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**Intra-annual variations of reef manta ray visitation patterns to a
remote cleaning station and the implications for conservation**

By

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1. Abstract

In the Chagos archipelago, British Indian Ocean Territory (BIOT), the subpopulation of reef manta ray (*Mobula alfredi*) inhabits an area which is mostly devoid of any anthropogenic stressors often seen in reef environments. Due to this, they can provide a baseline for looking at environmental drivers of behaviour while reducing any outside bias, and thus can inform the management of conservation for this and other similar species. However, this subpopulation of manta rays is currently one of the least studied in the world so there is a need for increased research.

This study used acoustic tags and weather data to determine which environmental conditions drive the presence of *Mobula alfredi* at a cleaning station at Egmont Atoll, as well as to what extent these drivers are more or less significant. Every time an individual *M. alfredi* came within 200 metres of a receiver it sent a signal to the system, creating a detection, as well as noting the tag ID, sex and maturity status of the manta. Once the environmental data (received from Meteoblue) was put alongside the tag data and analysed it was shown that hour of the day, month of the year and tide were found to be the most significant factors in determining manta presence. These components were the most important as the mantas show diurnal as well as seasonal patterns which change dependent upon their feeding patterns or need for cleaning services provided at this site. It was shown that patterns for visitation to the cleaning stations was in direct correlation with the opposite of that found at feeding sites, as these behaviours run in conjunction with one another, demonstrating a trade-off.

This research can be used to better develop current conservation management as it demonstrates that the presence of these mantas is not a constant, but is dynamic. Therefore, the protection put in place must also be the most effective available to defend the species successfully.

2. Introduction

Manta rays together with devil rays comprise the family Mobulidae, which are varied groups of planktivorous elasmobranchs with filter feeding, pelagic lifestyles, similar to that of baleen whales or whale sharks (White et al., 2017). These species have a wide geographical range spread worldwide ranging from temperate, sub-tropical and tropical waters (Couturier et al., 2012). Within this family, there has been a total of 11 species recognised, which includes the largest of all identified ray species the giant manta ray (*Mobula birostris*), with a disc width that has been recorded extending up to 7 metres (Marshall, Compagno and Bennett, 2009). Recently, the genus *Manta* has been described as encompassing two nominal species, the reef manta, *Mobula alfredi* (*M. alfredi*) (Kreffft, 1868), and the giant manta, *Manta birostris* (*M. birostris*) (Walbaum, 1792).

In 2016 Hinojose-Alveres et al, presented that there may be evidence found near the Yucatán Peninsula in support of a third, genetically distinct *Manta* species. It has been theorised that they diverged recently, under 100,000 years before present, from *M. birostris* following a fit to an isolation with migration model. Further in-depth taxonomical study is needed before this species can be formally named, which will include performing further confirmation of the genetic identity of existing type specimens. Individuals within the *Manta* species are found to be the larger of the species in the Mobulidae family, whereby they can reach a maximum disc width size usually ranging between five and seven metres. This can be compared to that of the *Mobula* species which rarely attain a disc width in excess of five metres, and it is more common to be found within the range of one to five metres in width (Notarbartolo di Sciara, Stevens and Fernando, 2020).

Mobula alfredi rays have conservative life histories, meaning that they are characterised as having late maturation rates, slow growth rates, and low fecundity rates, whereby they only give birth to one or two live pups every one to two years following a 12-month gestation period (Ward-Paige, Davis and Worm, 2013). They are also presumed to be long living, with most Mobulidae species assumed to live for up to 40 years; however, there are still only few published studies regarding in detail growth and ageing of Mobulidae species, despite being highly prevalent within fisheries (White et al., 2006). The difficulty in ageing these species

may be the reason why this information is sparse for Mobulidae species. For most elasmobranch species the typical ageing technique applicable to them is to section vertebral centra in the thoracic region (Cailliet et al., 2006). This is carried out because generally, it is visible to see growth band pairs to lesser or greater degrees within centra that is obtained from the anterior vertebrae of sharks (Goldman et al., 2004) and the posterior vertebrae of batoids (White et al., 2001). It is evident that some *Mobulid* species vertebral structure is highly derived, and *M. alfredi*, as well as *M. birostris*, do not have obvious calcified centra, which makes it difficult to apply this technique to them. Due to this the common practice in measuring the longevity of Mobulidae is by using photo identification and keeping a data base of all sighted mantas (Carpentier et al., 2019).

Due to the circumstances of their life history it results in these species being more vulnerable to exploitation as they do not have the ability to reproduce quickly enough in order to sustain healthy numbers in their populations once they have become depleted. Similar to that of many other elasmobranch species, it is likely that *M. alfredi*, as well as other mobulids, would not be able to sustain heavy fishing pressures put on their populations (Dulvy et al., 2014). Furthermore, the recovery succeeding the fishing pressure would be a very slow process due to the low birth rates combined with longer gestational periods in these species. As a result, the maximum rates of intrinsic population increase in large mobulid species amongst elasmobranchs are found to be some of the lowest (Pardo et al., 2016). Consequently, in regions where Mobulid species are profoundly overexploited to the point where recovery is not achievable there remains high probabilities of localised extinctions (Marshall and Bennett, 2010).

The populations of *M. alfredi* are widely distributed semi-circumglobally, whereby they are found in almost all oceans with the only exceptions being the East Pacific and West Atlantic Oceans (Kasiwagi et al., 2011), and are highly fragmented into multiple subpopulations. Similar to that of many elasmobranch species *Manta* species are found to be highly mobile species covering long migratory distances, to date the largest point-to-point movement of an individual *M. alfredi* was along the east coast of Australia measuring around 650km (Couturier et al., 2014). It is also evident that subpopulations located in tropical and subtropical oceans of the Indo-Pacific also travel similar distances between the atolls found in

these areas (Armstrong et al., 2019). During these migratory periods *M. alfredi* traverse a multitude of different habitats, within their broader home range, on which they become ecologically reliant upon (McCauley et al., 2014). Looking into the relative importance of these habitats over which mobile species span led to research being conducted on the significance of lagoons within atolls. This has shown that *M. alfredi* use this specific habitat due to their energy availability in both zooplankton abundance (Couturier et al., 2013), as well as positive isotopic turnover for their muscles (Malpica-Cruz et al., 2012), making lagoons very energy efficient locations to stop at during long migrations.

Despite their long migration distances, *M. alfredi*, as well as *M. birostris*, show strong site fidelity, returning to previously visited locations, and their aggregations are seasonal (Dewar et al., 2008). *Mobula alfredi* are often observed at the same locations on multiple separate occasions (Harris et al., 2020), which can generally be explained by them returning to previous feeding locations and cleaning stations they have visited before (Séret and Sire, 1999). Cleaning stations are located around reefs worldwide, and are examples of cooperative, symbiotic behaviour between species (Nicholson-Jack et al., 2021) in which cleaner fish, such as cleaner wrasse, whereby bacteria, dead or infected tissue, and ectoparasites are removed from the skin surface, gills and occasionally the mouth of larger fish (Murie, Spencer and Oliver, 2020). There appears to be a link between increased health of teleosts due to their interactions with cleaner fish due to their assistance in reducing their ectoparasitic burden, but there is less understanding in how these interactions benefit elasmobranchs (Ros et al., 2011). One explanation is as simple as this is a mutually beneficial exchange for both parties involved (Barbu et al., 2011), as the larger fish gets unwanted cells or ectoparasites removed from their bodies and the cleaner wrasse feed on what they have removed from the larger fish, making these cleaning interactions essential in maintaining healthy marine communities (Araujo et al., 2020). Even though Mobulid species, including *M. alfredi*, are capable of carrying out long distance movements of up to 500km between sites, they do this very infrequently and it is usually due to a seasonal motivation (Luiz et al., 2008) as they tend to concentrate the majority of their activities at specific locations to which they return. Reasons for these migrations may be due to feeding, mating and birthing, but more research is needed and currently being carried out in order to conclusively know their definitive reasons (Armstrong et al., 2021).

There are many anthropogenic threats faced by marine species globally. One of the greatest threats posed to Mobulids, as well as other elasmobranchs, is from fisheries, especially in the Indian Ocean where many countries have specific fisheries designated in targeting these species (Lawson et al., 2017). The majority of countries within the region of the Indo-Pacific have little to no restrictions in place regarding the catch of elasmobranch species (Asis et al., 2014). This results in there being no regulation in the amount of either targeted or bycatch product landed by fisheries, and even if there are some restrictions in place there is not infrastructure in place that is able to effectively enforce them (Stewart et al., 2016). A large proportion of the fisheries found in these areas are small scale, being defined as fisheries which operate solely for sustenance or local income generation but are not a part of the large-scale companies which operate fishery operations in the area (Temple et al., 2017). It is increasingly theorised that although these small-scale fisheries are seen as more sustainable than their large-scale counterparts, they and can transform into ecologically harmful operations over time (Hawkins and Roberts, 2004)). Over exploitation of these small-scale fisheries results in reduced biodiversity and lower catches due to more intense fishing practices due to a higher use of non-selective and destructive gear (Selgrath, Gergel and Vincent, 2018). Furthermore, even when they are not targeted manta rays can be caught as by-catch by fisheries (Oliver et al., 2015), which will land any catch they get to take to market, as well as boating injuries being prevalent and widely seen as scars on many mantas and other elasmobranchs (McGregor et al., 2019).

On the other hand, there is a market for elasmobranch products including gill plates, meat and fins that is constantly growing (O'Malley et al., 2014). The products are predominantly traded to and withing Chinese markets (Musik and Bonfil, 2005), where they are used in medicinal practices, thus this creates the need for targeted fisheries aiming to catch elasmobranch species in order to fill the demand, resulting in much higher catch rates than that of the small-scale fisheries. Many fisheries often occur very close to marine sanctuaries or protected areas where there are generally no take zones in place (Sanchirico et al., 2006). This is because these protected areas have higher species abundance due to the reduction of fishing pressures, thus fishing in the waters surrounding them guarantees quotas will be met from increased species presence as they move out of the 'safe' areas. Although mantas exhibit site fidelity they are also known to migrate between different areas over large

distances, which means that they travel out of the protected areas and into harm's way creating "spill over" (Ohayon, Granot and Belmaker, 2021). During these migrations they often have to cross waters which are prominently trawled by fishing vessels, this is notably seen in Indonesia (Germanov and Marshall, 2014). This is one rationale for the use of satellite tagging on *Manta* species for conservation efforts in order to track their migration patterns and discover where they become the most vulnerable. There is a wide range of gear types that these rays are caught in, including drift nets, harpoons, trawls, longlines, gill nets and purse seine nets. Unfortunately, in certain locations around the world, such as Australia and South Africa, manta rays can also be caught in bather protection nets by accident (Cliff and Dudley, 2011) due to their high abundance in shallow, coastal waters. All of this has led to *M. alfredi* being classified as Vulnerable on the IUCN Red List of Threatened Species (Marshall et al., 2022), with a continuously decreasing population trend where fishing pressure is greatest (IUCN, 2022). In areas such as Japan, Maldives and Australia where there is some level of protection the population numbers appear to be more stable due to the introduction of conservation strategies (Venables et al., 2016). Most population estimates for this species are based on diver sightings, for example this can be seen in Maui, Hawaii, where high proportions of reports of fishing entanglement injuries leading to a 94% decrease in recorded sightings of Manta rays (Deakos, Baker and Bejder, 2011). Examples of local extinction can already be seen in the Alor region of eastern Indonesia, where increased international trade led to severe drops in Manta populations and those fisheries had to move further afield to catch their target prey to fill the demand (Dewar, 2002).

This study will focus on the reef manta ray species *M. alfredi*, specifically within the Chagos Archipelagos. This collection of islands atolls is located in the Indian Ocean and makes up the world's largest marine protected area (MPA) and full no-take zone (Sheppard, Sheppard and Fenner, 2020). This protected area covers over half a million square kilometres, which includes more than 60,000 km² of shallow limestone platforms and reefs, hence doubling the global of similar MPAs (McCauley et al, 2015). The Chagos Archipelagos are one of the only sites in the Indian ocean, and one of the few worldwide, where extending as far back as the late 1970s there has been continued long term monitoring of the environmental condition (Wu, Duvat and Purkis, 2021). This has led to the coral reef, amongst other marine

life, thriving in these conditions where they remain in excellent condition with the world's largest area of adjoining undamaged reef (Sheppard et al., 2012). Although the reefs are still in excellent condition due to reduced impact from immediate anthropogenic influences, such as fishing pressures, they are not immune to indirect effects, like that of climate change. The Archipelagos have experienced periods of extreme warming events, most notably in 1998, which caused severe mortality on all Chagos reefs (Sheppard et al., 1999), as it did also throughout the rest of the Indian Ocean.

As with many community-wide feeding inter-relationships, when there is a disturbance in one of the lower trophic levels it will be seen through each of the levels both above and below where the impact is (Glynn, 2004). Evidence of coral recovery was apparent by 2006 (Sheppard et al., 2008), but this shows that even a healthy and protected ecosystem takes a long time to establish the conditions and energy required to commence a recovery.

Furthermore, what other effects do these warming events have on the Mantas present in Chagos aside from effecting their food source. Environmental conditions are proven to be extremely influential in the lives of large marine vertebrates, including influencing migration patterns as well as breeding and birthing locations. Sea temperatures have the ability to manipulate the physiology and long-term behavioural strategies, especially large ectothermic fishes (Sims, 2003), making it an important factor to be continually monitored for the role it plays in influencing these practices.

The current gap in research found in this area is what environmental factors are driving this species to return to the same cleaning station multiple times a year, and which of these are the most significant in causing the revisiting behaviour. Once this can be highlighted it may have importance in the way conservation practices are conducted in order to better protect *M. alfredi* more effectively in this location. *Mobula alfredi* are known to aggregate at several sites along migration pathways, stopping and these sites for extended periods of time. For example, by the use of photo identification and mark-capture methods it has been observed along the eastern coast of Australia that over 60% of individuals that were sighted during the sample study period were also resighted at least once during this time (Couturier et al., 2014). Many of these sites have manta rays present all year round, yet occur spikes in abundance at certain times and seasons throughout the year. For instance, Lady Elliot Island

in the southern Great Barrier Reef has peaks in abundance during the seasons of autumn and winter (Jaine et al., 2012). The reasons for these spikes are still unknown but research is ongoing into how the biophysical environment at the location can influence this occurrence. Most studies suggest that increased food availability is the main driver for this (Luiz et al., 2008), however, the environmental factors that create this increased abundance of food are also important to understand when looking at cleaning stations also. It has been documented by Barr and Abelson, 2019, that there is a 'trade-off' between feeding and cleaning. This shows that when conditions are less favourable for feeding then it will result in a higher presence of mantas at cleaning stations. But when environmental conditions are favourable for plankton aggregations the mantas will be out feeding and thus absent from the cleaning stations.

By investigating into the specific environmental factors which drive these aggregations of *M. alfredi* in the Chagos Archipelagos this knowledge can be included into current monitoring methods. If it is known what changes or specific ranges of the environment cause there to be a higher abundance of the species then these changes can be coordinated. This then means it could be predicted when the highest abundance will be, and more protection efforts can be put in place as well as protection along migration routes where they may travel between MPAs along unprotected passages where they are vulnerable. This information may also be transferred to other similar areas and species globally and provide important knowledge and testimony as to why mobile species need more dynamic conservation established.

