 Egypt Expedition, 2025 Thailand Expedition with Instructors from Blue Hippo

3.2 Research

The 2025 Egypt Expedition team conducted two research projects over the course of the expedition. Both projects were undertaken on the Abu Sauatir reef near El Quseir using SCUBA and snorkelling based methods by all team members. Each member learned and were able to carry out all surveys, thereby greatly developing their scientific diving techniques and handling as well as skills such as transect deployment, underwater video recording, underwater photography, underwater navigation and data analysis. The full project reports can be found in section 4.

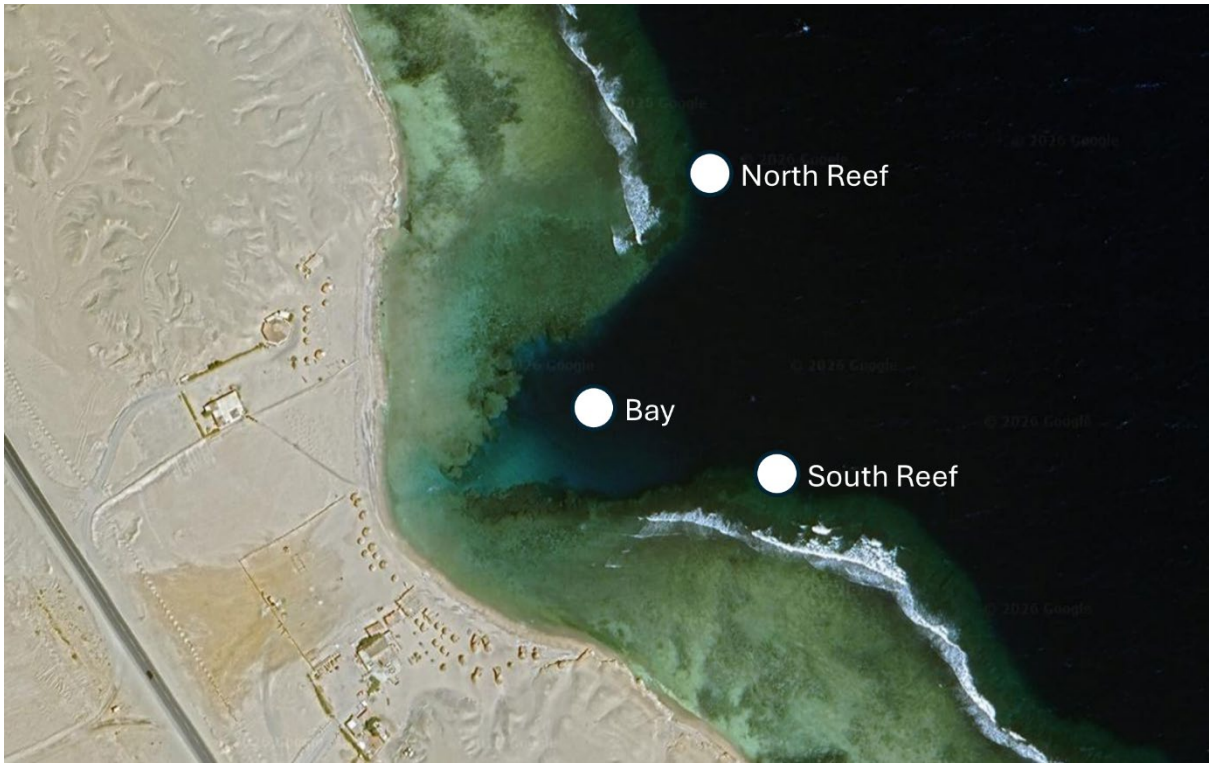
3.3 Personal Development

Prior to departure to Egypt, the team grew accomplished in skills such as grant writing, fundraising and problem solving. Through the multifaced nature of our data collection, all members of the team developed invaluable scientific skills and gained experience working within the field of marine biology. Beyond the achievement of their RAID Master Rescue Diver, each member of the team completed around 30 dives whilst on the expedition, allowing them to become not only confident SCUBA divers, but such ones competent in research diving which is a specific skill in itself. Team members also gained first-hand experience in experimental design and data collection, whether they were project leaders or not. This sets them up well with experience in scientific field work that will be beneficial not only to their degrees but to their future career prospects. In this report, short reflections written by each team member can be found, highlighting the skills they feel they have most developed during the expedition and their biggest take homes from the experience as a whole.

Above: Team member laying a transect during one of the dives

4. Research Projects

Two marine projects were conducted by the 2025 Egypt Expedition. The research projects and methods described below were completed in conjunction with and influenced by methods used by previous expeditions who have been collecting data on the reefs at El Quseir since 2014. The methods were determined after consultation with previous expedition members and our academic advisors regarding the best practices for the reefs and were subject to change after pilot studies were conducted during the first week of the expedition. Data collection for the two projects were conducted at the one site – Abu Sauatir, across two reefs – North and South and the bay. Dive sites are presented below.



Above: Map Showing Data Collection Sites For 2025 Egypt Marine Expedition.
Site locations shown as North Reef, South Reef, and Bay.

4.1 Depth and Twilight Variation of Acoustic Soundscapes in Abu Sauatir Reef in the Red Sea, Egypt

Mohit Raj

4.1.1 Abstract

The environment can be visualised acoustically through soundscapes. One aspect of environmental soundscapes is the biological component involving communicatory signals and simple acoustic by products of animal behaviour. Therefore, researchers are interested in using acoustic data as it is an abundant source of information in the environment. Marine bioacoustics is a rapidly growing discipline being recognised as an efficient way to compile environmental data. This has been used to establish baseline healthy soundscapes of coral reefs and compare them to soundscapes of areas undergoing coral restoration programs. To help determine effective rehabilitation of coral reefs by looking at functional diversity rather than solely coral coverage. However, little is known about the variation in baseline acoustic soundscapes within the same reef across different environmental gradients, such as depth and time. Here, I used three sample sites across the Abu Sauatir reef in Egypt to investigate how phonic metrices, such as phonic abundance and phonic richness, change accordingly to depth (5m, 10m and 15m) and twilight periods. I found that phonic abundance and richness both significantly decrease as a function of depth but show no significance regarding twilight periods. Furthermore, using MDS analysis significant groupings of acoustic communities suggest distinct acoustic soundscapes. My results show that there are different acoustic communities within the same reef across depth and twilight period. This novel study provides a foundation towards future research which aim to improve our comprehension of acoustic diversity within coral reef ecosystems. Accordingly, future studies should aim at focus on specific sound variation and using other metrices for measuring acoustic diversity, in conjunction with phonic abundance and richness, which provide a more detailed understanding of the variation in acoustic soundscapes.

4.1.2 List of Abbreviations

BOB ..... Buoyancy audio brick
FPT ..... Fast Pulse Train
HF ..... High Frequency
LF ..... Low Frequency
SPT ..... Steryotyped Pulse Train
UFPT ..... Ultra Fast Pulse train

4.1.3 Introduction

Environmental soundscapes can be described as all the encompassing acoustic inputs within an environment. Understanding the production, transmission and reception of sound in the environment is known as the discipline bioacoustics and is relevant in numerous areas of ecology. Environmental sounds typically originate from a biotic, geographic or anthropogenic source. Geographical sounds are mainly associated with weather-conditions or extreme landscape events. Wind and rain are the most common source, having large impacts during extreme weather events like hurricanes, heavy rainfall or typhoons. However, during relatively calm days there can be little sound production (Larsen and Radford., 2018). Whereas biotic sounds originate with either the intention of communication or simply as a by-product of animal behaviour.

Production of a communicatory auditory signal is produced by a sender, is propagated through the medium and received by a receiver. Communication is a vital ability as it allows the sharing of information which subsequently facilitates coordination between individuals for survival and reproduction. Observed throughout the evolutionary tree, chemical communication has been hypothesised as the oldest form of communication which can still be seen today cellularly through hormones for intercellular communication which allows for co-ordinational growth and development (Oliveira, Rebelo and Homem., 2021). Similarly, pheromonal communication expands the communication to between organisms using chemicals. For example, commonly seen within rodents, they show advanced pheromonal control to convey numerous messages such as sexual attraction, courtship initiation, food presence and threats (Bind et al., 2013). However, chemical communication is slow and is limited by distance due to the degradation of organic chemicals in the environment. The evolution of acoustic communication grants faster and distant signalling as seen in the African elephant's (*Loxodonta spp.*) ability to identify individuals of their parade at distances greater than a kilometre (McComb et al., 2003).

Sound propagation through the environment is well-studied area of bioacoustics since acoustic properties can vary in different environments. A classic example is the distance sound waves can travel through water. The density of particles in the medium allows easier transfer of energy between particles allowing for the well-known long-distance communication of marine mammals (Tyack, P. L., 2008). However, within the same medium acoustic propagation can be modelled differently. In shallow water echoes are created through the reflection of sound waves against the water surface and benthic floor making modelling more complex. Sea floor composition, wind stress and physical movement of water can further complicate the propagation pathway through different absorption rates, reflecting angles and by enhancing dissipation (Larsen and Radford., 2018).

Marine bioacoustics is a rapidly emerging area as a non-invasive and passive method of sampling the environment (Larsen and Radford., 2018). Traditional methods of sampling the terrestrial environment such as visual observation and cameras is known to be less effective in the marine environment. Visual observations can be hindered by increased turbidity, the absorption of light with depth and the associated decrease in visual prowess with diving. While cameras are limited to diurnal samples, as night vision is inhibited by the absorption of infrared light especially at deeper depths (Mooney et al., 2020). Popularly marine bioacoustics is used to monitor marine mammals, monitor environmental health, improve our understanding of biology and the impacts of anthropogenic noise on the ecosystem (Coppolaro et al., 2024; Curé et al., 2025; Lamont et al., 2022).

Coral reefs are one of the most biodiverse and acoustically rich regions on the planet, hosting a third of marine life despite having such a small global coverage (Fisher et al., 2015). Often called the

"rainforests of the sea" they are compared to their terrestrial counterpart, tropical rainforests, which dominate in terms of global coverage but are thought to come short regarding biodiversity per unit area (Reaka-Kudla., 1997). Reef acoustic communities are constructed by the low-frequency sound production of fish either passively or purposely. Rapid turns require strong, sharp muscular contractions resulting in a singular passive auditory output. Possession of a gas-filled organ, the swim bladder, allows the production of more elaborate sound productions typically with purpose in courtship or territorial defence. As seen in the Lusitanian Toadfish *(Halobatrachus didactylus*)*,* during the mating season males produce a long (~800ms), low-frequency (60Hz) sound, coined boat whistle, to attract female partners to their shelter. However, to other males the signal indicates a defensive warning that the shelter is occupied (Amorim et al., 2006; Amorim et al., 2015). Invertebrates also contribute greatly towards the acoustic community, such as scraping sounds produced by feeding urchins (*Echinoidea)* or defensive rumbling by the mantis shrimp *(Hemiisquilla californiensis*). By far the most dominant invertebrate sound comes from the snapping shrimp (*Synalpheus paranemeris*) creating acoustic choruses which show major ecological importance in larval settlement (Lillis, Bohnensteihl and Eggleston., 2015). These extremely valuable ecosystems provide numerous ecosystem services such as buffers to coastal erosion, food services, tourism, habitats for endemic species and medicinal resources (Weijerman et al., 2018). Valued at $350,000 per hectare on average in 2012 and has likely increased over the past 14 years (de Groot et al., 2012). Yet, coral reefs are faced with many threats resulting in their rapid decline of global coral coverage (Norström et al., 2009). Threats include ocean acidification, ocean warming, boat traffic, pollution, overfishing and invasive species such as the crown of thorns starfish which is destroying Indo-Pacific reefs by feeding on coral tissue (Harvey et al., 2018; Jensen et al., 2025). Coral reefs are therefore a main target of marine conservation.

Anthropogenic sources are the leading cause for coral health decline (Setter, Franklin and Mora., 2022). Humans have been exploiting the ocean for over 100,000 years but the rate of exploitation has drastically increased since the industrialisation of fishing (McClenachan and Colby., 2026). In parallel, so has the production of anthropogenic noise from industry (fishing, oil rigs, docks, offshore windfarms) and recreational practices (diving, jet-skis, cruises). The impacts of anthropogenic noise on organisms are of rising concern as evidence piles up proving detrimental effects on marine life physically, physiologically and behaviourally. The European Green Crab (*Carcinus maenas*) is a largely intertidal species considered to be an important member of their native communities acting as a very important trophic level due to their high abundance (Neal and Piazzolla., 2008). However, studies using ship playback sounds have shown behaviour and physiological changes such as reduced anti-predator behaviours and increased oxygen consumption which indicates stress. This species is a highly tolerant organism shown by its dominance globally as an invasive species but in response to repeated playbacks oxygen consumption rate did not lower suggesting an inability to habituate (Williams et al., 2015).

Coral restoration projects look to rehabilitate damaged reefs usually by asexual means which involve the transplantation of healthy coral fragments (Boström-Einarsson et al., 2020). With the evidence for this method of rehabilitation, having an emphasis on coral coverage recovery which does not appropriately represent ecosystem recovery since there is no account for benthic and demersal community restoration. Phonic richness is a metric which measures the acoustic diversity and is a more robust measure of ecosystem recovery as there is a collinearity with community restoration (Lamont et al., 2022). Acoustic enrichment is a new method of coral reef restoration involving the attraction of fish communities to damaged reef areas through acoustic displays of a healthy reef (Jézéquel et al., 2025). However, coral reefs are dynamic, complex and not uniform across

environmental gradients so spatial distribution of fish populations is not uniform. Consequently, what could be considered a healthy baseline soundscape can vary on reef location. Shallow reef areas host a greater abundance and biodiversity of fish while deeper areas typically house more predatory species like groupers or snappers (Osuka et al., 2022). Community distribution also varies as a function of time. Light intensity triggers the emergence and retreating behaviour of diurnal and nocturnal species during the twilight periods thus changing the communities (Rickel and Genin., 2005). Studies also show reefs which are geographically close show different acoustics signatures (Minier et al., 2023) but there is little to no knowledge on acoustic soundscape variation as a function of depth and time within the same reef. The absence in acoustic data as a function of depth and time fails to provide baseline soundscapes for comparisons with future studies.

To investigate this gap in knowledge, this research project aims to investigate the variation of acoustic soundscapes by measuring the change in acoustic metrics, phonic richness and phonic abundance, across depth and twilight periods of Abu Sauatir reef in the Red Sea, Egypt. It is hypothesised that both metrics will decrease as depth increases and during dusk period because of spatial and temporal distribution of fish communities. This will provide baseline depth and crepuscular acoustic data for future studies to compare too.

4.1.4 Methods

4.1.4.1 Sample Site

Audio recordings were taken from Abu Sauatir (26^{o} N, 34^{o} E) reef found North of El Quseir situated on the coast of the Red Sea, Egypt. A lagoon splits the reef into a North and South Reef, which are exposed to different intensities of wave action. Strong winds blow over a greater fetch before reaching the South reef resulting in large, high-energy waves; whereas the fetch to the North reef is shorter resulting in smaller, low energy waves. For this reason, sampling was done across the North Reef. This investigation was carried alongside a long-term coral monitoring study ran by the University of Glasgow with Open Ocean Science Centre. So, site selection was done in conjunction with the coral monitoring project. Three sample sites were set up across the outer reef (see figure 1.), separated by 25 meters and marked using a tag. At each site audio recordings were taken during twilight periods at 5m, 10m and 15m depths. Although the average depth of the North reef was around 45m, the university risk assessment did not allow dives deeper than 18m. Abu Sauatir reef is situated beside two dive resorts, Roots Red Sea and Rocky Valley Diver Camp. So, the reef has been commercialised by divers and therefore experiences more anthropogenic influence than an isolated reef.

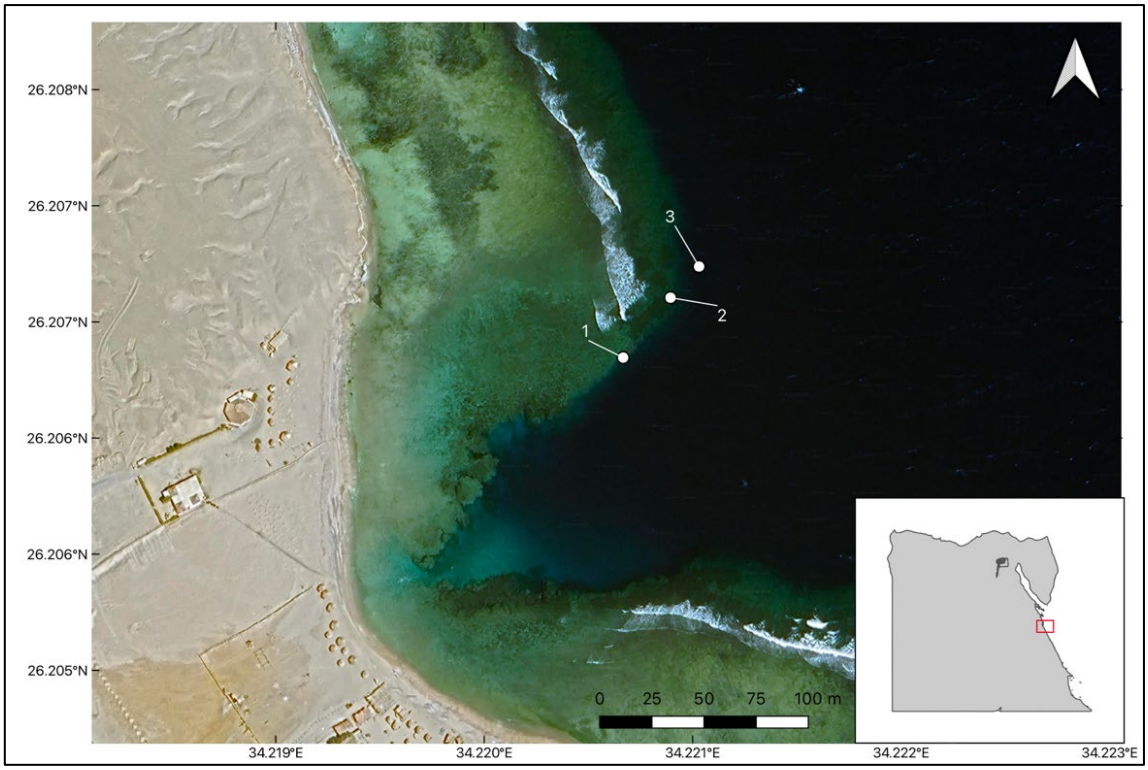


Figure 1. is a map which shows the three sample sites located at Abu Sauatir reef, Egypt. Map was generated using QGIS (QGIS Development Team, 2023) and satellite image was taken of google satellite using the quick map services available on QGIS. Egypt silhouette vector was taken from (Simplemaps, 2016). Both dive camps can also be identified in the bottom-left of the map.

4.1.4.2 Data Collection

Data collection took place from the 19th of June to the 2nd of July 2025, at 3 sample sites. Acoustic recordings were taken using three audiomoths. These are highly versatile, cost-effective microphones typically used for passive acoustic monitoring. To use them in the marine environment they are encased in a watertight case. Audiomoths record relatively unidirectionally, so correct orientation is required to record the environment. The Buoyancy audio brick (BOB) is a rig which holds the audiomoth in the correct orientation and its components provide structural integrity preventing pushover from waves (see figure 2.). BOB was made using a metallic pole perpendicularly inserted into a brick, holes were drilled into the pole to allow a rope to pass through and tightly bind the pole to the brick. Two kilograms of dive weights were attached symmetrically to the BOB using biodegradable zip ties to add extra weight. Community turnover between nocturnal and diurnal fish communities has been shown to be triggered by light intensity (Rickel and Genin., 2005) therefore audiomoths were configurated to record for 10 minutes in 1-minute segments after dawn and dusk. Specific timings of sunrise and sunset were taken from National Oceanic and Atmospheric Administration's (US Department of Commerce., 2024) online website by inputting the coordinates 26° N, 34° E. Other potential environmental confounding variables were also recorded, these included cloud coverage (%), wave size (m), wind strength (kt) and sea surface temperature (°C) using an online weather service called windy.com (Windyty, S., 2026).

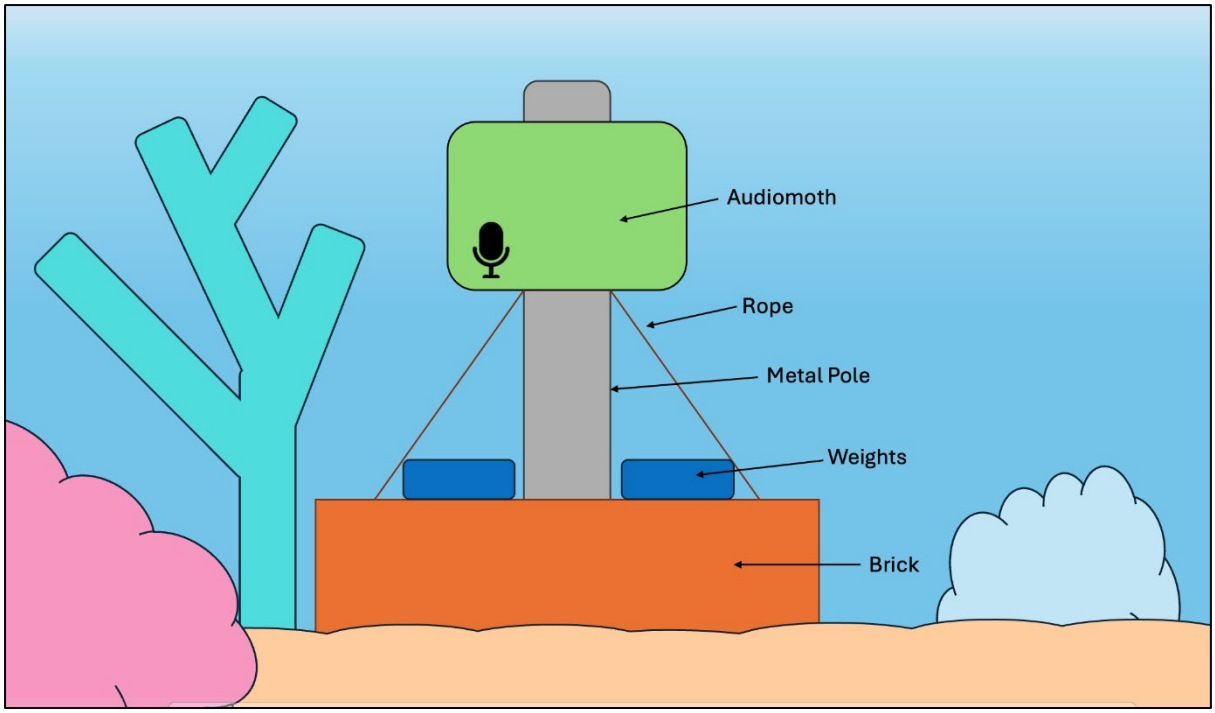


Figure 2. is an annotated graphic of a BOB amongst corals. Metallic pole was penetrated through a brick and reinforced using rope, 2kgs of dive weights were added to provide extra strength for wave resistance and audiomoth was tied to pole using zip ties. Microphone symbol represents the microphone's location and the direction of recording.

