

**The influence of environmental and anthropogenic variables on whale shark (*Rhincodon typus*) abundance in the South Ari Atoll.**



Sophie Gibson

Bsc Marine Biology with Oceanography

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## **Abstract**

*Rhincodon typus* is a large filter feeding elasmobranch that aggregates in shallow coastal waters such as the South Ari atoll Marine Protected Area (S.A. MPA) in the Maldives. They are known to travel large distances, however little is known about what causes these movements throughout the oceans and into aggregation sites. This study aims to determine whether whale shark seasonality is present in the South Ari Atoll as well as recognise what environmental and anthropogenic factors influence whale shark abundance in the area.

Whale shark sightings data collected by the Maldives Whale Shark Research Programme (MWSRP) from the S.A. MPA from 2013 to 2016 was analysed for seasonality and then relationships with variables using correlations and linear regression.

It was discovered that there was no seasonality between months in the years from 2013 to 2016. Therefore it is assumed there is a subpopulation of whale sharks in the South Ari Atoll remaining loyal to the area. Whale shark abundance for all years increases with Sea Surface Temperature anomaly (SSTa) most likely due to the optimal functioning of the shark's metabolism being within this temperature causing them to remain within a specific range. Average maximum number of people present on the day had a negative effect on abundance for all years, most likely due to prolonged exposure to humans leading to avoidance behaviour by local whale sharks. Overall it was thought that the local subpopulation moved into the South Ari Atoll dependent on SST and the number of people swimming on the reef.

This analysis along with further research may allow further insight into the drivers and timings of aggregations. It may also serve to highlight the implications on the distribution and aggregations of whale sharks from increasing temperatures due to climate change as well as the impact on their behaviour from ecotourism.

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# Introduction

## 1.1 Biology of Species

*Rhincodon typus* (Smith, 1828) is a large Chondrichthyes elasmobranch. The species can be described as having a flattened head, a large mouth at the front of the head, five gill slits, three ridges along its side, and a pattern of white spots and stripes with a dark blue body (Colman, 1997). These patterns are unique to each individual and it is thought they could be used as a form of camouflage (Wilson and Martin, 2003).

*R. typus* feeds on a variety of prey including phytoplankton, zooplankton such as krill and copepods, small schooling fish and finally on rare occasions, larger fish like tuna (Colman, 1997). Feeding may either be ram filter feeding; swimming forward with its mouth open using rakers; a filtering apparatus (Heyman *et al.*, 2001) or suction feeding when the shark lies stationary horizontally or vertically in the water column before opening the mouth to suck in prey and removing the water from the gills (Compagno, 1984). *R. typus* has a few natural predators; blue sharks have been known to eat juveniles (Kukuyev, 1996) while adults have been known to be attacked by white sharks (Fitzpatrick *et al.*, 2006) and orca's (O'Sullivan, 2000). The species is a "lecithotrophic livebearer" meaning that multiple eggs grow and hatch inside the womb (Joung *et al.*, 1996). They are slow growing and have late maturation which makes them even more vulnerable to the anthropogenic factors already destructing them (Pravin, 2000).

## 1.2 Distribution and aggregations

### *Global distribution and aggregation sites*

*R. typus* has a wide distribution (Figure 1) through tropical and warm temperate oceans (Colman, 1997) usually between latitudes 30°N and 35°S (Compagno, 1984). However there have also been sightings as far North as the Azores archipelago in Portugal (Afonso *et al.*, 2014) and the Bay of Fundy in Canada (Turnbull and Randell, 2006). They are epipelagic and solitary but often aggregate in coastal waters which may be linked to feeding on high productivity events (Wilson

2001) (Stevens, 2007). It is possible that aggregations could have a role in mating, however in the South Ari atoll it is unlikely due to the aggregation being made up of mostly male and immature sharks. However in other areas with more adults and females this may be the case (Martin, 2007). The term aggregation can describe an area with as little as two sharks or a large seasonal occurrence depending on the literature one is referring to. There are large known aggregation sites in the Philippines, Mexico, Ningaloo Reef (Australia), Indonesia, the Maldives, Mauritius, Mozambique, South Africa, the Seychelles, Sri Lanka, Thailand and the Galapagos (Rowat, 2007). Most studies are carried out at aggregation sites compared to open ocean as it is difficult to track and observe them in open water. Therefore little is known about where whale sharks move between aggregation sites and why. There is especially little data regarding pregnant females and young whale sharks as they are rarely encountered. Hearn *et al.* (2013) tagged pregnant females and found they underwent return migrations to the Galapagos . However more research in this area may give more insight into life histories and movements (Rowat and Brooks, 2012).

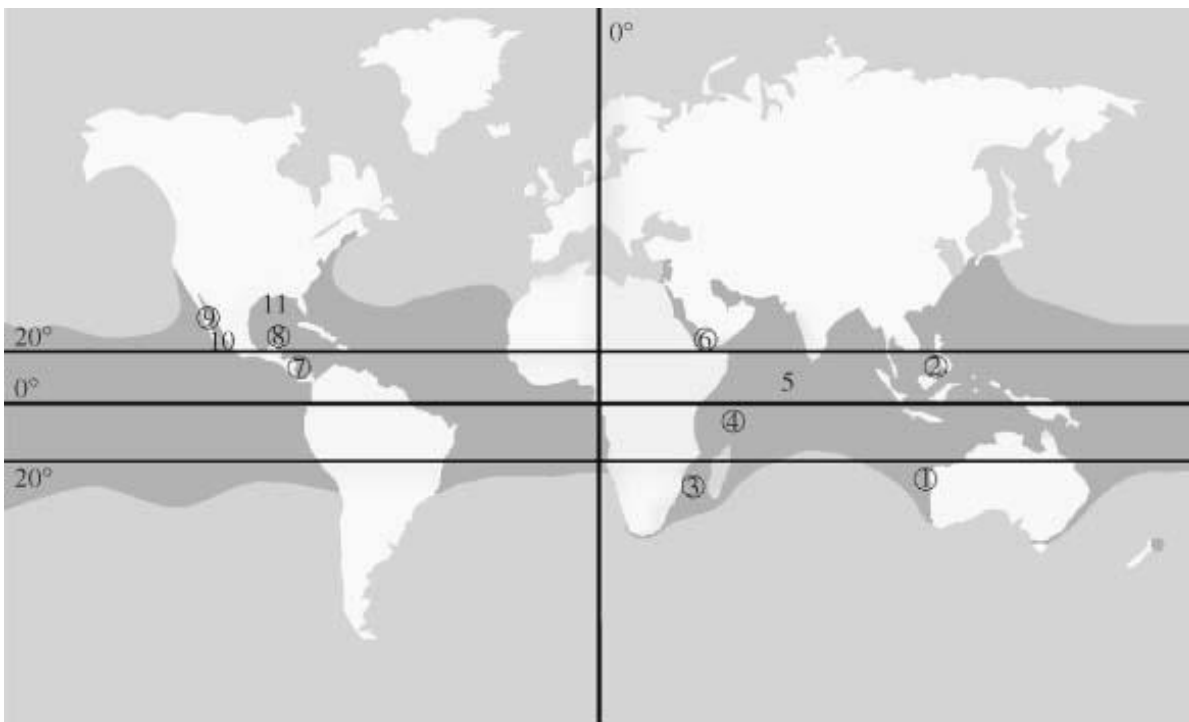


Figure 1: A map showing global whale shark distribution (dark grey) and large known aggregation sites. 1 : Ningaloo reef; 2 :Philippines, 3: Mozambique, 4: Seychelles, 5: Maldives, 6: Djibouti, 7: Belize, 8: Holbox, 9 and 10: Gulf of California, 11: Gulf of Mexico. Circled numbers show areas with dedicated *R. typus* tourism activities (Rowat and Brooks, 2012).

### *Global movements*

In order to give insight into their migratory and aggregation behaviour there needs to be a method to calculate abundance, population and distribution. Originally this was done by a mark – recapture methodology (Lincoln, 1930) either by using natural scars and markings to identify or by creating a visible tag. However there were issues with markings changing over time or tags being lost. Eventually it was discovered that each shark's spot patterns are unique to that individual (Arzoumanian *et al.*, 2005) in particular in the 'lateral area behind the gill slits' (Rowat and Brooks, 2012). Arzoumanian *et al.* (2005) developed an algorithm program, originally used for astronomical data into a software called I<sup>3</sup>S that could match *R.typos* spots pattern to those already in the database, allowing for identification. I<sup>3</sup>S is now used by many organisations to look at aggregation sites, population structure and site fidelity. However there are issues in that it does not give indication of the movements of the shark between two sighting areas.