There is a need for more productive conservation for the subpopulation of *Mobula alfredi* in the Chagos Archipelago due to the increasing threats they face due to climate change, fishing pressures and incidental bycatch. Successful conservation relies upon more in detail understandings on how these species are utilising their habitat as well as the recognition of the environmental factors which influence their distribution within the environment. The aim of this study is to establish the intra-annual variations which effect the patterns of manta ray visits to cleaning stations in the Chagos Archipelago. The objectives include (1) analysing acoustic tag data on reef manta ray visitation patterns to a cleaning station on Egmont Atoll in Chagos Archipelago; (2) investigating the links between visitation and

environmental conditions inter-annually, such as tidal state, wind speed and direction, sea surface temperature; (3) intra-annual detections in *M. alfredi* will be assessed for changes between factors including gender, adult/juvenile, time of the day/night, month of the year, moon phase. Which of these factors is most prominent in determining sightings at the cleaning station? Also, what are the implications this has for the conservation of *M. alfredi* and other Mobulid, and even elasmobranch, species.

There is a need to study *M. alfredi* at cleaning stations as by coming to these reef locations they make themselves more vulnerable to the threats of predation, as seen in Dewar et al (2008). Around the world, including the Maldives and Australia, mantas gather in larger numbers at these cleaning stations as they are a vital part of the health of *M. alfredi* after they visit feeding sites. This site fidelity can also make them more vulnerable to the threats of illegal fishing as they are known to aggregate in large numbers within these locations, making them easier targets. It is also not known within the Chagos Archipelagos, as it is in other locations, all of the locations that they migrate to as well as between islands where they can become exposed and cross large fishing lanes. With further advancements in the knowledge of what drivers influence the presence of *M. alfredi* a better understanding of their habitat use could lead to better management of the conservation area, even with limited active resources, as is often the case in remote locations such as this.

3. Methods

3.1 Study area

The Chagos Archipelago is a part of British Indian Ocean Territory (BIOT) (Figure 1). It is comprised up of a collection of atolls and small, low lying islands located at the southernmost point of the Lakshadweep–Maldives–Chagos ridge, 500 kilometres south of the Maldives Islands (Sheppard et al., 2012). The archipelago has been almost completely uninhabited for the last 50 years, as a result, there is a lack of contamination from anthropogenic pollution and disturbance is minimal (Readman et al. 2013).

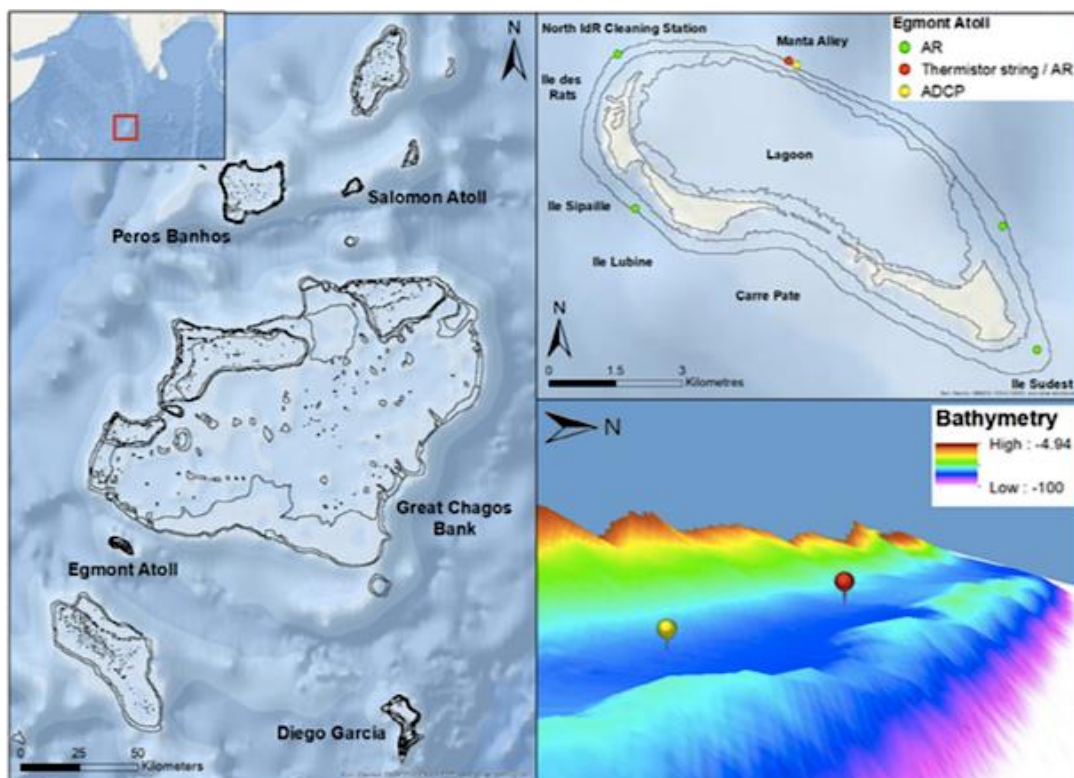


Figure 1. The central Indian Ocean with the Chagos Archipelagos (BIOT) indicated with the red box (left insert). The Chagos Archipelago with Egmont Atoll indicated within the red box (left). Egmont Atoll and the oceanographic and acoustic receiver mooring in Manta Alley (red and yellow dots) and four acoustic receivers (green dots) (top right). Bathymetry view of Manta Alley (bottom right). (Harris et al., 2021)

The current study focuses on the North IdR Cleaning station, the only reef manta ray cleaning station that has been identified in the archipelago, which is located in the northwest of Egmont Atoll (top right box of figure 1, indicated with a green dot in the left of the diagram)

3.2 Acoustic tag deployment

Tagging activities carried out in Egmont Atoll between November 19th, 2019 and March 13th, 2010 while freediving (Harris et al., 2021). Twenty VEMCO V16-4xacoustic transmitter tags (Vemco Inc.) were deployed. Each of these tags was tethered, with small diameter cable, to a titanium anchor (Wildlife Computers). These were deployed on the right dorsal musculature of *M. alfredi* by using a Hawaiian hand sling, that had been modified for this particular purpose, while swimming behind the Manta. Each of the tags had been set to work at a frequency of 69kHz, while transmitting uniquely coded acoustic signals between every 30 and 90 seconds at random intervals. For identification purposes, the underside of each *M. alfredi* was photographed before the tag was deployed in order to acquire their unique natural markings, which are a one of a kind to them as fingerprints are to humans (Venables et al., 2019). These are then used to create data bases of identifiers for individuals in the species for use in looking at population size and structure, or residency and movements (Marshal & Pierce, 2012). The sex and size class of the tagged mantas was also recorded as a proxy for maturity status, which can be used alongside photo identification when investigating population dynamics (Kitchen-Wheeler, Ari and Edwards, 2012). All activities were approved by the University of Plymouth Animals in Science Ethics Committee under permit ETHICS-24-2019.

Once deployed to the manta rays, the tags emit codes each time the individual comes within a 200-metre range of an acoustic receiver. Eventually, these tags can become inactive. Tags are considered inactive when there has not been a detection for the individual manta in a continuous 6-month period. This could mean that the tag is either lost or has been left in the area where it became detached from the manta. However, there are instances where a manta reappears and becomes active once again after an extended period of inactivity (e.g. 18 months). If this does happen, then the tag will be considered active for the whole of the period, even though there were no detections. This is the case for the individual with manta ID CG-MA-0165 in this data (Table 3). Another individual with the manta ID CG-MA-0034 was never detected and thus was classified as inactive after a 6-month period of inactivity (Table 3).

Manta-ID	Tag-ID	Sex	Maturity status	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2020	2021	2021	2021	2021	2021	2021	Notes
				March	April	May	June	July	August	September	October	November	December	January	February	March	April	May			
CG-MA-0034	57701	M	Adult	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	This tag was never detected so was classed as inactive 6 months after deployment
CG-MA-0035	18890	F	Juvenile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
CG-MA-0037	57700	F	Juvenile	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	
CG-MA-0046	18892	F	Adult	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	
CG-MA-0054	57698	F	Juvenile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
CG-MA-0070	18891	F	Adult	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
CG-MA-0080	57697	M	Juvenile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
CG-MA-0088	18897	M	Juvenile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
CG-MA-0094	18894	F	Juvenile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
CG-MA-0112	18893	M	Juvenile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
CG-MA-0117	18887	F	Juvenile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
CG-MA-0118	18900	M	Juvenile	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	
CG-MA-0119	18901	F	Juvenile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
CG-MA-0120	18902	F	Adult	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
CG-MA-0121	18903	M	Juvenile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
CG-MA-0124	18885	M	Adult	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
CG-MA-0125	18895	M	Juvenile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
CG-MA-0128	18886	F	Juvenile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
CG-MA-0139	18899	F	Adult	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
CG-MA-0140	18898	M	Juvenile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
CG-MA-0141	18889	F	Adult	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	
CG-MA-0142	18884	F	Juvenile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
CG-MA-0151	18896	M	Adult	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
CG-MA-0161	18888	M	Adult	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
CG-MA-0163	57695	F	Juvenile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
CG-MA-0164	57696	F	Juvenile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
																					This tag was not detected until September 2021, but it still counts as active
CG-MA-0165	57693	M	Adult	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
CG-MA-0166	57692	F	Juvenile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
CG-MA-0167	57702	F	Juvenile	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	
CG-MA-0168	57694	F	Adult	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
CG-MA-0169	57703	F	Juvenile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
CG-MA-0170	57699	F	Juvenile	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
			Total active tags each month	32	32	32	31	31	30	28	27	25	24	24	22	19	17				15

Table 3 – Manta ID showing months of active and inactive deployment throughout months of data collection for the research study. Total number of tags for each month is present at the bottom of each column.

3.3 Acoustic receiver

An array of five VR2W-69 kHz omnidirectional; acoustic receivers (Venmco Inc.) at depth ranges of between 12 to 22 metres below sea level were deployed on the reef flat in close proximity to the reef slope at sites which corresponded to current knowledge of known aggregation sites for *M. alfredi* around the outer rim of the Egmont Atoll area (Figure 1). One of these receivers was deployed at North IdR Cleaning Station, approximately three meters from the cleaning station itself. The receiver was suspended in the water column at approximately 2 metres above the seabed. The acoustic tags previously attached to *M. alfredi* were detected when the individuals came within 160 metres of one of these receivers, where they then emitted the code every time an individual was close enough in proximity to the receivers (Harris et al., 2021).

3.4 Analysis Methodology

All of the detection data received from the tags was imported into VUE software (version 2.6.2) and filtered for active tags. Additionally to this, environmental data was secondarily obtained through Meteoblue, where weather history for the Chagos Archipelago area was acquired. With both the tag data and historical environmental data analysis was conducted on interpreting how each of the external factors affected the presence and number of mantas present. Firstly, pivot tables were conducted on the data to obtain a primary example of how the number of mantas present changes in accordance with changing factors. These showed how the number of mantas present changes between months, hours, tides, sea surface temperature, or by sex and maturity status in each of these factors. Next, the majority of the statistical analysis on this data set was carried out through the operating system R (R Core Team, 2021).

For this particular data set a regression model was used in order to identify how each of the environmental factors, such as tide state or wind direction, effects the number of reef manta rays present. Firstly, an ANOVA linear regression was used with the `lm` function in order to predict a continuous outcome on the basis of one categorical predictor. This function is used in efforts to identify population distribution models in the R package (Yao and Li, 2013). This model comes with five assumptions in its use; there is a linear relationship, multivariate normality, no or little multicollinearity, no autocorrelation, and homoscedasticity (Casson and Farmer, 2014). Subsequently, a multiple linear regression technique was carried out to examine the effect of multiple explanatory variables influence on the outcome of the response variable, being the number of mantas present. It was presumed at the beginning that the predictor variables were insignificant unless contrarily determined to be important through the null hypothesis test on the regression parameters (Khemet and Richman, 2018). The regression analysis carried out determined whether or not each of the predictor variables was significant, and how important these variables may be. The significance used in this study is determined by the p-value. The p-value for each individual independent variable tests the null hypothesis that there is no correlation between the independent and dependent variable. If there is no correlation seen, then there is no association between the changes in the independent variable and the shifts shown by the dependent variable. A p-value of 0.05 or less indicates that the null

hypothesis, that no difference has been seen, can be rejected and conclude that a significance does exist. For this specific form of regression using the `lm` function it can also be observed in the estimate column of results the effect of the independent variable on the dependent variable. For instance, an increase of 1 in the dependent variable will be associated with the estimate number for each of the variables in linear regression. For multiple linear regression the estimate number is the increase of the independent variable on the dependent variable that has been adjusted for the other independent variables that have been included in the model. The multiple R squared displayed also shows the percentage of variation in dependent variable that can be explained by our model and the independent variables influencing it.

3. Results

3.1 Tag Data

In total, throughout the tagging period, there were 32 individual *M. alfredi* tagged. These included a non-biased collection of both males and females as well as a variety of maturity statuses, which were each given a size class that was registered depending on their overall sizes. These acoustic tags were deployed in a time frame between the 19th November 2019 and the 13th March 2020. All tags were deployed around Egmont Atoll but at varying locations; Ile Tattamuca, Ile Lubine, Ile Carre Pate, Ile Sipaille, North IDR Cleaning Station, and East Lagoon. A total of 20 female and 12 male *M. alfredi* were recorded, of which there were a higher proportion of both juvenile males (7, 58%) and juvenile females (14, 70%) (Table 1).