4.1.4.3 Gain and Sample Rate Selection

Audiomoth configuration consists of two settings, gain and sample rate. The former relates to the amplification of auditory signal without distorting the input and the later refers to the quality of the audio by the number of samples it takes per second (kHz). Different combinations of these two settings can change how the acoustic environment is perceived.

There are five levels of gain (low, low-med, medium, med-high and high), each was tested simultaneously to deduce which gain level would be best suited for this environment. Testing included collecting audio samples from the same location then comparing the spectrograms. Med-high gain was selected as it maximised acoustic inputs while simultaneously reducing the risk of audio clipping. Sample rate was selected based of literature on fish bioacoustic studies which typically use a sample rate of ~48KHz as it provides high quality audio capture encapsulating most fish sounds (Mouy et al., 2023).

To ensure confidence in BOB's structural integrity, it was tested by leaving a prototype for a couple nights on the reef crest on the South Reef. This location was chosen due to the harsher wave action associated with the South Reef and shallower depths. The prototype was found standing a couple days later, so the structural integrity would confidently withstand the wave action of the North reef at deeper depths.

4.1.4.4 Acoustic Analysis

Soundscapes were analysed visually and acoustically through a software called Raven Pro 1.6.5 (Lisa-Yang., 2026). Settings controlling the visual display (brightness, contrast and focus) of the spectrograms were kept identical throughout the analysis to prevent bias towards identification of sounds. Spectrograms were also enhanced to visualise a range from 0 – 2kHz as most fish acoustics fall within this range (Ladich., 2019). Audio clips were broken down into one-minute segments and given a unique identification name which stated the minute, depth, date and twilight period. Clips were then randomly selected and analysed manually by sorting identified sounds into classification groups using a dichotomous key (see figure 3.). Inspired by fish bioacoustic literature, sounds were grouped by three main characteristics (1) Number of pulses (2) duration of pulse periods and (3) the frequency (Bolgan et al., 2022; Bolgan et al., 2020; Desiderà et al., 2019). A pulse is a single rapid auditory input followed by rapid deplete in energy (see figure 3b), numerous pulses (**≥** 3) would be considered a pulse train. A pulse series comes from **≥** 2 pulse trains which are within 1.5 seconds of the adjacent train(s). The duration between two adjacent pulse peaks is called the pulse period (see figure 3b). Within a pulse train the pulse period can show uniform or variable characteristics where the duration between pulses is either stereotyped or irregular respectively. In a stereotyped pulse train the uniform pulse period duration can also vary by being slow, fast or ultra-fast. This classifies the sounds into seven straightforward groups (Table 1.) which forms the foundation for further classification. Every sound could fall into a classification group then further be characterised through frequency. Frequency could separate sounds into four groups based on the four levels of frequency: low, high, broad and full. Thus, creating the simple classification system.

Samples taken from the 28th onwards was analysed twice, due to the addition of extra classification groups based of a new frequency level, between, and the distinguishment of sounds which previously would have fallen within the same classification. Consequently, two data sets were achieved (1) a simple set taken from samples throughout the data collection period using the simple classification system and (2) a complex set made from samples only taken from the 28th onwards and using an extended classification system which is a further breakdown of the simple classification system. For a full breakdown of sound descriptions and classification guidelines refer to appendix 1. A third data set was created by removing snap observations to investigate if snaps are driving observed trends in phonic abundance.

Table 1. describes the sounds of the seven main classification groups that all sounds identifiable sounds can fit in before further classification through frequency.

Sound Name	**Description**
Pulse	Singular auditory input.
Quaver	Two auditory inputs within 0.5 seconds of each other.
IPT	An Irregular Pulse Train is a pulse train where the pulse periods are different from one another.
Rallentando / Accelerando	A type of IPT where the pulse periods are different from one another but in a systematic way such as decreasing or increasing in length respectively.
UFPT	Ultra-Fast Pulse Train the pulse periods are inaudible.
SPT	Stereotyped Pulse Train the pulse periods are uniform and last longer than 0.1 seconds.
FPT	Fast Pulse Train the pulse periods are audible and are shorter than 0. 1 seconds.

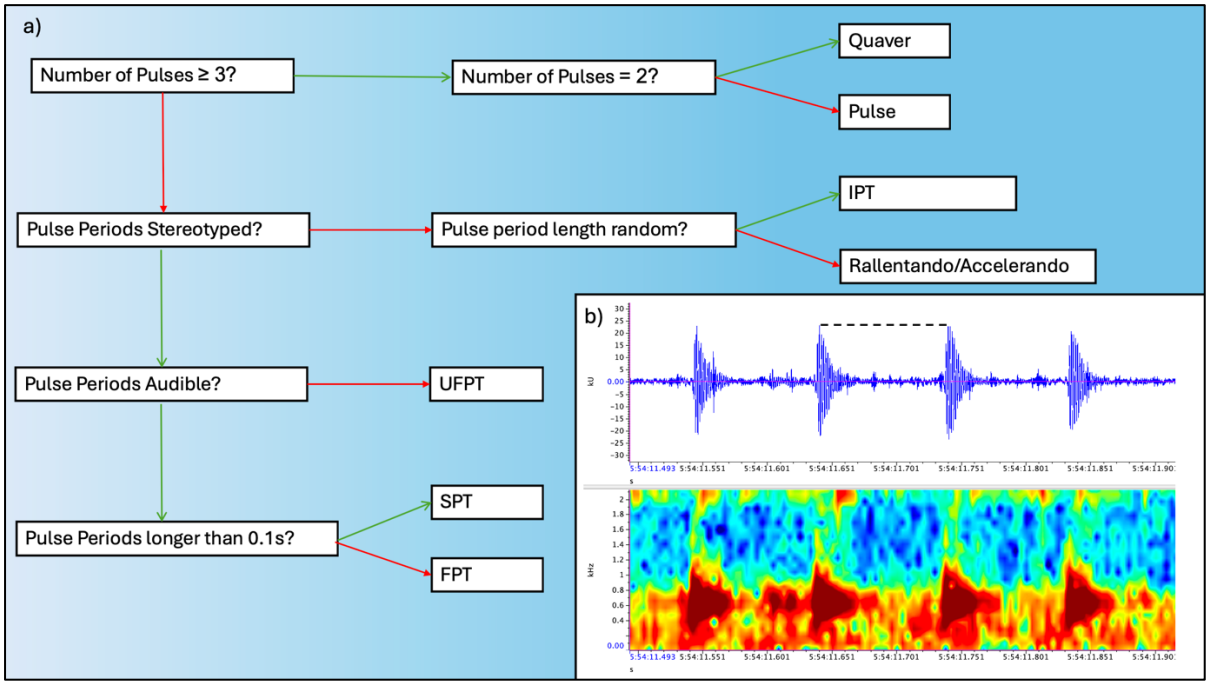


Figure 3. demonstrates the decision-making process of sound classification (a) Dichotomous key which groups sounds into groups depending on 'yes' (green arrow) or 'no' (red arrow) answers to number of pulses and pulse period characteristics. Once assigned a group further classification can be done by fitting the sound to a frequency group (b) Visualisation of a pulse train in both waveform (above) and spectrogram form (below), also shows how pulse period (dashed line) is measured.

4.1.4.5 Statistical Analysis

Audio recordings taken at sample site two during the 21st (dusk) and 22nd (dawn) was lost and not used in analysis. Nevertheless, three data sets were generated and analysed (1) Simple data set which uses the simple classification system shaped before the 28th and includes all audio samples (2) Complex data set encompasses observations from the 28th onwards using a more refined and elaborate classification system derived from the simple system (3) Snap removed data is a modification of both previous data sets where the snaps have been removed from the phonic abundance calculation to account for snaps potential driving significance.

All analysis was done on the R studio interface alongside the R coding language version 4.5.2 (R Core Team, 2025) and to generate all graphics and models the packages ggplot2 v4.0.2, ggpubr v0.6.3, patchwork v1.3.2, Matrix v1.7.4, MASS v7.3.6, lme4 v2.0.1, car v3.1.5 and vegan v2.7.3 were used (Wickham., 2016; Kassambara., 2026; Pedersen., 2025; Bates, Maechlar and Jagan., 2025; Venables and Ripley., 2002; Bates et al 2015; Fox and Weisberg., 2019; Oksanen et al., 2016). Full reproducible code and further package information is available in appendix 2. Statistical significance was tested for in both phonic abundance and phonic richness as a function of depth and twilight period using a negative binomial generalised linear mixed model (GLMM) to account for overdispersion. Sample site and date of recordings were included as random effects in the model. Akaike Information Criterion (AIC) tests disclosed the ideal models best fitted to explain the variation of the data, see appendix 3 for AIC tables. To test significant differences between depth levels a Tukey's Honestly Significant Difference (HSD) post-Hoc test was utilised.

Multi-dimensional scaling (MDS) ordination was used in conjunction with the Bray-Curtis dissimilarity index to visualise separate acoustic communities through the clustering of data points. To identify if the acoustic communities were distinct across different depth and twilight period pairings ANOSIM test was performed using the vegan package. Complementarily, ADONIS2 was employed to carry out a PERMANOVA to test the significance of the explanatory variables in the distribution of data within the multivariate space.

4.1.5 Results

4.1.5.1 Overall Phonic Abundance

In the simple data 22,600 auditory observations were recorded and classified across 47 sound groups, as shown in figure 4. Snaps were found to be the most dominant sound throughout the soundscapes with 5436 observations followed distantly by pop with 3280 observations. There were also 340 unidentified acoustic inputs (shown by "?" in figures 4 and 5) which have been used to calculate phonic abundance but excluded in the phonic richness calculation. Figure 5 shows the complex data set with only 12,736 observations but spread across 83 classification groups. Both sets show similarities with the most dominant sound again being snap with 2850 observations followed by pop with 1955. Furthermore, the distribution of sounds relative to frequency shows that high frequency (HF) sounds are typically more common than their other frequency counterparts.

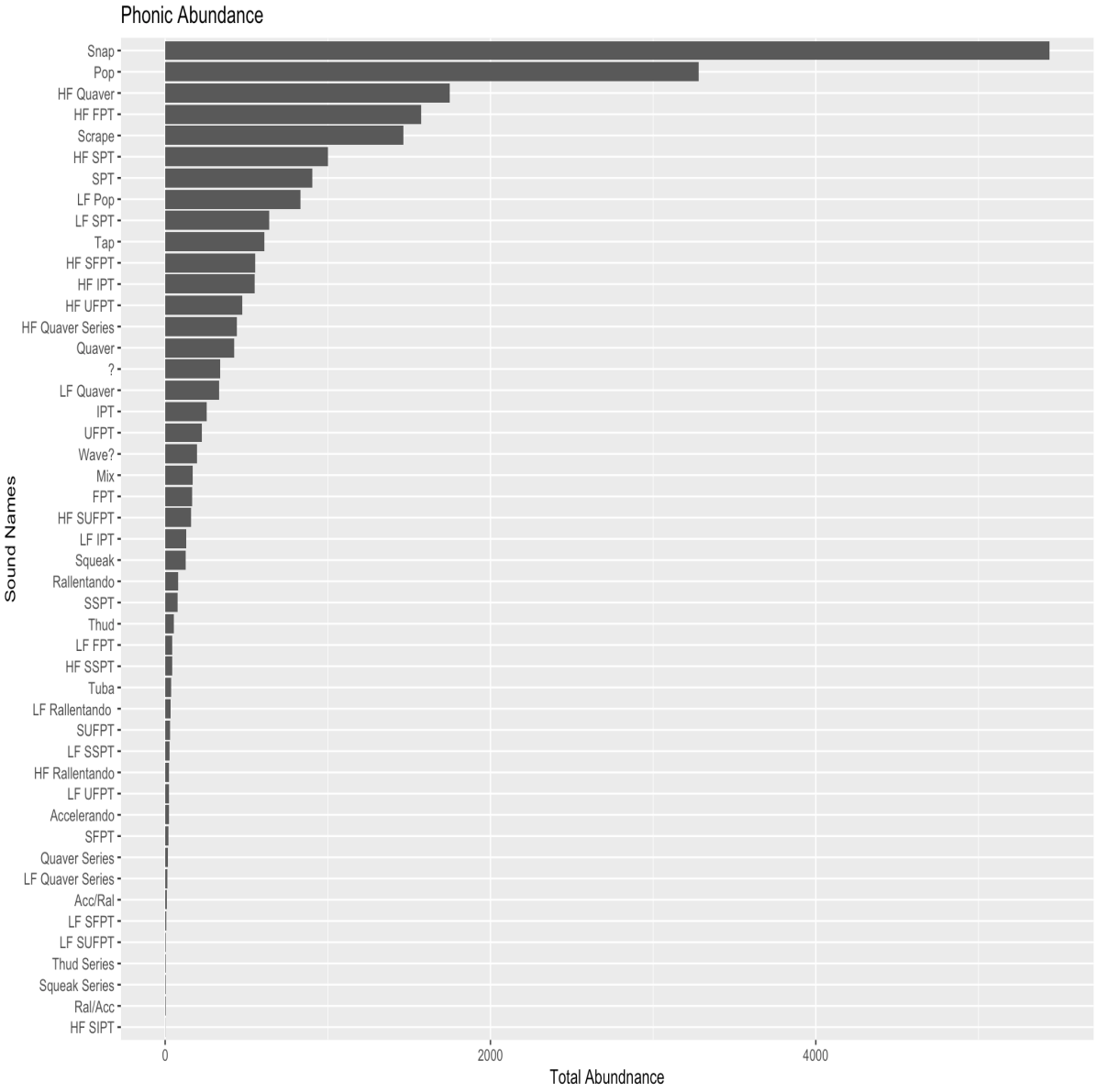


Figure 4. histogram which shows the total phonic abundance of the simple acoustic data. A total of 22,600 observations were made through spectrogram analysis with snaps dominating the soundscapes with over 5000 observations and some of the less common sounds being observed less than 100 times.

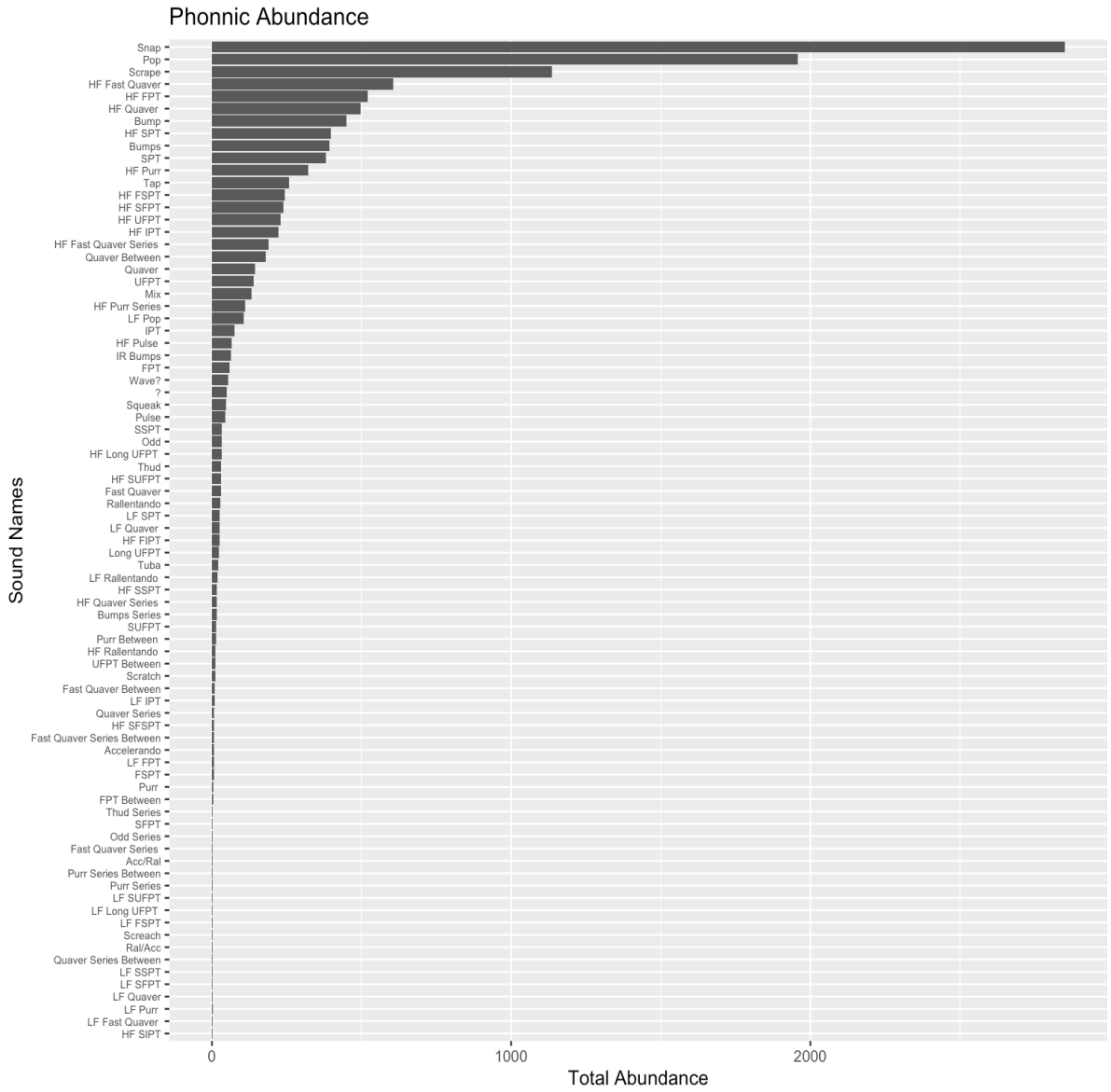


Figure 5. histogram of the complex data where there is more in detailed classifications. Again, shows phonic abundance and the dominance of the snap sound. There are similarities to figure 4, with which sounds typically dominate the soundscape, most of which are high frequency.

4.1.5.2 Depth and Twilight Effects

Using the simple data, both GLMMs reported statistically significant differences of phonic abundance (X^2 = 184.625, df = 2, p <0.001) and phonic richness (X^2 = 14.765, df = 2, p < 0.001) as a function of depth. However, TukeyHSD test revealed that while all depth level comparisons within phonic abundance was significant (p < 0.05) in phonic richness significance was absent between 10m and 15m (p > 0.05). Generally, both trends showed a negative relationship as a result of an increasing depth (see figure 6). Similarly, in the complex data set a statistically significant depth effect can be identified in phonic abundance (X^2 = 165.556, df = 2, p < 0.001) and phonic richness (X^2 = 17.023, df = 2, p <0.001). Figure 7 shows the same negative relationship in the metrices as a function of depth with all differences between levels being significant (p < 0.05) from TukeyHSD test. There were also no changes to the significance of the relationships with depth when snap observations were removed from the data.

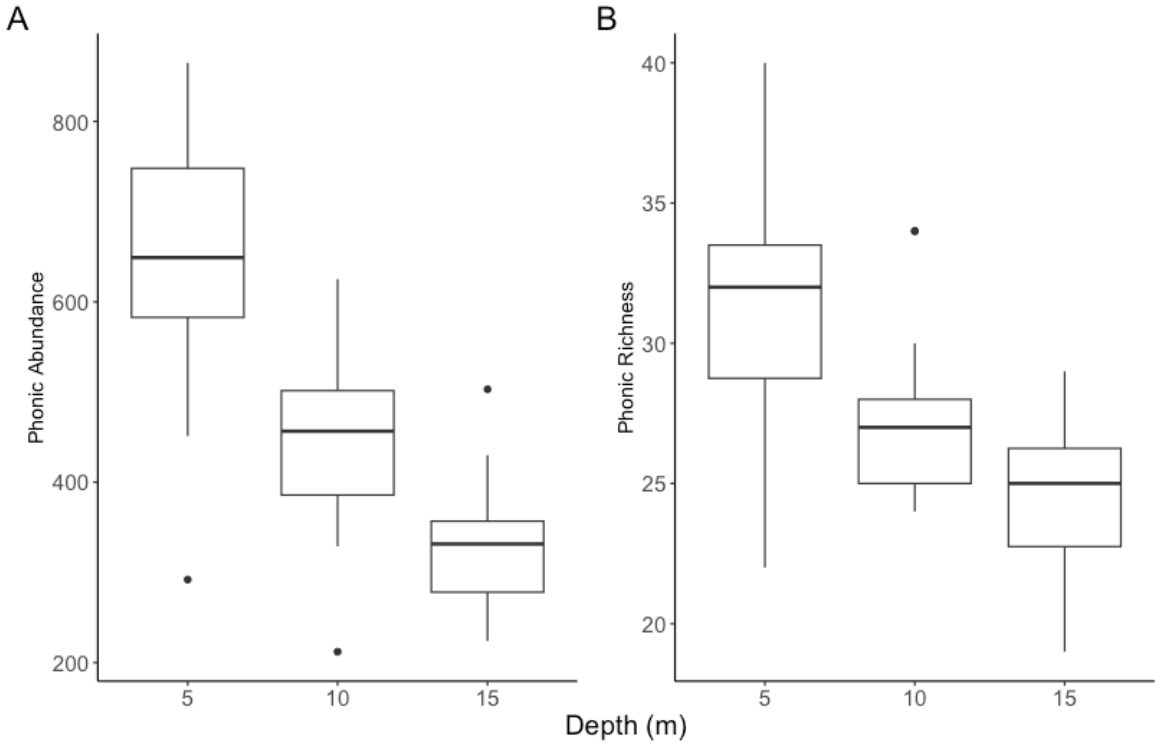


Figure 6. boxplots which show the relationship between depth and phonic abundance (A) and phonic richness (B) using the simple data set.

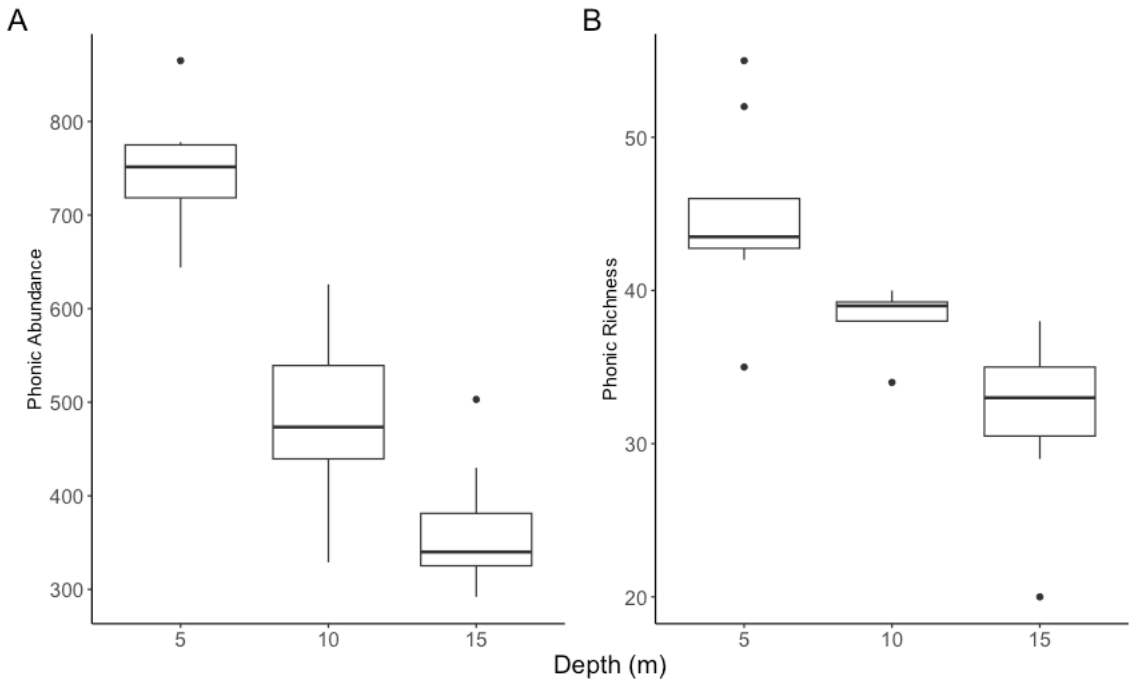


Figure 7. boxplots which show the relationship between depth and phonic abundance (A) and phonic richness (B) using the complex data set.