To try and overcome this limited spatial scale, satellite tagging was increasingly used. Pop Up Satellite Tags (PSAT's) are attached to the dorsal fin and data is relayed when the shark surfaces. These tags have shown that great distances can be covered by *R.typos* between aggregation sites and that these routes are often varied (Eckert and Steward, 2001). It is also thought that they can tolerate great temperature fluctuations. During a satellite study by Wilson (2006) many sharks were seen undergoing vertical migration and deep diving behaviour which would therefore also involve extreme temperature variations. There are issues with limited funding for these projects due to the high cost of the tags, as well as issues with premature detachment due to biofouling and mortality (Graham *et al.*, 2006).

Population genetics has also been increasingly studied to see how individuals in separate aggregations around the world are related. Vignaud *et al.* (2014) stated whale sharks exist in two distinct populations with minimal connectivity between the Indo-Pacific and the Atlantic Ocean.

### *South Ari Atoll aggregation site*

The Ari atoll is one of the atolls in the Maldives consisting of many separate islands. Whale shark aggregations in the Maldives (Figure 1) began to be researched by Anderson and Ahmed (1993) when whale sharks were still being hunted. Since then the MWSRP (Maldives Whale Shark Research Programme) have set up their base in Dhigurah; one of the islands in the South Ari Atoll and there has been more research into the sharks in this specific area by them since 2006.

The aggregation in the South Ari atoll comprises of a higher male to female ratio, this is not uncommon and has been seen at other aggregation sites (Eckert and Stewart, 2001). The average shark's size is smaller compared to Ningaloo reef, however there are cases of size segregation between sites suggesting many of the sharks in the South Ari Atoll are juvenile. Riley *et al.* (2010) found that overall 87% of sharks sighted in the South Ari Atoll were immature males. This is consistent with the theory that most global coastal aggregations are usually dominated by immature males of around 4-7m (Meekan, 2006).

Riley *et al.* (2010) also found that there were cases of repeated sightings of the same individuals over a three year period showing some sharks may be faithful to the aggregations site. The same study even found some individuals were re-sighted over a six years period suggesting that these may be permanent members of the area. During a study of the Indian ocean Rowat (2007) and later Donati *et al.* (2016) also confirmed that the South Ari Atoll most likely has a loyal subpopulation of whale sharks. It may be that in some years there are two seasonal groupings, December to March and May to October as found by Riley *et al.* (2010). Anderson and Ahmed (1993) found that whale sharks may be found in the west during the Northeast monsoon, and in the east during the Southwest monsoon. However, recent findings suggest that weather conditions affecting sampling effort and location during the different seasons may account for some or all of these perceived movements.

### 1.3 Effect of environmental factors

It is thought that *R.typus*' global movements are widespread and relate to ocean currents, water temperature, wind speed and timing with productivity events as well as other environmental influences affecting arrival (Compagno, 1984).

The relationship between abundance and these factors have been analysed in several cases. For instance at Ningaloo reef, Wilson *et al.* (2001) found signs of a relationship between SST and abundance. Several other studies also found a relationship with SST such as Hacothen-Domené (2015) and Sequeria (2011) whilst in Mozambique there was no apparent correlation (Rohner *et al.*, 2013). Wilson (2006) found that temperature can be used as a predictor of distributions, which also shows that with climate change increasing aggregation locations could shift. All this knowledge could be used to benefit conservation efforts by predicting whale shark aggregation areas, then altering shipping routes to avoid these areas and lower boat collision risks (Speed *et al.*, 2008).

Wind speeds' influence on sightings was observed by Rowat *et al.* (2009) in the Seychelles, Rohner *et al.* (2013) in Mozambique and Sleeman (2010) in Australia with different effects being found. Rohner *et al.* (2013) also looked at how surface conditions can affect visibility. However it is unknown whether any observed effects are due to behavioural changes in the sharks or to better conditions increasing visibility (Rowat *et al.*, 2009).

Sea level can be used as a proxy to show the Leeuwin current in Ningaloo reef (Sleeman *et al.*, 2010). It is thought that the Leeuwin current could provide a "transport system" for sharks, offering directional cues during their migration (Wilson, 2001). In Mozambique, Rohner *et al.* (2013) also studied the effect of moon illumination and tidal data on *R.typus*.

Larger global scale influencers such as La Nina and El Nino as well as indicators of these events were thought to affect shark abundances (Wilson, 2001).

Finally food availability and productivity is possibly an influencer on movement and aggregation areas (Cárdenas-Palomo *et al.*, 2014). Productivity can be difficult to assess and therefore chlorophyll *a* is often used as a proxy. Sleeman *et al.* (2007)

and Rohner *et al.* (2013) both looked at the effect of chlorophyll a on whale shark abundance.

Understanding the effect of environmental variables on whale shark aggregations is important for understanding why aggregations occur in only some locations.

#### **1.4 Effect of anthropogenic factors**

There are also anthropogenic factors affecting *R. typus*. It was first listed as 'vulnerable' on the IUCN Red List in 2000 and has since been re-categorised as endangered since 2016 (IUCN,2017). There has been a history of killing and finning whale sharks (Stewart & Wilson 2005) in various parts of the world including Taiwan, the Philippines and the Maldives. They were targeted for meat known as tofu shark, for their fins to sell dried, in soup or as trophies and finally to collect their liver oil which is then used to treat wooden boats (Chen *et al.*, 1997). Liver oil was especially popular in the Maldives where a fishery was set up to meet the demand (Anderson and Ahmed, 1993). Hunting has been banned in most parts of the world, including the Maldives, since 1995 (Cagua *et al.*, 2014) due to realisation of the impact upon the species as well as their new importance to the tourism industry and aid in tuna fishing. It is thought however in some areas that illegal hunting is still carried out. In a study on whale sharks at Ningaloo reef it was observed that their average size had decreased over the study decade. This was thought to be most likely due to overfishing pressures (Bradshaw *et al.*, 2008).

There are many cases of whale sharks being caught as bycatch in purse seine and gill nets aimed to catch tuna (Romanov, 2002). Whale sharks can act as an indicator of tuna presence and nets are often set around them, although in most cases they are set free alive there are still cases of mortality (Rowat and Brooks, 2012).

*R.typus* has a great role in bringing tourism to the countries where it is found. It is thought that at Ningaloo reef the whale shark tourism business is worth 12 million dollars (Wilson, 2001). This tourism increases income and jobs to the region and has reduced hunting due to locals making more profit from the sharks this way. Anderson and Ahmed (1993) found that a living grey reef shark in the Maldives could be worth 100 to 1000 times more alive than dead, leading many fishermen to alter their trade.

It has since been found whale shark tourism can bring up to 9.4 million US dollars a year in South Ari (Cagua *et al.*, 2014). However there are impacts on the species from the increased amount of boats and people, especially when people break the code of conducts in place. Avoidant behaviour and deep diving are often observed with human presence (Quiros, 2007) and even if this is not seen immediately , behaviour may be affected over time (Catlin and Jones, 2010). Long term issues could be disruption of natural feeding patterns, avoidance of areas as well as injury or possibly mortality from boat strikes (Quiros, 2007) (Norman, 2005) (Norman, 2002). Boat strikes are often seen to cause injury in whale sharks in the Indian Ocean, however it is difficult to calculate the amount of fatal strikes occurring due to them sinking after death (Speed *et al.*, 2008).

Climate change due to increasing greenhouse emissions could be set to influence *R.typus* in many ways. As seen in other species, distributions could be shifted closer to the Poles (Sequeira *et al.*, 2014) as well as food and suitable habitat availability decreasing (Robinson, 2009). Overall the full extent of issues that whale sharks could face with climate change is unknown, however it is likely to affect their already decreasing numbers.

## **1.5 Aims and Hypotheses**

The aim of this study was to see whether there is seasonality present in the whale shark aggregation in the South Ari Atoll. It is also to see if environmental variables such as sea surface temperature, wind speed, visibility as well as anthropogenic factors like maximum boats and people at the encounter influenced *R.typus* sightings using in situ data collected by the MWSRP.

There has been little research carried out into this area and currently no published literature on the effects of environmental or anthropogenic factors on whale shark abundance in the South Ari Atoll. This study would be useful in understanding the South Ari Atoll aggregation's seasonal cycle as well as the possible environmental drivers of these aggregations. It would also highlight the effects of eco-tourism on the sharks from human and boat numbers and the effects of SST, visibility and wind speed which are likely to adjust with climate change. This information would give an

insight into how vulnerable sharks are to these increasing pressures and may give incentive into preventing further impact to the species.