Tag ID	Tag Type	Serial Number	Date	Time	Species	Morph	Manta ID	Sex	Maturity status	Size Class	Tag loc on body	Atoll	Location	Lat	Long
18884	V16-4x-069k-2	1326496	02/12/2019	10:05:00	M.a	Chevron	CG-MA-0142	F	Juvenile	3	R	Egmont	Ile Tattamuca	-6.69781	71.39904
18885	V16-4x-069k-2	1326497	20/11/2019	09:20:00	M.a	Chevron	CG-MA-0124	M	Adult	3	R	Egmont	Ile Lubine	-6.67093	71.32287
18886	V16-4x-069k-2	1326498	21/11/2019	09:48:00	M.a	Chevron	CG-MA-0128	F	Juvenile	2	R	Egmont	Ile Lubine	-6.66999	71.32206
18887	V16-4x-069k-2	1326499	20/11/2019	09:37:00	M.a	Chevron	CG-MA-0117	F	Juvenile	3	R	Egmont	Ile Lubine	-6.67093	71.32287
18888	V16-4x-069k-2	1326500	02/12/2019	10:30:00	M.a	Chevron	CG-MA-0161	M	Adult	3	R	Egmont	Ile Carre Pate	-6.67446	71.35206
18889	V16-4x-069k-2	1326501	28/11/2019	15:58:00	M.a	Chevron	CG-MA-0141	F	Adult	4	R	Egmont	Ile Lubine	-6.67174	71.32346
18890	V16-4x-069k-2	1326502	20/11/2019	10:00:00	M.a	Chevron	CG-MA-0035	F	Juvenile	3	R	Egmont	Ile Sipaille	-6.66752	71.32
18891	V16-4x-069k-2	1326503	01/12/2019	08:59:00	M.a	Chevron	CG-MA-0070	F	Juvenile	3	R	Egmont	Ile Lubine	-6.67106	71.32395
18892	V16-4x-069k-2	1326504	25/11/2019	14:42:00	M.a	Chevron	CG-MA-0046	F	Adult	4	R	Egmont	Ile Tattamuca	-6.6914	71.37536
18893	V16-4x-069k-2	1326505	01/12/2019	08:34:00	M.a	Chevron	CG-MA-0112	M	Juvenile	2	R	Egmont	Ile Lubine/Sipaille	-6.6633	71.31414
18894	V16-4x-069k-2	1326506	30/11/2019	08:41:00	M.a	Chevron	CG-MA-0094	F	Juvenile	2	R	Egmont	Ile Sipaille	-6.66394	71.31447
18895	V16-4x-069k-2	1326507	20/11/2019	10:23:00	M.a	Chevron	CG-MA-0125	M	Juvenile	2	R	Egmont	North IDR Clear	-6.63686	71.31524
18896	V16-4x-069k-2	1326508	01/12/2019	09:55:00	M.a	Chevron	CG-MA-0151	M	Adult	3	R	Egmont	Ile Lubine	-6.67528	71.33427
18897	V16-4x-069k-2	1326509	28/11/2019	10:27:00	M.a	Chevron	CG-MA-0088	M	Juvenile	2	R	Egmont	Ile Lubine	-6.66939	71.32251
18898	V16-4x-069k-2	1326510	30/11/2019	15:54:00	M.a	Chevron	CG-MA-0140	M	Juvenile	2	R	Egmont	North IDR Clear	-6.63686	71.31524
18899	V16-4x-069k-2	1326511	25/11/2019	14:29:00	M.a	Chevron	CG-MA-0139	F	Adult	4	R	Egmont	Ile Tattamuca	-6.6914	71.37536
18900	V16-4x-069k-2	1326512	19/11/2019	08:14:00	M.a	Chevron	CG-MA-0118	M	Juvenile	2	R	Egmont	Ile Sipaille	-6.66418	71.3138
18901	V16-4x-069k-2	1326513	19/11/2019	08:26:00	M.a	Chevron	CG-MA-0119	F	Juvenile	2	R	Egmont	Ile Sipaille	-6.66798	71.31963
18902	V16-4x-069k-2	1326514	19/11/2019	08:45:00	M.a	Chevron	CG-MA-0120	F	Juvenile	3	R	Egmont	Ile Sipaille	-6.66778	71.31952
18903	V16-4x-069k-2	1326515	19/11/2019	09:00:00	M.a	Chevron	CG-MA-0121	M	Juvenile	2	R	Egmont	Ile Sipaille	-6.66734	71.31926
57692	V16-4x-069k-2	1340306	11/03/2020	08:57:00	M.a	Chevron	CG-MA-0166	F	Juvenile	3	R	Egmont	East Lagoon	-6.65903	71.3762
57693	V16-4x-069k-2	1340307	11/03/2020	07:59:00	M.a	Chevron	CG-MA-0165	M	Adult	3	R	Egmont	East Lagoon	-6.65966	71.3826
57694	V16-4x-069k-2	1340308	13/03/2020	09:02:00	M.a	Chevron	CG-MA-0168	F	Adult	4	R	Egmont	East Lagoon	-6.65659	71.3738
57695	V16-4x-069k-2	1340309	11/03/2020	08:04:00	M.a	Chevron	CG-MA-0163	F	Juvenile	3	R	Egmont	East Lagoon	-6.65966	71.3826
57696	V16-4x-069k-2	1340310	11/03/2020	08:11:00	M.a	Chevron	CG-MA-0164	F	Adult	4	R	Egmont	East Lagoon	-6.66087	71.3815
57697	V16-4x-069k-2	1340311	11/03/2020	08:22:00	M.a	Chevron	CG-MA-0080	M	Juvenile	2	R	Egmont	East Lagoon	-6.65907	71.3827
57698	V16-4x-069k-2	1340312	12/03/2020	07:04:00	M.a	Chevron	CG-MA-0054	F	Juvenile	3	R	Egmont	East Lagoon	-6.65834	71.3819
57699	V16-4x-069k-2	1340313	13/03/2020	09:21:00	M.a	Chevron	CG-MA-0170	F	Juvenile	3	R	Egmont	East Lagoon	-6.65597	71.3741
57700	V16-4x-069k-2	1340314	12/03/2020	08:35:00	M.a	Chevron	CG-MA-0037	F	Adult	4	R	Egmont	East Lagoon	-6.66146	71.3815
57701	V16-4x-069k-2	1340315	13/03/2020	09:08:00	M.a	Chevron	CG-MA-0034	M	Adult	3	R	Egmont	East Lagoon	-6.65776	71.3729
57702	V16-4x-069k-2	1340316	12/03/2020	08:15:00	M.a	Chevron	CG-MA-0167	F	Juvenile	3	R	Egmont	East Lagoon	-6.65894	71.383
57703	V16-4x-069k-2	1340317	13/03/2020	09:11:00	M.a	Chevron	CG-MA-0169	F	Juvenile	3	R	Egmont	East Lagoon	-6.65797	71.3726

Table 1 – Tag data for deployed acoustic tags on *M. alfredi* at Egmont atoll deployed during survey between 2019-2020. Includes tag type, serial numbers and Manta ID for identification at future detection. Also includes sex and maturity status. Size categories range from 1-4 for females and 1-3 for males (Table 2).

Size class	Disc width (cm)	Female life stage	Male life stage
1	< 210	Juvenile	Juvenile
2	210 - 270	Juvenile	Juvenile / Subadult
3	271- 320	Juvenile	Adult
4	> 320	Adult	N/A

Table 2 – Size class of manta rays with the corresponding disc width (cm) and life stage.

3.2 Environmental Raw Data

The raw data for environmental factors was collected through a secondary partner, Meteoblue (Weather - meteoblue, 2022), whereby historical data for the time period in question was received as a hindcast model. The data in question included, sea surface temperature (SST) mean sea level pressure, wind speed and wind direction (900 hPa) – shown in figure 2. The constant monitoring of the weather conditions over the Chagos Archipelagos allows for research to be conducted including historical data, showing how it has changed over time. This displays the changes in weather conditions that the location experiences through the course of a year, and over multiple years. Some patterns can be seen, such as the way wind speed and direction tend to decrease and switch course, respectively, as the sea level pressure increases, and vice versa (Figure 2).

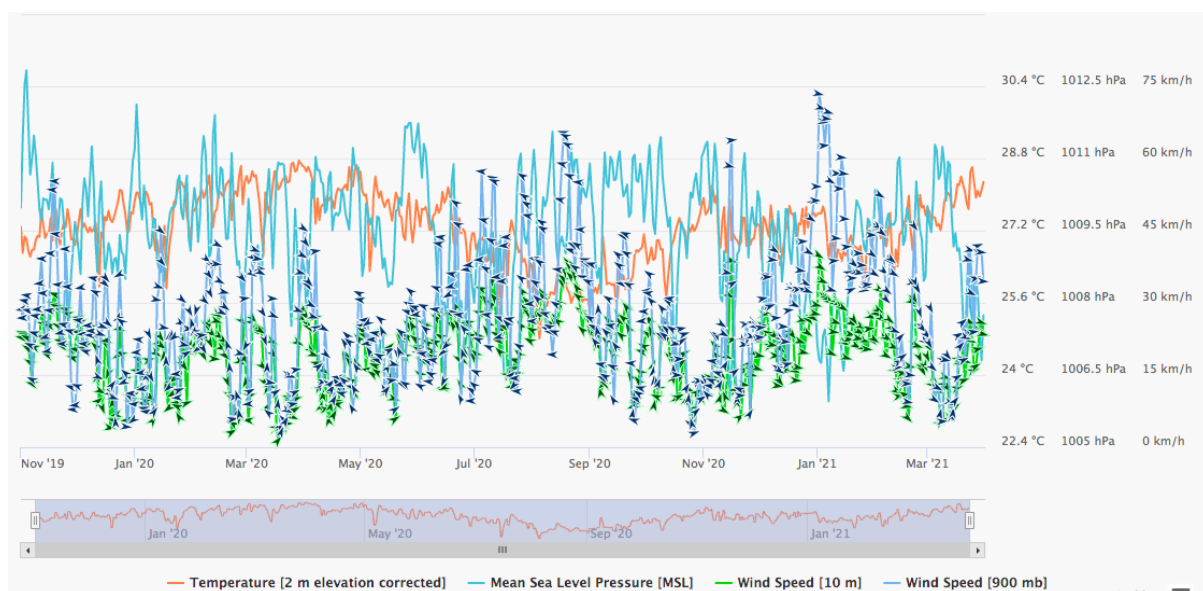


Figure 2 – Graph showing environmental conditions for the Chagos Archipelago between November 2019 and April 2021. Showing temperature (orange), mean sea level pressure (light blue), wind speed (green with arrows) and wind direction (blue with arrows).

The direction of the wind was also further investigated as a separate factor in order to determine the orientation of the prevailing winds during the course of the research period. In doing so, a radar chart was created by inputting all of the gathered data on the wind direction and detected from start to finish. This was performed in order to ascertain which direction was the most prominent and the average speed of the wind experienced during that time. It can be seen clearly from this diagram that the prevailing winds in this area are

most prominently towards the west, with nearly 25% of all winds blowing in this direction. The next most prevalent direction is towards the south east at around 12% presence. Wind speed is also shown on this chart and the size of each coloured section shows the value for each speed designation. This chart shows that the most frequent wind speeds include those between 8-12, 12-16 and >28 mph.

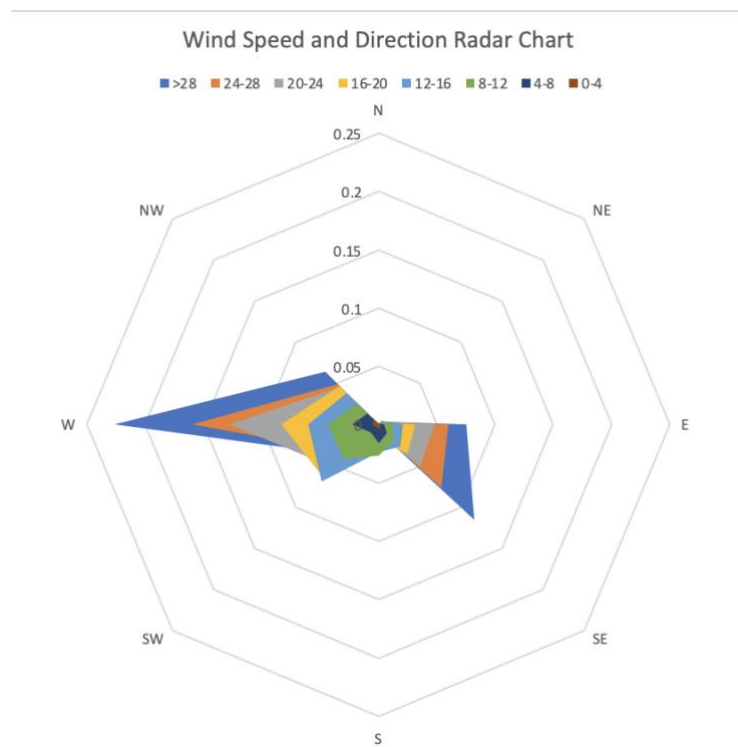


Figure 3 – Radar chart demonstrating the wind direction most prominent through the study period, made using excel (Microsoft Corporation, 2018). Each point on the octagon is given an orientation on a compass, and each line out increases the percentage of each orientations presence by 5%. The chart also demonstrates the average wind speed that transpired with the direction. Each colour on the chart is a different wind speed, becoming greater the closer to the edge of the internal shape with red in the centre a speed of 0-4mph and dark blue representing a wind speed of over 28mph.

Additionally, the lunar cycles for the time during the research period were assessed to see if moon phases had any significance on the presence of manta rays at the cleaning station. This information was gathered from an external website (Moon phases – Lunar calendar for Chagos Archipelago, 2022) to collect the information needed, including the times for the different moon phases; new moon, first quarter, full moon and third quarter (Figure 4).

Figure 4 – Table also showing the moon phases but including the date and exact time for each of the moon phases throughout both 2020 (above) and 2021 (below). The duration for each of the lunar cycles is also shown in the final column to the right.

Lunation	New Moon		First Quarter		Full Moon		Third Quarter		Duration
1200			3 Jan	10:45	11 Jan	01:21	17 Jan	18:58	29d 16h 29m
1201	25 Jan	03:42	2 Feb	07:41	9 Feb	13:33	16 Feb	04:17	29d 17h 50m
1202	23 Feb	21:32	3 Mar	01:57	9 Mar	23:47	16 Mar	15:34	29d 17h 56m
1203	24 Mar	15:28	1 Apr	16:21	8 Apr	08:35	15 Apr	04:56	29d 16h 58m
1204	23 Apr	08:25	1 May	02:38	7 May	16:45	14 May	20:02	29d 15h 13m
1205	22 May	23:38	30 May	09:29	6 Jun	01:12	13 Jun	12:23	29d 13h 03m
1206	21 Jun	12:41	28 Jun	14:15	5 Jul	10:44	13 Jul	05:29	29d 10h 51m
1207	20 Jul	23:32	27 Jul	18:32	3 Aug	21:58	11 Aug	22:44	29d 9h 09m
1208	19 Aug	08:41	25 Aug	23:57	2 Sep	11:22	10 Sep	15:25	29d 8h 19m
1209	17 Sep	17:00	24 Sep	07:54	2 Oct	03:05	10 Oct	06:39	29d 8h 31m
1210	17 Oct	01:31	23 Oct	19:22	31 Oct	20:49	8 Nov	19:46	29d 9h 36m
1211	15 Nov	11:07	22 Nov	10:45	30 Nov	15:29	8 Dec	06:36	29d 11h 09m
1212	14 Dec	22:16	22 Dec	05:41	30 Dec	09:28			29d 12h 44m
Lunation	New Moon		First Quarter		Full Moon		Third Quarter		Duration
1212							6 Jan	15:37	29d 12h 44m
1213	13 Jan	11:00	21 Jan	03:01	29 Jan	01:16	4 Feb	23:37	29d 14h 06m
1214	12 Feb	01:05	20 Feb	00:47	27 Feb	14:17	6 Mar	07:30	29d 15h 15m
1215	13 Mar	16:21	21 Mar	20:40	29 Mar	00:48	4 Apr	16:02	29d 16h 10m
1216	12 Apr	08:30	20 Apr	12:58	27 Apr	09:31	4 May	01:50	29d 16h 29m
1217	12 May	00:59	20 May	01:12	26 May	17:13	2 Jun	13:24	29d 15h 53m
1218	10 Jun	16:52	18 Jun	09:54	25 Jun	00:39	2 Jul	03:10	29d 14h 24m
1219	10 Jul	07:16	17 Jul	16:10	24 Jul	08:36	31 Jul	19:15	29d 12h 34m
1220	8 Aug	19:50	15 Aug	21:19	22 Aug	18:01	30 Aug	13:13	29d 11h 02m
1221	7 Sep	06:51	14 Sep	02:39	21 Sep	05:54	29 Sep	07:57	29d 10h 14m
1222	6 Oct	17:05	13 Oct	09:25	20 Oct	20:56	29 Oct	02:05	29d 10h 09m
1223	5 Nov	03:14	11 Nov	18:45	19 Nov	14:57	27 Nov	18:27	29d 10h 28m
1224	4 Dec	13:43	11 Dec	07:35	19 Dec	10:35	27 Dec	08:23	29d 10h 51m

3.3 Initial Detection Analysis

The process of data analysis for this study began with the creation of pivot tables using Excel. This method allowed for clear representation of patterns observed in the data to be seen and interpreted. By including this introductory stage, before any further statistical analysis, it also means that any results and patterns can be measured against what can be seen from the raw data to ensure that it is consistent throughout. This was carried out for sea surface temperature (appendix), moon (by hour), tide, month and hour against the number of manta ray detections present.