Twilight periods showed no statistically significant differences in phonic abundance ($X^2 = 2.755$, df = 1, p = 0.097) or in phonic richness ($X^2 = 1.487$, df = 1, p = 0.223; see figure 8.) of the complex data set. In the simple data set unexpectedly there was a significant relationship between dusk and an increasing phonic abundance (SE = 0.048, z = 1.99, p = 0.047) whereas phonic richness is insignificant as a function of twilight periods ($X^2 = 1.728$, df = 1, p = 0.189; see figure 9.). However, when accounting for the snaps the significance in the relationship between dusk and phonic abundance disappears (SE = 0.052, z = -0.202, p > 0.05).

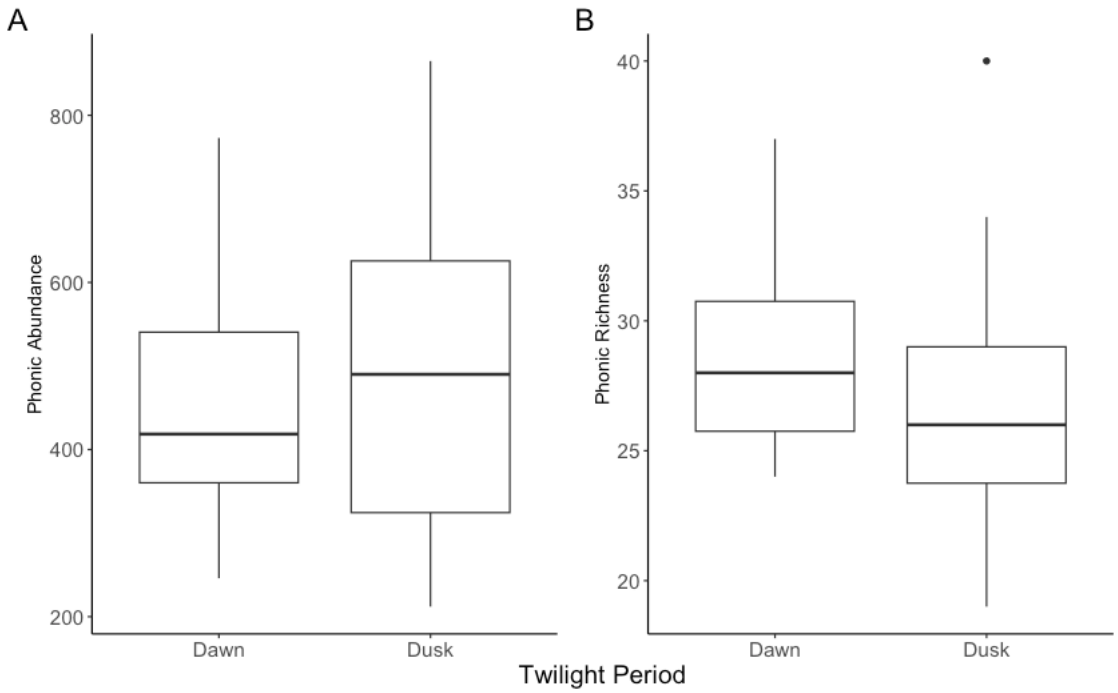


Figure 8. shows the differences in phonic abundance (A) and phonic richness (B) between twilight periods, dawn and dusk, in the simple data set.

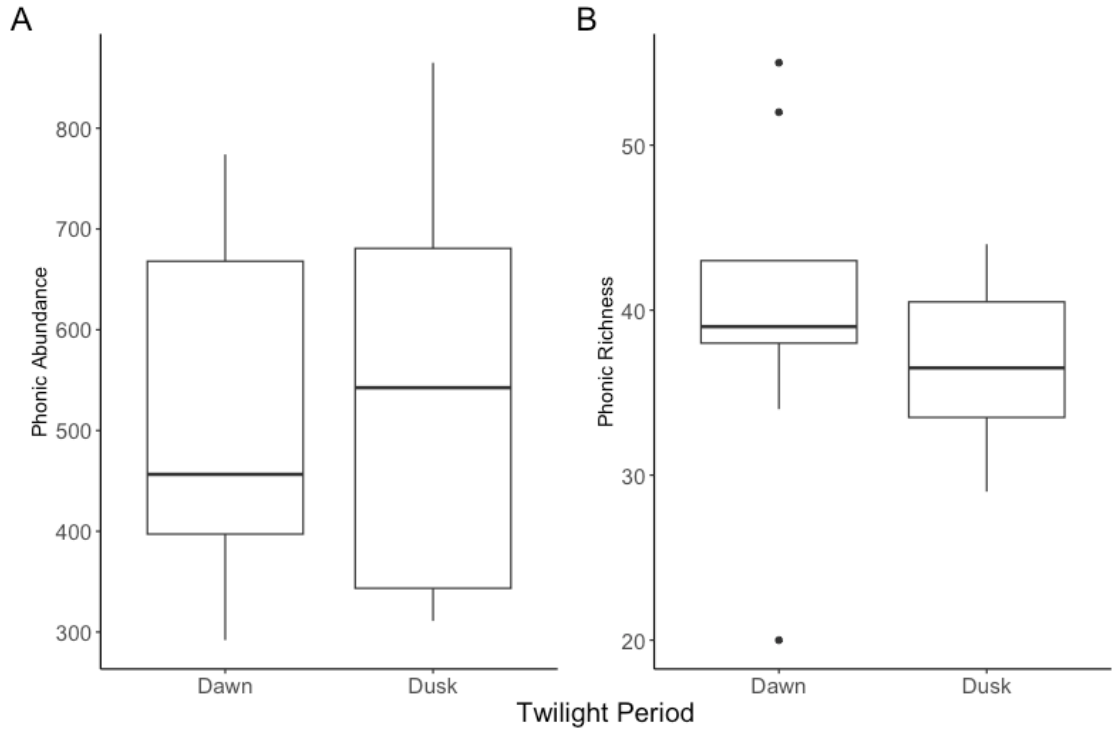


Figure 9. shows the differences in phonic abundance (A) and phonic richness (B) between twilight periods, dawn and dusk, in the complex data set.

4.1.5.3 Multi-Dimensional Scaling Ordination

In the simple data phonic community similarities showed significant differences in response to depth and twilight periods using ANOSIM (R = 0.39, p = 0.001), suggesting a moderate between group similarity variation (see figure 10). Between group similarities showed greater variation compared to within group variation which showed to be more homogenous, denoting variation in phonic community structure across depth and twilight periods. PERMANOVA test using ADONIS shows significance in both variables' depth ($F_{2,44}$ = 8.385, R_2 = 0.261, p = 0.001) and twilight period ($F_{1,44}$ = 3.540, R_2 = 0.055, p = 0.005) on the spatial arrangement of data. Complex data shows similar trends with phonic community similarities with the differences being slightly more substantial (R = 0.437, p = 0.001) suggesting greater phonic community structure with more detailed acoustic classifications. Highlighted in figure 11, with less overlap and more distinctive grouping. PERMANOVA, again shows significance in both depth ($F_{2,20}$ = 5.970, R_2 = 0.346, p = 0.001) and twilight periods ($F_{1,20}$ = 2.600, R_2 = 0.075, p = 0.026).

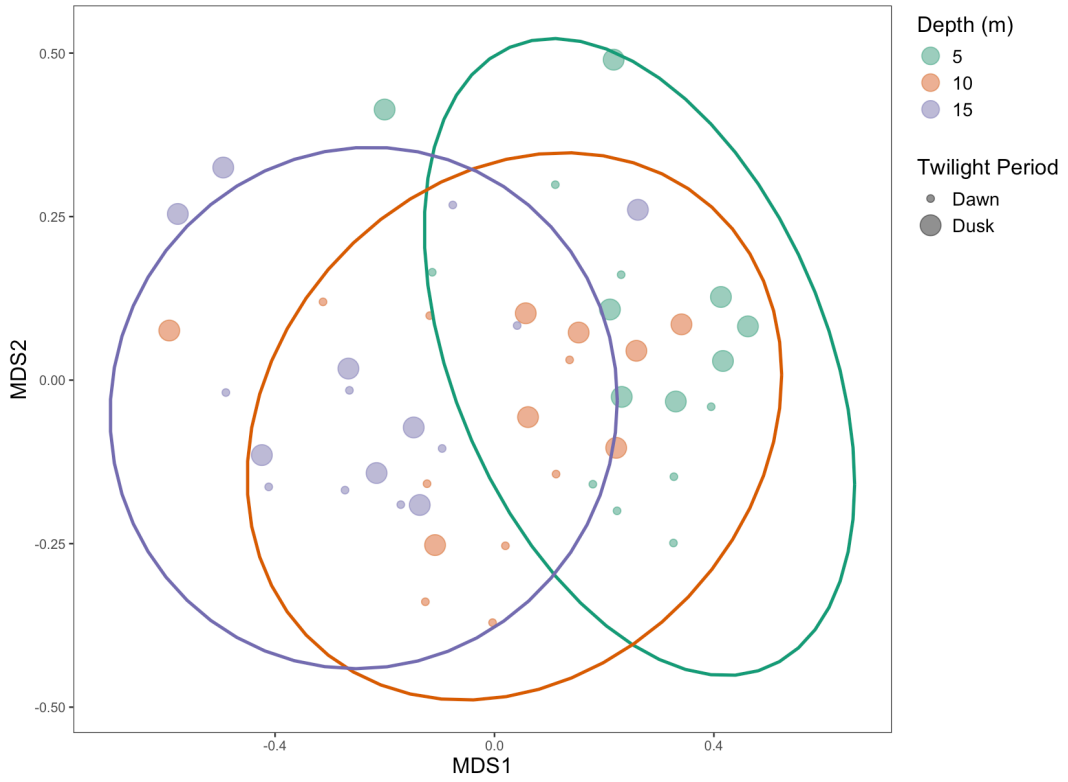


Figure 10. MDS ordination of phonic community samples using the simple data set (stress = 0.17) and based on Bray-Curtis Dissimilarity index. Each point represents a sample with the colour representing the depth (m) and the size referring to the twilight period the sample was taken at.

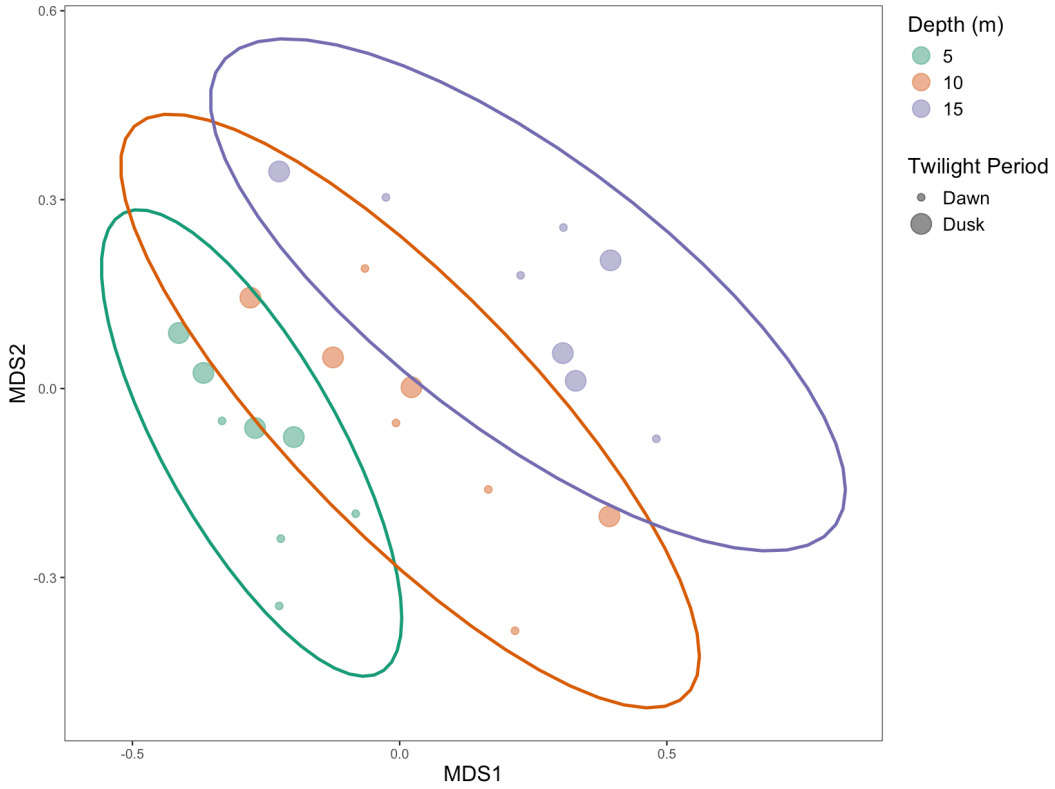


Figure 11. MDS ordination of phonic community samples using the complex data set (stress = 0.11) and based on Bray-Curtis Dissimilarity index. Each point represents a sample with the colour representing the depth (m) and the size referring to the twilight period the sample was taken at.

4.1.6 Discussion

Here, I investigated the relationship of environmental phonic metrics, phonic richness and phonic abundance, as a function of depth and twilight periods in Abu Sauatir reef in the Red Sea. Done as an attempt to address the gap in knowledge of the variation in acoustic soundscapes within the same reef. I found that both metrics showed a significant negative relationship with depth but unexpectedly no relationship with twilight periods. Visualisation of similarities between data points revealed clustering of samples taken at the same depth and twilight period while hosting greater differences with samples taken at other levels. Proposing, unique within reef acoustic identities.

Research within marine bioacoustics lacks papers investigating the variation of soundscapes with depth, except for numerous studies focused in French Polynesia on vertical acoustic stratification across large depth changes (20m, 60m, 120m and 300m; Raick et al., 2023; Raick, et al., 2025). These papers present a negative relationship between phonic richness and depth regardless of sampling time. However, only a very weak negative relationship with phonic abundance during diurnal times and no relationship at dusk. Furthermore, the deepest sample was found to have the greatest phonic abundance. Considering this, my results show little similarities in regard to these studies. There is no significance on either metric as a function of twilight periods and phonic abundance shows a strong negative relationship with both explanatory variables. It is already known that acoustic soundscapes vary across geographically different locations even when within close proximity (Minier et al., 2023). I speculate that the contrast in results comes down to the study location. French Polynesia hosts diversity related to the Pacific which is different to the Red Sea which shows high degrees of endemism (DiBattista et al., 2016). These studies also focused on the mesophotic and rariphotic reef regions

whereas in my study shallow reef regions were only accessible. Deep reefs have large homogenous ecological space for individuals with similar niches to share whereas in the shallow reef greater heterogeneity in space resulting in more noticeable stratification of community richness (Pinheiro, H.T. et al., 2023).

Several studies show an ecological trend that the fish abundance typically decreases with greater depth in shallow reefs (Andradi-Brown et al., 2016; Farghal, Abou and Fouda., 2021; MacDonald, Bridge and Jones., 2016). This corresponds with change observed in the phonic abundance across depth. Some fish species have narrow depth ranges whereas some are more generalist (MacDonald, Bridge and Jones., 2016). These assemblages differ across depths due to different habitat preferences. Corallivores are found at high abundance in shallower depths where primary productivity is greatest and decline with depth, as seen in parrot fish (*Scaridae spp.*). Predatory species typically occupy deeper depths as they are not reliant on corals (Andradi-Brown et al., 2016). However, Abu Sauatir reef is clear and shallow so the whole outer reef could be considered a suitable habitat for corallivores. I purpose other ecological drivers, like predation and larval settlement, to be the cause for the trend in abundance. While the space occupied by the predatory species is also a suitable niche for shallower species the predatory threat may drive them from exploring these depths (Vail and McCormick., 2011). As for parrot fish which may explore these depths due to their large size thus reduced predatory risk (Zaret., 1980; Christensen., 1996) their preference for shallow reefs could be a consequence of depth preferred larval settlement (Manning and McCoy., 2023).

Twilight periods are intervals of community shifts as light intensity triggers the switch between diurnal and nocturnal communities giving rise to unique coral reef soundscapes (Rickel and Genin., 2005; Azofeifa-Solano et al., 2025). Therefore, it was hypothesised a change in acoustic metrics would be brought about. Nevertheless, transition between twilight periods unexpectedly did not show any changes in phonic abundance or phonic richness suggesting that the acoustic communities between dawn and dusk are equivalent. It was not considered that while community shift was taking place, universally twilight periods were also known as peak periods for sound production (Au and Richlen., 2009). Hence, no difference in phonic abundance. Potentially, a more insightful difference can be noticed if the study was planned to record diurnal and nocturnal acoustic communities rather than crepuscular. However, diurnal acoustic sampling is more vulnerable to anthropogenic noise (Burnham et al., 2021) and due to the nature of the sampling sight it would have been unavoidable. Hereafter, studies should examine diurnal and nocturnal differences in phonic abundance while considering the sample sites vulnerability to anthropogenic noise.

While phonic richness is a desirable measure it is not sensitive to dominant sounds which means that a less abundant sound has the same weight of contribution towards the phonic richness value. Not considering dominance can lead to misunderstanding of the phonic diversity comparison between levels. Future considerations could incorporate a metric measure which accounts for dominance like the Simpson's index when measuring species diversity. It should also be noted that artificial reef studies investigating day-night diversity shifts have found that there is no change in diversity of common species but a shift in rare species (Cardoso et al., 2020). Consequently, acoustic soundscapes may not vary greatly between twilight hours when focused on dominant sounds.

In future studies focus should be given to the mannerism of sounds individually in response to depth and twilight period transitions. The presence-absence and abundance should be considered then compared between groups. This would provide a more detailed understanding of acoustic community changes and if you can distinguish unique community identities within the reef. Acoustic complexity

index could also be incorporated in following studies. It looks at the acoustic intensity across a recording and used in numerous aquatic studies to measure biodiversity as it complements shifts with phonic richness (Cerulo et al., 2018; Davies et al., 2020; Harris et al., 2016) and provides resistance to anthropogenic noise (Pieretti, Farina and Morri., 2011).

No differences were seen between the simple and complex data sets. Both showed significant and insignificant results in their models regarding the same explanatory variables. Except the relationship between dusk and phonic abundance which showed a significant relationship in the simple data set and not the complex. However, introducing a third data set where the dominant snap sounds have been removed the significance previously stated is likely a false positive (Type 1 error) driven by snaps. While there are no differences in the results based on the complexity of sound classification careful consideration should be given during analysis where a single sound could be driving community differences. Dominant sounds will benefit from being analysed separately as while the community differences may not be significant the specific differences could be giving a comprehensive understanding of community shift.

Numerous times I have suggested to look at the individual changes in specific sounds across the different levels of the explanatory variables. This stems from the MDS visualisation and PERMANOVA. Despite twilight period having no significant differences in the metrics, PERMANOVA displayed significance in the spatial distribution of data points. Since, the foundation of the visualisation uses the Bray-Curtis dissimilarity this means that the acoustic abundance compositions are different between data points. This suggests that there are individual sound variations that are more compelling between groups than within groups. My understanding is that considering the GLMM outputs of twilight period effects the soundscapes at dawn and dusk are possibly unique in their composition.

4.1.7 Conclusion

In general, it can be said that this study shows variation in acoustic soundscapes within the same coral reef across depth but not twilight periods using phonic measures. However, the understanding of this trend is distinctly specific to this region. In this regard, it gives us greater understanding to how the acoustic communities differ across depth and crepuscular times in Abu Sauatir and therefore baseline data has been achieved for this reef in the Red Sea and other similar reefs across the coastline. However, little can be extrapolated to make inferences about other reefs across the world. For that it would be interesting for comparable studies to be carried out in geographically distinct reefs and evaluate the similarities in phonic trends.

4.2 Spatial and Behavioural Ecology in Bluespotted Ribbontail Rays (Taeniura lymma) in Abu Sauatir Reef, Egypt

Poppy Voce

4.2.1 Abstract

Bluespotted ribbontail rays are ecologically important in coral reefs, but their spatial ecology, behaviour and population dynamics are not fully understood. This study aims to address these gaps in spatial and behaviour ecology in bluespotted ribbontail rays using photo-identification and field surveys to investigate their behaviour, movement patterns, habitat use, depth range and population size. Snorkelling and diving surveys were used to record behavioural and habitat observations, and GPS locations. Photos were analysed to identify individuals, and the population size was estimated using the Lincoln-Petersen mark-recapture calculation. The study found that habitat significantly influenced behaviour probability, with rays being more likely to rest in the reef habitat while feeding and moving more in the sand habitat. Feeding probability was highest in the afternoon compared to the morning. Population size was estimated to be 22 individuals, with individual rays being found at different depths. These findings show that rays exhibit limited movement, individuals occupy different areas and show a preference for reef habitat. These patterns concentrate individuals into patches, reducing connectivity and increasing the likelihood of population fragmentation. The restricted home ranges and varied individual depth ranges observed in this small population indicate that rays rely on small, well-defined areas but use a broad depth range within these areas.

4.2.2 Introduction

4.2.2.1 Behaviour and Spatial Ecology in Marine Species

Behavioural ecology helps us understand the interaction between an individual's behaviour and its environment, which can help inform conservation efforts (Dill., 2017). An animal's behaviour can influence its interaction with other species and the environment, with the environment also influencing an animal's behaviour (Dill., 2017). It is expected that individuals will pick a habitat that benefits them, while balancing access to an abundance of resources associated with higher predation risk, as predators target prey feeding sites (Dill., 2017). Spatial ecology helps determine how the distribution of marine organisms and their associated habitats influence ecological processes and population dynamics (National Research Council., 2025). This can help determine how environmental changes affect marine population sizes (National Research Council., 2025).