The Null Hypotheses were:

1.  $H_0$  – Whale sharks abundance in the South Ari Atoll is not seasonal (is constant throughout the year).
2.  $H_0$  – Whale shark sightings are not influenced by environmental factors such as:
  - a) Surface Sea Temperature
  - b) Surface Sea Temperature Anomaly
  - c) Wind Speed
  - d) Visibility
  - e) Maximum number of people at encounter
  - f) Maximum number of boats at encounter

## Materials and Methods

### 2.1 Data collection route

There was one boat used for collecting data by the MWSRP typically 9.00-4.30 Sunday to Thursday inclusive but was dependent primarily on weather conditions. The boat was a traditional Maldivian dhoni with a motor. It had a spotting deck which was where most staff and volunteers spent the searching time. There were usually around 2 staff members, 6 volunteers, one crew member and the captain however this was very varied. The search area for *R.typus* consisted of a track along the S.A. MPA in fairly shallow water over the reef at slow speed (Figure 2). The exact route taken each day was dependent on weather, sea conditions and sightings of *R.typus* by other boats in the area. Start time, end time and break time were all recorded.



Figure 2: Maps created in Google Earth showing a) the Maldives as a whole within a white square area, b) the South Ari Atoll as a whole in the white square area and finally c) the search track for *R.typus* carried out by MWSRP along the S.A. MPA.

## **2.2 Measuring environmental variables**

Environmental variables were measured upon each *R.typus* encounter. The variables measured on the boat included wind speed (Beaufort Scale), Surface Sea Temperature (°C) and visibility.

Wind Speed was recorded using an anemometer by holding it directly into the wind and recording the value. If multiple values were given an average was taken.

Surface Sea temperature was taken using a bucket on deck to collect a sample of ocean water. The bucket was first washed out twice to ensure it was the same temperature as the seawater and had not warmed up in the sun whilst being on the deck. A mercury spirit level style thermometer was then used to record the temperature. SSTa is the difference between each temperature measurement and the average for the 4 year total period. It is used in addition to SST as it allows a positive or negative difference from the 4 year mean to be seen.

Visibility was calculated using a black and white Secchi disk which was placed into the water column and lowered until no longer visible. It was then pulled up until the white parts of the disk were visible; this depth was then recorded using the 0.5m and 1.0m markers on the disks' rope. The disk was then pulled up until the entire disk, both black and white parts, could be seen and again this depth was recorded using the 0.5m and 1.0m markers on the rope as it was pulled back on deck. Dependent on the depth recorded, visibility was then classified into Good, Average and Poor which were further quantified into a scale of 1-3 (with 1 being Poor) for statistical analysis.

## **2.3 Measuring *R.typus* encounters**

During the encounter behaviour type, swimming type, code of conduct violations, change in direction by the shark, length, sex and injuries were all taken note of.

### *Spotting *R.typus**

*R.typus* were found by looking for dark shadows beneath the surface from the spotting deck on the boat by volunteers and staff members. On sighting a shark the spotter called loudly and pointed to alert others on deck as well as the captain who would then manoeuvre the boat nearer the shark. Someone remained on the top

deck pointing and recording initial data such as time, coordinates and the environmental variables. The other people on board put on snorkelling equipment and after asking the captain if it was safe, entered the water. On reaching *R.typos* the first person raised their hand as a signal to others. The arrival of the first person was when the encounter began unless there were already snorkelers from dive and excursion boats in the water with the shark before MWSRP arrived. If others were already present the number of people and boats already at the site were counted.

#### *Human and Shark behaviour*

Behaviour was classified into evasive, cruising, inquisitive and feeding, multiples of these could be used for one encounter. Cruising behaviour was when the shark was swimming without paying any attention to people in the water. Feeding was when the shark was undergoing any form of feeding. Evasive was when the shark was actively trying to avoid the people in the water, often by diving deeply or changing direction abruptly and Inquisitive was when the shark was actively engaging with people in the water, often swimming towards and near them. Swimming was split into slow, fast or banking and change of direction into steep, gradual or circular. Human interaction was monitored to see if anyone on the encounter, including members of the public who were not with the MWSRP, were breaking the code of conduct. This included getting closer than 4m to the shark, touching the shark, using flash photography or obstructing the shark.

#### *Biology of Shark*

Length was estimated or measured by two people using a tape measure for a more precise measurement. *R.typos* was sexed by swimming beneath the caudal fin in order to view the sexual organs. Injuries were spotted and noted as old or new in the field depending on when the individual was last spotted by the staff in the water. This may have been changed when the individual was identified as all past injury information would have been accessible. ID shots were taken of the left hand side and right hand side of the area between the 5<sup>th</sup> gill slit and the posterior edge of the pectoral fin with an underwater camera. These ID shots were later used to identify the sharks encountered using I<sup>3</sup>S. A triangular area was appointed between the top of the 5<sup>th</sup> gill slit, bottom of the 5<sup>th</sup> gill slit and the point on the bottom edge of the shark that runs parallel to where the pectoral fin ends and the brightest twelve spots

are highlighted. The software then ran and came up with a list of likely matches from which an accurate identification was made.

#### *Human presence at encounter*

The number of boats and people at the encounter were measured on arrival and throughout the encounter in order to record the maximum present. These were counted by the staff still on board the spotting boat as well as people in the water to get the best chance of an accurate value. Then maximum and minimum number of boats and people throughout the encounter were noted down.

## **2.4 Data input**

At the end of each research day the raw data collected that day was entered into spreadsheets on two MWSRP laptops; one for data input and one for photo ID and Big Fish Network (BFN) MWSRP log. The MWSRP also used the BFN to gain encounter information from other groups patrolling the S.A MPA collecting data such as Island Divers, Boutique Beach resort, Manta Trust, Maafushivaru resort, LUX resort, Diamonds and Constance resorts, Four seasons resort , Vakaru falhi resort and local diving liveboards including the 'Carpe Diem' which were then added into the long term database once approved.

## **2.5 Statistical Analysis**

Sigma Plot was used to analyse the results of this data. Pearson Product Moment correlations and Linear Regressions were used to measure if there was a relationship between sightings and environmental and anthropogenic variables. A T-test was used to test if seasonality was present in the South Ari Atoll population.

## Results

### 3.1 Sightings Analysis

Overall, over the 4 year period from January 2013 to December 2016, a total of 2,367 whale shark encounters were recorded over 815 searching days.

Due to the fact that each month the number of searching days varied, encounter results were standardised by calculating Sightings Per Unit of Effort (SPUE) by dividing the encounters that month by the days spent searching.