Count of Sex		Column Labels												
Row Labels		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Grand Total
F		284	115	1180	866	671	450	425	427	457	438	347	180	5840
Adult		120	65	298	170	135	57	55	44	77	81	162	72	1336
Juvenile		164	50	882	696	536	393	370	383	380	357	185	108	4504
M		334	54	342	337	269	66	57		28	98	137	221	1943
Adult		121	13	17	109	65	34			16	75	39	78	567
Juvenile		213	41	325	228	204	32	57		12	23	98	143	1376
Grand Total		618	169	1522	1203	940	516	482	427	485	536	484	401	7783

Figure 5 – Pivot table showing the number of manta detections in one year. For this there was one single year of data used in order to ensure that there were no doubles of months within the data pool which would create a higher abundance of mantas detections in those duplicated months. The number of manta detections is shown in sections for female adults and juveniles, as well as for male adults and juveniles, while including totals for the sex (bold rows and right column), maturity status (right column), month (bottom row) and overall for the year (bottom right corner).

From figure 5 it can be seen that, by month overall, the most detections were present in March (1522), and closely followed by April (1203). On the other hand, the least overall detections were found to be in the months of February (169) and December (401). The most detections were consistent through both female and male juveniles and adults as the total detections for this month accounted for around 21% of all detections out of the grand total for the sex and maturities. However, for the least detections it was contrasting to males at both maturity states as there were no detections for both during the month of August, as well as no detections found for adult males during July. This disparity may be due to the fact that in general there were three times as many detections for females (counting both juveniles and adults) as there were for males, thus the number of female detections will sway the data in their favour to the months where they are more present.

Count of Sex		Column Labels		F Total		M Total		Grand Total
Row Labels	Adult	Juvenile		Adult		Juvenile		
00	32	92	124	3	14	17	141	
01	18	78	96	4	25	29	125	
02	23	53	76	3	11	14	90	
03	24	39	63	10	20	30	93	
04	14	60	74	15	21	36	110	
05	11	53	64	8	13	21	85	
06	7	43	50	2	11	13	63	
07	53	80	133	31	79	110	243	
08	58	152	210	26	84	110	320	
09	61	218	279	32	62	94	373	
10	68	318	386	17	71	88	474	
11	97	343	440	24	85	109	549	
12	137	258	395	57	110	167	562	
13	99	332	431	60	114	174	605	
14	123	344	467	73	82	155	622	
15	78	366	444	63	98	161	605	
16	116	532	648	42	117	159	807	
17	87	354	441	43	101	144	585	
18	92	319	411	30	61	91	502	
19	42	234	276	19	66	85	361	
20	32	115	147	4	56	60	207	
21	26	73	99	1	29	30	129	
22	31	77	108		17	17	125	
23	22	72	94		29	29	123	
Grand Total	1351	4605	5956	567	1376	1943	7899	

Figure 6 – Pivot table showing the overall count of mantas present by hour of the day. Columns for male and females at both juvenile and adult maturity statuses are included, as well as grand totals for each hour (right column) and each maturity status (bottom row).

The number of manta detections by hour can be seen in figure 6, which shows that the most detections are present in the early afternoon, whereas the least during the late hours of the night and very early in the day. There can be a disparity described between both males and females as with juveniles and adults. Juveniles were consistent in both sexes, having the highest presence at 16:00, whereas adult females (12:00) and adult males (14:00) tended to not be in high numbers when the other or juveniles were present, particularly with the adult males. Each of the times of most detections represent a total of approximately 10% of all detections for the maturity status

Sum of Prez_abz	Prez	0	1
Flood	-6	0	29
	-5	0	131
	-4	0	137
	-3	0	142
	-2	0	128
	-1	0	147
Flood Total		0	714
High Tide	0	0	125
High Tide Total		0	125
Ebb	1	0	138
	2	0	121
	3	0	121
	4	0	111
	5	0	127
	6	0	29
Ebb Total		0	647
Low Tide	-6	0	106
	-7	0	27
Low Tide Total		0	133
Grand Total		0	1619

Figure 7 – Pivot table showing number of presences at each tidal states. Tide states including flood, high ebb and low tide as well as totals for each of these included. Also incorporated is the time to high tide on a scale of -6 (flood tide), 0 (high tide), to +6 (full ebb tide).

Figure 7 shows that the greatest number of presences for manta rays was found to be at a

-1 flood tide (147), just before high tide, as well as at +1 ebb tide, just after a high tide. On the contrary, the least number of presences was established to be at a -7 low tide, with only 27 presences throughout the study period.

Sum of Prez_abz	Column Labels				
Row Labels	1st quarter	3rd quarter	full moon	New moon	Grand Total
00:00:00	2	0	0	0	2
01:00:00	0	1	1	0	2
02:00:00	3	0	1	0	4
03:00:00	2	0	2	0	4
04:00:00	1	2	0	0	3
05:00:00	3	0	2	0	5
06:00:00	2	0	1	1	4
07:00:00	4	1	3	2	10
08:00:00	9	1	2	1	13
09:00:00	7	4	2	4	17
10:00:00	5	1	2	2	10
11:00:00	5	3	4	2	14
12:00:00	5	1	5	5	16
13:00:00	8	2	2	5	17
14:00:00	6	4	4	6	20
15:00:00	6	1	5	6	18
16:00:00	9	3	4	7	23
17:00:00	10	5	4	2	21
18:00:00	6	4	2	3	15
19:00:00	6	3	1	4	14
20:00:00	3	0	2	1	6
21:00:00	2	1	0	1	4
22:00:00	1	1	2	1	5
23:00:00	1	1	1	0	3
Grand Total	106	39	52	53	250

Figure 8 – Pivot table showing the number of manta presences at each hour of the day for each of the moon phases. Presences for first quarter, full moon, third quarter and new moon are included as well as totals for each of the phases (bottom row) and each hour of the day (right column).

The sample for looking at presences at different moon phases (figure 8) was collated by way of three months out of the total sample of the research period. These months were chosen using a random generator in order to remove any bias from selecting the months to be included. This allowed for a smaller sample size, as the data was a very large sample, and thus patterns are able to be clearly identified. Therefore, it can be evidently seen that there were more presences detected during a first quarter moon (106) than any other. During the first quarter moon there were also more mantas present in the early morning period, 00:00 to 08:00, compared to on a new moon where detections only started at 06:00 and only became more significant at 14:00. There were a greater number of presences during the day for both full moons and third quarter than the other phases.

3.4 Statistical Analysis

The raw data collected for both detections and environmental factors are loaded into a programming language for statistical computing and graphics R (R Core Team, 2022). Once uploaded to the system, the first test conducted was a Shapiro-Wilks test for normality. However, the data set in use was found to be too large in sample size to use this test, and thus the Anderson-Darling test was conducted in replacement (Jiang et al., 2019). The

Anderson-Darling test is a goodness-of-fit test that is rendered in order to determine how well the data set will fit into a given distribution. This will see if the data will follow a pattern of normal distribution or not. The null hypothesis is that the data is normally distributed. If the p value is under or equal to 0.05 the null hypothesis is rejected, meaning that the data is not normally distributed (Nelson, 1998). For the data set used in this study it was found that the p value was less than 0.05 for all factors tested against (Figure 9), implicating that the null hypothesis can be rejected, and the data is not normally distributed.

```
The downloaded binary packages are in
/var/folders/tm/6g68xcd95lgc6ct6pnlq9gtm0000gn/T//RtmpamzFFD/downloaded_packages
> library(nortest)
> ad.test(base_data$SST)

Anderson-Darling normality test

data: base_data$SST
A = 48.041, p-value < 2.2e-16

> ad.test(base_data$Hour)

Anderson-Darling normality test

data: base_data$Hour
A = 115.83 secs, p-value < 2.2e-16
```

Figure 9 – Example of Anderson-Darling test conducted on hour and sea surface temperature. The rest of Darling tests are found in the appendix.

After testing for normality a test for linear regression was conducted in order to predict the value of mantas present based upon the environmental factors. The linear regression was conducted using the lm function in R studio (Figure 10), instead of the more widely used ANOVA aov function, as the data contained categorical as well as numerical values. This was conducted on hour, month, SST, tidal state, tide time, wind direction and wind speed, in order to see which category was most significant in causing change in the number of mantas present. To assess this the F value, was looked at. The bigger the F value the more likely it is that the variation seen in the dependent variable is caused by the independent variable and not due to chance or errors.


```

> mod<- lm(base_data$`Number of mantas present`~SST)
> summary(mod)

Call:
lm(formula = base_data$`Number of mantas present` ~ SST)

Residuals:
    Min       1Q   Median       3Q      Max
-0.3598 -0.2689 -0.2200 -0.1640  13.7101

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -1.772770   0.257758  -6.878 6.47e-12 ***
SST          0.069921   0.008971   7.794 7.19e-15 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.6629 on 9504 degrees of freedom
Multiple R-squared:  0.006351, Adjusted R-squared:  0.006246
F-statistic: 60.74 on 1 and 9504 DF,  p-value: 7.188e-15

```

Figure 10 – Linear regression using lm model for SST against number of mantas present. Showing p value, f values as well as r squared values.

```

> modd4<- lm(base_data$`Number of mantas present`~base_data$`Wind Speed`)
> summary(modd4)

Call:
lm(formula = base_data$`Number of mantas present` ~ base_data$`Wind Speed`)

Residuals:
    Min       1Q   Median       3Q      Max
-0.2448 -0.2376 -0.2341 -0.2307  13.7671

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  0.2450163  0.0182710  13.410 <2e-16 ***
base_data$`Wind Speed` -0.0004788  0.0008467  -0.566  0.572
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.665 on 9504 degrees of freedom
Multiple R-squared:  3.365e-05, Adjusted R-squared:  -7.156e-05
F-statistic: 0.3198 on 1 and 9504 DF,  p-value: 0.5717

```

Figure 11 – Linear regression using lm model for wind speed against number of mantas present. Showing p value, f values as well as r squared values.

Examples of the linear regression are shown for SST (figure 10) and for wind speed (figure 11), the rest of the linear regression models are shown in the appendix of this paper. These two examples are shown to display the difference in F values found between the environmental factors tested for. In figure 9 it can be clearly shown that the F value for SST is 60.74, whereas figure 10 shows an F value of only 0.3 for wind speed. A greater f value means that the factor being tested is more significant in influencing the dependent variable, meaning that SST has the greatest effect on the number of mantas present out of all factors tested against, but on the other hand wind speed has the least significance.

The final test conducted was a multiple linear regression whereby more than two variables were used to predict the outcome of the dependent variable. This was also conducted using the lm function in R studio. This analysis technique allows for the determination of the variation in the model and the contribution provided by each of the independent variables. The null hypothesis for the multiple linear regression is that there is no correlation between the environmental factors and the changes in manta rays present. If the p value is equal to or greater than 0.05 then the null hypothesis can be rejected, meaning that there is significance in the causation of the dependent variable due to the independent factors. It can be seen in figure 11 that not all of the independent factors tested for are shown to have a significant impact on the result of the dependent variable. All months, with the exclusion of February, were found to be significant in influencing the number of mantas present, whether that be increasing or decreasing the numbers. The only other factors found to be the most influential were wind direction, tide time and all tide states.

```

> mod2<- lm(base_data$`Number of mantas present`~SST+Hour+base_data$Month+WD+WS+tideT+base_data$`Tide state`)
> summary(mod2)

Call:
lm(formula = base_data$`Number of mantas present` ~ SST + Hour +
    base_data$Month + WD + WS + tideT + base_data$`Tide state`)

Residuals:
    Min       1Q   Median       3Q      Max
-0.5053 -0.2846 -0.2055 -0.1002  13.5991

Coefficients:
                Estimate Std. Error t value Pr(>|t|)
(Intercept)    -2.292e+00  5.098e-01  -4.496 7.01e-06 ***
SST              7.989e-02  1.689e-02   4.731 2.27e-06 ***
Hour            1.836e-06  2.718e-07   6.754 1.52e-11 ***
base_data$MonthAugust  -4.928e-02  4.662e-02  -1.057  0.2905
base_data$MonthDecember -7.790e-02  3.644e-02  -2.138  0.0326 *
base_data$MonthFebruary -1.757e-01  3.892e-02  -4.514 6.45e-06 ***
base_data$MonthJanuary  4.329e-02  4.520e-02   0.958  0.3382
base_data$MonthJuly    -5.282e-02  4.155e-02  -1.271  0.2037
base_data$MonthJune    -4.025e-02  3.960e-02  -1.016  0.3095
base_data$MonthMarch   8.568e-03  2.923e-02   0.293  0.7694
base_data$MonthMay     6.727e-02  3.456e-02   1.947  0.0516 .
base_data$MonthNovember 1.904e-03  3.465e-02   0.055  0.9562
base_data$MonthOctober 2.026e-02  3.695e-02   0.548  0.5835
base_data$MonthSeptember 4.046e-02  4.768e-02   0.849  0.3961
WD               3.228e-04  1.381e-04   2.338  0.0194 *
WS              4.431e-03  1.082e-03   4.095 4.25e-05 ***
tideT           -2.143e-03  4.879e-03  -0.439  0.6604
base_data$`Tide state`Flood  3.024e-02  3.383e-02   0.894  0.3714
base_data$`Tide state`High Tide 2.151e-02  3.011e-02   0.714  0.4751
base_data$`Tide state`Low Tide 1.729e-02  5.242e-02   0.330  0.7415
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.6585 on 9486 degrees of freedom
Multiple R-squared:  0.02147, Adjusted R-squared:  0.01951
F-statistic: 10.96 on 19 and 9486 DF, p-value: < 2.2e-16

```

Figure 11 – Multiple linear regression with lm function in R. Showing results for SST, hour, months of the year, wind direction (WD), wind speed (WS), tide states (flood, high and low) and tide time (tideT).

4. Discussion

Acoustic tag detection data suggests that there were differences in site visitation patterns dependent upon both the sex and maturity status of the manta rays, which is a known occurrence for manta species in the areas including the Maldives (Stevens, 2016). At the North IDR cleaning station in the Chagos Archipelago it was found that there was a disparity between the times of day that adult and juvenile *Mobula alfredi* were the most present (figure 6). Juveniles for both males and females had the most detections at 16:00, whereby the adults of both sexes had significantly lower presences during this time, and the surrounding hours. The number of detections for juveniles was also significantly higher throughout the study, compared to that of adults, showing a greater level of site fidelity (Perryman et al., 2022). There are a variety of reasons for juveniles to display a higher site attachment, most notably the fact that juveniles are more vulnerable due to the threat of predators when they travel away from the safety of reefs (Peel et al., 2019, Stewart et al., 2018), where the cleaning station is located. Another explanation for the higher abundance of juvenile detections may be that they lack the same experience as the adults in locating appropriate foraging locations offshore (Sims et al., 2006), as well as having limited abilities for deeper diving into cooler waters due to their smaller body masses (Jaine et al., 2014). In addition, or alternatively, juvenile *M. alfredi* have a lower swimming efficiency, compared to fully grown adults, due to their smaller size and stature which may impede movement behaviour (Nøttestad et al., 1999), making it less efficient for them to travel further afield from the safer site of the cleaning station reefs.