4.2.2.2 The Biology and Behavioural Ecology of Bluespotted Ribbontail Rays

Bluespotted ribbontail rays (Taeniura lymma) are part of the order Rajiformes (University of Florida., 2025) and are found across the shores of the Indo-West Pacific region (Sutton., 2017). They are found in abundance in the Red Sea due to its diversity of coral reefs (Levy et al.,2024) and mainly found in sandy lagoons and shallow waters near reefs (University of Florida., 2025). They can grow up to 35cm in diameter and 80cm in length and are found between depths of 1-30m (Sutton., 2017). They have a yellow-green body with two eyes that sit on top of their head (Sutton., 2017), and pectoral and pelvic fins that are used for movement (Madduppa et al., 2019). The blue spots found on their bodies are unique to individuals, allowing individual identification (Sutton., 2017) as spot patterns remain similar over their lifetime (McIvor et al., 2024). They are ovoviviparous, meaning they have internal fertilization and give birth to a small number of live young (Sutton., 2017) that have similar spot patterns to their parents (McIvor et al., 2024). However, data on reproductive lifecycle and lifespan are limited (Levy et al., 2024).

Bluespotted ribbontail rays are a good model species for studies as they are bio-indicators, meaning their presence can indicate the health and functionality of habitats and ecosystems (Levy et al., 2024). Bluespotted ribbontail rays are suitable species for investigating behavioural and spatial ecology as well as habitat use, as they can easily be observed (Levy et al., 2024). Researchers can track behavioural and movement patterns of individuals over time due to their unique spot patterns (McIvor et al., 2024).

Bluespotted ribbontail rays are considered nocturnal feeders that hide under coral overhangs to hide from predators (Sutton et al., 2017) and occasionally hide in the sand (University of Florida., 2025). When the tide comes in, they migrate to sandy waters to feed, and when the tide recedes, they hide in coral crevices (Miller., 2002). Although rays are known for being solitary animals, they sometimes rest together (Murray et al., 2024). They catch their prey by swimming in zigzag patterns whilst kicking up the sediment, and use their powerful mouthparts called plates to crush their prey (Sutton., 2017). They prey on molluscs such as snails, polychaetes and benthic fish (Sutton., 2017) and detect prey through the sand by highly developed electromagnetic sensors and lateral lines (Sutton., 2017). The ray's movements are affected by the pectoral (used for paddling), ventral (used for manoeuvring), dorsal and caudal (used for defence) fins (Madduppa et al., 2019).

4.2.2.3 Mark and Recapture Studies

The interactive individual identification system (I3S) Classic was developed for researchers to quickly identify animals, focusing on those with unique spot patterns (Hartog and Reijns., 2014). It allows researchers to select reference points and compare individuals to others in the database (Hartog and Reijns., 2014). Studies have used I3S to identify individuals such as whale sharks (Rhincodon typus) (Hartog and Reijns., 2014), white spotted eagle rays (Aetobatus narinari) (Speed et al., 2007) and marine turtles (Sandoval and Barrios-Garrido., 2025). Photo-based identification offers a less invasive method compared to tagging (McIvor et al., 2024). By using photo identification, behavioural and population changes can be tracked over time, which is particularly important with the increasing threat of human activities (McIvor et al., 2024). The use of photo identification provides a cheap and effective way to monitor populations long-term, whereas tags tend to fall off (McIvor et al., 2024). The ability to apply I3S to most animals with unique spot patterns means they can be used in mark-recapture studies to provide accurate data on population size (Speed et al., 2007). The ability to identify individuals allows researchers to learn about individual behaviours, habitat use and movements (Speed et al., 2007).

4.2.2.4 Biological Context

Bluespotted ribbontail rays are important for conservation research as they play a vital role in controlling species composition in coral reefs via bioturbation (Samantha et al., 2020) and being secondary consumers (Miller., 2002). Rays' movements help oxygenate sediment and redistribute nutrients (Samantha et al., 2020). Their numbers have declined since the 1950s, mainly due to human activities, including tourism and the aquarium trade (Levy et al., 2024). Human activities have seriously impacted ray populations, as they are slow reproducers, so populations struggle to recover (California Academy of Science., 2025). Population declines have been amplified by habitat destruction and climate change, which are a direct result of human activities (California Academy of Science., 2025). Bluespotted ribbontail rays are seen as habitat engineers (Simmonds et al., 2020). They churn up sand

whilst searching for food, creating micro-habitats and providing food for other marine species (Simmonds et al., 2020).

Despite the ecological importance of bluespotted ribbontail rays, there are several gaps in our understanding of their ecology in the Red Sea, including their importance in the maintenance of ecosystems, which can be seen through movement, behavioural patterns, and their population size (Flowers et al., 2021). Due to their cryptic nature and the fact that they are frequently overlooked, rays have received less focused research compared to other species such as sharks (Sherman., 2019). Movement patterns could inform conservation efforts by helping explain changes in ray population size (Sherman., 2019). This study will help address the gaps in research on bluespotted ribbontail rays by estimating the number of rays in the bay, which allows targeted protection and the evaluation of the effectiveness of conservation management in small reef areas (Hammond et al., 2021). By examining the interaction between habitat and behaviour, the ecology of bluespotted ribbontail rays can be better understood in terms of the role they play in ecosystems (Gooden et al., 2025). By identifying individuals, we can estimate the population size and visualise their distributions to see if individuals show certain movement patterns (Levy et al., 2024). This would allow more accurate monitoring of population trends, enabling researchers to track and detect population declines and apply targeted conservation measures (Levy et al., 2024). By studying ray behaviours, we can identify behavioural patterns and social structures that may influence their spatial distribution, helping researchers know where targeted conservation is needed.

4.2.2.5 Overall Approach to the Investigation

This project investigated the spatial ecology, habitat use and behaviour of bluespotted ribbontail rays in the Abu Sauatir reef. A combination of snorkelling and scuba diving was used to locate, identify and record bluespotted ribbontail rays. A systematic search pattern was followed to ensure that the entire reef was covered, allowing reproducibility for every survey. When a ray was encountered, GPS for mapping, photos for individual identification, time, habitat, behaviour, area and depth(m) were recorded. Repeated sightings of individual rays allowed for a population estimate using mark-recapture models. Behaviour and habitat data were used to test feeding activity and habitat preferences in the bluespotted ribbontail ray.

4.2.2.6 Aims and Objectives

The aims and objectives of this project were:

Aim 1: To quantify activity and behavioural patterns in bluespotted ribbontail rays
Objectives:

- Determine how feeding activity varies across the day
- Assess how behaviour probability differs across habitat types

Aim 2: To characterise spatial distribution and habitat association
Objectives:

- Map ray distribution across the Abu Sauatir reef
- Evaluate how habitat type and location influence ray presence
- Test whether individuals show consistent movement patterns and depth ranges

Aim 3: To estimate the population size
Objective:

- To estimate the ray population size using mark-recapture

We hypothesized that the hour of day would have a positive effect on feeding behaviour, with higher feeding probability in the afternoon. Based on habitat structure, we hypothesized that the reef habitat would show a greater probability of resting behaviour compared to sand and rubble (Macquarie University., 2022). For investigating ray distribution, it was hypothesized that more rays would be seen in the north reef due to its larger area and having more coral crevices (Stacey., 2024). We hypothesized that ray presence would be higher in the reef habitat and lowest in the sand habitat (Jaine et al., 2012). We hypothesized that individuals would show high site fidelity (Cooper et al., 2025). We hypothesized that some individuals would consistently use deeper depths while others would use shallower depths (Andrzejaczek et al., 2020). We estimated the bluespotted ray population in the Abu Sauatir reef to be around 25 individuals based on Abdullah., 2022's study on manta rays in Egypt.

4.2.3 Methods

4.2.3.1 Study Site

The field study was carried out between the 11th of June 2025 and the 3rd of July 2025 in the Abu Sauatir reef (26°12' 21.06" N, 34°13'10.632" E), which is located off the coast of El Quseir, Egypt (Figure 12). The Abu Sauatir reef has coral gardens with reefs to the north and south and reaches depths of 30m+ (Ubaldi., 2025).

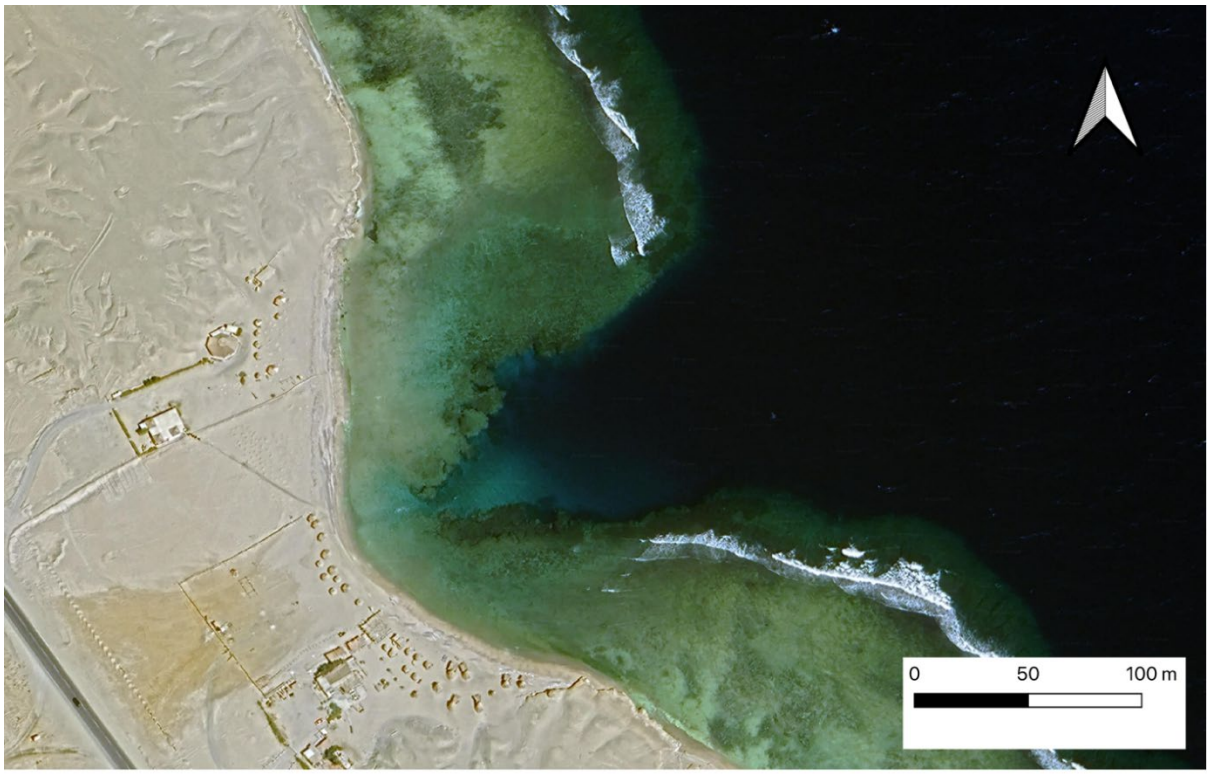


Figure 12. Satellite image of Abu Sauatir reef (Google Maps).

4.2.3.2 Experimental Design

Data was collected by a combination of snorkelling and diving surveys using a systematic search pattern to ensure full reef coverage. An ethogram was created to standardise behaviours (Table 2). The behaviour recorded was the behaviour at the first sighting of the ray. A study by McIvor et al., 2024 demonstrated the accuracy and reliability of using spot patterns in I^3S as a tool to monitor populations and to gain a better understanding of bluespotted ribbontail ray ecology by doing a validation test using 20 known individuals.

Behaviour	Description
Feeding	Active searching or digging up substrate with visible disturbance of sediment
Resting	Stationary on the bottom of the substrate
Moving	Moving without obvious foraging

Table 2. Ethogram summarising the 3 behaviours of rays during surveys. Feeding refers to the active searching or digging within the substrate. Resting describes individuals remaining stationary on the substrate surface. Moving is moving without obvious foraging.

4.2.3.3 Field Methodology

Bluespotted ribbontail rays were studied at set times between 9 am and 5 pm over 18 days. Surveys consisted of 1-hour dives or snorkels following a search pattern with one survey per day. The two methods used were snorkelling on the surface with free diving and snorkelling and diving combination. Snorkelling with free diving surveys were carried out up to a depth of 12m, and snorkelling and diving combination up to 16m. These two methods ensured full reef coverage.

The search pattern for snorkelling with free diving consisted of swimming out on the surface. Then followed a zigzag pattern from 12m in the north to the shore (Figure 13) with snorkelers spaced out 2m apart. Snorkelling surveys were done in a group of at least 2 people. One snorkeller recorded variables on a slate and GPS, and another free dived, taking photos of the rays. When a ray was spotted, GPS was recorded on the surface above the ray using a TG4 camera, and the free diver took a photo with their hand, with their finger showing the ray number for that day and then took pictures of the ray. After 5 rays had been seen, the observer reset their count by holding up 1 finger for the 6^{th} ray, then 2 fingers for the 7^{th} ray and so on. Ray number, time, habitat, behaviour, picture (yes or no), depth (m) and area were recorded on the slate. Areas recorded were north (N), south (S) and bay (B). Behaviours recorded were resting (R), moving (M) and feeding (F). Habitats recorded were reef (R), rubble (RU) and sand (S). When the free diver was approaching the ray, they approached from above at least 1m away to ensure the full back of the ray was visible. This meant the photos were easy to analyse in I^3S.

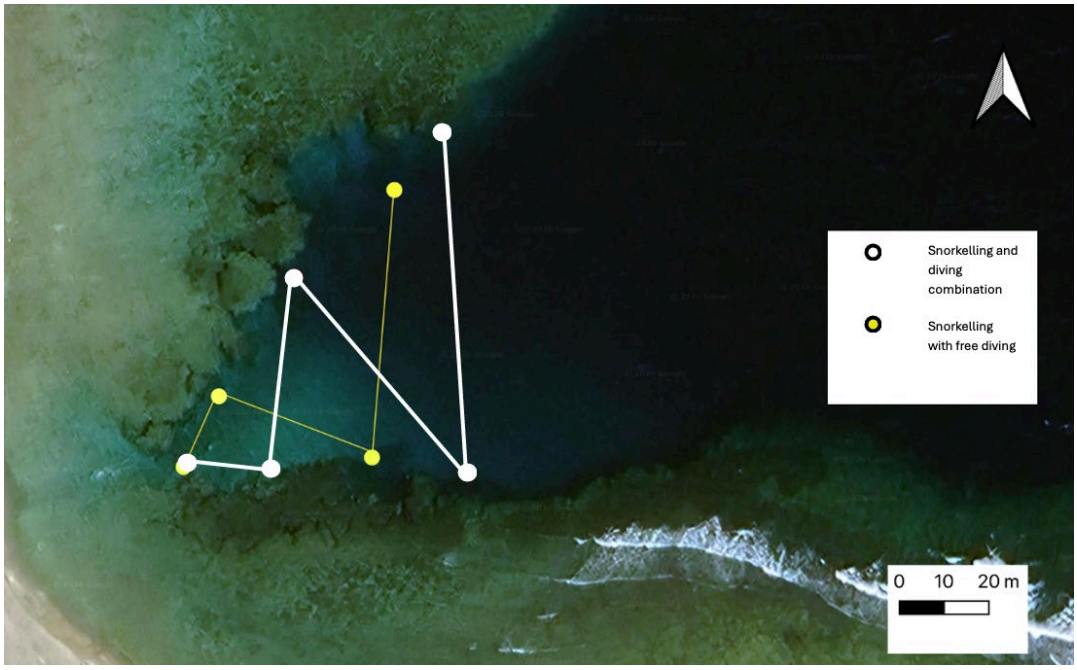


Figure 13. Search pattern for snorkelling with free diving and snorkelling and diving combination. For snorkelling with free diving, searched from 12m (depth from the water surface to the seabed) in the north reef to the shore in a zigzag pattern seen by the yellow line. Checkpoints for snorkelling with free diving (12m, 6m, 2m and shore) are represented by yellow dots. For snorkelling and diving combination, searched from 16m in the north reef to the shore in a zigzag pattern, seen by the white line. Checkpoints for snorkelling and diving combination (16m, 12m, 8m, 2m and shore) are represented by white dots. Depth values at checkpoints refer to the depth from the water surface to the seabed.

The search pattern for snorkelling and diving combination consisted of divers swimming out under the water to 16m in the north reef and snorkellers swimming out on the surface following the surface marker buoy (SMB) (Figure 14). Then followed an agreed zigzag pattern from 16m in the north to the shore (Figure 13). Divers and snorkellers worked in buddy pairs. One diver led the dive, held the SMB and recorded variables on the slate whilst the other diver took photos of rays using a TG4 camera. When a ray was found, divers signalled to the snorkellers using a torch flash. Snorkellers signalled back with an okay once they had received the message and recorded a GPS position above the ray. The diver took a photo of their hand with their fingers showing the ray number for that day and photos of the ray whilst the other diver recorded the ray number, time, habitat, behaviour, picture (yes or no), depth (m) and area on the slate. After 5 rays had been seen, the observer reset their count by holding up 1 finger for the 6^{th} ray, then 2 fingers for the 7^{th} ray and so on. Areas recorded were north (N), south (S) and bay (B). Habitats recorded were reef (R), rubble (RU) and sand (S). Behaviours recorded were resting (R), moving (M) and feeding (F). Snorkellers signalled back to divers with an okay once GPS was recorded, and divers continued searching.

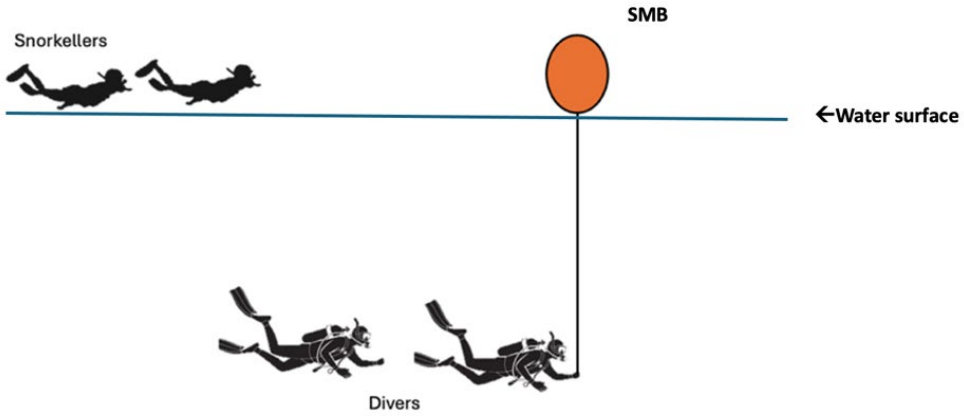


Figure 14. Diver and snorkelling combination set up. One diver was holding the surface marker buoy (SMB) and slate, and another diver was following with the TG4 camera. The two snorkellers would follow the divers via the SMB on the surface and would record GPS when a ray was spotted.

Once the survey was complete, slate recordings were transferred onto an Excel spreadsheet with columns for area, location, GPS (latitude and longitude), date, time, habitat, behaviour, depth (m), ray number from slate, ray number, ray name, photo name, photo for analysis, picture (yes or no), notes and I3S complete (see Appendix 10.1.1). Data entry was completed at the end of the day, and photos were numbered and sorted. The clearest photo of each ray was used for photo identification in I^3S and was recorded in the spreadsheet. An ID sheet was created with each individual found with the ray number, name, picture and notable features (see Appendix 10.1.2).

4.2.3.4 Photo Identification in Interactive Individual Identification System (I^3S)

I^3S Classic (Version 4.02) was used to analyse the best photo from each ray sighting (166 photos). Each photo was labelled with 3 reference points: 1) point at nose, 2) start of tail, and 3) left side of ray body (created by a straight line through the eyes and where that line touched the left side of the ray), which formed a triangle (Figure 15). From this triangle, up to 30 unique reference points were picked, starting from the central line out to the edge of the ray's body (Hartog and Reijns., 2014). The method of picking spots was standardised by only one person, creating the triangles on the rays and picking the spots on I^3S. Spots on the triangle line were not used, and blurry or bad-angled photos were not included in the I^3S database.

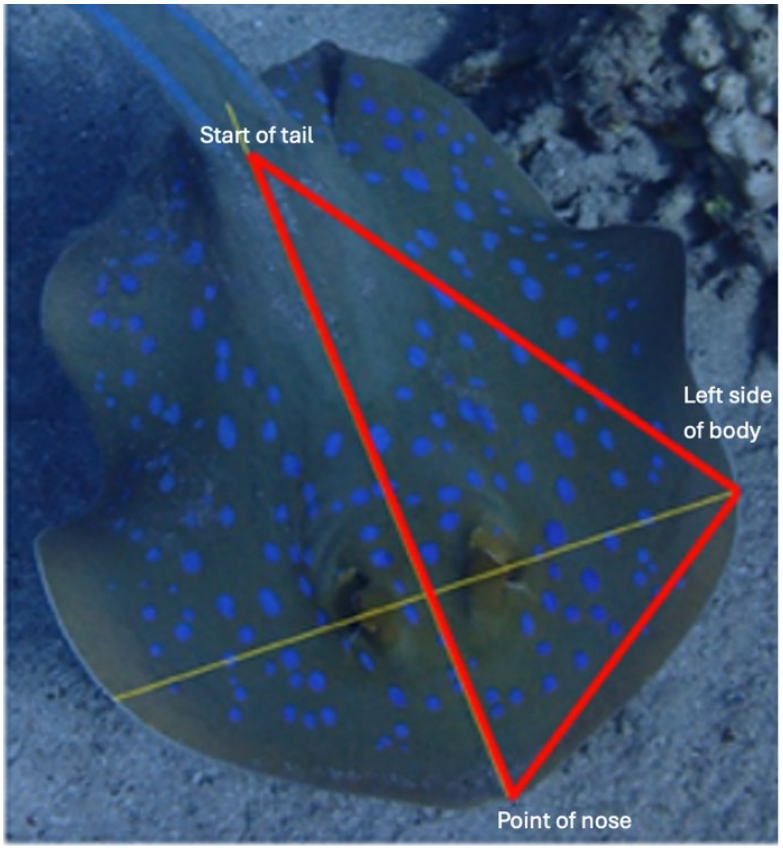


Figure 15. Image of a ray with reference points for I^{3}S. 1) point at nose, 2) start of tail, and 3) left side of ray body (created by a straight line through the eyes and where that line touched the left side of the ray as seen by the yellow line), which formed a triangle seen in red.

The best photo from each ray sighting was put into the I^{3}S software and compared to all others in the database. A low score comparison indicated a high similarity between that image and an image in the database (Hartog and Reijns., 2014). If it was a match, a visual comparison was done by a point cloud (Figure 16) where the spots were compared to a similar image in the database (Van Tienhoven et al., 2007). The spots are considered a match if the nearest spot is double the distance of the current match (Van Tienhoven et al., 2007). Each new ray that wasn't already in the database was analysed by eye, given a name and added to the database.