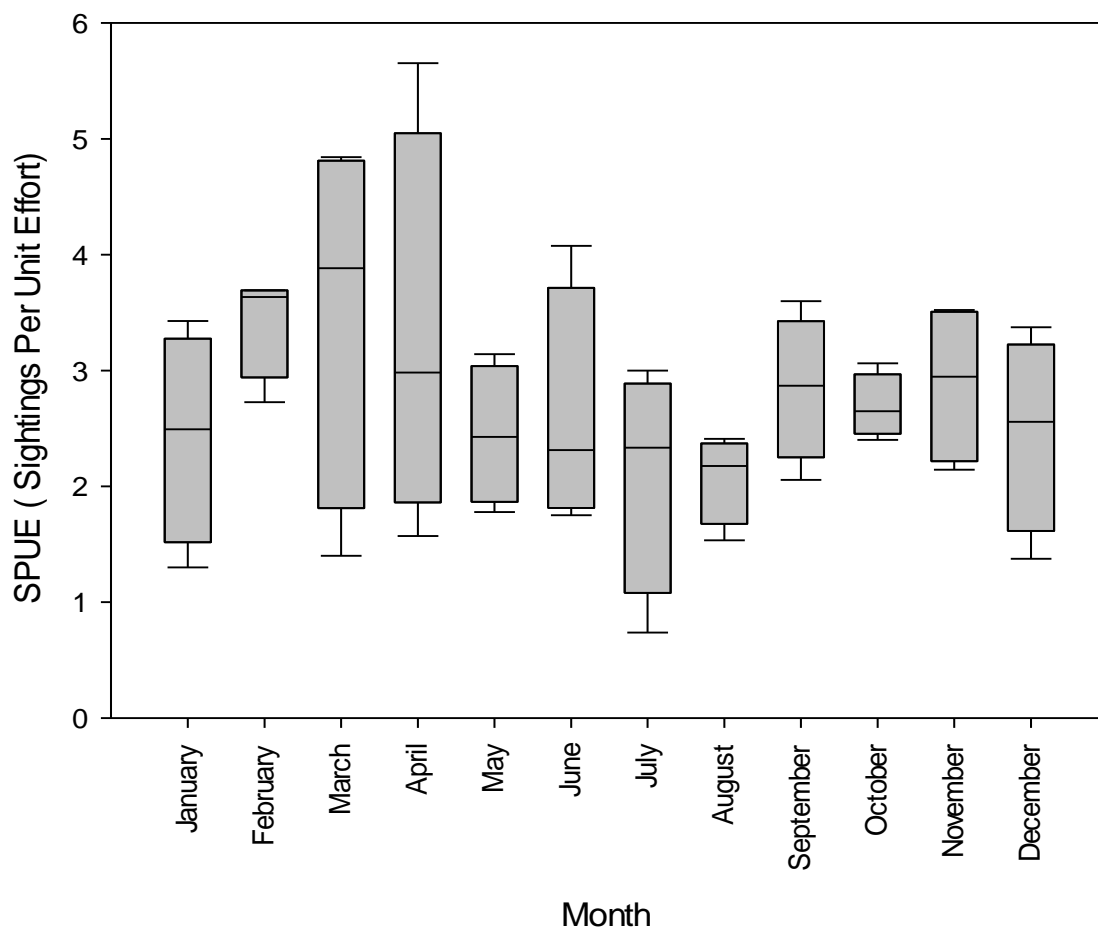


Figure 3: Box plot showing monthly SPUE (Sightings Per Unit Effort) averaged for the 4 year period from January 2013 to December 2016. The upper and lower boundaries of the grey boxes indicate the 75th and 25th percentiles; the line inside the boxes indicates the median value and whiskers extend to the full range.

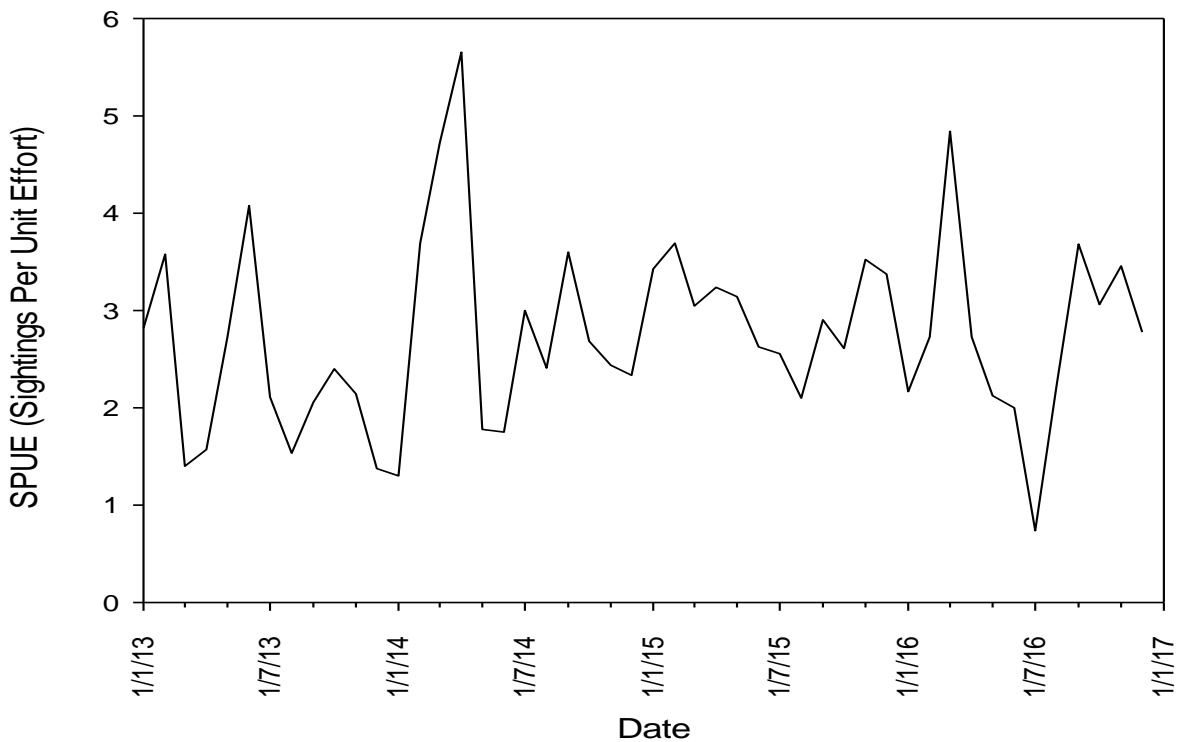


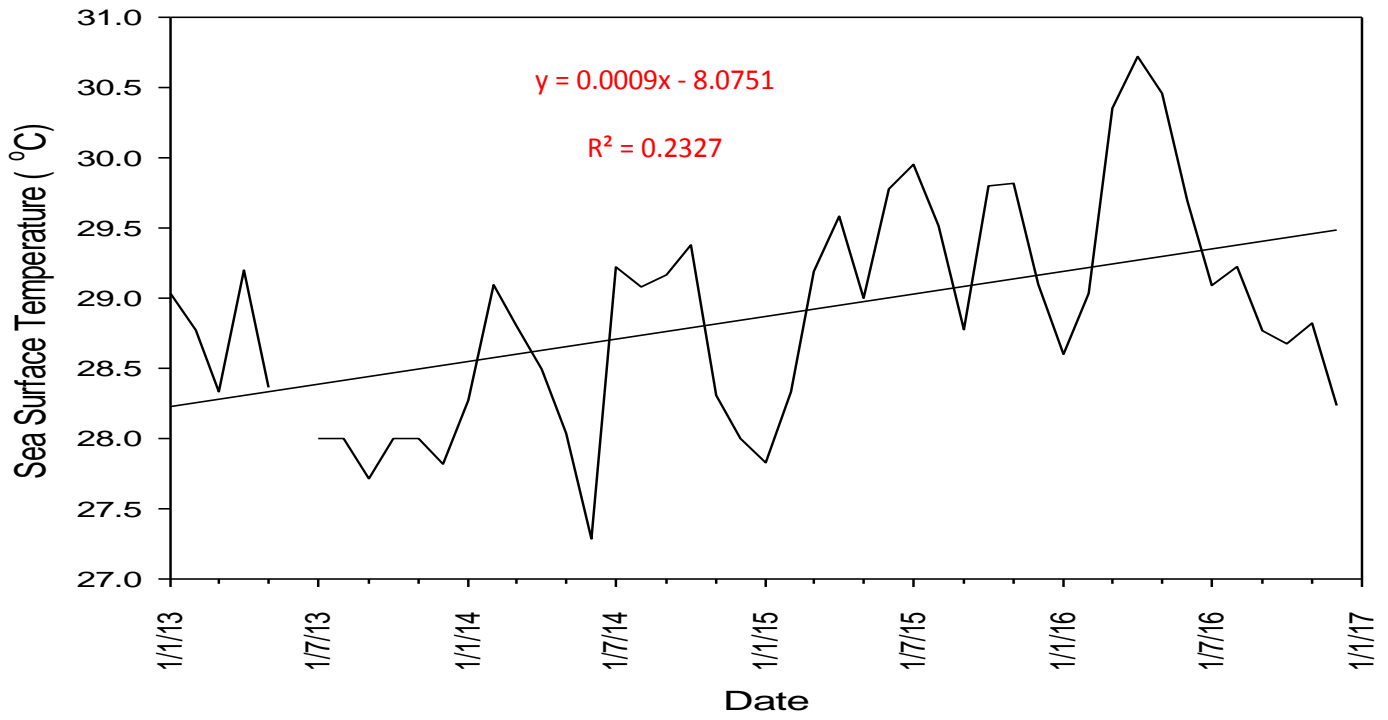
Figure 4: A time series of monthly SPUE (Sightings per unit effort) over the 4 year period from January 2013 to December 2016. Both graphs show data gathered from the South Ari Atoll area.

In the graphs there appears to be a decrease in sightings in May – August during the Monsoon season (Figure 4). This seems to be shown in the time series as well however, there is also a slight decrease around December/January. This is not shown as clearly in the box plot due to the large amount of variation.