The data also suggests a difference between the number of visitations to the cleaning sites between males and females. It can be seen clearly in figure 5 that there was triple the number of detections for females as there were for males. This may be due to the distinct mate-seeking behaviour that the sexes display. It is known that sexually mature females tend to visit favoured aggregation sites more frequently due to there being bountiful food sources, cleaning opportunities, as well as greater safety (Deakos et al., 2011). Another explanation for a heavy female bias may be that the location is close to suitable pupping grounds, and thus will be more suitable for pregnant females (Marshall and Bennett, 2010). Although there were times of higher or lower abundances, the continued detections

throughout the year demonstrate a very high site fidelity for females (Stevens et al., 2016) which is not shown for the males of the species. In contrast, male rays tend to move between different aggregation sites in order to find females, meaning they have lower site fidelity and higher migratory movements (Germanov et al., 2019).

In figure 6 it is clearly shown that the greatest presence of *M. alfredi* is during daylight hours and it is evident that all mantas, regardless of sex or maturity status, show diurnal variation patterns which are typical of the species (Couturier et al., 2018). There may be an association with these patterns and that of foraging opportunities available to the manta rays arising due to the diel vertical migrations of the zooplankton that are associated with reefs (Leichter et al., 2013). The surface waters of these reef environments can become heavily enriched with an abundance of zooplankton during daylight hours, as they have the greatest capability for photosynthetic growth (Alldredge and King, 2009), making them opportune feeding grounds. After the acts of feeding, the rays will need to seek out the designated cleaning stations (Dewar et al., 2008). This results in daylight hours being more popular for their presence than at night, as to remove any bacteria, or parasites and other cells, remaining after a feeding period (Clark, 2010). Furthermore, the cleaner fish associated with these cleaning stations are active during daylight hours (Côté, 2000), thus when the fish are not there to clean the rays there is no benefit for *M. alfredi* to being present. As the acoustic receivers are only placed at locations immediately surrounding the atoll, such as cleaning and feeding sites, there was not information gathered in this study about where the mantas travel to during the night. However, it has been suggested by Braun et al (2014) that *M. alfredi* occupy deeper water at night performing dives of over 150 metres, then returning to the reef habitats during daylight hours.

The pivot table created (figure 5) for detections of manta rays for each month of the year demonstrates clear signs of seasonal favourability. This is shown by clear peaks in the months of March and April, which is concordant with the results found by Couturier et al (2011), who by way of photographic identification, discovered that there were more individuals of *M. alfredi* present during the summer months when the waters begin to warm. This increase in March followed by gradual reductions in manta presences at the cleaning station may be due to the fact that the south west monsoon season starts between

April and May with reversing winds driving alternating ocean currents during this timeframe (Anderson et al., 2011). As monsoon currents pass over the area, including both the Chagos Archipelago and the Maldives, it begins the process of upwelling whereby nutrients from lower in the water column are brought upwards and mix with those found in the euphotic zone (Radice et al., 2019). Nutrient enrichment of the surface waters caused by the upwelling can result in phytoplankton blooms (Wilkerson et al., 2006) due to the greater abundance of their food source becoming available. Seasonally high primary production and the creation of phytoplankton blooms provide plentiful food sources for planktivores, creating a link between monsoons and manta rays, which is comparable to that of linking wind to the presence of whales off the coast of California (Croll et al., 2005). Further support for this is shown in figure 3 where it can be distinctly seen that the most common wind direction was to the west as the route the monsoons will be travelling would most likely be west and southwest. Through the intensification of the South Asian monsoon (SAM) wind, climate change has influenced the rates of primary production in the Indian Ocean through history (Gupta et al., 2004). For instance, there has been observable suppression of warming over India's land masses caused by anthropogenic emissions (Roxy et al., 2015), which then reduces the land to sea thermal gradient (Turner and Annamalai, 2012). By reducing these thermal contrasts there are adverse effects on the seasonal migration of the inter-tropical convergence zone, the shift of these conditions is crucial to both the onset and retreat of the SW monsoon (Yadav, 2013), on which mantas rely so heavily upon. This is just one way in which *M. alfredi*, as well as other elasmobranch species, will be indirectly affected by climate change.

Analysis of the environmental data collected for the study period found that of all the factors evaluated, through the process of linear regression, sea surface temperature was the most significant factor in influencing the number of manta rays present (figure 10). It appeared that *M. alfredi* avoided water cooler than 27 degrees Celsius in this location, with an optimum temperature range of 28-30 degrees (Rohner et al., 2013). This is consistent with the months in which the mantas are most present being the warmer months of the year. Many large, planktivorous elasmobranchs, such as whale sharks (Rowat et al., 2009), have optimum temperature ranges in which they tend to stay between which impacts their distribution (Sequeira et al., 2014). The change in temperatures experienced through the

seasons is a major driver of migration for many species, like manta rays (Hacohen-Domené et al., 2017). When temperatures either drop or increase, it is a cue for ray species, such as *M. alfredi*, as to when they should be travelling to different locations in order to optimise their energy expenditure, as well as feeding opportunities, with this behaviour reflecting that of increased primary productivity found at inshore areas (Freedman and Sen Roy, 2012). However, this can pose a problem for conservation efforts whereby mantas travel between atolls and reef systems, following the optimum environment and highest productivity available, as this migration often occurs outside and between MPAs and areas that are protected (Graham et al., 2012). By foraging over large spatial scales or too far offshore to be included within the existing networks of MPAs, they can end up crossing over major shipping lanes or into areas prominent for fisheries (Halpern et al., 2008), that will either be targeting the species or capture them as bycatch, instead of their intended target. By monitoring both the changes in temperature at these locations, as well as the migration patterns that *M. alfredi* follow between islands, there can be better implementation of where it is most important to have MPAs and conservation measures in effect to ensure that these unfortunate incidents do not happen, and so the species remains protected throughout the seasons.

The study demonstrates a correlation between the tidal state and the presence of *M. alfredi*. This is concordant with other studies where tides have been seen to influence both cleaning and foraging behaviour of *M. alfredi* in the Great Barrier Reef (Jaine et al., 2012), where these behaviours were observed most commonly at a high tide, as well as after an ebb tide (O'Shea et al., 2010). The particular reason for this circumstance may be that tag detection peaks at feeding sites increase leading up to a low tide, and approaching a full moon (Harris et al., 2020), as the opportunities for foraging tend to occur when strong lunar currents draw up plankton rich water from depths outside the shallow reaches of the atoll (Harris and Stevens, 2021). This means that after the feeding has occurred there will be a higher presence of *M. alfredi* at cleaning stations to remove any parasites or bacteria they may have acquired during this process, usually during high tide periods (O'Shea et al., 2010). Additionally, another explanation for foraging behaviour being conducted at low tide is that this behaviour often occurs in deep water, compared to that at cleaning stations, which are typically located on reefs that are at depths of only around 10 metres (Stewart et al., 2016).

These cleaning reefs will be at the influence of tides more significantly than deeper feeding sites and mantas as large as *M. alfredi* cannot risk becoming stranded in shallower water when the tide retreats (Dewar et al., 2008). Furthermore, although there are detections during a full moon, they are not detected until later in the morning (Andrzejaczek et al., 2021). This may be because the mantas use the lunar illumination to guide their journeys offshore, as well as to aid their foraging behaviours (Braun et al., 2014). Similar patterns to this have been seen in multiple species of elasmobranch that inhabit coral reef environments (Vianna et al., 2013). Current belief is that this is thought to reflect variation of the prey distribution and risk of predation to individuals of the species due to increased light levels in the upper levels of the water column (Hammerschlag et al., 2017, Hays, 2003). Moreover, the combination of lunar and tidal circumstances that coincide with either foraging or cleaning align themselves with the same patterns as that of their prey (Sims, 1999). Many prey, such as zooplankton, express diurnal vertical migrations, whereby they spend the days at great depths offshore but during the night they follow the lunar illumination provided by the moon and travel to surface waters (Meilland et al., 2018). Planktivorous species, such as *M. alfredi*, can exploit these migrations of their prey without always having to dive to such great depths in order to feed, thus this reduces the energy expenditure needed for foraging behaviours (De Robertis et al., 2000).

To sum up all that has been stated in this study, even though the Chagos Archipelagos feature one of the largest MPAs in the world, the management in place needs to be more effectively implemented. For mobile species, such as *M. alfredi*, there is a need to assess collections of environmental data in order to identify what conditions create influxes or vacancies of populations. This knowledge can be used for conservation management for the specific environments in which they are shown to inhabit frequently with specific conditions, and to protect them from anthropogenic influences (Murray et al., 2019). It has been shown similarly in the Maldives (Stevens, 2018) the effect of disturbances by anthropogenic cause on key habitats. Although *M. alfredi* inhabit all of the atolls and islands in the archipelago, there is not active enforcement and protection covering all of the aggregation sites. By knowing when the mantas will be present at certain sites it means diligent maintenance can occur during these periods of high presence, thus protecting a large quantity of the species in one area (Harris, 2021). Furthermore, by increasing the

number of mantas tagged, by use of satellite taggers, there can be more known about their migration patterns both offshore for feeding as well as between the islands and atolls, where they are at the greatest risks from illegal fisheries (Braun et al., 2015). Conservation efforts for the future should aim to encompass the entire network of key aggregation sites for *M. alfredi*, as well providing a safe passage for those individuals that make the journey between sites.

Declarations

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Ethics approval

All tagging techniques implemented in this project were approved by the Foreign and Commonwealth Office (FCO) BIOT Administration (BIOTA) and are covered under the University of California, San Diego (UCSD) animal care protocol: UCSD IACUC Protocol #S12116.

Availability of data and materials

The data that support the findings of this study are available from the Manta Trust, but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of the Manta Trust

References:

1. Alldredge, A. and King, J., 2009. Near-surface enrichment of zooplankton over a shallow back reef: implications for coral reef food webs. *Coral Reefs*, 28(4), pp.895-908.
2. Anderson, R., Adam, M. and Goes, J., 2011. From monsoons to mantas: seasonal distribution of *Manta alfredi* in the Maldives. *Fisheries Oceanography*, 20(2), pp.104-113.
3. Andrzejaczek, S., Schallert, R., Forsberg, K., Arnoldi, N., Cabanillas-Torpoco, M., Purizaca, W. and Block, B., 2021. Reverse diel vertical movements of oceanic manta rays off the northern coast of Peru and implications for conservation. *Ecological Solutions and Evidence*, 2(1).
4. Araujo, G., Miranda, J., Allen, H., Labaja, J., Snow, S., Ponzo, A. and Legaspi, C., 2020. Whale sharks *Rhincodon typus* get cleaned by the blue-streak cleaner wrasse *Labroides dimidiatus* and the moon wrasse *Thalassoma lunare* in the Philippines. *Journal of Fish Biology*, 97(4), pp.1247-1251.
5. Armstrong, A., Armstrong, A., Bennett, M., Richardson, A., Townsend, K. and Dudgeon, C., 2019. Photographic identification and citizen science combine to reveal long distance movements of individual reef manta rays *Mobula alfredi* along Australia's east coast. *Marine Biodiversity Records*, 12(1).
6. Armstrong, A., Armstrong, A., Bennett, M., Richardson, A., Townsend, K., Everett, J., Hays, G., Pederson, H. and Dudgeon, C., 2021. Mutualism promotes site selection in a large marine planktivore. *Ecology and Evolution*, 11(10), pp.5606-5623.
7. Armstrong, A., Armstrong, A., Jaine, F., Couturier, L., Fiora, K., Uribe-Palomino, J., Weeks, S., Townsend, K., Bennett, M. and Richardson, A., 2016. Prey Density Threshold and Tidal Influence on Reef Manta Ray Foraging at an Aggregation Site on the Great Barrier Reef. *PLOS ONE*, 11(5), p.e0153393.
8. Asis, A., Lacsamana, J. and Santos, M., 2014. Illegal trade of regulated and protected aquatic species in the Philippines detected by DNA barcoding. *Mitochondrial DNA*, 27(1), pp.659-666.
9. Barbu, L., Guinand, C., Bergmüller, R., Alvarez, N. and Bshary, R., 2011. Cleaning wrasse species vary with respect to dependency on the mutualism and behavioural adaptations in interactions. *Animal Behaviour*, 82(5), pp.1067-1074.
10. Barr, Y. and Abelson, A., 2019. Feeding – Cleaning Trade-Off: Manta Ray “Decision-Making” as a Conservation Tool. *Frontiers in Marine Science*, 6.
11. Biot.gov.io. 2022. *History | British Indian Ocean Territory*. [online] Available at: <<https://biot.gov.io/about/history/>>.
12. Braun, C., Skomal, G., Thorrold, S. and Berumen, M., 2014. Diving Behavior of the Reef Manta Ray Links Coral Reefs with Adjacent Deep Pelagic Habitats. *PLoS ONE*, 9(2), p.e88170.
13. Braun, C.D., Skomal, G.B., Thorrold, S.R. and Berumen, M.L., 2015. Movements of the reef manta ray (*Manta alfredi*) in the Red Sea using satellite and acoustic telemetry. *Marine biology*, 162(12), pp.2351-2362.

14. Cailliet, G., Smith, W., Mollet, H. and Goldman, K., 2006. Age and growth studies of chondrichthyan fishes: the need for consistency in terminology, verification, validation, and growth function fitting. *Environmental Biology of Fishes*, 77(3-4), pp.211-228.
15. Carpentier, A., Berthe, C., Ender, I., Jaïne, F., Mourier, J., Stevens, G., De Rosemont, M. and Clua, E., 2019. Preliminary insights into the population characteristics and distribution of reef (*Mobula alfredi*) and oceanic (*M. birostris*) manta rays in French Polynesia. *Coral Reefs*, 38(6), pp.1197-1210.
16. Casson, R. and Farmer, L., 2014. Understanding and checking the assumptions of linear regression: a primer for medical researchers. *Clinical & Experimental Ophthalmology*, 42(6), pp.590-596.
17. Clark T.B., 2010. Abundance, home range, and movement patterns of manta rays (*Manta alfredi*, *M. birostris*) in Hawai'i. PhD Thesis, University of Hawai'i at Manoa
18. Cliff, G. and Dudley, S., 2011. Reducing the environmental impact of shark-control programs: a case study from KwaZulu-Natal, South Africa. *Marine and Freshwater Research*, 62(6), p.700.
19. Co  te, I.M., 2000. Evolution and ecology of cleaning symbiosis in the sea. In: Gibson RN, Barnes M, editors. *Oceanography and Marine Biology: An Annual Review*. London: Taylor & Francis; p. 311–55.
20. Couturier, L., Dudgeon, C., Pollock, K., Jaïne, F., Bennett, M., Townsend, K., Weeks, S. and Richardson, A., 2014. Population dynamics of the reef manta ray *Manta alfredi* in eastern Australia. *Coral Reefs*, 33(2), pp.329-342.
21. Couturier, L., Marshall, A., Jaïne, F., Kashiwagi, T., Pierce, S., Townsend, K., Weeks, S., Bennett, M. and Richardson, A., 2012. Biology, ecology and conservation of the Mobulidae. *Journal of Fish Biology*, 80(5), pp.1075-1119.
22. Couturier, L., Newman, P., Jaïne, F., Bennett, M., Venables, W., Cagua, E., Townsend, K., Weeks, S. and Richardson, A., 2018. Variation in occupancy and habitat use of *Mobula alfredi* at a major aggregation site. *Marine Ecology Progress Series*, 599, pp.125-145.
23. Couturier, L., Rohner, C., Richardson, A., Marshall, A., Jaïne, F., Bennett, M., Townsend, K., Weeks, S. and Nichols, P., 2013. Stable Isotope and Signature Fatty Acid Analyses Suggest Reef Manta Rays Feed on Demersal Zooplankton. *PLoS ONE*, 8(10), p.e77152.
24. Croll, D., Marinovic, B., Benson, S., Chavez, F., Black, N., Ternullo, R. and Tershy, B., 2005. From wind to whales: trophic links in a coastal upwelling system. *Marine Ecology Progress Series*, 289, pp.117-130.
25. De Robertis, A., Jaffe, J.S. and Ohman, M.D., 2000. Size-dependent visual predation risk and the timing of vertical migration in zooplankton. *Limnology and Oceanography*, 45(8), pp.1838-1844.
26. Deakos, M., Baker, J. and Bejder, L., 2011. Characteristics of a manta ray *Manta alfredi* population off Maui, Hawaii, and implications for management. *Marine Ecology Progress Series*, 429, pp.245-260.