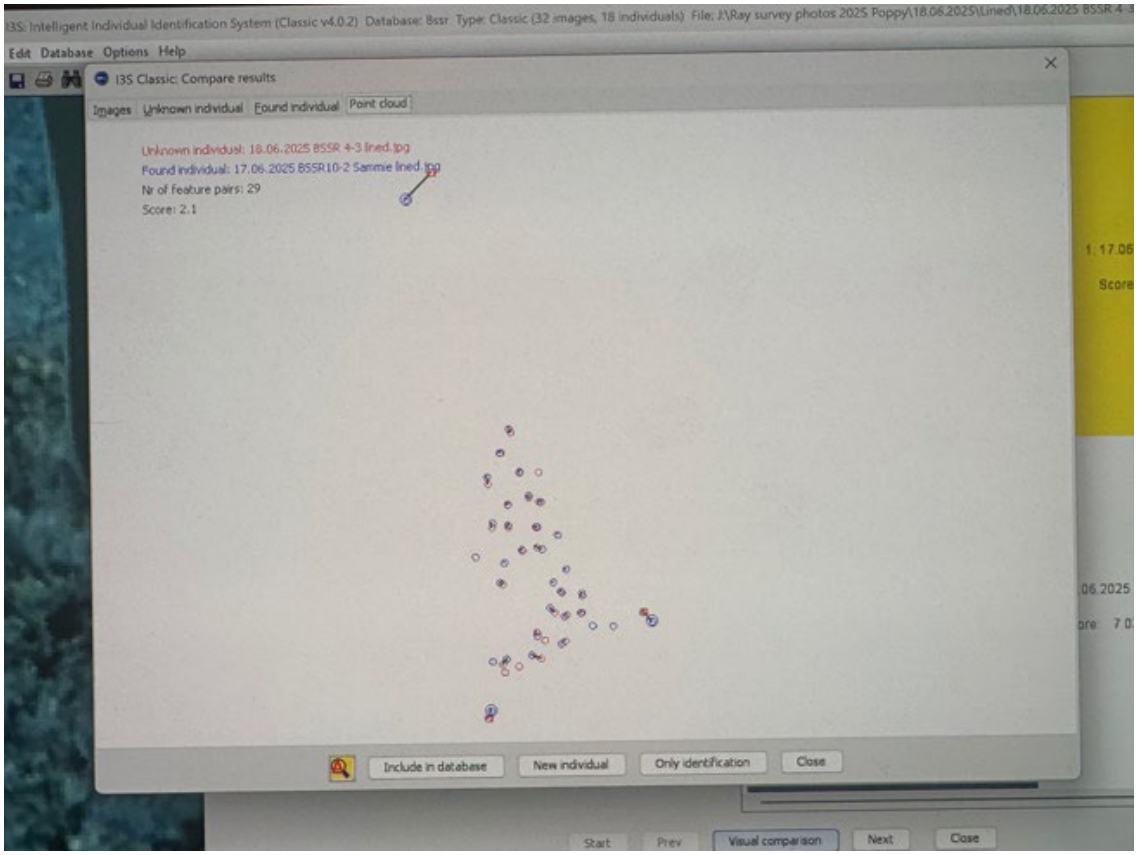


Figure 16. Point cloud showing low score comparison of two images of individual Sammie in I^3S. The red spots are the reference points selected in I^3S, and the blues are the spots of a similar individual in the database.

After all photos had been entered into the software, a batch compare was done to get the I^3S score for each photo from its best match (Hartog and Reijns., 2014). The cut-off point was where the rate of true positives was highest and where false positives were lowest using Youden's index (McIvor., 2024). Ray sightings that did not have a picture could not be identified and so were not included in the analysis, but were included in the QGIS map of all rays. Photo angles and body position have been shown to affect the identification accuracy of I3S (Van Tienhoven et al., 2007). This is due to I^3S relying on 2-dimensional transformations and assumes that individuals exist on a linear 2-dimensional plane (Van Tienhoven et al., 2007). To avoid this problem, only photos where the ray's body was flat were put into the I3S database.

4.2.3.5 Mark and Recapture

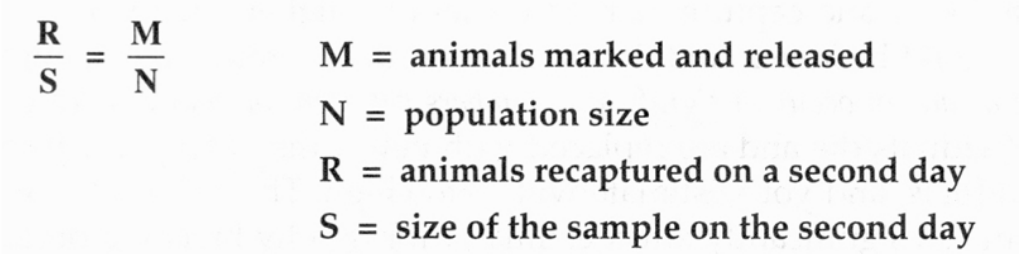


Figure 17. Lincoln Petersen mark recapture estimate (Brown and Kingsolver., 2010).

Population size was estimated using the Lincoln-Petersen mark-recapture estimate, as seen in Figure 6. The Lincoln Petersen mark recapture estimate can be rearranged to work out the population size N= (M x S)/R (Brown and Kingsolver., 2010). However, this method depends on many assumptions, including that individuals with marks have the same survival probability as other members of the population, marked individuals mix with the population and don't leave the survey area (Brown and Kingsolver., 2010).

Rays surveyed on the first day were individuals that were marked and released (M), with marking being done by individual identification. Rays surveyed on the second day were the sample size for the second day (S), and individuals seen again were the recaptured individuals (R). This was repeated 3 times across different days, and population sizes were averaged across the 3 repeats. Mark recapture provides accurate data on individual mortality rates and population size, making it a good method to use for this study (Brown and Kingsolver., 2010).

4.2.3.6 Statistical Analysis

All statistical analyses and graphs were produced in R (Version 4.3.1) using the CSV file (see Appendix 1.2) (R Core Team., 2025). Feeding probability was analysed using binomial GLM with a logit link. The full model included hour of day as the explanatory variable, feeding probability as the response variable and ray name as a fixed effect to control for between-individual differences.

Behaviour probability was analysed using a multilevel multinomial model (package brms). The full model included habitat as a categorical explanatory variable, behavioural probability as a continuous response variable and ray name as a random intercept. No interactions were included. All ray sightings were mapped in QGIS (Version 3.38.3-Grenoble) to visualise the spatial distribution in the reef (QGIS Development Team., 2026). To show individual movement patterns, QGIS was used to map all rays with 5 or more encounters (Figure 23).

To test whether individual rays differed in their mean observed depth, linear mixed effects models were fitted using the nlme package. The full model included habitat, area, time and behaviour as fixed effects and ray name as a random intercept. Backwards stepwise Akaike's information criterion (AIC) comparison was used to select the final model. Behaviour was excluded from the final model as it did not improve model fit, while habitat, area and time reduced AIC and were kept in the final model. Model validation was done using a Q-Q plot, which showed normally distributed residuals.

To determine if ray presence varied by habitat and location, a Poisson GLM with a log link was used. The full model included habitat, area, location, time and behaviour as fixed effects. Backwards stepwise AIC was used to determine the final model. AIC model comparison showed that area, time

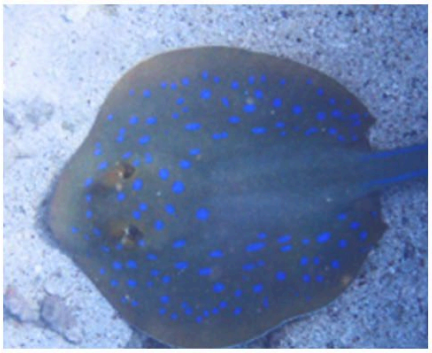
and behaviour did not improve the model, but habitat and location did, so they were kept in the final model. Model validation was done using a Q-Q plot, which showed that most residuals followed the expected distribution and no overdispersion.

4.2.4 Results

4.2.4.1 Individual Bluespotted Ray Identification

Out of 166 photos of individual ray sightings, 111 photos were analysed in I^3S Classic. Of the 55 excluded photos, 6 did not have enough reference spots, and the others were at bad angles or blurry. A total of 22 individuals were identified and used in the statistical analysis. Of the 22 individuals, 13 had 5 or more encounters, which were used in QGIS. Two individuals are listed below (Figure 18) detailing ray name, ray number, number of encounters, average depth, most common habitat and behaviour, and notable feature. Other 11 individuals can be found in Appendix 3.

Catherine (7), 14 encounters at an average depth of 9.9m. Most common habitat was reef and behaviour was resting. Notable feature of crown of dots round head



Cleo (17), 7 encounters at an average depth of 5.1m. Most common habitat was reef and behaviour was resting. Notable feature of pyramid shape on right hand side of body

Figure 18. Individual identification summary for two individual bluespotted ribbontail rays. Summary shows name, ray number, number of encounters, average depth, most common habitat and behaviour, and notable feature for Catherine (left) and Cleo (right).

4.2.4.2 Bluespotted Ribbontail Ray Feeding Activity

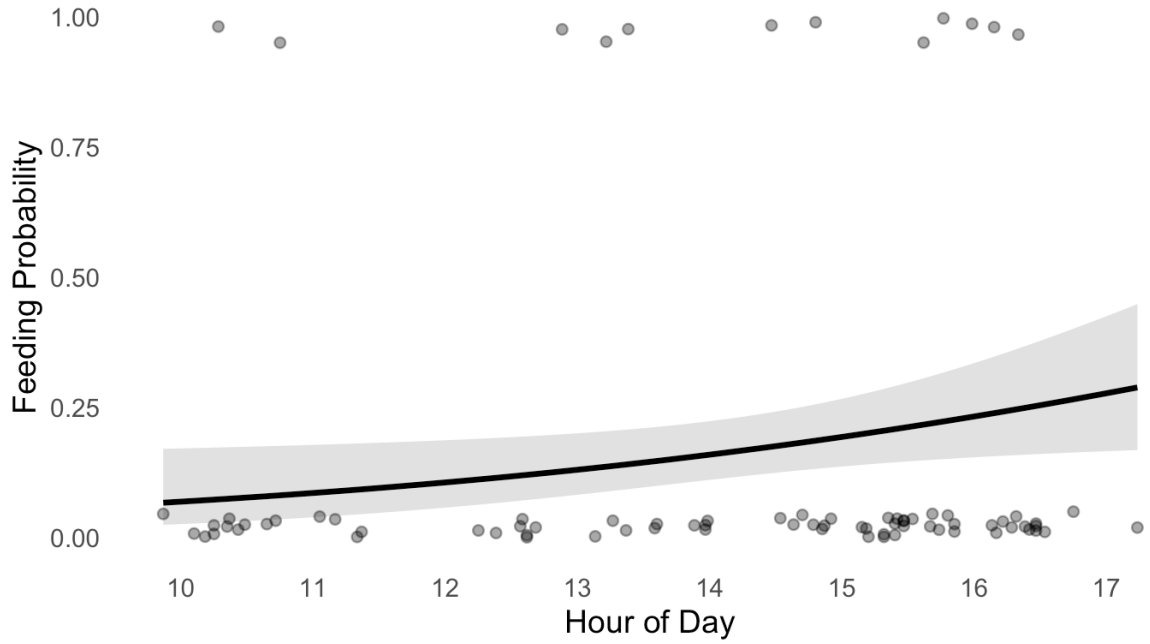


Figure 19. Influence of hour of day on feeding probability. Line graph showing predicted feeding probability over time. Model estimated feeding probability (black line) by hour of day, with the shaded region representing the 95% confidence interval. Feeding probability increased gradually over the course of the day. Raw feeding events are plotted as binary points seen by the grey dots (1= feeding, 0= not feeding), jittered to illustrate the underlying distribution of observations.

To assess how feeding behaviour varied across the day, feeding probability was calculated by dividing the number of feeding rays by the total number of sightings. When testing feeding probability against hour of day, feeding probability differed throughout the day (Figure 19) with the lowest probability in the morning (0.091, n=44), increasing in the afternoon (0.213, n=75) and being highest in the late afternoon (0.158, n=57). The binomial GLM showed a significant positive effect of hour of day on feeding probability (n= 176, B=0.37 +/- 0.14 SE, $p<0.05$), indicating rays were more likely to feed in the afternoon.

4.2.4.3 Behaviour Variation Across Habitat

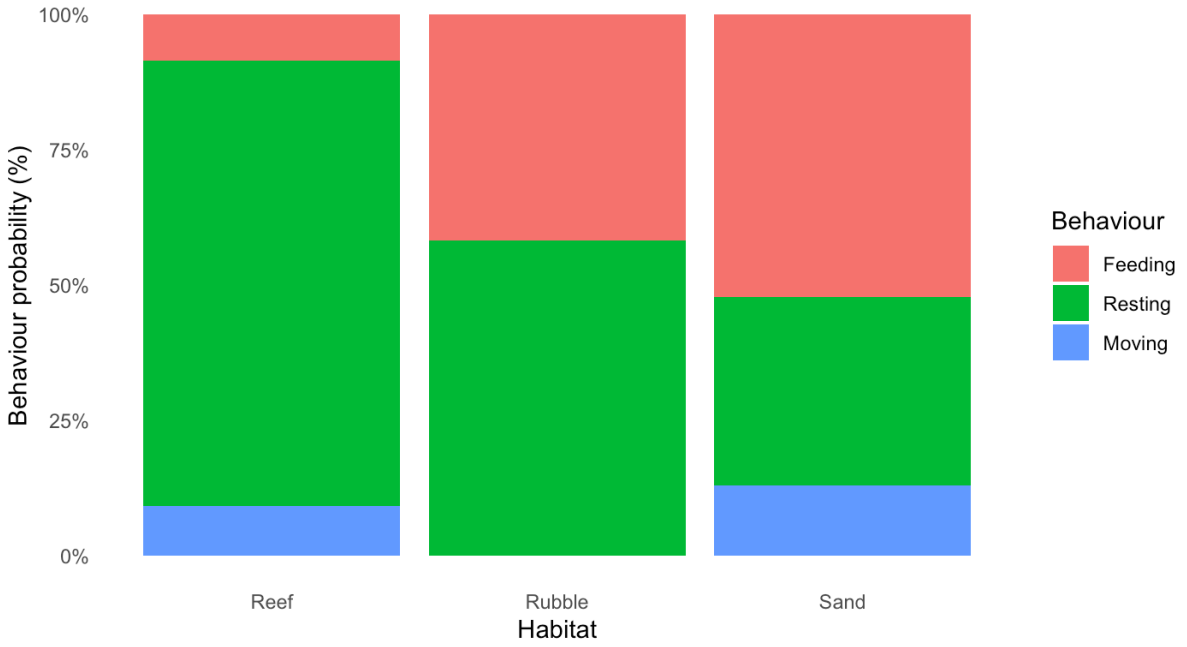


Figure 20. Behaviour probability across habitats. Stacked bar chart showing the proportion of three behavioural categories: feeding, moving and resting across three habitat types: reef, rubble and sand. Bars represent the percentage probability of each behaviour occurring within a given habitat, standardised to 100% behaviour probability per habitat.

To assess how behaviour varied across habitats, behavioural probability was calculated by the proportion of each behaviour within each habitat type. When testing behaviour probability against habitat, behaviour differed across habitats (Figure 20). Rays in reef habitat mostly rested (82.3%), while in sand, feeding was the dominant behaviour (52.2%). In rubble, resting was the dominant behaviour (58.3%) but had a noticeably higher proportion of feeding (41.7%) compared to the reef habitat (8.51%). From the multilevel multinomial model, habitat significantly influenced behaviour probability when accounting for repeated sightings of individual rays ($p<0.05$). Rays were significantly less likely to rest on rubble (Estimate= -3.43, CI= -6.06 to -1.33) and sand habitats (Estimate= -2.21, CI= -3.81 to -0.60) compared to reef habitat (Estimate= 2.97, CI= 1.81 to 4.38). Movement was lower in rubble habitat (Estimate= -37.70, CI= -135.71 to -2.63) compared to reef habitat, although movement in sand did not differ significantly from reef (Estimate= -1.13, CI= -2.95 to 0.66). Ray name was included as a random intercept and showed substantial individual-level differences in resting behaviour (sd=1.99), indicating behavioural specialization and a moderate difference in movement (sd=0.63).

4.2.4.4 Bluespotted Ribbontail Ray Distribution

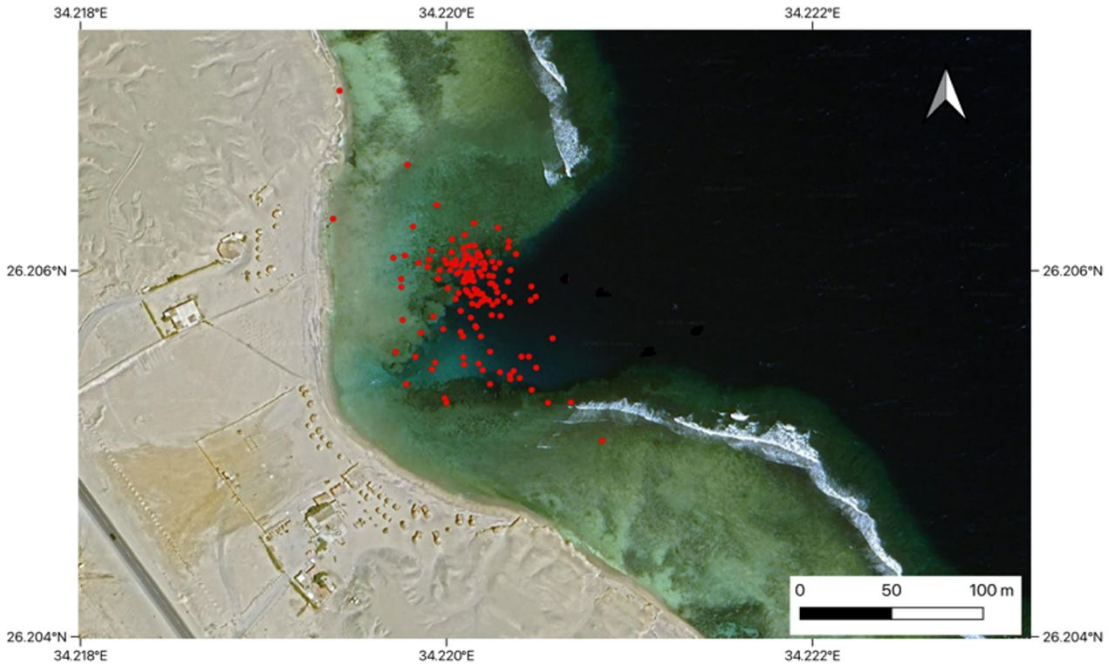


Figure 21. Map of all rays in QGIS. Red spots represent each ray sighting.

It was found that more rays were seen in the north reef (143 sightings) compared to the south (22 sightings), with a cluster of red spots in the north reef (Figure 21, n=171).

4.2.4.5 Presence of Rays by Location and Habitat

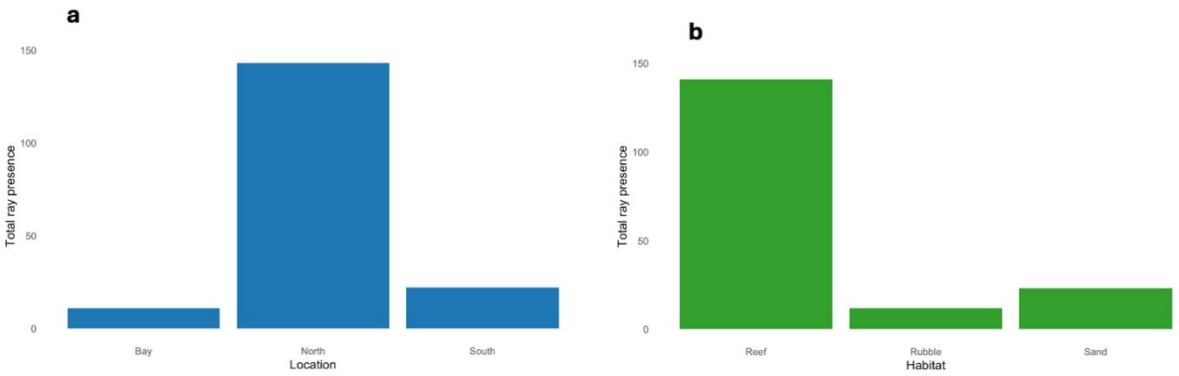


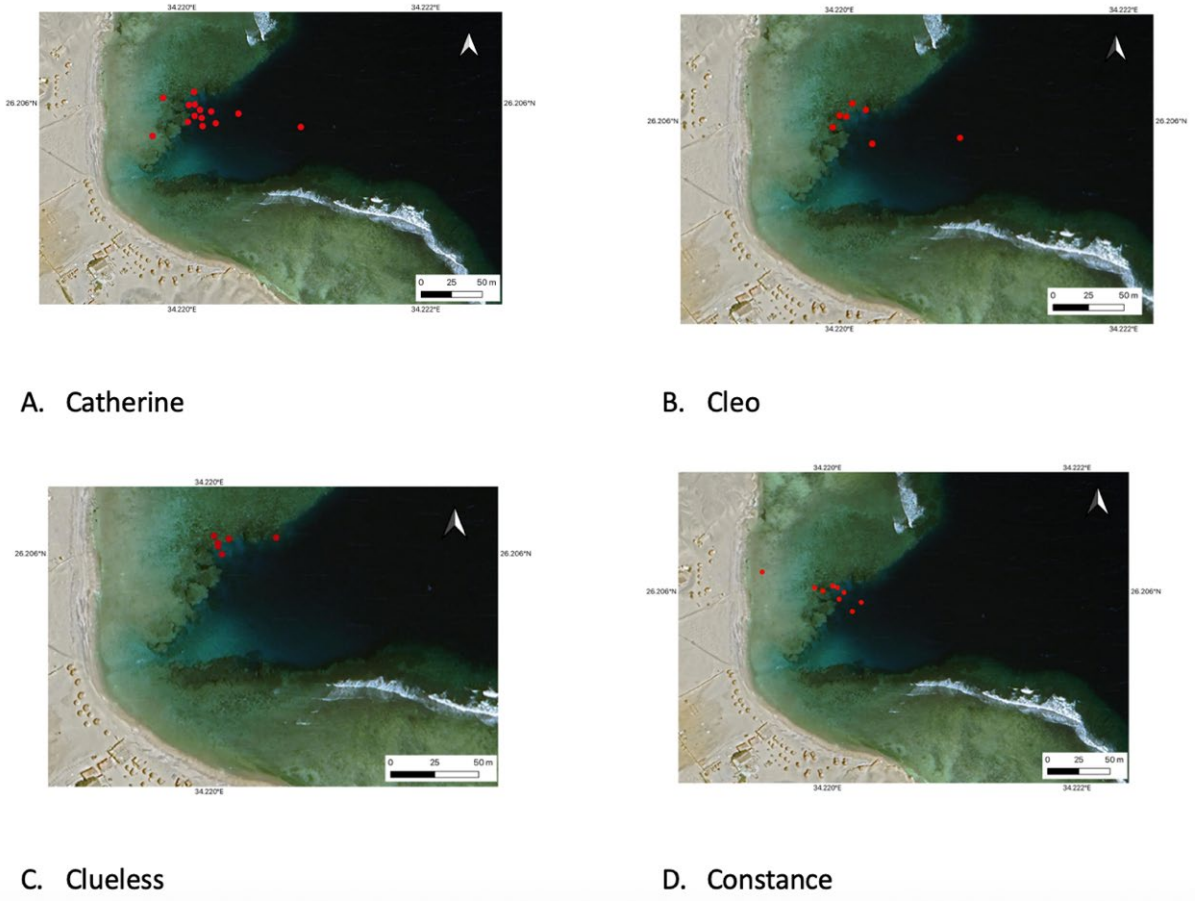
Figure 22. Total ray presence across habitat types and location. a) Bar plot showing the sum of rays recorded in each location. Locations were north, bay and south. Total ray presence was calculated by the sum of daily presence values across each location. b) Bar plot showing the sum of rays recorded in each habitat. Habitats were reef, rubble and sand. Total ray presence was calculated by the sum of daily presence values across each habitat.