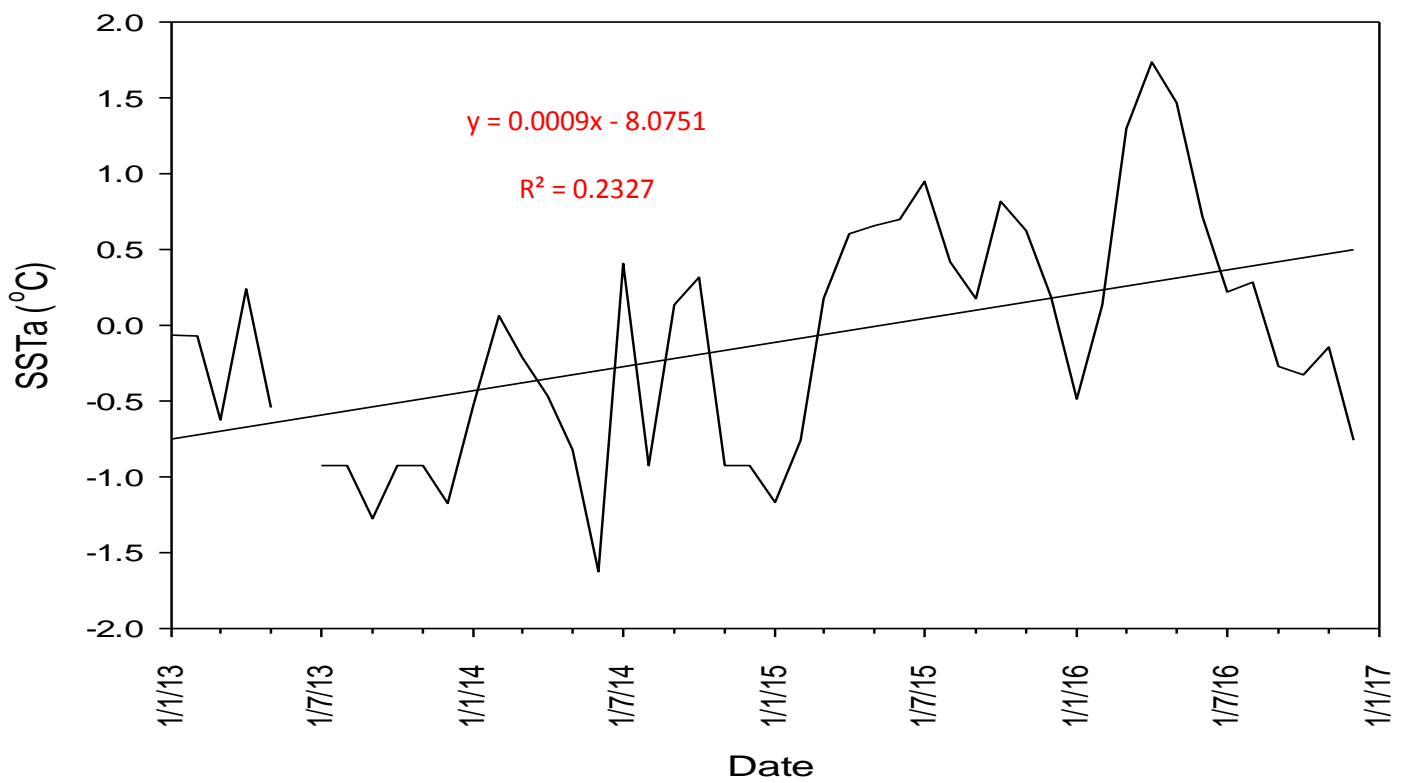
It appears that overall there is low seasonality and there is no significant difference in SPUE between months suggesting that the population in the South Ari Atoll is fairly consistent throughout the year.

### 3.2 Environmental factors

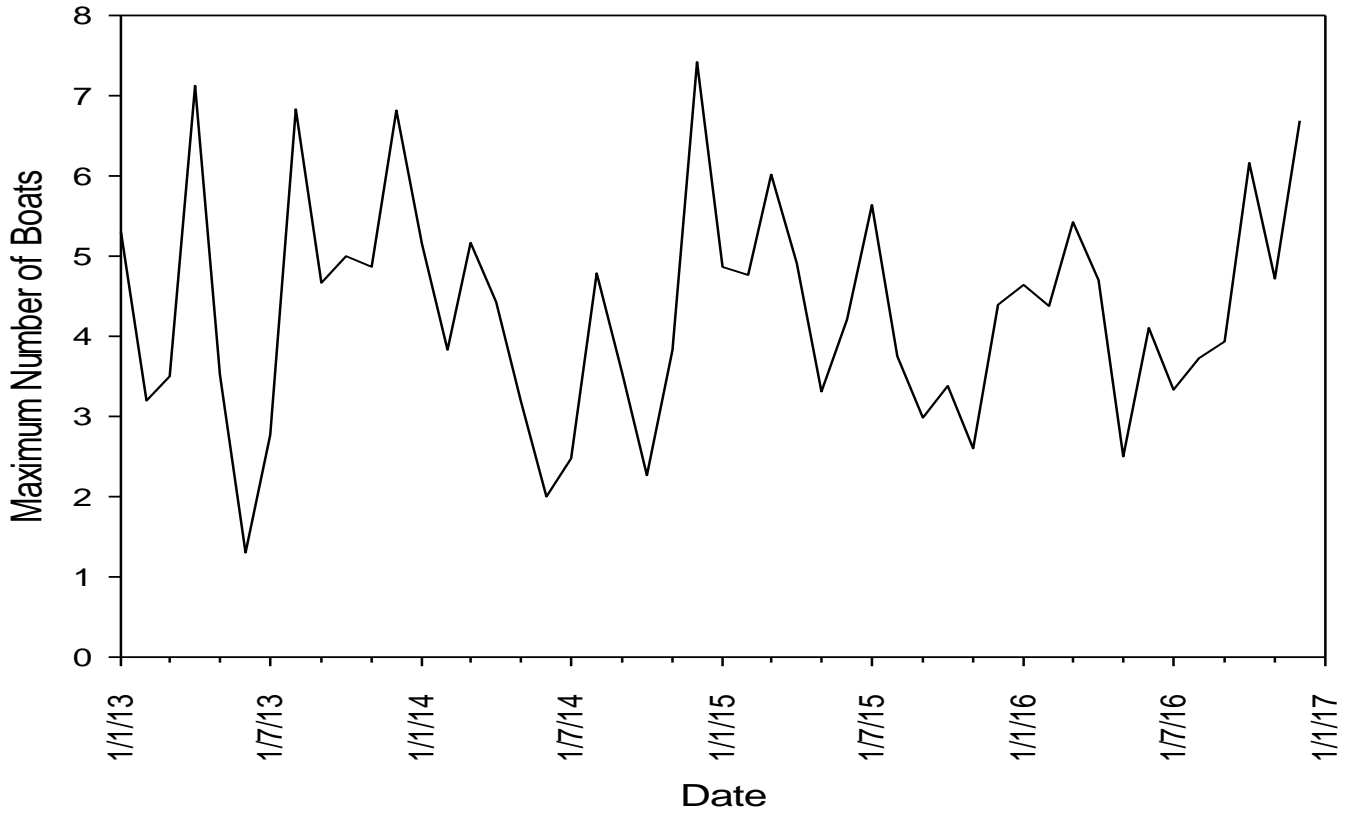
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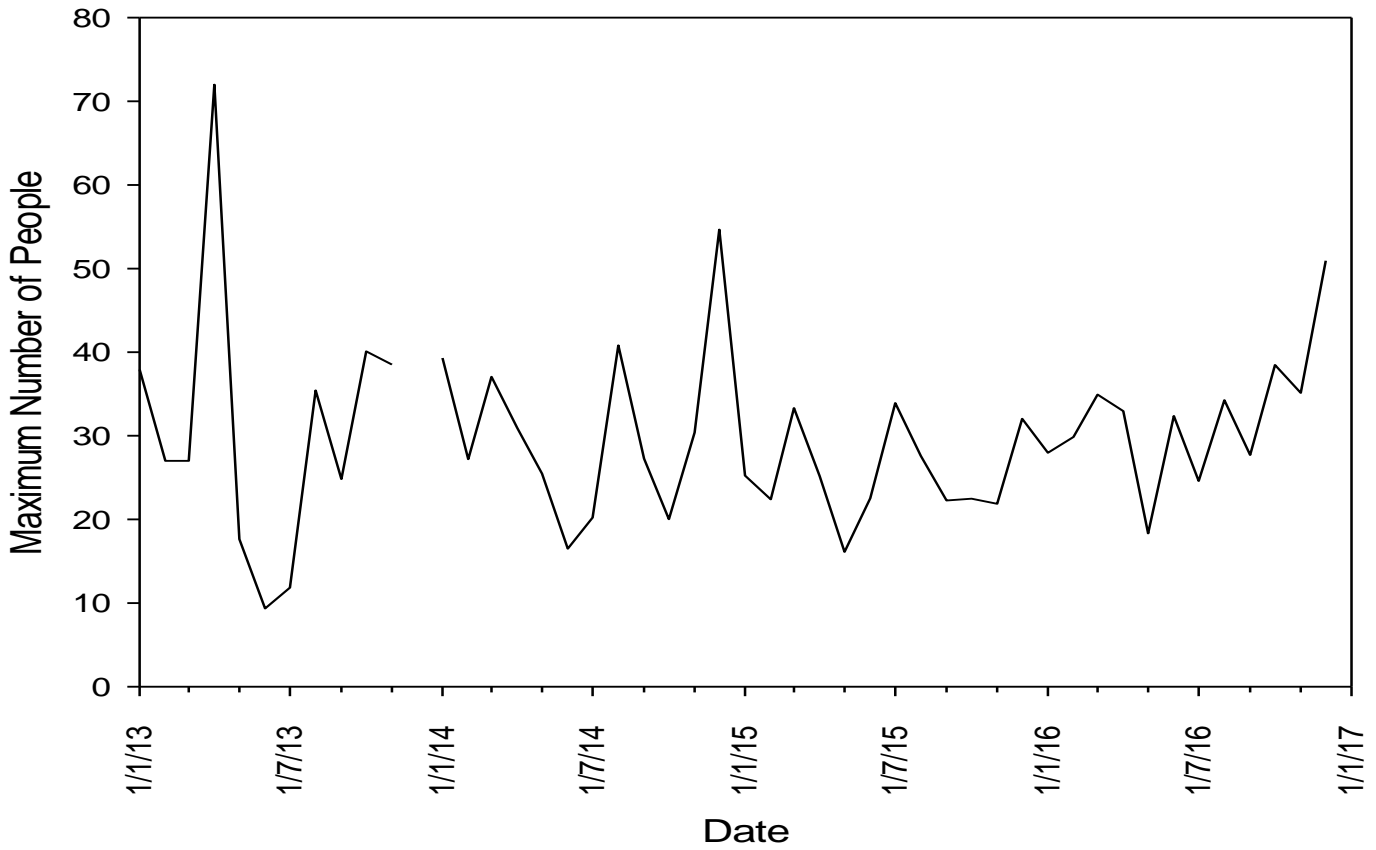
b)