27. Deakos, M., Baker, J. and Bejder, L., 2011. Characteristics of a manta ray *Manta alfredi* population off Maui, Hawaii, and implications for management. *Marine Ecology Progress Series*, 429, pp.245-260.
28. Dewar, H. 2002. Preliminary report: Manta harvest in Lamakera. Report from the Pflieger Institute of Environmental Research and the Nature Conservancy
29. Dewar, H., Mous, P., Domeier, M., Muljadi, A., Pet, J. and Whitty, J., 2008. Movements and site fidelity of the giant manta ray, *Manta birostris*, in the Komodo Marine Park, Indonesia. *Marine Biology*, 155(2), pp.121-133.
30. Dulvy, N., Pardo, S., Simpfendorfer, C. and Carlson, J., 2014. Diagnosing the dangerous demography of manta rays using life history theory. *PeerJ*, 2, p.e400.
31. Freedman, R. and Sen Roy, S., 2012. Spatial patterning of *Manta birostris* in United States east coast offshore habitat. *Applied Geography*, 32(2), pp.652-659.
32. Germanov, E. and Marshall, A., 2014. Running the Gauntlet: Regional Movement Patterns of *Manta alfredi* through a Complex of Parks and Fisheries. *PLoS ONE*, 9(10), p.e110071.
33. Germanov, E., Bejder, L., Chabanne, D., Dharmadi, D., Hendrawan, I., Marshall, A., Pierce, S., van Keulen, M. and Loneragan, N., 2019. Contrasting Habitat Use and Population Dynamics of Reef Manta Rays Within the Nusa Penida Marine Protected Area, Indonesia. *Frontiers in Marine Science*, 6.
34. Gilmartin, M. and Revelante, N., 1974. The 'island mass' effect on the phytoplankton and primary production of the Hawaiian Islands. *Journal of Experimental Marine Biology and Ecology*, 16(2), pp.181-204.
35. Glynn, P., 2004. High Complexity Food Webs in Low-diversity Eastern Pacific Reef Coral Communities. *Ecosystems*, 7(4), pp.358-367.
36. Goldman, K., Musick, J. and Bonfil, R., 2004. *Elasmobranch fisheries management techniques*. Singapore: Asia Pacific Economic Cooperation, pp.97-132.
37. Graham, R., Witt, M., Castellanos, D., Remolina, F., Maxwell, S., Godley, B. and Hawkes, L., 2012. Satellite Tracking of Manta Rays Highlights Challenges to Their Conservation. *PLoS ONE*, 7(5), p.e36834.
38. Gupta, A.K., Singh, R.K., Joseph, S., and Thomas, E., 2004. Indian Ocean high-productivity event (10-8 Ma): Linked to global cooling or the initiation of the Indian monsoons? *Geology*, 32, 753,756
39. Hacothen-Domené, A., Martínez-Rincón, R., Galván-Magaña, F., Cárdenas-Palomo, N. and Herrera-Silveira, J., 2017. Environmental factors influencing aggregation of manta rays (*Manta birostris*) off the northeastern coast of the Yucatan Peninsula. *Marine Ecology*, 38(3), p.e12432.
40. Halpern, B.S, Walbridge, S., Selkoe, K.A., Kappel, C.V., Micheli, F., 2008. A Global Map of Human Impact on Marine Ecosystems. *Science*. 319, pp.948–952
41. Hammerschlag, N., Skubel, R., Calich, H. and Nelson, E., 2016. Nocturnal and crepuscular behavior in elasmobranchs: a review of movement, habitat use, foraging, and reproduction in the dark. *Bulletin of Marine Science*, 93, pp.355-374.

42. Harris, J. 2019. Reef manta rays, *Mobula alfredi*, of the Chagos Archipelago: Habitat use and the effectiveness of the region's marine protected area.
43. Harris, J. and Stevens, G., 2021. Environmental drivers of reef manta ray (*Mobula alfredi*) visitation patterns to key aggregation habitats in the Maldives. *PLOS ONE*, 16(6), p.e0252470.
44. Harris, J., Hosegood, P., Robinson, E., Embling, C., Hilbourne, S. and Stevens, G., 2021. Fine-scale oceanographic drivers of reef manta ray (*Mobula alfredi*) visitation patterns at a feeding aggregation site. *Ecology and Evolution*, 11(9), pp.4588-4604.
45. Harris, J., McGregor, P., Oates, Y. and Stevens, G., 2020. Gone with the wind: Seasonal distribution and habitat use by the reef manta ray (*Mobula alfredi*) in the Maldives, implications for conservation. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 30(8), pp.1649-1664.
46. Hawkins, J. and Roberts, C., 2004. Effects of Artisanal Fishing on Caribbean Coral Reefs. *Conservation Biology*, 18(1), pp.215-226.
47. Hays, G., 2003. A review of the adaptive significance and ecosystem consequences of zooplankton diel vertical migrations. *Hydrobiologia*, 503(1-3), pp.163-170.
48. Hinojosa-Alvarez, S., Walter, R., Diaz-Jaimes, P., Galván-Magaña, F. and Paig-Tran, E., 2016. A potential third Manta Ray species near the Yucatán Peninsula? Evidence for a recently diverged and novel genetic Manta group from the Gulf of Mexico. *PeerJ*, 4, p.e2586.
49. IUCN Red List of Threatened Species. 2022. *The IUCN Red List of Threatened Species*. [online] Available at: <<https://www.iucnredlist.org/>>.
50. Jaine, F., Couturier, L., Weeks, S., Townsend, K., Bennett, M., Fiora, K. and Richardson, A., 2012. When Giants Turn Up: Sighting Trends, Environmental Influences and Habitat Use of the Manta Ray *Manta alfredi* at a Coral Reef. *PLoS ONE*, 7(10), p.e46170.
51. Jaine, F., Rohner, C., Weeks, S., Couturier, L., Bennett, M., Townsend, K. and Richardson, A., 2014. Movements and habitat use of reef manta rays off eastern Australia: offshore excursions, deep diving and eddy affinity revealed by satellite telemetry. *Marine Ecology Progress Series*, 510, pp.73-86.
52. Jiang, L., Li, Y., Ye, Y., Chen, Y., Jin, M. and Zhang, H., 2019. Unilateral left-tail Anderson Darling test-based spectrum sensing with Laplacian noise. *IET Communications*, 13(6), pp.696-705.
53. Kashiwagi, T., Marshall, A., Bennett, M. and Ovenden, J., 2011. Habitat segregation and mosaic sympatry of the two species of manta ray in the Indian and Pacific Oceans: *Manta alfredi* and *M. birostris*. *Marine Biodiversity Records*, 4.
54. Khemet, B. and Richman, R., 2018. A univariate and multiple linear regression analysis on a national fan (de)Pressurization testing database to predict airtightness in houses. *Building and Environment*, 146, pp.88-97.
55. Kitchen-Wheeler, A., Ari, C. and Edwards, A., 2012. Population estimates of Alfred mantas (*Manta alfredi*) in central Maldives atolls: North Male, Ari and Baa. *Environmental Biology of Fishes*, 93(4), pp.557-575.

56. Krefft, G. (1868) *Deratoptera alfredi* (Prince Alfred's ray). Illustrated Sydney News (11 July), 5(50), 1–16.
57. Lawson, J., Fordham, S., O'Malley, M., Davidson, L., Walls, R., Heupel, M., Stevens, G., Fernando, D., Budziak, A., Simpfendorfer, C., Ender, I., Francis, M., Notarbartolo di Sciara, G. and Dulvy, N., 2017. Sympathy for the devil: a conservation strategy for devil and manta rays. *PeerJ*, 5, p.e3027.
58. Leichter, J., Alldredge, A., Bernardi, G., Brooks, A., Carlson, C., Carpenter, R., Edmunds, P., Fewings, M., Hanson, K., Hench, J., Holbrook, S., Nelson, C., Schmitt, R., Toonen, R., Washburn, L. and Wyatt, A., 2013. Biological and Physical Interactions on a Tropical Island Coral Reef: Transport and Retention Processes on Moorea, French Polynesia. *Oceanography*, 26(3), pp.52-63.
59. Luiz, O., Balboni, A., Kodja, G., Andrade, M. and Marum, H., 2008. Seasonal occurrences of *Manta birostris* (Chondrichthyes: Mobulidae) in southeastern Brazil. *Ichthyological Research*, 56(1), pp.96-99.
60. Malpica-Cruz, L., Herzka, S., Sosa-Nishizaki, O. and Lazo, J., 2012. Tissue-specific isotope trophic discrimination factors and turnover rates in a marine elasmobranch: empirical and modeling results. *Canadian Journal of Fisheries and Aquatic Sciences*, 69(3), pp.551-564.
61. Marshall, A. and Bennett, M., 2010. Reproductive ecology of the reef manta ray *Manta alfredi* in southern Mozambique. *Journal of Fish Biology*, 77(1), pp.169-190.
62. Marshall, A. D., & Pierce, S. J. (2012). The use and abuse of photographic identification in sharks and rays. *Journal of Fish Biology*, 80(5), 1361– 1379.
<https://doi.org/10.1111/j.1095-8649.2012.03244.x>
63. Marshall, A., Barreto, R., Carlson, J., Fernando, D., Fordham, S., Francis, M.P., Herman, K., Jabado, R.W., Liu, K.M., Pacoureaux, N., Rigby, C.L., Romanov, E. & Sherley, R.B. 2022. *Mobula alfredi* (amended version of 2019 assessment). *The IUCN Red List of Threatened Species 2022*:
e.T195459A214395983. <https://dx.doi.org/10.2305/IUCN.UK.2022-1.RLTS.T195459A214395983.en>
64. Marshall, A., Compagno, L. and Bennett, M., 2009. Redescription of the genus *Manta* with resurrection of *Manta alfredi* (Krefft, 1868) (Chondrichthyes; Myliobatoidei; Mobulidae). *Zootaxa*, 2301, pp.1-28.
65. McCauley, D., DeSalles, P., Young, H., Papastamatiou, Y., Caselle, J., Deakos, M., Gardner, J., Garton, D., Collen, J. and Micheli, F., 2014. Reliance of mobile species on sensitive habitats: a case study of manta rays (*Manta alfredi*) and lagoons. *Marine Biology*, 161(9), pp.1987-1998.
66. McCauley, D., Pinsky, M., Palumbi, S., Estes, J., Joyce, F. and Warner, R., 2015. Marine defaunation: Animal loss in the global ocean. *Science*, 347(6219).
67. McGregor, F., Richardson, A.J., Armstrong, A.J., Armstrong, A.O. and Dudgeon, C.L., 2019. Rapid wound healing in a reef manta ray masks the extent of vessel strike. *PLoS One*, 14(12), p.e0225681.

68. Meilland, J., Siccha, M., Weinkauff, M.F., Jonkers, L., Morard, R., Baranowski, U., Baumeister, A., Bertlich, J., Brummer, G.J., Debray, P. and Fritz-Endres, T., 2019. Highly replicated sampling reveals no diurnal vertical migration but stable species-specific vertical habitats in planktonic foraminifera. *Journal of Plankton Research*, 41(2), pp.127-141.
69. meteoblue. 2022. *Weather - meteoblue*. [online] Available at: <<https://content.meteoblue.com/en/meteoscool/weather>>.
70. Microsoft Corporation, 2018. Microsoft Excel, Available at: <https://office.microsoft.com/excel>.
71. Murray, A., Garrud, E., Ender, I., Lee-Brooks, K., Atkins, R., Lynam, R., Arnold, K., Roberts, C., Hawkins, J. and Stevens, G., 2019. Protecting the million-dollar mantas; creating an evidence-based code of conduct for manta ray tourism interactions. *Journal of Ecotourism*, 19(2), pp.132-147.
72. Musick, J.A. and Bonfil, R., 2005. 14. Shark utilization. In: *Management techniques for elasmobranch fisheries* (No. 474). Food & Agriculture Org
73. Nelson, L., 1998. The Anderson-Darling Test for Normality. *Journal of Quality Technology*, 30(3), pp.298-299.
74. Nicholson-Jack, A., Harris, J., Ballard, K., Turner, K. and Stevens, G., 2021. A hitchhiker guide to manta rays: Patterns of association between *Mobula alfredi*, *M. birostris*, their symbionts, and other fishes in the Maldives. *PLOS ONE*, 16(7), p.e0253704.
75. Notarbartolo di Sciara, G., Stevens, G. and Fernando, D., 2020. The giant devil ray *Mobula mobular* (Bonnaterre, 1788) is not giant, but it is the only spinetail devil ray. *Marine Biodiversity Records*, 13(1).
76. Nøttestad, L., Giske, J., Holst, J. and Huse, G., 1999. A length-based hypothesis for feeding migrations in pelagic fish. *Canadian Journal of Fisheries and Aquatic Sciences*, 56(S1), pp.26-34.
77. O'Malley, M., Townsend, K., Hilton, P., Heinrichs, S. and Stewart, J., 2016. Characterization of the trade in manta and devil ray gill plates in China and South-east Asia through trader surveys. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 27(2), pp.394-413.
78. O'Shea, O.R., Kingsford, M.J., Seymour, J., 2010. Tide-related periodicity of manta rays and sharks to cleaning stations on a coral reef. *Mar Freshw Res*, 61, 65–73
79. Ohayon, S., Granot, I. and Belmaker, J., 2021. A meta-analysis reveals edge effects within marine protected areas. *Nature Ecology & Evolution*, 5(9), pp.1301-1308.
80. Oliver, S., Braccini, M., Newman, S.J. and Harvey, E.S., 2015. Global patterns in the bycatch of sharks and rays. *Marine Policy*, 54, pp.86-97.
81. Pardo, S., Kindsvater, H., Cuevas-Zimbrón, E., Sosa-Nishizaki, O., Pérez-Jiménez, J. and Dulvy, N., 2016. Growth, productivity and relative extinction risk of a data-sparse devil ray. *Scientific Reports*, 6(1).