We recorded ray presence across 3 locations (north, south and bay) with 176 observations. When testing location against total ray presence, the north reef had the highest total ray presence (143 sightings) while the south and bay had substantially lower presence (22 and 11 sightings, respectively) (Figure 22a). Poisson GLM showed ray presence varied significantly across location ($p<0.05$), with ray presence being higher in the north reef (estimate= 0.92, $z=2.66$, $p<0.05$) while the south reef showed

a non-significant reduction (estimate= -0.66, z=-1.64, p>0.05). Bay was used as the reference, so coefficients for north and south represent changes in the expected log count relative to the bay.

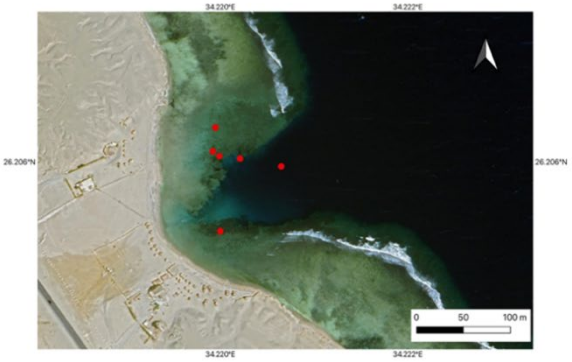
We recorded ray presence across 3 habitats (reef, rubble and sand) with 176 observations. When testing habitat against total ray presence, reef habitat had the highest total ray presence (141 sightings) while rubble and sand had substantially lower presence (12 and 23, respectively) (Figure 22b). Poisson GLM showed ray presence varied significantly across habitat ($p<0.05$), with ray presence being lower in rubble (estimate= -1.34, z=-4.44, $p<0.05$) and sand habitats (estimate= -1.85, z=-4.38, $p<0.05$) compared to the reef. Although sand was the most abundant habitat (personal observation), it supported the fewest rays, suggesting that it was actively avoided despite its availability. Reef habitat was used as the reference, so coefficients for rubble and sand represent the changes in expected log count relative to the reef.

4.2.4.6 Individual Movement Patterns

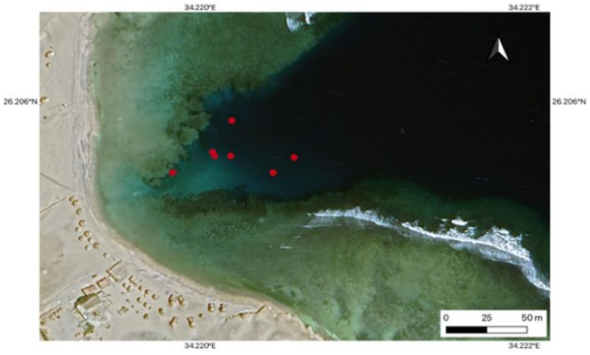


E. Dalmatian

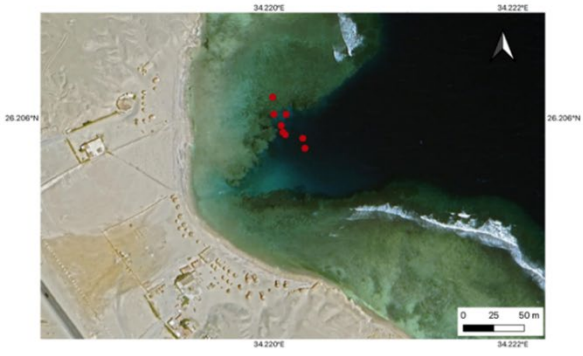
F. Dave



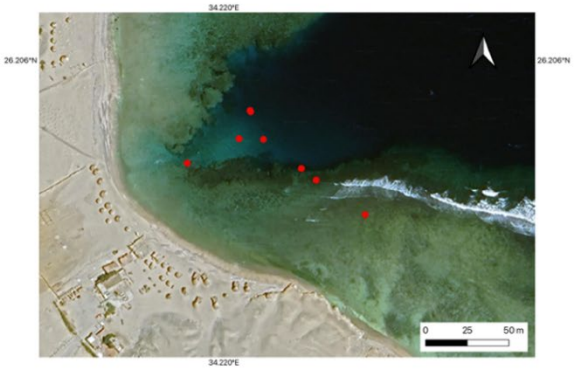
G. Debbie



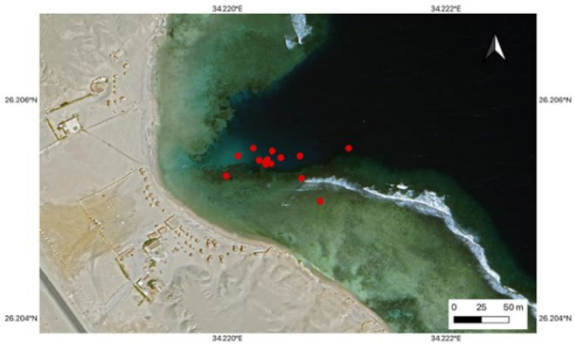
H. Love



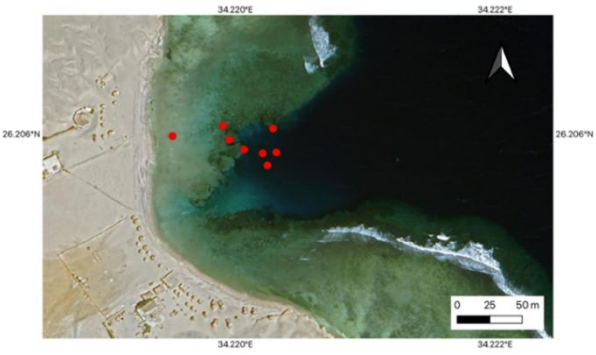
I. Petal



J. Ron



K. Sammie



L. Sherlock

Figure 23. Individual movement patterns of bluespotted ribbontail rays. Panels A-M show the spatial distribution for individual rays encountered 5 or more times during surveys. Red spots represent each ray sighting.

To determine individual movement patterns within the reef, QGIS was used to generate spatial data to assess whether rays showed consistent location use over the study. Maps from QGIS show that individuals either prefer the north or south reef and were generally found in similar areas each time a survey was conducted. For example, individual Sammie (K from figure 23) is seen consistently in the south reef and individual Petal (I from figure 23) is seen consistently in the north reef, indicating individual movement patterns within the reef.

4.2.4.7 Individual Depth Ranges

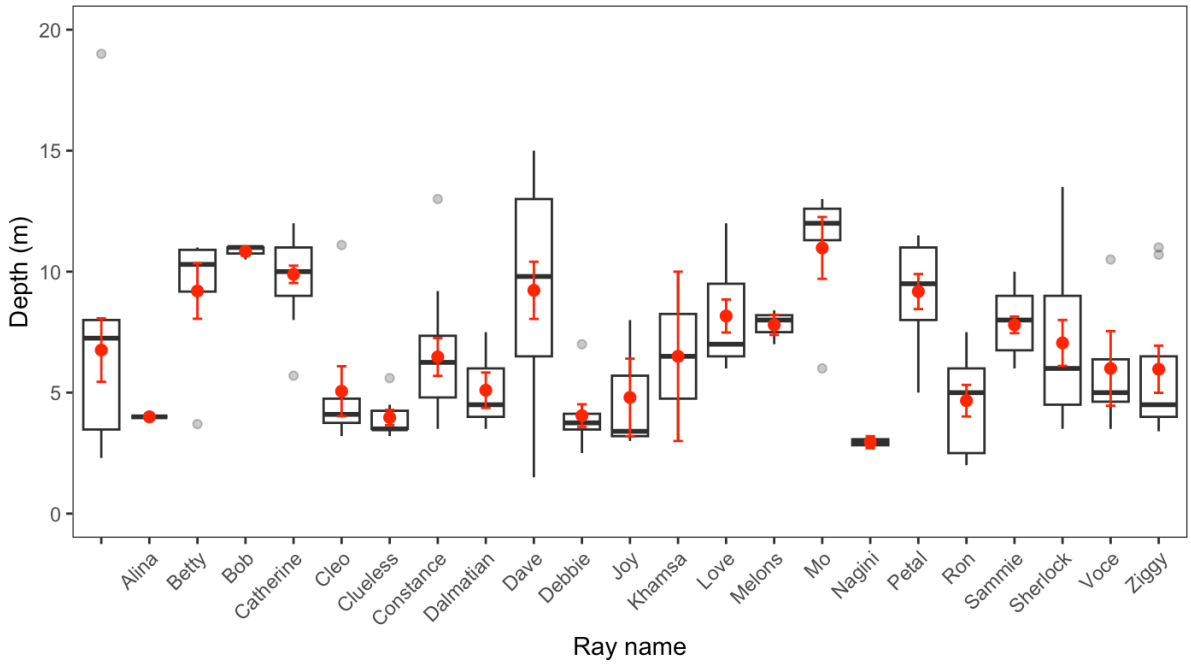


Figure 24. Depth distributions of individual rays across the survey period. The boxplot shows the distribution of depths (m) for individual rays. Red markers indicate the mean (+/- standard error). The black whiskers mark the 5th and 95th percentiles, and values above or below these are considered outliers marked by grey dots. Rays varied in the mean depth at which they were found.

Depth was examined to determine whether individual rays were seen at different depths. When testing the ray name against depth, depth varied between individuals (Figure 24), with the random intercept showing among-individual variation in mean observed depth (SD= 2.02). Habitat use significantly affected depth ($F_{2,134} = 8.35$, $p < 0.05$), with rays in rubble habitat being found 2m shallower than those in reef habitat. Area also influenced depth ($F_{3,134} = 3.33$, $p<0.05$), with individuals in the bay being found 0.5m shallower than the north and south areas. Time of day showed rays were found in shallower depths in the afternoon ($F_{1,134} = 3.69$, $p=0.057$).

4.2.4.7 Population Size Estimate

	Frequency (calculation 1)	Frequency (calculation 2)	Frequency (calculation 3)	
Animals marked and released (M)	12	12	10	
Animals recaptured on second day (R)	7	6	4	
Size of sample on second day (S)	11		12	9

Table 3. Summary of mark recapture data used to estimate the average population size using the Lincoln-Petersen method.

Using the values from Table 3, the Lincoln-Petersen method estimated the average population size to be 22 individuals, with all assumptions being met. The study found 22 unique individuals (see Appendix 10.2.2).

4.2.5 Discussion

4.2.5.1 Individual Identification

Of the 22 individuals identified, 18 were seen in the north, 1 was seen in the south, 2 were seen in the north and bay, and 1 was seen in all 3 areas (Figure 23). Most individuals were seen in only one of the 3 areas, suggesting that bluespotted ribbontail rays have small home ranges. Individual home ranges varied from 112m wide for Ron to 9m wide for Nagini. This spatial pattern is seen in other marine species, including the spotted skate (Rohner et al., 2025) and *Manta birostris* (Stewart et al., 2016). These findings suggest that rays have low dispersal distances and home ranges compared to other ray species, such as devil rays, which have large home ranges (di Sciara et al., 2025). This is important as low dispersal increases the likelihood that the population is fragmented (Teunissen et al., 2025). If the bay is isolated, the number of rays could decline to a size where inbreeding and reduced genetic diversity become a massive problem, reducing their long-term persistence (Kardos., 2021).

4.2.5.2 Ray Feeding Activity

Rays were most likely to be observed between 3 pm and 5 pm and least likely between 10 am and 12 pm. This pattern is consistent with Peel et al., 2019 who found that manta rays were regularly seen feeding during the day due to prey abundance. This suggests that bluespotted ribbontail ray feeding times may be linked to their prey's abundance as described for other marine species (Bartes et al., 2025). Small benthic fish that rays feed on come out at dusk when predation is low (Prenda et al., 2000), which is seen in this study with the increase in ray activity in the late afternoon. These results refine our understanding of the diel activity patterns of bluespotted ribbontail rays by showing a late afternoon peak in feeding activity.

4.2.5.3 Behaviour Variation Across Habitat

Rays were most likely to rest in the reef habitat while feeding and moving more in the sand habitat. This aligns with Martins et al., 2020 where stingrays were seen resting more in mangrove edges and sand flats, suggesting that rays feed in sandy areas. These results contribute to our understanding of ray behaviour, suggesting that more complex habitats in terms of prey and species richness can affect the behaviours that rays exhibit at specific habitats (Guo et al., 2024).

4.2.5.4 Bluespotted Ribbontail Ray Distribution

The study found that more rays were seen in the north (143 sightings) compared to the south and bay (22 and 11, respectively), indicating that certain locations have more favourable environments. This is seen in a study by Dethier and Schoch., 2005 who found that benthic species differed between the north and south beaches with a unidirectional trend. This suggests that the sediment distribution may play a role in ray distribution as the south area had a greater sand coverage (personal observation) than the north (Dethier and Schoch., 2005). These results reveal a new insight into the distribution patterns of bluespotted ribbontail rays, showing that ray distribution is not uniform across the reef, with more rays seen in the north.

4.2.5.5 Ray Presence by Location and Habitat

This study found that there was a higher ray presence in the north reef (143 sightings) compared to the south and bay (22 and 11, respectively). This aligns with a study by Osuka et al., 2022 who found higher numbers of marine fish in certain sites. This suggests that more rays were found in the north due to more favourable conditions, such as higher nutrient availability (Farmer et al., 2022). These results highlight the ecological importance of spatial variation in influencing ray presence.

Ray presence was higher in reef habitat (141 sightings) compared to rubble and sand (12 and 23, respectively), indicating that rays use reef habitat as a central foraging place, as sand near reefs is more nutrient-rich than sand further away. A study by Martins et al., 2020 who found that stingrays used sand habitats more than the reef habitats due to lower densities of coral in the sand habitat, which contradicts the findings of this study. This suggests that there is variation in habitat use between ray species, so when looking at conservation efforts, this should be considered. Given their preferred habitat being the reef, the population could be vulnerable to fragmentation as the reef habitat is found in patches throughout the bay. These findings highlight that habitat use is a driver for ray presence and that rays are not randomly distributed and are found in specific ecological conditions.

4.2.5.6 Individual Movement Patterns

Individuals showed a clear preference for either the north or south reef and were generally seen in similar areas each time the survey was conducted, indicating site fidelity. This is consistent with Doggett et al., 2018 who found that most undulate rays remain in similar areas and all sightings of individual rays were within 3-4m of each other. These findings suggest that rays have small home ranges so their needs can be met locally (Ono and Haines., 2021). These results help refine our current understanding of ray movements and distribution, which could help monitor population changes and identify protected areas in the future (Sherman., 2019).

4.2.5.7 Individual Depth Ranges

The average ray depth was 7m, with the largest individual depth range being 13.5m for Dave and the smallest being 0.5m for Alina. This is seen in a study by Lassauce et al., 2025 who reported that most individuals were seen between 0-50m depth, indicating depth overlaps in individuals. Rays could avoid deeper water due to the greater risk of predation (Osuka et al., 2022), mainly from hammerheads (California Academy of Sciences., 2025), with shallower depths offering more foraging opportunities

and reduced predation (Bartes et al., 2025). These findings indicate that rays within the population differ in their vertical habitat use, suggesting individual specialisation, with some rays exploiting greater depth ranges and some remaining in shallower waters. This is important for conservation as rays were seen in depths less than 30m, suggesting that movement between the bay and other bays could be limited, increasing the potential for population fragmentation.

4.2.5.8 Population Size in the Abu Sauatir Reef

The number of ray residents in the reef was 22 individuals using photo identification and mark-recapture. This is seen in a study by McIvor et al., 2024 who used this method to identify 161 individuals, showing mark-recapture and photo identification to be effective in identifying individuals based on spot patterns. Due to bluespotted ribbontail rays having low fecundity and no larvae, their dispersal relies on the movement of adults (Nehemia., 2024). This suggests that the bluespotted ribbontail ray population may have low genetic variance due to small population size and the reef being quite isolated (Furlan et al., 2012). Therefore, they will struggle to adapt to environmental changes (Furlan et al., 2012) and could experience reduced connectivity, which increases their chance of inbreeding (Nehemia., 2024). These results enhance our understanding of ray population sizes, which is important as they act as ecosystem engineers (Levy et al., 2024), so population estimates could help us understand if they are under threat and help inform targeted management (Hammond et al., 2021).

4.2.5.9 Limitations

In low visibility conditions, some rays may not have been seen, which could have led to underestimates of encounter rates. There were some limitations to the I3S Classic software, mainly due to photo quality. In juvenile rays, their spot patterns can change as they grow, which could hinder identification in the future (McIvor et al., 2024) as I^3S doesn't account for the size of markings, only their position in relation to other markings (Hartog and Reijns., 2014).

4.2.5.10 Further Research

This study found that bluespotted ribbontail rays in the Abu Sauatir reef have small home ranges, a late-afternoon feeding peak, vary in their behaviour and habitat use across areas and depth, and the population is concentrated in the north reef.

The next step for the study would be to do long-term individual tracking, such as satellite tracking. This could be addressed by tagging individuals using McIvor et al., 2024's method to investigate population changes and investigate if rays live in similar areas over time. Based on the results of this study, several hypotheses emerged that could be investigated, including whether rays aggregate in the north reef as it offers higher habitat quality than other areas, whether depth drives habitat use, with shallower areas used more for foraging and deeper areas more for resting, and whether rays choose to forage later in the afternoon to maximise foraging.

Future studies could test these hypotheses by combining spatial tracking with habitat surveys to determine whether habitat quality in the north reef drives ray aggregation. Integrating depth and behavioural data would see whether shallow areas are used more for foraging and deeper areas for resting. Recording feeding behaviour across the full diel cycle would allow an assessment of whether rays forage more later in the afternoon to maximise foraging.

4.2.6 Conclusion

This study shows that bluespotted ribbontail rays have small home ranges, late-afternoon feeding peaks, spatial and behavioural variation across habitat types, with rays more likely to rest in the reef habitat and feed and move more in the sand habitat. Individual rays were found at different depth ranges, and the population was clustered in the north. These patterns indicate that ray behaviour and distribution are shaped by habitat structure and location. The aggregation of rays in the north reef, combined with individual depth differences, suggests that habitat structure and quality are key drivers of distribution in the population. These findings show how behaviour, habitat type and spatial structure interact to shape bluespotted ribbontail ray ecology, which can help inform targeted conservation management. This allows future studies to look at long-term tracking and assess habitat quality, depth use and foraging strategies.

5. Personnel

The 2025 Egypt Expedition team consisted of two leaders and five undergraduate students studying at the University of Glasgow. Below is an overview of each team member, their role on the team, and a personal reflection on their experiences on the expedition and the skills they believe they developed while on the team.

5.1 Leaders

5.1.1 Leo Yokota

Pronouns:	He/Him
Age:	25
Status:	Undergraduate
Nationality:	British
Languages:	English, Japanese
Year of Study:	2nd
Course:	Marine & Freshwater Biology
Role:	Expedition Co-Leader

This was my second scientific expedition experience, building on top of the 2024 Thailand expedition I co-lead. As I had this experience of co-leading an expedition once, I set my aim for this expedition to build on top of what I have achieved and learned to further develop my skill set.

As the Egypt expedition allows the students to have more control over the research projects, I saw this as a good opportunity to develop my scientific research skillset further, which aligned with my development of studies at university itself. I was able to work closely with the two project leads and our academic supervisors to try and understand how we can collect data to answer the research questions we had. This was also beneficial going into third years as the focus of the courses shifts more towards experimental design and execution.

Organising and preparing for the expedition itself was far easier than the last expedition as I had experienced doing everything once, however, this year we faced a reduction in funding which was a difficult aspect to navigate. We had to reduce the overall expedition duration from 6 to 4 weeks which gave us a tighter margin for error. Although we had this issue, we were able to complete data collection for both projects which I am extremely proud of.

On a more personal level, I was able to be more involved in the supervision of any SCUBA diving and snorkelling data collections as I had progressed my qualifications prior to the expedition. Although, this brought more responsibilities, I enjoyed helping less experienced divers try to get better at scientific diving and see their progress during the duration of the expedition.

I am extremely proud of the team for what they have achieved through this expedition and cannot thank them enough for their hard work to accomplish what we have. I will take on what I have learnt from this expedition and try to apply and develop these skillsets further in future opportunities.

5.1.2 Catherine Mou

Pronouns:	She/Her
Age:	27
Status:	Graduated
Nationality:	Taiwanese
Languages:	English, Cantonese
Year of Study:	N/A
Course:	N/A
Role:	Expedition Co-Leader

Due to personal circumstances, a reflective statement is not available.

5.2 Team Members

Name:	**Ziggy Macnaughton**
Pronouns:	He/Him
Age:	25
Status:	Undergraduate
Nationality:	British
Languages:	English
Year of Study:	Masters
Course:	Masters in Research
Role:	Project Supervision & Grants Officer
Profile:	Prior to the expedition, I built on my previous fundraising experience by taking an active role in assisting the project's financial side. I assisted with grant writing and helped with local fundraising efforts in Glasgow, including bucket-shaking events. This role supported the team's logistics and also improved upon my ability to communicate scientific goals to potential donors and grant bodies, a skill that has proved essential in my work since. Unlike previous trips where my focus was on gaining basic qualifications, I entered this expedition as an experienced PADI Rescue Diver. This allowed me to step up as a scientific dive leader during the expedition without needing entry-level training. I helped refine advanced fieldwork competencies, specifically in experimental design and equipment calibration. For instance, during hydrophone array testing, we mapped the acoustic sensitivity of our equipment by conducting grid-pattern click tests underwater, trying to identify blind spots and ensure accurate data collection on how depth affects the phonic richness of the reef. The expedition's relative autonomy forced us to troubleshoot independent research problems in real time. Beyond the acoustic study, I developed proficiency with i3s pattern-matching software to identify and track Blue Spotted Stingrays. The opportunity to master new software and lead survey dives has left me confident in my ability to adapt to new methodologies and manage field data collection. I came away from Egypt not only with improved technical research skills but with a mature understanding of the psychological demands of remote fieldwork.

Name:	**Mohit Raj**
Pronouns:	He/Him
Age:	21
Status:	Undergraduate
Nationality:	British
Languages:	English
Year of Study:	4th
Course:	Zoology
Role:	Project Leader & Fundraising Officer
Profile:	The Egypt expedition was a fantastic opportunity for me develop as an individual and as part of a team. Being able to carry out my own scientific research to satisfy my own curiosity gave me clarity to the direction of my future career towards research. Not only was I given clarity but also developed skills which I learnt from working independently and skills which I've learnt from other members of the team. I have improved my knowledge of the scientific method and the amount of effort required for scientific discovery. Before the expedition I did not know a lot about Egyptian culture and the circumstances in the country. Working alongside Open Ocean Science Centre I saw the challenges local communities struggled with and how we could get involved. I also received a life changing experience of diving which had always been a bucket list item for me and being able to use it for research was truly life changing.