c)



d)



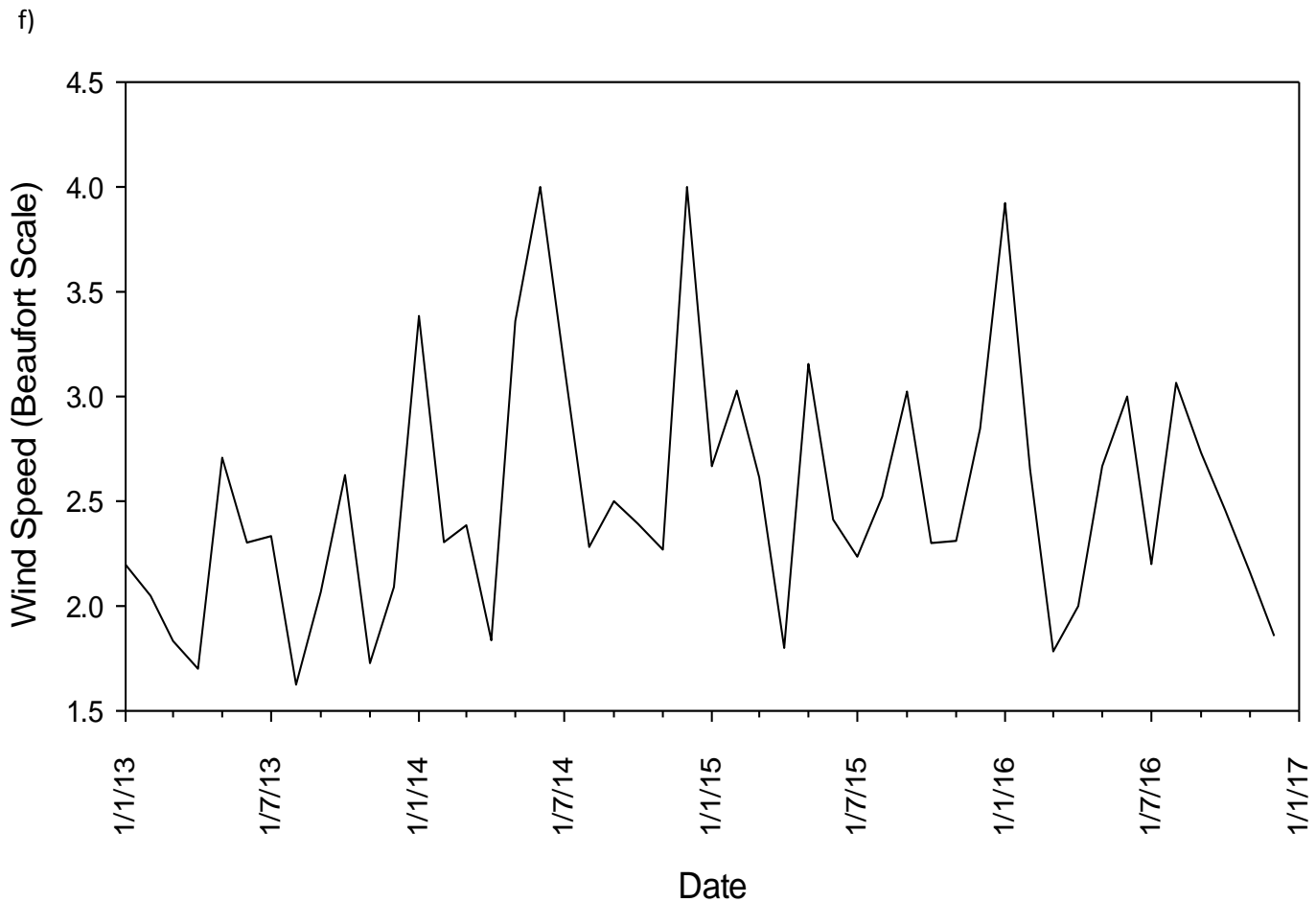
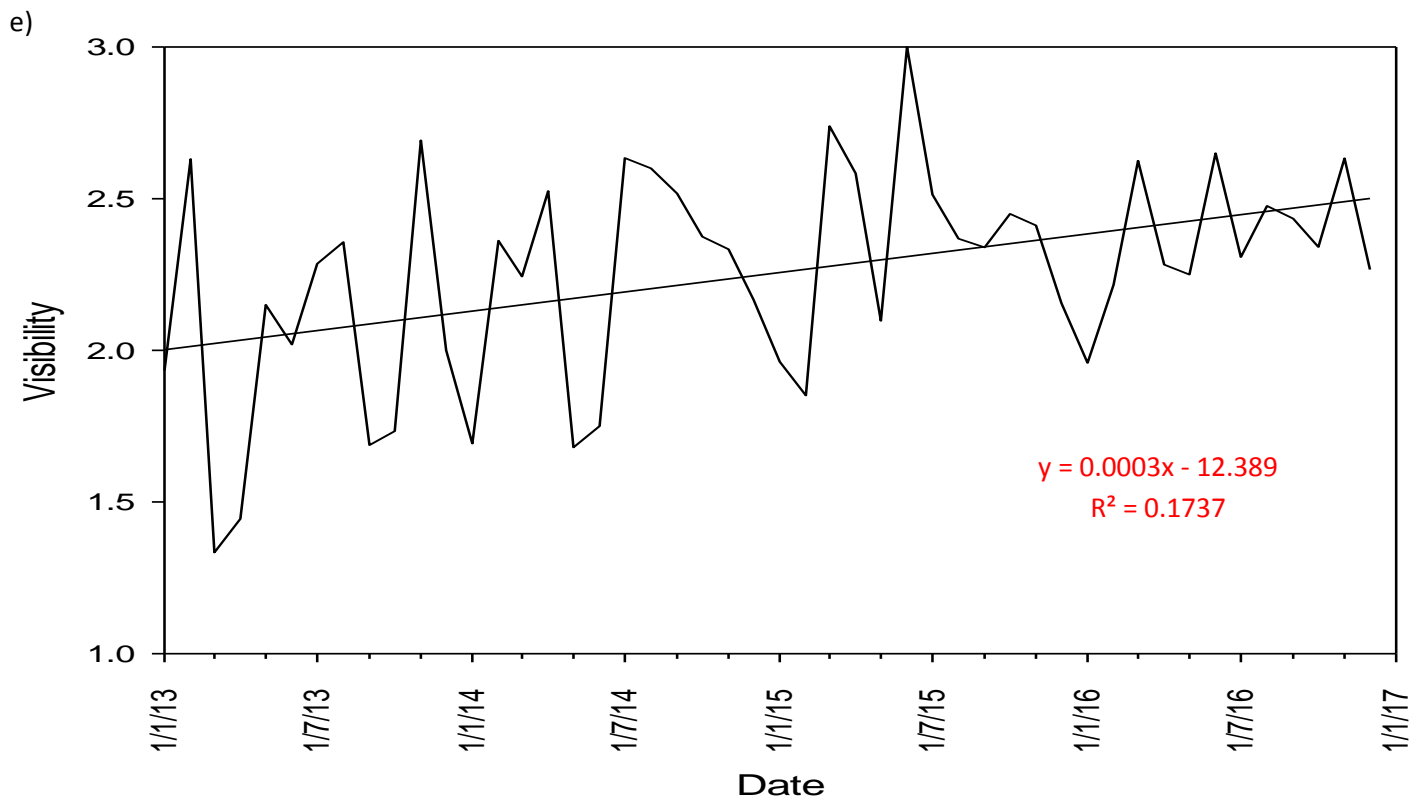


Figure 5: Time series of the monthly average a) SST b) SSTa c) Maximum Boats d) Maximum People e) Visibility f) Wind Speed over the 4 year period from January 2013 to December 2016 in the South Ari Atoll area. Linear regression lines were added if they showed a trend.