82. Peel, L., Stevens, G., Daly, R., Keating Daly, C., Lea, J., Clarke, C., Collin, S. and Meekan, M., 2019. Movement and residency patterns of reef manta rays *Mobula alfredi* in the Amirante Islands, Seychelles. *Marine Ecology Progress Series*, 621, pp.169-184.
83. Perryman, R., Mourier, J., Venables, S., Tapilatu, R., Setyawan, E. and Brown, C., 2022. Reef manta ray social dynamics depend on individual differences in behaviour. *Animal Behaviour*, 191, pp.43-55.
84. R Core Team (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria
85. Radice, V., Hoegh-Guldberg, O., Fry, B., Fox, M. and Dove, S., 2019. Upwelling as the major source of nitrogen for shallow and deep reef-building corals across an oceanic atoll system. *Functional Ecology*, 33(6), pp.1120-1134.
86. Rohner, C., Pierce, S., Marshall, A., Weeks, S., Bennett, M. and Richardson, A., 2013. Trends in sightings and environmental influences on a coastal aggregation of manta rays and whale sharks. *Marine Ecology Progress Series*, 482, pp.153-168.
87. Ros, A., Lusa, J., Meyer, M., Soares, M., Oliveira, R., Brossard, M. and Bshary, R., 2011. Does access to the bluestreak cleaner wrasse *Labroides dimidiatus* affect indicators of stress and health in resident reef fishes in the Red Sea?. *Hormones and Behavior*, 59(1), pp.151-158.
88. Rowat, D., Gore, M., Meekan, M., Lawler, I. and Bradshaw, C., 2009. Aerial survey as a tool to estimate whale shark abundance trends. *Journal of Experimental Marine Biology and Ecology*, 368(1), pp.1-8.
89. Roxy, M.K., Ritika, K., Terray, P., Murtugudde, R., Ashok, K. and Goswami, B.N., 2015. Drying of Indian subcontinent by rapid Indian Ocean warming and a weakening land-sea thermal gradient. *Nature communications*, 6(1), pp.1-10.
90. Sanchirico, J., Malvadkar, U., Hastings, A. and Wilen, J., 2006. When are no-take zones an Economically Optimal Fishery Management Strategy?. *Ecological Applications*, 16(5), pp.1643-1659.
91. Selgrath, J., Gergel, S. and Vincent, A., 2018. Shifting gears: Diversification, intensification, and effort increases in small-scale fisheries (1950-2010). *PLOS ONE*, 13(3), p.e0190232.
92. Sequeira, A., Mellin, C., Fordham, D., Meekan, M. and Bradshaw, C., 2014. Predicting current and future global distributions of whale sharks. *Global Change Biology*, 20(3), pp.778-789.
93. Séret, B. and Sire, J., 1999. *Proceedings of the 5th Indo- Pacific fish conference*. Paris: Société française d'ichtyologie, pp.209-216
94. Sheppard, C., 1999. Coral decline and weather patterns over 20 years in the Chagos Archipelago, central Indian Ocean. *Ambio*, 28, pp.472-478.
95. Sheppard, C., Ateweberhan, M., Bowen, B., Carr, P., Chen, C, et al. 2012. Reefs and islands of the Chagos Archipelago, Indian Ocean: why it is the world's largest no-take marine protected area. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 22(2), pp.232-261.

96. Sheppard, C., Ateweberhan, M., Bowen, B., Carr, P., Chen, C., Clubbe, C., Craig, M., Ebinghaus, R., Eble, J., Fitzsimmons, N., Gaither, M., Gan, C., Gollock, M., Guzman, N., Graham, N., Harris, A., Jones, R., Keshavmurthy, S., Koldewey, H., Lundin, C., Mortimer, J., Obura, D., Pfeiffer, M., Price, A., Purkis, S., Raines, P., Readman, J., Riegl, B., Rogers, A., Schleyer, M., Seaward, M., Sheppard, A., Tamelander, J., Turner, J., Visram, S., Vogler, C., Vogt, S., Wolschke, H., Yang, J., Yang, S. and Yesson, C., 2012. Reefs and islands of the Chagos Archipelago, Indian Ocean: why it is the world's largest no-take marine protected area. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 22(2), pp.232-261.
97. Sheppard, C., Harris, A. and Sheppard, A., 2008. Archipelago-wide coral recovery patterns since 1998 in the Chagos Archipelago, central Indian Ocean. *Marine Ecology Progress Series*, 362, pp.109-117.
98. Sheppard, C., Sheppard, A. and Fenner, D., 2020. Coral mass mortalities in the Chagos Archipelago over 40 years: Regional species and assemblage extinctions and indications of positive feedbacks. *Marine Pollution Bulletin*, 154, p.111075.
99. Simpfendorfer, C. A., Huveneers, C., Steckenreuter, A., Tattersall, K., Hoenner, X., Harcourt, R., & Heupel, M. R. (2015). Ghosts in the data: False detections in VEMCO pulse position modulation acoustic telemetry monitoring equipment. *Animal Biotelemetry*, 3(1), 1–10. <https://doi.org/10.1186/s40317-015-0094-z>
100. Sims, D., 2003. Tractable models for testing theories about natural strategies: foraging behaviour and habitat selection of free-ranging sharks. *Journal of Fish Biology*, 63, pp.53-73.
101. Sims, D., Witt, M., Richardson, A., Southall, E. and Metcalfe, J., 2006. Encounter success of free-ranging marine predator movements across a dynamic prey landscape. *Proceedings of the Royal Society B: Biological Sciences*, 273(1591), pp.1195-1201.
102. Sims, D.W., 1999. Threshold foraging behaviour of basking sharks on zooplankton: life on an energetic knife-edge?. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, 266(1427), pp.1437-1443.
103. Stevens, G., Hawkins, J. and Roberts, C., 2018. Courtship and mating behaviour of manta rays *Mobula alfredi* and *M. birostris* in the Maldives. *Journal of Fish Biology*, 93(2), pp.344-359.
104. Stevens, G.M.W., 2016. *Conservation and population ecology of manta rays in the Maldives* (Doctoral dissertation, University of York).
105. Stevens, G.M.W., Froman, N., 2018. The Maldives Archipelago. In: Sheppard C, editor. *World Seas: An Environmental Evaluation: Volume II: The Indian Ocean to the Pacific*. 2nd ed. London: Academic Press. p. 211–36
106. Stewart, J., Beale, C., Fernando, D., Sianipar, A., Burton, R., Semmens, B. and Aburto-Oropeza, O., 2016. Spatial ecology and conservation of *Manta birostris* in the Indo-Pacific. *Biological Conservation*, 200, pp.178-183.

107. Stewart, J., Nuttall, M., Hickerson, E. and Johnston, M., 2018. Important juvenile manta ray habitat at Flower Garden Banks National Marine Sanctuary in the north western Gulf of Mexico. *Marine Biology*, 165(7).
108. Stewart, J.D., Hoyos-Padilla, E.M., Kumli, K.R. and Rubin, R.D., 2016. Deep-water feeding and behavioral plasticity in *Manta birostris* revealed by archival tags and submersible observations. *Zoology*, 119(5), pp.406-413.
109. Temple, A., Kiszka, J., Stead, S., Wambiji, N., Brito, A., Poonian, C., Amir, O., Jiddawi, N., Fennessy, S., Pérez-Jorge, S. and Berggren, P., 2017. Marine megafauna interactions with small-scale fisheries in the southwestern Indian Ocean: a review of status and challenges for research and management. *Reviews in Fish Biology and Fisheries*, 28(1), pp.89-115.
110. Timeanddate.com. 2022. *Moon Phases 2022 – Lunar Calendar for Chagos Archipelago, British Indian Ocean Territory, British Indian Ocean Territory*. [online] Available at: <<https://www.timeanddate.com/moon/phases/@1281792>> [Accessed 26 July 2022].
111. Turner, A.G. and Annamalai, H., 2012. Climate change and the South Asian summer monsoon. *Nature Climate Change*, 2(8), pp.587-595.
112. Venables, S., Marshall, A., Germanov, E., Perryman, R., Tapilatu, R., Hendrawan, I., Flam, A., van Keulen, M., Tomkins, J. and Kennington, W., 2019. It's not all black and white: investigating colour polymorphism in manta rays across Indo-Pacific populations. *Proceedings of the Royal Society B: Biological Sciences*, 286(1912), p.20191879.
113. Venables, S., McGregor, F., Brain, L. and van Keulen, M., 2016. Manta ray tourism management, precautionary strategies for a growing industry: a case study from the Ningaloo Marine Park, Western Australia. *Pacific Conservation Biology*, 22(4), p.295.
114. Vianna, G., Meekan, M., Meeuwig, J. and Speed, C., 2013. Environmental Influences on Patterns of Vertical Movement and Site Fidelity of Grey Reef Sharks (*Carcharhinus amblyrhynchos*) at Aggregation Sites. *PLoS ONE*, 8(4), p.e60331.
115. Walbaum, K.J. (1792). *Petri artedi sueci genera piscium*. Grypeswaldiae: A.F. Rose.
116. Ward-Paige, C., Davis, B. and Worm, B., 2013. Global Population Trends and Human Use Patterns of Manta and Mobula Rays. *PLoS ONE*, 8(9), p.e74835
117. White, W., Corrigan, S., Yang, L., Henderson, A., Bazinet, A., Swofford, D. and Naylor, G., 2017. Phylogeny of the manta and devilrays (Chondrichthyes: mobulidae), with an updated taxonomic arrangement for the family. *Zoological Journal of the Linnean Society*, 182(1), pp.50-75.
118. White, W., Giles, J., Dharmadi and Potter, I., 2006. Data on the bycatch fishery and reproductive biology of mobulid rays (Myliobatiformes) in Indonesia. *Fisheries Research*, 82(1-3), pp.65-73.
119. White, W., Platell, M. and Potter, I., 2001. Relationship between reproductive biology and age composition and growth in *Urolophus lobatus* (Batoidea: Urolophidae). *Marine Biology*, 138(1), pp.135-147.

120. Wilkerson, F., Lassiter, A., Dugdale, R., Marchi, A. and Hogue, V., 2006. The phytoplankton bloom response to wind events and upwelled nutrients during the CoOP WEST study. *Deep Sea Research Part II: Topical Studies in Oceanography*, 53(25-26), pp.3023-3048.
121. Wu, M., Duvat, V. and Purkis, S., 2021. Multi-decadal atoll-island dynamics in the Indian Ocean Chagos Archipelago. *Global and Planetary Change*, 202, p.103519.
122. Yadav, R.K., 2013. Emerging role of Indian ocean on Indian northeast monsoon. *Climate dynamics*, 41(1), pp.105-116.
123. Yao, W. and Li, L., 2013. A New Regression Model: Modal Linear Regression. *Scandinavian Journal of Statistics*, 41(3), pp.656-671.

Appendices

Sum of Prez_abz	Column Labels	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Grand Total	
25.9																									0	
26																				0	1					0
26.1																			0	1						1
26.3		0																								0
26.4																					0					0
26.5																					1					1
26.6				0	0													0	0							0
26.7		0		0																	0	0				0
26.8		0	1	0	0	0						1				0				0	0					2
26.9		0		0	1	0				0	1				0	0			1	0	1	1		1	1	7
27		0	0	0	0	0	0	0	1	0	1	0	1			0				1	1	1	1			7
27.1		0	0	0	2	1	1	0	0	1	1	0		0	1	1	1	0	0		1	0	2	0	0	12
27.2		1	0	0	1	1	0	0	1	0	0	0	0	0	1	0	1	2	2	0	2	0	1	0	0	13
27.3		4	0	0	2	2	0	1	0	2	0	2	2	0	1	0	0	2	3	1	2	0	2	0	1	27
27.4		1	1	3	2	0	1	1	1	0	3	0	1	0	2	1	0	1	1	0	1	0	0	0	0	20
27.5		1	0	0	0	0	0	0	0	3	1	2	3	0	2	0	0	2	0	2	4	1	0	1	4	26
27.6		0	0	0	1	1	0	0	0	0	3	0	1	4	4	2	6	0	3	4	2	2	2	1	0	36
27.7		1	1	3	1	0	0	0	1	5	2	1	0	1	1	2	3	2	2	2	2	1	2	1	1	35
27.8		0	2	1	1	0	0	0	2	0	2	1	2	4	4	3	1	3	4	2	1	0	1	2	1	37
27.9		0	1	0	0	1	3	1	2	7	1	2	3	6	0	1	1	4	5	2	2	3	0	0	2	47
28		2	2	0	0	0	1	0	2	5	1	4	4	1	1	5	2	1	1	1	0	0	4	1	0	38
28.1		1	0	2	1	2	2	2	0	1	8	4	2	2	3	4	3	2	8	4	3	4	3	0	0	61
28.2		0	1	0	1	0	3	1	3	7	6	8	4	5	6	7	6	10	8	6	5	4	1	1	1	94
28.3		0	1	1	2	1	3	4	3	2	3	7	6	7	7	7	6	5	5	6	1	1	1	0	3	82
28.4		0	1	2	1	1	1	2	1	3	3	4	3	4	1	4	3	0	5	4	2	1	1	0	0	47
28.5		0	1	1	2	0	1	0	2	3	4	1	4	4	4	5	3	6	2	5	1	1	2	0	1	53
28.6		0	1	1	1	1	1	2	1	3	7	3	7	3	7	9	9	5	5	7	0	0	2	2	0	77
28.7		0	0	0	1	1	1	0	2	2	2	3	2	6	5	1	3	3	2	1	3	0	1	1	0	40
28.8		1	1	2	1	1	1	0	1	3	5	3	2	2	4	4	2	4	8	2	3	2	0	1	1	54
28.9		1	0	2	2	1	1	1	2	4	5	3	6	7	4	3	5	4	4	6	7	1	1	2	0	72
29		0	0	0	0	0	0	2	0	0	1	3	1	1	5	3	1	4	4	5	2	0	0	1	0	33
29.1		0	1	0	1	3	1	3	3	2	3	1	1	1	4	2	3	5	2	4	1	0	2	1	0	44
29.2		1	0	0	1	0	2	1	6	1	0	1	3	4	1	4	2	4	1	1	3	2	0	0	1	39
29.3		1	2	2	0	2	1	0	0	2	3	2	1	4	4	1	0	2	4	4	1	1	1	0	1	39
29.4		2	5	4	2	3	2	3	5	2	2	4	4	1	2	2	6	3	4	1	3	5	4	1	1	71
29.5		6	3	9	4	4	2	1	4	7	8	6	5	9	6	6	1	8	3	2	3	7	2	5	5	116
29.6		1	2	3	4	1	0	0	1	3	3	7	4	2	3	6	4	8	6	5	5	5	2	3	1	79
29.7		5	2	1	1	4	3	1	4	3	3	1	7	8	12	4	8	12	5	2	6	4	4	4	4	108
29.8		0	1	0	1	0	1	2	0	1	2	1	2	5	6	6	7	5	4	5	5	2	0	2	0	58
29.9		3	2	0	1	5	0	1	3	2	1	1	2	2	3	5	6	5	2	3	3	5	2	0	3	60
30		2	2	1	0	0	1	1	0	3	0	0	2	4	6	1	4	3	4	2	1	1	0	1	0	39
30.1		1	1	0	0	0	1	0	2	0	0	0	2	2	3	2	3	2	1	3	0	1	0	1	1	26
30.2						0				0	0	1	0	0	1	2	1	1	2	0	1	1	1	1	1	11
30.3						1				0	0	0	1	1					2	1	0	1			7	
30.4				0	0	0								0	0				0	0					0	
30.5																			0	0					0	
Grand Total		35	35	38	37	37	35	30	52	78	83	77	88	102	113	101	101	119	113	96	80	57	44	34	34	1619

Figure 12 – Pivot table showing the sum of presences of manta rays at temperatures for each hour of the day. Totals for each temperature (right column) and for each hour (bottom row) included.