Name:	**Poppy Voce**
Pronouns:	She/Her
Age:	21
Status:	Undergraduate
Nationality:	British
Languages:	English
Year of Study:	4th
Course:	Zoology
Role:	Project Leader & Social Media Manager
Profile:	The expedition marked a turning point in how I see myself as a field ecologist. Gaining my PADI Open Water prior to the expedition was something I would have never done if it wasn't for the expedition. Working on the stingray project pushed me beyond the structure of university learning and allowed me to gain hands on experience in a marine setting. I really enjoyed the community engagement we did with the local school- playing games and doing litter picks. The expedition sharpened my practical skills, deepened my confidence in the field, and strengthened my love for marine conservation which I will take with me to further my career.

Name:	**Thea Jones**
Pronouns:	She/Her
Age:	20
Status:	Undergraduate
Nationality:	British
Languages:	English
Year of Study:	3rd
Course:	Marine and Freshwater Biology
Role:	Grants Officer
Profile:	Our trip to Egypt was inspiring. I had never been part of a research team before, and it was an eye-opening experience. A perfect combination of education and down time, I thoroughly enjoyed jumping in the deep end and learning loads of different research techniques. Days filled with exploring the reef via both snorkelling and diving trips, and being awarded my rescue diver qualification made all the prep we did feel very worthwhile. Alongside copious amounts of delicious food, our free time was spent frolicking in the pool and relaxing by the weekly bonfire. The odd trip into the local village was a window into how the locals live their lives: a foreign world that is filled with colour and joy. The owners of the camp we were staying in were welcoming and enthusiastic, while the other residents that were holidaying during our expedition were interested in the research we were carrying out: some of whom our team members are still in touch with! The dive guides who took us on dives to explore local reefs made sure we saw cool things: multiple turtle sightings and many hidden octopus! I feel much more confident in marine research settings thanks to this awesome trip with a fun-filled group of people.

Name:	**Alina Chauhan**
Pronouns:	She/her
Age:	20
Status:	Undergraduate
Nationality:	Indian
Languages:	English, Hindi/Urdu, Marwari
Year of Study:	2nd
Course:	Marine and Freshwater Biology
Role:	Secretary
Profile:	The Egypt Expedition was an essential learning opportunity for me as before the expedition, I wasn't too sure about whether I truly want to pursue marine biology or not as I did not have any experience in any kind of marine biology fieldwork or any diving experience either. The expedition gave me the opportunity to explore and learn new skills which will surely be useful to me in the future. In fact, based on my experience in Egypt, I was able to look for similar opportunities in India and fortunately I have been able to start a brand-new expedition to Andaman and Nicobar Islands, India starting in 2026. On top of that, I have gained confidence in my diving skills and learned to carry out quality research dives in tropical waters. I hope to expand this skill set in different regions and climates. This expedition also allowed me to understand the nuances of eco-tourism and conservation and its implications on the local population. This insight will help me navigate our new expedition to Andaman.

5.3 Academic Advisors

5.3.1 Dr. David Bailey

David.bailey@glasgow.ac.uk

Dr David Bailey is a marine biologist and Reader in Ecology and Environmental Change at the University of Glasgow. His research group studies marine environments from the Antarctic to tropical coral reefs, with conservation and management of marine systems the common theme across his work. With a longstanding interest in deep-water biology, some of his work has involved studying the physiological characteristics and behaviour of deep-water fish. More recently, he has focused on fish distribution and how this has changed with time. Through his work, Dr Bailey has helped demonstrate how fishing impacts spread deep into the oceans as well as that deep-water fish communities can change dramatically due to natural climatic variations. Dr. Bailey was the advisor of the "Blue spotted ribbon tailed ray's habitat preferences and distribution in El Quseir, Egypt" as well as the entire expedition (see 4.2).

5.3.2 Dr. Laurence de Clippele

Laurence.DeClippele@glasgow.ac.uk

Dr. Laurence de Clippele, a Lecturer in Ecology & Environmental Change at the University of Glasgow since 2023, specializes in marine ecology with a focus on benthic habitats. Her research includes studying cold-water coral reefs, sponge grounds, and seagrass meadows, with interests in marine biodiversity and ecosystem functioning. Dr. Clippele was the advisor of the "An Investigation into the Temporal Variation in Marine Biodiversity in the Red Sea Using Marine Soundscapes" (see 4.1).

5.3.3 Dr. Peter Koene

Peter.Koene@glasgow.ac.uk

Dr Peter Koene is a lecturer in Ecology and Environmental Change at the University of Glasgow, specialising in evolutionary ecology and fish biology in freshwater fish. Dr. Koene was the advisor of the "An Investigation into the Temporal Variation in Marine Biodiversity in the Red Sea Using Marine Soundscapes" (see 4.1).

5.4 Expedition Advisors

5.4.1 Dr. David Bailey

David.bailey@glasgow.ac.uk

See 5.3.1.

5.4.2 Dr. Deborah McNeill

Deborah.McNeill@glasgow.ac.uk

Dr Deborah McNeill is a marine biologist and the director of the Glasgow Science Festival at the University of Glasgow. Her research studies marine environments from the Uk to tropical coral reefs, with a wide range of investigations from distribution and abundance of species to the use of different

systems and technologies for marine research. She has founded the Glasgow Science Festival in 2006 and has run this annual festival to showcase the Science scene in Glasgow. Deborah is also an advisor for the entire expedition.

5.4.3 Dr. Donald Reid

Donald.reid@glasgow.ac.uk

Dr Donald Reid is a lecturer in the School of Biodiversity, One Health & Veterinary Medicine at the University of Glasgow. His research interests lie in the ecophysiology and life-history strategies of fish. His previous research has explored links between metabolism, physiology and behaviour in a range of fish species across Norway, Italy and the U.K. He has a substantive educational role as Teaching Lead for Integrated Quantitative Skills for the University's undergraduate Life Science degrees portfolio.

5.4.4 Guy Henderson

Field Work Advisor at ROOTS Red Sea / Open Ocean Science Centre
gphenderson81@gmail.com

Guy Henderson works for ROOTS Red Sea / Open Ocean Science Centre in El Quseir, providing assistance on student expeditions and field trips. He provided invaluable support in ensuring research projects were conducted effectively. He supervised the team during data collection and oversaw dive practises. He is a BSAC Dive Leader and marine biologist.
Due to the support the team received from Guy Henderson, a Glasgow University advisor was not required to travel to Egypt in person with the team but instead could be contacted via zoom to ensure field work was running smoothly when necessary.

6. Training

6.1 SCUBA Diving Training

To ensure research was undertaken safely and to a high standard, all team members completed the appropriate SCUBA diving training prior to commencing data collection dives, with PADI qualified instructors based in and around Glasgow and RAID qualified instructors in Egypt. As a result, all team members were PADI Rescue Diver certified or equivalent (BSAC Sports Diver, RAID Rescue Diver). All team members were thus equipped with a high level of dive and rescue knowledge. Research diving did not take place until all divers had PADI Rescue Diver or equivalent, as well as 25 logged dives, and the dive officer in conjunction with the expedition and project leaders was confident in team member's ability to look after both themselves and their buddy whilst conducting research. See 8.2 SCUBA Diving Safety for further information on SCUBA specific safety.

Above: 4 members of the 2025 Egypt Expedition team after completion of the Master Rescue Diver Certification

6.2 First Aid Training

All team members received first aid training, whether that be a first aid course facilitated through the University of Glasgow Exploration Society or as part of their PADI Rescue Diver certification, which results in the student receiving an Emergency First Responder (EFR) qualification. This included underwater, surface, and shore rescue training. While in Egypt the team was equipped with a fully stocked first aid kit.

6.3 Scientific Methodology Training

Team meetings ran by the project leaders prior to departure informed team members on the scientific methods of all research projects and additional team meetings were conducted if research plans changed. The identification of potentially dangerous local flora and fauna was discussed and how to treat injuries from potentially dangerous organisms. Each team member familiarised themselves with the prospectus and read and signed the risk assessment, with the opportunity to address any questions/concerns they may have had. Each team member was aware of potential risks and hazards during the expedition. All members not familiar with the data collection methodologies were trained in the pool by members with previous experience and were supervised by these members or by staff that have experience in the methodology in the open water.

7. Logistics

7.1 Transport and Accommodation

The expedition ran from the 9th of June until the 7th of July. All team members departed from Glasgow airport and flew to Hurghada airport in Egypt. From Hurghada airport, the team were met by a transfer bus arranged to ROOTS Red Sea. ROOTS Red Sea contained an air-conditioned lab to allow data input and analysis. Food and soft drinks were provided by ROOTS Red Sea including three meals a day for all team members. The cost of accommodation, transport, food, and water was covered by expedition funding.

7.2 Expedition Itinerary

7.2.1 Brief Itinerary

Prior to Departure	Project planning Expedition logistics Fundraising Team Building Grant applications

Week one	
Days 1	Flight from Glasgow to Hurghada Minibus from Hurghada to ROOTS Red Sea
Days 2 - 7	Pharoah Dive Club induction and training Pilot studies by already qualified members RAID Master Rescue Course
Week Two - Three	
Days 1 - 7	Fieldwork carried out 3 days SCUBA and 1 day off Snorkel Surveys
Days 6 - 7	Prepared for fieldwork in upcoming weeks Amended experimental design with supervision from advisors
Week Four	
Days 1 - 5	Final week of data collection as needed
Day 6	Equipment inventory taken Clean-up of accommodation Preparation for departure
Days 7 - 8	Return to Glasgow
Upon Return	Data analysis Report write up Media collation Grant reports

7.2.2 Data Collection Day Sample Itinerary

Time	Activity
8:00	Breakfast
8.45	Prepare to go to the dive centre
9:00	Briefing and Equipment preparation
09:30	1st Dive / 1st Snorkel Data Input & Analysis (Dry)
10:30	Debrief
11:30	2nd Dive /2nd Snorkel Data Input & Analysis (Dry)
12:30	Debrief
13:00	Lunch
14:30	3rd Dive / 3rd Snorkel Data Input & Analysis (Dry)
15:30	Debrief & Tidy Equipment
16:00	Data Input & Analysis
19:00	Dinner Whole team debrief & planning for next day
20:30	Free time

7.2.3 Non-Data Collection Day Sample Itinerary

Time	Activity
9:00	Breakfast Morning meeting
10:00	Data entry/analysis/back up Social media/blog updates Equipment maintenance Dive log entries Laundry Beach cleans
13:00	Lunch
14:00	Data entry/analysis/back up Social media/blog updates Equipment maintenance Dive log entries Laundry Beach cleans
19:30	Dinner Day debriefs
20:30	Free time

8. Safety

8.1 Risk Assessment

A risk assessment was created by the expedition leaders in conjunction with the project leaders and in line with the University of Glasgow School of Biodiversity, One Health, and Veterinary medicine, under which marine research takes place. All aspects of the expedition apart from the scientific dives were covered under this risk assessment. The risk assessment was approved by the expedition advisors before being read and signed by all team members, giving them the opportunity to ask for clarification as needed. Although not included in this report, the full signed risk assessment is available upon request.

8.2 SCUBA Diving Safety

A dive project and plan document was created by the expedition leaders in conjunction with the project leaders and in line with the University of Glasgow School of Biodiversity, One Health, and Veterinary medicine, under which marine research takes place. This document served as a risk assessment for the scientific diving only to allow the risks of diving to be evaluated and safety measures implemented in greater detail. The dive project and plan document was approved by the university dive supervisor Dr. David Bailey prior to any data collection dives were conducted. Although not included in this report, the full dive project and plan document is available upon request.

Each member was required to obtain PADI Rescue Diver or an equivalent certification alongside 25 logged dives to ensure all team members were safe during dives (see 6.1 SCUBA Diving Training). No one conducted research without having received full training.

Before diving, a buddy check was undertaken by each dive buddy pair. All dives were logged by the dive officer, including maximum depth, dive time, stops taken, environmental conditions, and any problems encountered. A copy of these logs were stored, and each team member kept logs of the dives they completed.

9. Acknowledgements

The 2025 Egypt Expedition would not have been possible without a number of important funders, advisors, and scientists. We are incredibly grateful for the support of everyone listed below as well as anyone else who enabled this expedition to go ahead.

First, we would like to thank all of our grant funders. These include The British Sub-Aqua Jubilee Trust, Gilchrist Educational Trust, Glasgow Natural History Society (Blodwen Lloyd Binns Bequest Fund), University of Glasgow Chancellor's Fund, Turing Fund, and Lord's Mayor 800th Grant. These grant funding was vital enabling the expedition to go ahead and it would not have been possible without these incredibly generous organisations. Similarly, we want to thank every who came to our fundraising events and donated through our Easy Fundraising. This report should highlight that all the money we received was well spent.

We need to thank the staff at the University of Glasgow who advised our Expedition Leaders and Project Leaders to ensure our expedition was safe, undertaking good work, and so our projects were to the highest possible standard. These include Dr. David Bailey, Dr. Deborah McNeil, Dr. Lawrance DeClippe, Dr. Peter Koene, Dr. Stewart White, and Dr. Donald Reid.

Last, but far from least, we must thank the owners, staff and volunteers at ROOTS Red Sea, namely Steve Rattle, Claire Rattle, Sammie Claire, and Guy Henderson for making us feel welcomed and assisting us throughout our stay.

10. Appendix

10.1. Appendix for Project 4.1

10.1.1 Sound Classification Table

The following tables show all the sound classification groups with a sound description and the different frequency variations of that sound. For example, a 'Pop' can be found as either a 'HF Pop' or a 'LF Pop'. Every sound will have a lowest and highest frequency, both values of a specific sound must fall within a certain range for it to be grouped into the corresponding frequency level. Except for broad frequency where the two values must fall within different ranges (See table 4). Each frequency variation of a sound should be considered as a different classification. Table 5 shows the sound classification for the simple system except the between-frequency variations of FPT, UFPT, quaver and quaver series. Table 6 is the additional sounds which have been added to the simple system to make the complex classification system.

Table 4. *shows the frequency range that the lowest and highest frequency value of a sound must fall in for classification into different frequency levels.*

Frequency Levels	**Frequency Range (Hz)**
Low Frequency	0 – 200
High Frequency	200 - 1000
Broad	0 – 100 (Lowest Frequency), 400 – 1000 (Highest Frequency)
Between	100 - 400
Full	0 – 23,000

Table 5. *shows all the sound classification groups in the simple classification system except for the between-frequency variation of FPT, UFPT, Quaver and Quaver Series.*

Name	**Description**	**Frequencies found at…**
Accelerando	Subsequent pulse periods shorten creating an acceleration effect.	Broad
Rallentando	Subsequent pulse periods lengthen creating a slowing effect.	HF, Broad, LF
Acc/Ral	Accelerando followed by rallentando	Broad
Ral/Acc	Rallentando followed by accelerando	Broad
Pop	Singular audio pulse	HF, LF
SPT	Stereotyped pulse train has ≥ 3 pulses with uniform pulse periods	HF, Broad, LF
SSPT	Series of SPT is when ≥ 2 SPTs occur in a row with each being within 1.5s of the adjacent train.	HF, Broad, LF
FPT	Fast pulse train have short, stereotyped pulse periods < 0.1s	HF, Broad, LF, Between
SFPT	Series of FPT is when ≥ 2 FPTs occur in a row with each being within 1.5s of the adjacent train.	HF, Broad, LF
IPT	Irregular pulse train has ≥ 3 pulses with pulse periods being irregular (not stereotyped)	HF, Broad, LF
SIPT	Series of IPT is when ≥ 2 IPTs occur in a row with each being within 1.5s of the adjacent train.	HF
UFPT	Ultra-fast pulse train has ≥ 3 pulses with pulse periods so fast they are inaudible	HF, Broad, LF, Between

SUFPT	Series of UFPT is when ≥ 2 UFPTs occur in a row with each being within 1.5s of the adjacent train.	HF, Broad, LF
Quaver	Two auditory inputs within 0.5s of each other	HF, Broad, LF, Between
Quaver Series	Quaver Series is when ≥ 2 quavers occur in a row with each being within 1.5s of the adjacent train.	HF, Broad, LF, Between
Snap	Singular auditory input where the frequency spans the whole spectrogram.	Full
Scrape	Singular auditory input where the frequency spans the whole spectrogram, but the sound duration is longer than a snap and sounds like a scrape.	Full
Squeak	Single auditory input with broad scale frequency with an emphasis at the between level frequency, sounds distinctively like a squeak.	Broad
Tap	Singular auditory input with a broad frequency range.	Broad
Thud	Singular auditory input with a broad frequency range but increased emphasis on the low frequency band.	Broad
Thud Series	Thud series has ≥ 3 pulses with uniform pulse periods.	Broad
Tuba	Like a LF Pop but lasts longer (~0.2s)	Low
Mix	Multiple auditory inputs showing no structure in frequency. Each input could be a different frequency.	Mixed
Wave	A continuous pulse which spans >0.5s across a broad scale frequency	Broad

Table 6. *shows all the addition classification groups added to the simple system to make the complex classification method.*

Name	**Description**	**Frequencies found at…**
Bump	Singular auditory input with a between-frequency	Between
Bumps	≥ 3 bump with uniform pulse periods	Between
Bumps Series	Series of bumps is when ≥ 2 bumps occur in a row with each being within 1.5s of the adjacent.	Between
IR	Irregular bumps has ≥ 3 bumps with pulse periods being irregular (not stereotyped)	
FSPT	Fast SPTs are SPTs where the pulse periods are short but not quite as short as the FPT.	HF, Broad, LF
FIPT	Fast IPTs are IPTs where the pulse periods while still irregular on average are ~0.1s	HF
SFSPT	Series of Fast SPT is when ≥ 2 FSPTs occur in a row with each being within 1.5s of the adjacent.	HF
Long UFPT	UFPT which lasts longer than >0.5s	HF, Broad, LF

Odd	Pulse train where the first pulse is broad frequency and all subsequent pulses are high frequency.	Mixed
Odd Series	Odd series is when ≥ 2 odds occur in a row with each being within 1.5s of the adjacent.	Mixed
Purr	Very similar to a FPT but pulse periods are slightly longer, and the sound is quite distinctive to a purr.	HF, Broad, LF, Between
Purr Series	Series of purrs is when ≥ 2 purrs occur in a row with each being within 1.5s of the adjacent.	HF, Broad, Between
Fast Quaver	Two auditory inputs < 0.05s of each other	HF, Broad, LF, Between
Fast Quaver Series	Series of fast quavers is when ≥ 2 fast quavers occur in a row with each being within 1.5s of the adjacent.	HF, Broad, Between
Scratch	Singular auditory input where the frequency spans the whole spectrogram, but the sound duration is double a scrape and sounds like a scratch.	Full
Screech	Like a scratch but more high frequency focused.	Full

10.1.2 Replicable R Code

The following is all the r code, in rmarkdown format, used to generate all graphics and models used in this project.

````
Install all relevant packages for graphics and models
```{r}
install.packages(c(
"rmarkdown",
"ggplot2",
"ggpubr",
"patchwork",
"Matrix",
"MASS",
"lme4",
"car"
), repos="https://cloud.r-project.org")
```
```{r}
library("ggplot2")
library('ggpubr')
library("patchwork")
library("Matrix")
library("MASS")
library("lme4")
library("car")
library("rmarkdown")
```
Set working directory

Read histogram data for both simple and complex data sets
```{r}
Hist<-read.csv('DetailedHistogram.csv')
Hist2<-read.csv('SimpleHistogram.csv')
```
````

Create histogram for the complex data set (Complex classifications)

```{r}
ggplot(Hist, aes(x = reorder(Name, Total.Abundance), y = Total.Abundance)) +
  geom_bar(stat = "identity") +
  coord_flip() +
  ggtitle("Phonic Abundance") +
  xlab("Sound Names") +
  ylab("Total Abundance") +
  theme(axis.text.y = element_text(size = 6))
```

Create histogram for the simple data set (simple classifications)

```{r}
ggplot(Hist2, aes(x = reorder(Name, Total.Abundance), y = Total.Abundance)) +
  geom_bar(stat = "identity") +
  coord_flip() +
  ggtitle("Phonic Abundance") +
  xlab("Sound Names") +
  ylab("Total Abundance") +
  theme(axis.text.y = element_text(size = 9))
```

Read Simple data set and make sure that depth and twilight periods are factor variables.

```{r}
SimpleData<-read.csv('SimpleData.csv')
SimpleData$Depth<-as.factor(SimpleData$Depth)
SimpleData$Dawn.Dusk<-as.factor(SimpleData$Dawn.Dusk)
```

Create graphs using simple data for the effect of depth on phonic abundance and phonic richness. Combine into one graph.

```{r}
C<-ggplot(data = SimpleData, aes(x=Depth, y=Phonic.Abundance)) + geom_boxplot()+
  ylab("Phonic Abundance") + xlab("Depth (m)") +
  theme(text=element_text(size=16),
        panel.background = element_blank(),
        axis.line = element_line(colour = "black"))

D<-ggplot(data = SimpleData, aes(x=Depth, y=Phonic.Richness)) + geom_boxplot()+
  ylab("Phonic Richness") + xlab("Depth (m)") +
  theme(text=element_text(size=16),
        panel.background = element_blank(),
        axis.line = element_line(colour = "black"))

(C|D) + plot_layout(axes = "collect") + plot_annotation(tag_levels = 'A') &
  theme(axis.title.y = element_text(size = 12))
```

Create graphs using simple data for the effect of twilight period on phonic abundance and phonic richness. Combine into one graph.

```{r}
G<-ggplot(data = SimpleData, aes(x=Dawn.Dusk, y=Phonic.Abundance)) +
geom_boxplot()+
  ylab("Phonic Abundance") + xlab("Twilight Period") +
  theme(text=element_text(size=16),
        panel.background = element_blank(),
        axis.line = element_line(colour = "black"))

H<-ggplot(data = SimpleData, aes(x=Dawn.Dusk, y=Phonic.Richness)) + geom_boxplot()+
  ylab("Phonic Richness") + xlab("Twilight Period") +
  theme(text=element_text(size=16),
        panel.background = element_blank(),
        axis.line = element_line(colour = "black"))

(G|H) + plot_layout(axes = "collect") + plot_annotation( tag_levels = 'A') &
  theme(axis.title.y = element_text(size = 12))
```

```
Phonic Abundance is a count data so follows poisson distribution so run a generalised linear model using the simple data
```{r}
M9 <- glm(Phonic.Abundance~Depth + Dawn.Dusk, family = poisson, data=SimpleData)
summary(M9)
```
Over dispersion recognised as residual deviance much higher than residual DFs, run negative binomial models including models where sample site and date are included as random effects.
```{r}
M10 <- glm.nb(Phonic.Abundance~Depth + Dawn.Dusk, data = SimpleData)

M11 <- glm.nb(Phonic.Abundance~Depth, data = SimpleData)

M12 <- glm.nb(Phonic.Abundance~Dawn.Dusk, data = SimpleData)

MM10 <- glmer.nb(Phonic.Abundance ~ Depth + Dawn.Dusk + (1 | Sample.Site) + (1 | Date),
                 data = SimpleData)