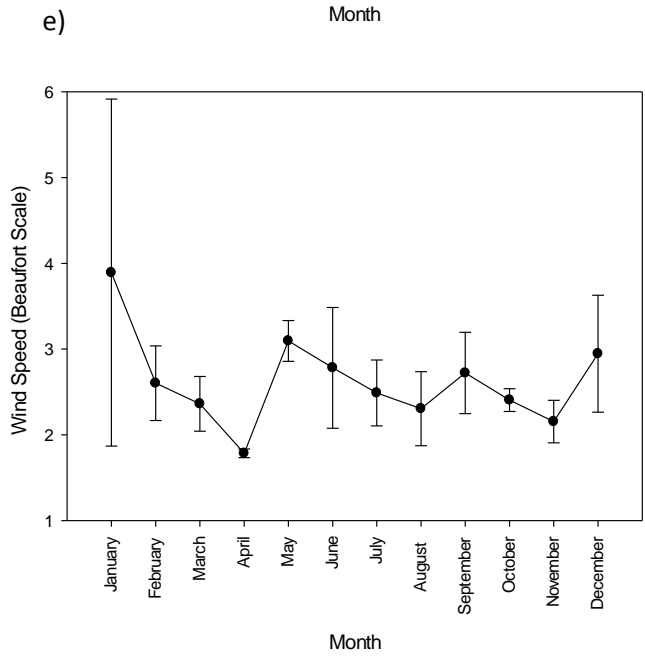
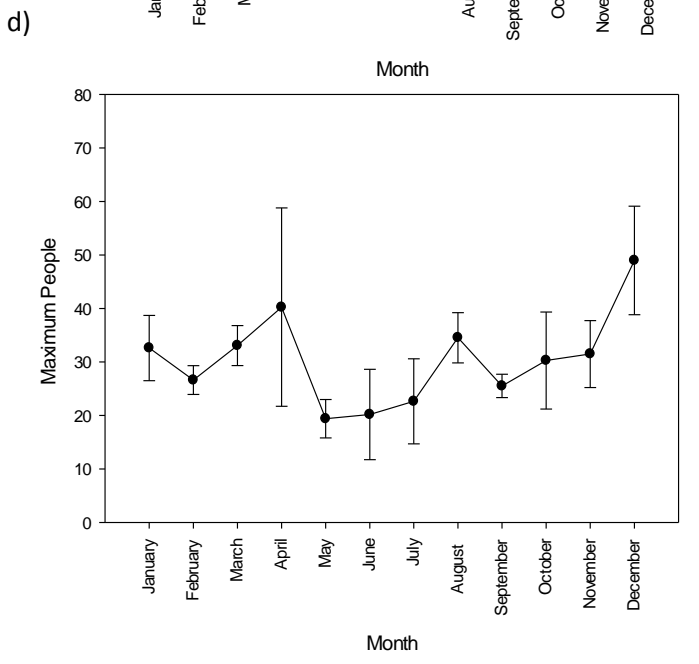
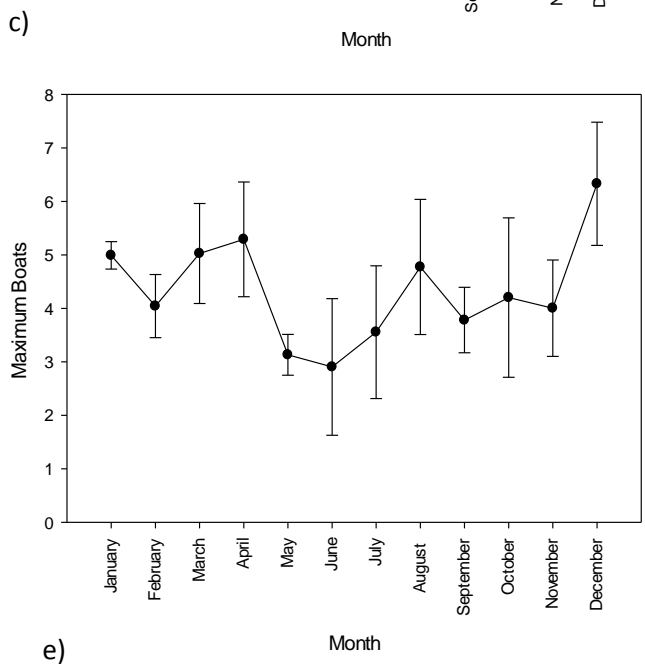
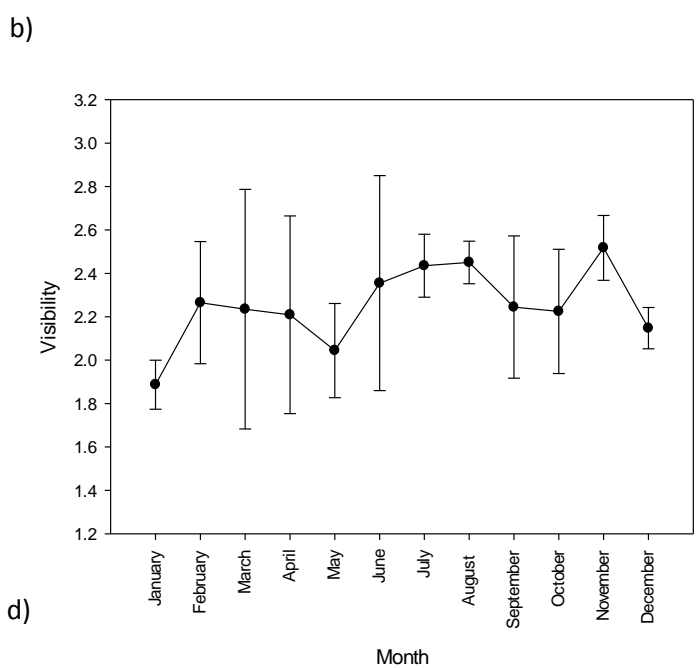
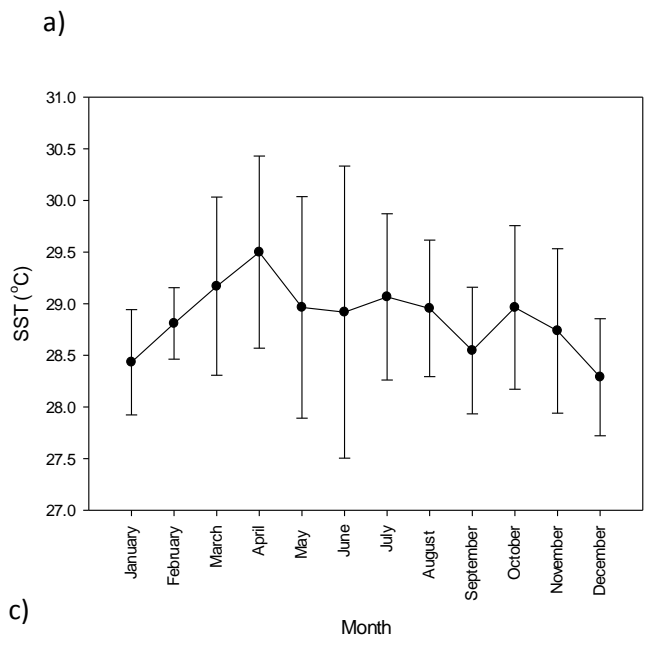


Figure 6: A composition of scatter line plots with error bars showing average monthly a) Sea Surface Temperature b) Visibility c) Maximum Boats d) Maximum People e) Wind speed averaged for the 4 year period from January 2013 to December 2016 in the South Ari Atoll area. Error bars show the upper and lower standard deviation from the mean (data point).