Sum of Prez_abz	Column Labels	February	March	April	May	June	July	August	September	October	November	December	Grand Total	
25.9	0												0	
26	0												0	
26.1	0												0	
26.3												1	1	
26.4												0	0	
26.5												1	1	
26.6	0								0			0	0	
26.7	0								0		0	0	0	
26.8	0					1			1			0	2	
26.9	2					0		0	4		0	1	7	
27	2					0		0	4		0	1	7	
27.1	5					0	0	0	6		0	1	12	
27.2	6							2	4		0	1	13	
27.3	19					1		3	4			0	27	
27.4	7	0				2	0	4	7		0	0	20	
27.5	4	0				0	0	2	18		0	2	26	
27.6	10	1				0	0	1	9	12	1	2	36	
27.7	12	1		0		0	0	0	5	12	3	2	35	
27.8	23	0				0	1	0	3	4	4	2	37	
27.9	28	6				1	1	1	4		2	4	47	
28	14	5	0			0	4	2	2	7	0	2	38	
28.1	15	8				0	3	8	11	9	1	3	61	
28.2	12	5	0			0	7	24	22	8	4	6	94	
28.3	6	6				16	17	15	4	8	7	3	82	
28.4	1	4				0	7	6	6	0	12	7	47	
28.5	3	0				0	5	4	9	3	15	10	53	
28.6	0	5	1	1	2	2	7	6		2	39	7	77	
28.7	4	0				1	6	6		12	4	7	40	
28.8	0	0	0	4	11	3			0	12	6	18	54	
28.9	0	0	0	8	10	18			0	15	5	16	72	
29	0	3	0	2	5	4				6	3	10	33	
29.1	0	4	1	7	4					5	9	14	44	
29.2	0	9	1	8	5					5	5	6	39	
29.3	0	9	4	12	3					3	5	3	39	
29.4	1	29	16	12	1					4	6	2	71	
29.5	0	23	46	32						4	11	0	116	
29.6	0	19	26	20						2	11	1	79	
29.7	1	41	25	32							8	1	108	
29.8		18	13	24							3	0	58	
29.9	0	20	27	9							4		60	
30	0	16	17	1							5		39	
30.1	0	12	8								6		26	
30.2		7	4								0		11	
30.3		6	1								0		7	
30.4		0	0										0	
30.5		0											0	
Grand Total		166	50	217	190	174	95	101	100	113	147	143	123	1619

Figure 13 – Pivot table showing the sum of presences of manta rays at temperatures for each month of the year. Totals for each temperature (right column) and for each month (bottom row) included.

```

The downloaded binary packages are in
/var/folders/tm/6g68xcd951gc6ct6pn1q9gtm0000gn/T//RtmpamzFFD/downloaded_packages
> library(nortest)
> ad.test(base_data$SST)

Anderson-Darling normality test

data: base_data$SST
A = 48.041, p-value < 2.2e-16

> ad.test(base_data$Hour)

Anderson-Darling normality test

data: base_data$Hour
A = 115.83 secs, p-value < 2.2e-16

> ad.test(base_data$Month)
Error in x - mean(x) : non-numeric argument to binary operator
In addition: Warning message:
In mean.default(x) : argument is not numeric or logical: returning NA
> ad.test(base_data$`Wind Direction`)

Anderson-Darling normality test

data: base_data$`Wind Direction`
A = 365.76, p-value < 2.2e-16

> ad.test(base_data$`Wind Speed`)

Anderson-Darling normality test

data: base_data$`Wind Speed`
A = 31.095, p-value < 2.2e-16

> ad.test(base_data$`Tide state`)
Error in x - mean(x) : non-numeric argument to binary operator
In addition: Warning message:
In mean.default(x) : argument is not numeric or logical: returning NA
> ad.test(base_data$`Time to high tide`)

Anderson-Darling normality test

data: base_data$`Time to high tide`
A = 131.39, p-value < 2.2e-16

```

Figure 14 – Full darling test for all numerical values – was not conclusive for categorical factors.

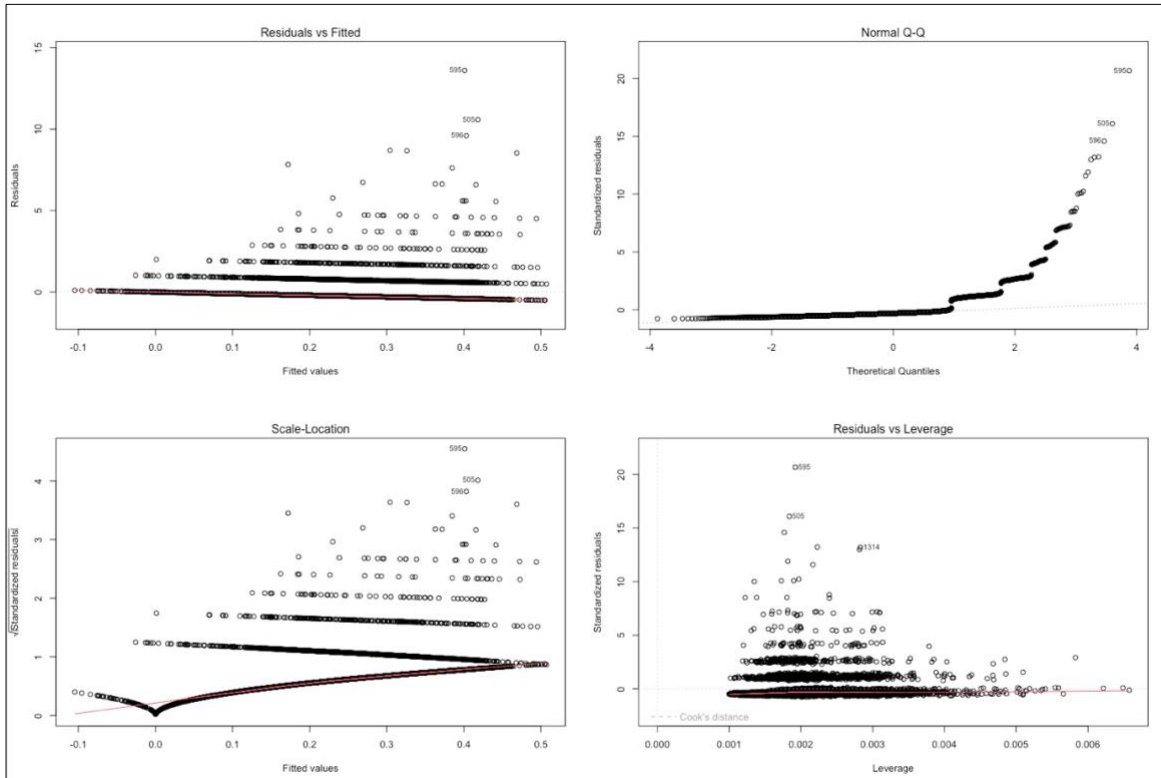


Figure 15 – Residual, q-q, scale-location and residuals vs leverage graphs. The residual graphs show no pattern as the line is fairly flat and neat, meaning the linearity assumptions have been met. The q-q plot is not normally distributed as the plots do not fall into a consistent diagonal line. Regression diagnostic is run to check the validity of the assumptions. These show that there are too many variables in the sample to be able to visualise the relationship between them.

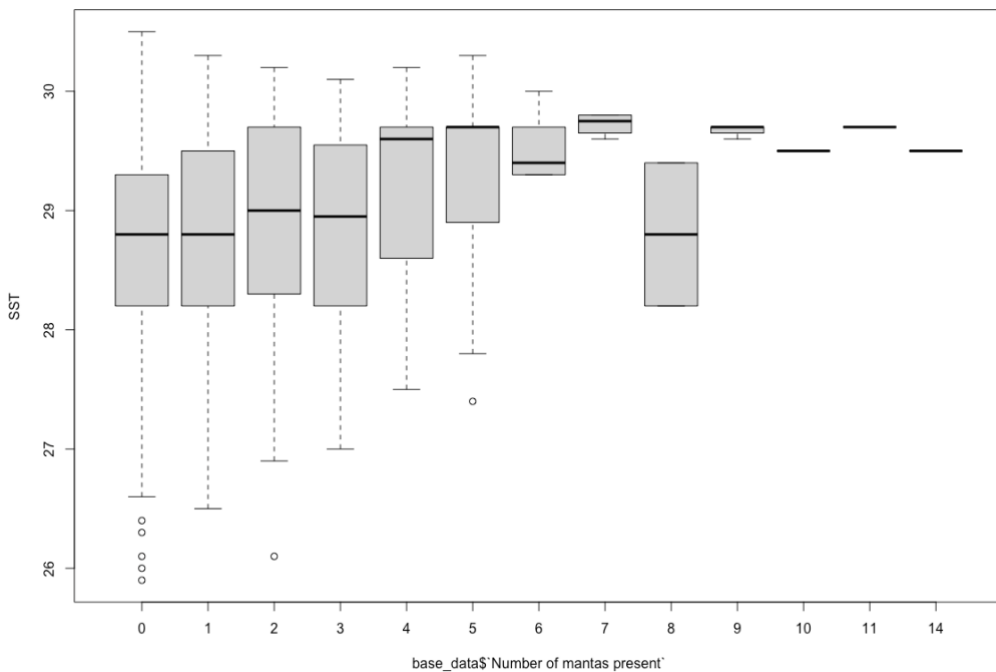


Figure 16 – Box plot of number of manta rays present for each average temperature (degrees Celsius). The majority of detections are between 28°C and 30°C, showing the optimum range for the *M. alfredi*. There is a larger disparity for the lower number of mantas as there are less detections, and thus less variation, as the detections increase.

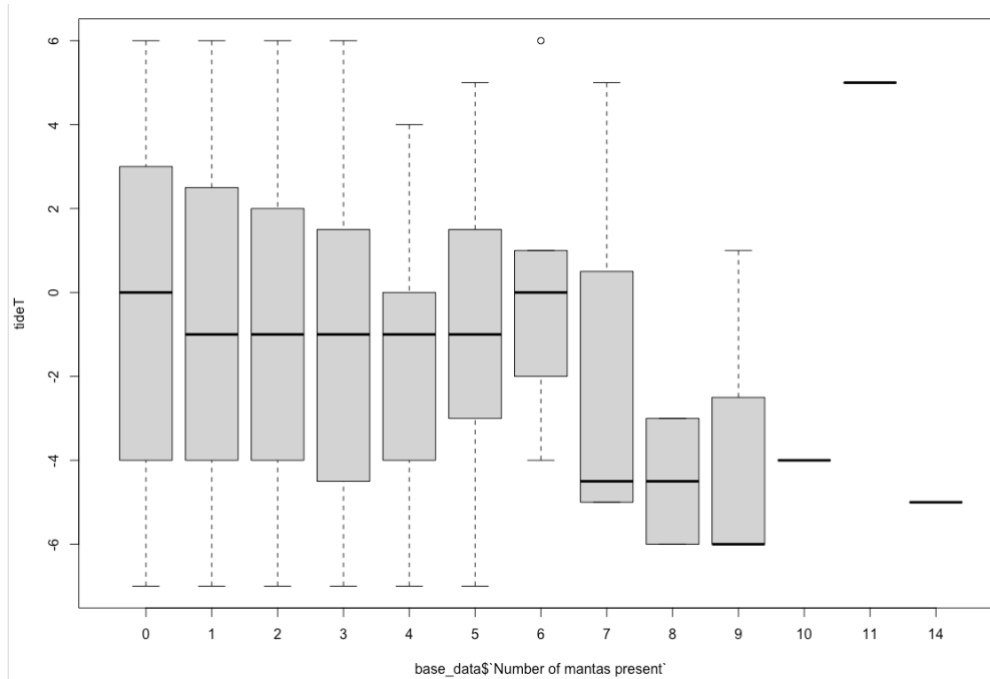


Figure 17 – Box plot of the number of mantas present against the tidal state. Most average detections are at around -1, which signifies 1 hour before a high tide. Once detections reach 7 and over the data is no longer concordant with this average and is at a very low flood tide.

```

> #SST
> model.1<- aov(base_data$`Number of mantas present`~base_data$SST, data = base_data)
> summary(model.1)
              Df Sum Sq Mean Sq F value    Pr(>F)
base_data$SST  1    27  26.693    60.74 7.19e-15 ***
Residuals    9504  4176   0.439
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

> model.2<- aov(base_data$`Number of mantas present`~base_data$Hour, data = base_data)
> summary(model.2)
              Df Sum Sq Mean Sq F value    Pr(>F)
base_data$Hour  1    21  20.94    47.6 5.57e-12 ***
Residuals    9504  4182   0.44
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

> model.3<- aov(base_data$`Number of mantas present`~base_data$Month, data = base_data)
> summary(model.3)
              Df Sum Sq Mean Sq F value    Pr(>F)
base_data$Month 11    49   4.456    10.18 <2e-16 ***
Residuals    9494  4154   0.438
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

> model.4<- aov(base_data$`Number of mantas present`~base_data$`Wind Direction`, data = base_data)
> summary(model.4)
              Df Sum Sq Mean Sq F value    Pr(>F)
base_data$`Wind Direction`  1    2   2.376    5.375 0.0204 *
Residuals    9504  4201   0.442
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

> model.5<- aov(base_data$`Number of mantas present`~base_data$`Wind Speed`, data = base_data)
> summary(model.5)
              Df Sum Sq Mean Sq F value    Pr(>F)
base_data$`Wind Speed`  1    0   0.1414    0.32 0.572
Residuals    9504  4203   0.4422
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

> model.6<- aov(base_data$`Number of mantas present`~base_data$`Tide state`, data = base_data)
> summary(model.6)
              Df Sum Sq Mean Sq F value    Pr(>F)
base_data$`Tide state`  3    4   1.2635    2.859 0.0355 *
Residuals    9502  4199   0.4419
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

> model.7<- aov(base_data$`Number of mantas present`~base_data$`Time to high tide`, data = base_data)
> summary(model.7)
              Df Sum Sq Mean Sq F value    Pr(>F)
base_data$`Time to high tide`  1    3   3.268    7.396 0.00655 **
Residuals    9504  4200   0.442
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

```

Figure 18 – ANOVA run in R system for all environmental factors. This test was not used in the final analysis as was not as appropriate as the lm function linear regression for the data type.

```

> summary(base_data)
Date_time      Number of mantas present  Prez_abz      SST      Hour      Month      Wind Direction  Wind Speed  Tide state
Length:9506    Min. : 0.0000      Min. :0.0000  Min. :25.90  Length:9506  Length:9506  Min. : 0.8303  Min. : 0.36  Length:9506
Class :character 1st Qu.: 0.0000      1st Qu.:0.0000  1st Qu.:28.20  Class1:hms   Class :character 1st Qu.:134.4327 1st Qu.:13.79  Class :character
Mode :character  Median : 0.0000      Median :0.0000  Median :28.80  Class2:difftime Mode :character  Median :184.7636  Median :20.77  Mode :character
Mean : 0.2354      Mean :0.1703      Mean :28.72      Mean :205.8478  Mean :20.02
3rd Qu.: 0.0000      3rd Qu.:0.0000  3rd Qu.:29.40      3rd Qu.:287.1565  3rd Qu.:25.86
Max. :14.0000      Max. :1.0000      Max. :30.50      Max. :360.0000  Max. :48.15

Time to high tide
Min. : -7.0000
1st Qu.: -4.0000
Median : 0.0000
Mean : -0.4986
3rd Qu.: 3.0000
Max. : 6.0000
> |

```

Figure 19 – Mean and medians, made in R, for each of the environmental factors analysed.