MM11 <- glmer.nb(Phonic.Abundance ~ Depth + (1 | Sample.Site) + (1 | Date),
                  data = SimpleData)

MM12 <- glmer.nb(Phonic.Abundance ~ Dawn.Dusk + (1 | Sample.Site) + (1 | Date),
                  data = SimpleData)
```
Test which model is the best fit for this data set using Akaike Information Criterion (AIC)
```{r}
AIC(M10)
AIC(M11)
AIC(M12)
AIC(MM10)
AIC(MM11)
AIC(MM12)
```
According to the AIC values MM10 is the best suited model
```{r}
summary(MM10)
Anova(MM10, type = "II")
```
Again, phonic richness also follows a poisson distribution so first run a generalised linear model
```{r}
M13 <- glm(Phonic.Richness~Depth + Dawn.Dusk, family = poisson, data=SimpleData)
summary(M13)
```
Over dispersion can be identified again by the residual deviance, so again use negative binomial with sample site and date as random effects.
```{r}
M14 <- glm.nb(Phonic.Richness~Depth + Dawn.Dusk, data = SimpleData)

M15 <- glm.nb(Phonic.Richness~Depth, data = SimpleData)

M16 <- glm.nb(Phonic.Richness~Dawn.Dusk, data = SimpleData)

MM14 <- glmer.nb(Phonic.Richness ~ Depth + Dawn.Dusk + (1 | Sample.Site) + (1 | Date),
                  data = SimpleData)

MM15 <- glmer.nb(Phonic.Richness ~ Depth + (1 | Sample.Site) + (1 | Date),
                  data = SimpleData)
```
```

```
MM16 <- glmer.nb(Phonic.Richness ~ Dawn.Dusk + (1 | Sample.Site) + (1 | Date),
                 data = SimpleData)
```
Find the best model using AIC
```{r}
AIC(M14)
AIC(M15)
AIC(M16)
AIC(MM14)
AIC(MM15)
AIC(MM16)
```
M15 is the best fitted model, although the difference between M15 and M14 is <0.5. So, there is almost no difference. M14 will be used to extract statistical results as it also includes twilight periods which is need to report their insignificance.
```{r}
summary(M14)
anova(M14)
```
Run a Post-Hoc test to look at significant differences between depth levels for both phonic abundance and richness.
```{r}
Tukey2 <- aov(Phonic.Abundance ~ Depth, data = SimpleData)
tukey_result2 <- TukeyHSD(Tukey2)
print(tukey_result2)
plot(tukey_result2)

TukeyPR2 <- aov(Phonic.Richness ~ Depth, data = SimpleData)
tukey_resultPR2 <- TukeyHSD(TukeyPR2)
print(tukey_resultPR2)
plot(tukey_resultPR2)
```
Repeat everything but for the complex data set. Start of with loading in the data and converting depth and twilight periods to factors.
```{r}
DetailData<-read.csv('DetailedData.csv')
DetailData$Depth<-as.factor(DetailData$Depth)
DetailData$Dawn.Dusk<-as.factor(DetailData$Dawn.Dusk)
```
Create the graphs for depth.
```{r}
A<-ggplot(data = DetailData, aes(x=Depth, y=Phonic.Abundance)) + geom_boxplot()+
  ylab("Phonic Abundance") + xlab("Depth (m)") +
  theme(text=element_text(size=16),
        panel.background = element_blank(),
        axis.line = element_line(colour = "black"))
B<-ggplot(data = DetailData, aes(x=Depth, y=Phonic.Richness)) + geom_boxplot()+
  ylab("Phonic Richness") + xlab("Depth (m)") +
  theme(text=element_text(size=16),
        panel.background = element_blank(),
        axis.line = element_line(colour = "black"))

(A|B) + plot_layout(axes = "collect") + plot_annotation( tag_levels = 'A') &
  theme(axis.title.y = element_text(size = 12))
```
And for twilight periods
```{r}
E<-ggplot(data = DetailData, aes(x=Dawn.Dusk, y=Phonic.Abundance)) +
geom_boxplot()+
  ylab("Phonic Abundance") + xlab("Twilight Period") +
  theme(text=element_text(size=16),
        panel.background = element_blank(),
```

```
        axis.line = element_line(colour = "black"))

F<-ggplot(data = DetailData, aes(x=Dawn.Dusk, y=Phonic.Richness)) + geom_boxplot()+
  ylab("Phonic Richness") + xlab("Twilight Period") +
  theme(text=element_text(size=16),
        panel.background = element_blank(),
        axis.line = element_line(colour = "black"))

(E|F) + plot_layout(axes = "collect") + plot_annotation( tag_levels = 'A') &
  theme(axis.title.y = element_text(size = 12))
```
```
Create model for phonic abundance using the complex data set. Poisson model since its count data.
```{r}
M1 <- glm(Phonic.Abundance~Depth + Dawn.Dusk, family = poisson, data=DetailData)
summary(M1)
```
```
Residual deviance indicates overdispersion so implement a negative binomial models with random effects, sample site and date.
```{r}
M2 <- glm.nb(Phonic.Abundance~Depth + Dawn.Dusk, data = DetailData)

M3 <- glm.nb(Phonic.Abundance~Depth, data = DetailData)

M4 <- glm.nb(Phonic.Abundance~Dawn.Dusk, data = DetailData)

MM2 <- glmer.nb(Phonic.Abundance ~ Depth + Dawn.Dusk + (1 | Sample.Site) + (1 | Date),
                data = DetailData)

MM3 <- glmer.nb(Phonic.Abundance ~ Depth + (1 | Sample.Site) + (1 | Date),
                data = DetailData)

MM3.1 <- glmer.nb(Phonic.Abundance ~ Dawn.Dusk + (1 | Sample.Site) + (1 | Date),,
                  data = DetailData)
```
```
Test for the best fitted using AIC
```{r}
AIC(M2)
AIC(M3)
AIC(M4)
AIC(MM2)
AIC(MM3)
AIC(MM3.1)
```
```
MM2 was the best fitted model so extract statistical results from the summary
```{r}
summary(MM2)
Anova(MM2, type = "II")
```
```
Now models for phonic richness using the complex data set. Utilising negative binomial models and random effects, sample site and date.
```{r}
M5 <- glm(Phonic.Richness~Depth + Dawn.Dusk, family = poisson, data=DetailData)
summary(M5) #Residual deviance much higher than residual DF

M6 <- glm.nb(Phonic.Richness~Depth + Dawn.Dusk, data = DetailData)

M7 <- glm.nb(Phonic.Richness~Depth, data = DetailData)

M8 <- glm.nb(Phonic.Richness~Dawn.Dusk, data = DetailData)
```
```

```
MM6 <- glmer.nb(Phonic.Richness ~ Depth + Dawn.Dusk+ (1 | Sample.Site) + (1 |
Date),
                data = DetailData)
MM7 <- glmer.nb(Phonic.Richness ~ Depth + (1 | Sample.Site) + (1 | Date),
                data = DetailData)
MM7.1 <- glmer.nb(Phonic.Richness ~ Dawn.Dusk + (1 | Sample.Site) + (1 | Date),
                data = DetailData)
```
Test best fitted model using AIC tests
```{r}
AIC(M6)
AIC(M7)
AIC(M8)
AIC(MM6)
AIC(MM7)
AIC(MM7.1)
```
Again, there is not a huge difference between the two best models (~0.5 difference) and to be able to report the insignificance of twilight periods M6 was used to report the stats.
```{r}
summary(M6)
anova(M6)
```
Use of Post-Hoc to look at individual significance between depth levels for both phonic abundance and richness. Using the complex data set.
```{r}
#PostHoc Test on Phonic.Abundance on detailed data
Tukey <- aov(Phonic.Abundance ~ Depth, data = DetailData)
tukey_result <- TukeyHSD(Tukey)
print(tukey_result)
plot(tukey_result)

TukeyPR <- aov(Phonic.Richness ~ Depth, data = DetailData)
tukey_resultPR <- TukeyHSD(TukeyPR)
print(tukey_resultPR)
plot(tukey_resultPR)
```
Now I want to test to see if removing the snap sound from my data in both simple and complex sets causes any changes in significance in the differences in phonic abundance. Therefore, determining snaps being the driving sound of the trend we are seeing.

First load the snapless data from the modified simple data set and change depth and twilight periods to factors.
```{r}
Snapless<-read.csv('Snapless.csv')
Snapless$Depth<-as.factor(Snapless$Depth)
Snapless$Dawn.Dusk<-as.factor(Snapless$Dawn.Dusk)
```
Use the same model which I have used for the data set including snaps
```{r}
MM18 <- glmer.nb(Phonic.Abundance ~ Depth + Dawn.Dusk + (1 | Sample.Site) + (1 |
Date),
                 data = Snapless)
summary(MM18)
Anova(MM18, type = "II")
```
Carry out a post-Hoc as well to find differences in significance between levels of depth
```{r}
Tukey3 <- aov(Phonic.Abundance ~ Depth, data = Snapless)
tukey_result3 <- TukeyHSD(Tukey3)
```

```
print(tukey_result3)
plot(tukey_result3)
```
Same thing, but with modified complex data set (where snaps have been removed), load the data and turn explanatory variables to factors
```{r}
DetailSnapless<-read.csv('DetailSnapless.csv')
DetailSnapless$Depth<-as.factor(DetailSnapless$Depth)
DetailSnapless$Dawn.Dusk<-as.factor(DetailSnapless$Dawn.Dusk)
```
Used the same model structure that was significant in the complex data set
```{r}
MM22 <- glmer.nb(Phonic.Abundance ~ Depth + Dawn.Dusk + (1 | Sample.Site) + (1 | Date),
                 data = DetailSnapless)
summary(MM22)
Anova(MM22, type = "II")
```
Multivariate analysis using Multi Dimensional Scaling (MDS) ordination, to do this we need to install a couple of packages.
```{r}
install.packages("vegan")
library(vegan)
```
Next load the community and environmental data. Let's do it for the simple data set first making sure explanatory variables are factors.
```{r}
SimpleCommunity<-read.csv('SimpleCommunity.csv')
Environment<-read.csv('Environment.csv')
Environment$Depth<-as.factor(Environment$Depth)
Environment$Dawn.or.Dusk<-as.factor(Environment$Dawn.or.Dusk)
```
We will be using the bray-curtis dissimilarity index to look at the differences between groups and within groups. You also want it in a form of X and Y coordinates so it can be plotted using ggplot2.
```{r}
bci.mds<-metaMDS(SimpleCommunity, distance = "bray", k = 2, autotransform =FALSE)

MDS_xy <- data.frame(bci.mds$points)
```
Produce the plot
```{r}
ggplot(MDS_xy, aes(MDS1, MDS2,
                   size = Environment$Dawn.or.Dusk,
                   color = Environment$Depth)) +
  geom_point(alpha = 0.5) +
  stat_ellipse(aes(group = Environment$Depth),
               level = 0.95,
               linewidth = 1,
               show.legend = FALSE) +
  scale_size_discrete() +
  scale_color_brewer(palette = "Dark2") +
  theme_bw() +
  theme(axis.title = element_text(size = 14),
        legend.title = element_text(size = 14),
        legend.text = element_text(size = 12),
        panel.grid.major = element_blank(),
        panel.grid.minor = element_blank(),
        legend.justification = c("center","top")) +
  guides(color = guide_legend(title = "Depth (m)",
                              override.aes = list(size = 5))) +
  guides(size = guide_legend(title = "Twilight Period"))
```

To see if the plot is actually viable we can test forits 2D stress value.
```{r}
bci.mds$stress
```
Plot is good but to get some statistics on the significance of the explanatory variables in the clustering an Adonis2 is ran and to see the significance in variation between group and within group an ANOSIM can be used.
```{r}
community_similarity<-vegdist(SimpleCommunity, method="bray")
adonis2(community_similarity ~ Environment$Depth + Environment$Dawn.or.Dusk, method = "bray", by = "margin")
permanova<-adonis2(community_similarity ~ Environment$Depth + Environment$Dawn.or.Dusk, method = "bray")
print(permanova)

group <- interaction(Environment$Depth, Environment$Dawn.or.Dusk)
anosim <- anosim(community_similarity, group, permutations = 999)
summary(anosim)
plot(anosim)
```
Same thing for the complex data set. Load the data in first and ensure explanatory variables are factors
```{r}
DetailCommunity<-read.csv('DetailCommunity.csv')
EnvDetail<-read.csv('EnvDetail.csv')
EnvDetail$Depth<-as.factor(EnvDetail$Depth)
EnvDetail$Dawn.Dusk<-as.factor(EnvDetail$Dawn.Dusk)
```
Using the same index
```{r}
bci.mds2<-metaMDS(DetailCommunity, distance = "bray", k = 2, autotransform =FALSE)

MDS_xy2 <- data.frame(bci.mds2$points)
```
Plot the graph
```{r}
ggplot(MDS_xy2, aes(MDS1, MDS2,
                    size = EnvDetail$Dawn.Dusk,
                    color = EnvDetail$Depth)) +
  geom_point(alpha = 0.5) +
  stat_ellipse(aes(group = EnvDetail$Depth),
               level = 0.95,
               linewidth = 1,
               show.legend = FALSE) +
  scale_size_discrete() +
  scale_color_brewer(palette = "Dark2") +
  theme_bw() +
  theme(axis.title = element_text(size = 14),
        legend.title = element_text(size = 14),
        legend.text = element_text(size = 12),
        panel.grid.major = element_blank(),
        panel.grid.minor = element_blank(),
        legend.justification = c("center","top")) +
  guides(color = guide_legend(title = "Depth (m)",
                              override.aes = list(size = 5))) +
  guides(size = guide_legend(title = "Twilight Period"))
```
Again, test for the viability of the plot.
```{r}
bci.mds2$stress
```
Then the significance
```{r}
```

```
community_similarity2<-vegdist(DetailCommunity, method="bray")
permanova2<-adonis2(community_similarity2 ~ EnvDetail$Depth + EnvDetail$Dawn.Dusk,
method = "bray",by = "margin")
print(permanova2)

group2 <- interaction(EnvDetail$Depth, EnvDetail$Dawn.Dusk)
anosim2 <- anosim(community_similarity2, group2, permutations = 999)
summary(anosim2)
plot(anosim2)
```
Finally, to reference all the packages I used throughout this statistical analysis as well as the version brough by sessionInfo()
```{r}
sessionInfo()
citation("rmarkdown")
citation("ggplot2")
citation("ggpubr")
citation("patchwork")
citation("Matrix")
citation("MASS")
citation("lme4")
citation("car")
citation("vegan")
```

10.1.3 AIC Value Tables

The following tables show each model created for testing the statistical significance of phonic abundance and richness in both simple and complex data sets. Models for the snapless data matched the models selected above to allow for an appropriate comparison between data sets. Models are ordered from lowest AIC value to the highest and the models in bold are the ones selected for analysis.

Table 7. *AIC value table for model selection on phonic abundance using the simple data set.*

Variables in Model	Random Effect Variables	AIC value
Depth, Dawn.Dusk	**Sample Site, Date**	**571.7817**
Depth	Sample Site, Date	573.3989
Depth	N/A	589.4252
Depth, Dawn.Dusk	N/A	590.9821
Dawn.Dusk	N/A	629.3625
Depth, Dawn.Dusk	Sample Site, Date	633.2077

Table 8. *AIC value table for model selection on phonic richness using the simple data set.*

Variables in Model	Random Effect Variables	AIC value
Depth	N/A	275.4741
Depth, Dawn.Dusk	**N/A**	**275.7466**
Depth	Sample site, Date	279.3313

Depth, Dawn.Dusk	Sample site, Date	279.6038
Dawn.Dusk	N/A	286.5121
Dawn.Dusk	Sample site, Date	290.3693

Table 9. *AIC value table for model selection on phonic abundance using the complex data set.*

Variables in Model	Random Effect Variables	AIC value
Depth, Dawn.Dusk	**Sample site, Date**	**284.8018**
Depth	Sample site, Date	285.0702
Depth	N/A	285.1334
Depth, Dawn.Dusk	N/A	286.0200
Dawn.Dusk	N/A	320.2659
Dawn.Dusk	Sample Site, Date	324.2659

Table 10. *AIC value table for model selection on phonic richness using the complex data set.*

Variables in Model	Random Effect Variables	AIC value
Depth	N/A	153.8381
Depth, Dawn.Dusk	**N/A**	**154.3513**
Depth	Sample site, Date	157.8331
Depth, Dawn.Dusk	Sample site, Date	158.3463
Dawn.Dusk	N/A	166.866
Dawn.Dusk	Sample site, Date	170.866

10.2 Appendix for Project 4.2

10.2.1 Raw Data Used for Statistical Analysis and Graphs

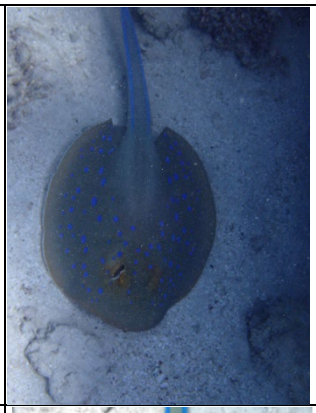
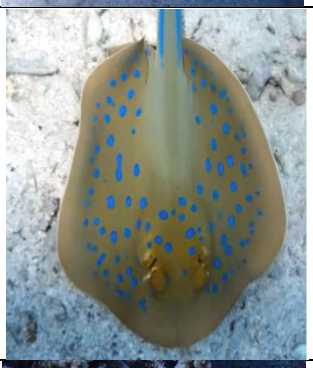
Raw data and data used for statistical analysis and graphs

1.Ray data photos FINAL.xlsx

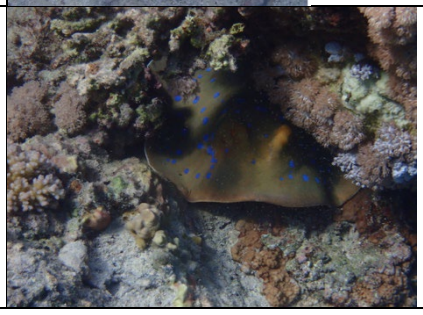
2. Ray data photos FINAL.csv

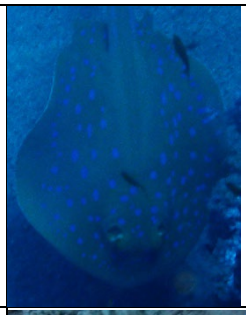
10.2.2 Bluespotted Ribbontail Ray Individual Identification Sheet

Ray number	Ray name	Picture	Notable feature
1	Dave		4 spots in a row at back right of body
2	Mo		4 spots left side of body that are stripes
3	Betty		Bent tail
4	Ziggy		Tadpole shape left back side of body

5	Constance		Big dipper shape right side of body
6	Petal		Flower shape on left side of body
7	Catherine		Crown (semi-circle of dots round head)
8	Love		Heart shape above eyes
9	Sammie		S shape dot on left side of body

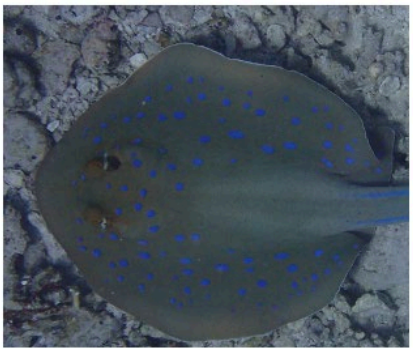
10	Ron		Freckle mark
11	Voce		V shape between eyes
12	Bob		Smiley face on right tail side
13	Sherlock		Ring of spots round left eye

14	Dalmatian		Double conjoined dots above the eyes
15	Clueless		Question mark above eyes
16	Debbie		Diamond at back of right side of tail
17	Cleo		Pyramid shape right side of body
18	Nagini		S shaped line of dots on face below eyes

19	Alina		Three dots in the shape of a triangle between eyes
20	Melons		Dots in the shape of an 8 of right side of body
21	Joy		2 Conjoined dots above left eye that make a line Smiley face right side of body above right eye
22	Khamsa		Dots shaped like a flower with 4 petals above eyes

10.2.2 Summary of the Other 11 Individual Bluespotted Ribbontail Rays

Clueless (15), 6 encounters at an average depth of 4.0m. Most common habitat was reef and behaviour was resting. Notable feature of question mark above eye



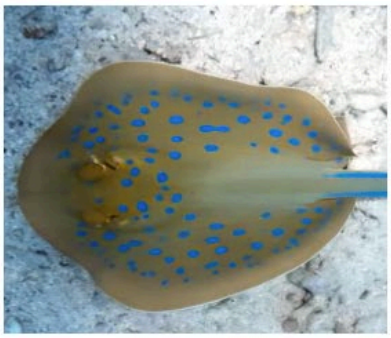
Constance (5), 9 encounters at an average depth of 6.5m. Most common habitat was reef and behaviour was resting. Notable feature of big dipper shape right hand side of body

Dalmatian (14), 5 encounters at an average depth of 5.1m. Most common habitat was reef and behaviour was resting. Notable feature of double conjoined spot above eye

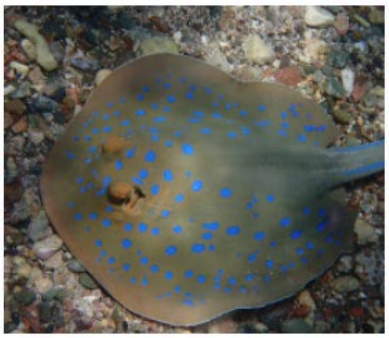
Dave (1), 10 encounters at an average depth of 9.2m. Most common habitat was reef and behaviour was resting. Notable feature of 4 spots in a row at back of body

Debbie (16), 6 encounters at an average depth of 4.1m. Most common habitat was reef and behaviour was resting. Notable feature of diamond on back right side near tail

Love (8), 7 encounters at an average depth of 8.2m. Most common habitat was sand and behaviour was feeding. Notable feature of heart shape above eyes

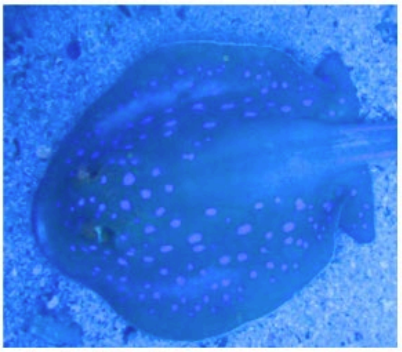


Petal (6), 8 encounters at an average depth of 9.2m. Most common habitat was reef and behaviour was resting. Notable feature of flower shape of left side of body



Ron (10), 8 encounters at an average depth of 4.7m. Most common habitat was sand and behaviour was feeding. Notable feature of freckle mark

Sammie (9), 14 encounters at an average depth of 7.8m. Most common habitat was reef and behaviour was resting. Notable feature of S shaped dot of left side of body



Sherlock (13), 8 encounters at an average depth of 7.1m. Most common habitat was reef and behaviour was resting. Notable feature of ring of spots round left eye

Ziggy (4), 7 encounters at an average depth of 6.0m. Most common habitat was reef and behaviour was resting. Notable feature of tadpole shape on left side of body

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