Both the time series and monthly average graphs were combined to look at likely variable patterns.

Sea Surface Temperature appeared to be fairly uniform throughout the year with very small changes between months. However there seemed to be a slight decrease in December – January. The linear regression line showed that SST increased over the 4 year period. The missing values in both SST and SSTa meant that no data was taken that month.

Wind Speed appeared to decrease in the early months of the year around February – April and again in October-November with increases in monsoon months and December-January. When processing the data extreme values over 7 were removed due to issues with other centres giving encounter data recordings in km/h as opposed to the Beaufort scale.

Visibility appeared to decrease in March –May and stayed fairly constant throughout the rest of the year. There also appeared to be a slight decrease in December/January. The linear regression line shows that visibility has increased over the last 4 years.

Maximum number of people in the water at the encounter appeared to be fairly uniform throughout the year however had a decrease around May – July during the monsoon season and a peak in December. The missing values meant that no data was taken that month.

Maximum number of Boats at the encounter appeared to follow the same pattern as people with a decrease in the monsoon season and a peak in December.

### 3.3 Comparison of Satellite SST to in situ SST

Thermometer readings are susceptible to error and can sometimes therefore be inaccurate. In this case NASA MODIS Aqua 11 $\mu$ m satellite data were compared to in situ SST data from 8 days over the course of 4 years. This was done to test the reliability of the in situ measurements.

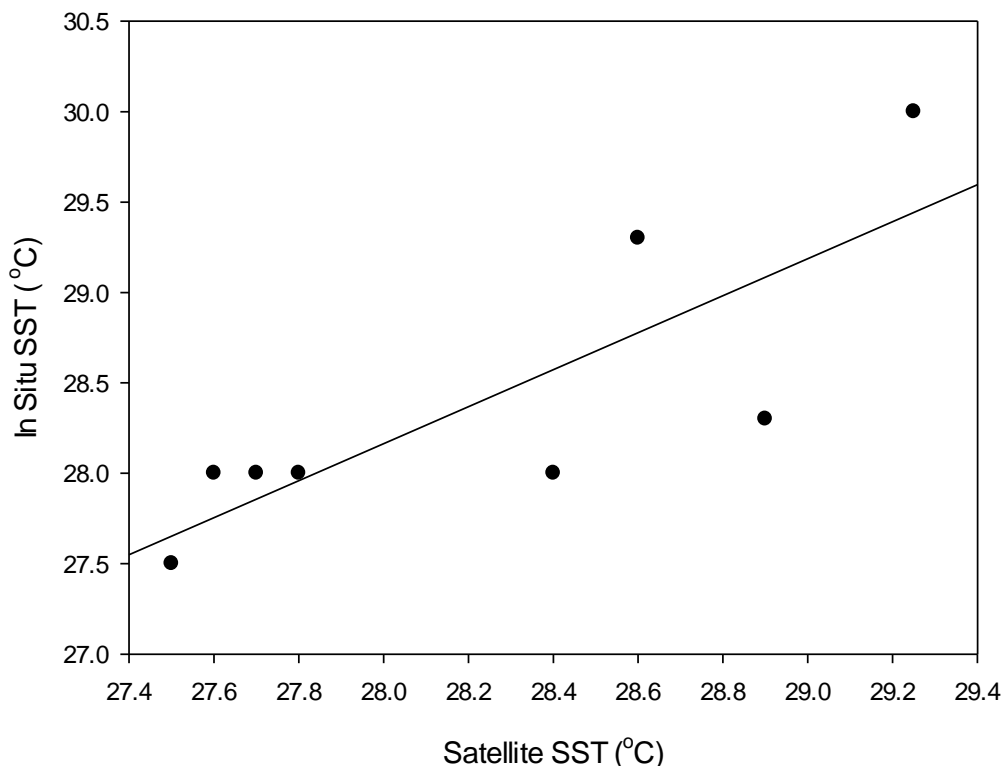


Figure 7: A scatter plot comparing in situ data to NASA MODIS Aqua 11 $\mu$ m satellite data from 8 days 6 months apart (or as close as possible). Both in situ and satellite data were plotted (11<sup>th</sup> January 2016, 23<sup>rd</sup> July 2016, 3<sup>rd</sup> January 2015, 9<sup>th</sup> July 2015, 4<sup>th</sup> January 2014, 15<sup>th</sup> July 2014, 8<sup>th</sup> January 2013 and 19<sup>th</sup> July 2013) from the South Ari Atoll area.

The values were obviously different however there was a strong significant correlation from a Pearson's Product Moment correlation ( $p=0.0140$ ).

A T-test also showed that there was no significant difference between the in situ and satellite data ( $p= 0.660$ ).

### 3.4 Relationships between Variables and Sightings

Statistical analysis was carried out using Sigma Plot 13.0. A Pearson Product Moment correlation showed that maximum people ( $p = 0.0224$ ) and SSTa ( $p = 0.0260$ ) were both significant. No other factors had a significant result. A Multiple Linear Regression also showed that maximum people ( $p = 0.010$ ) and SSTa ( $p = 0.026$ ) could both predict SPUE.

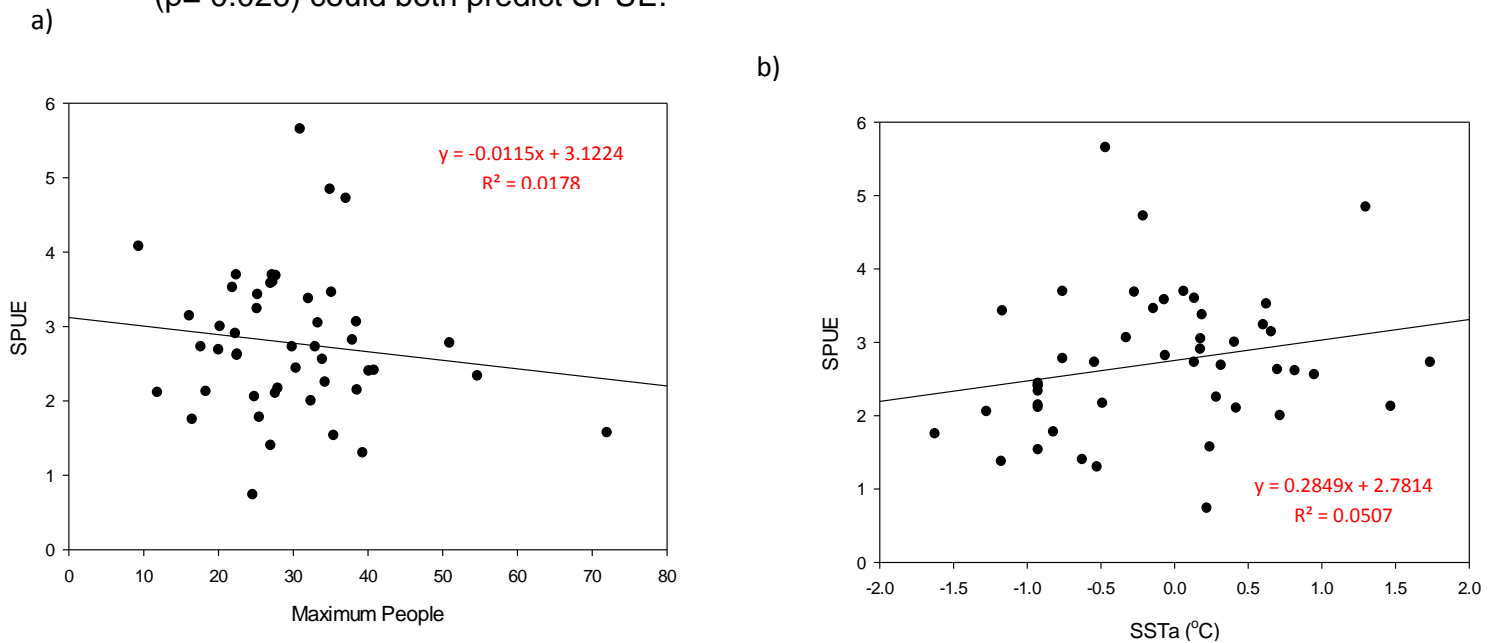


Figure 8: Scatter plots showing the relationship between SPUE (Sightings Per Unit Effort) and a) Maximum People b) SSTa. The data points are monthly averages over the 4 year period from January 2013 to December 2016 in the South Ari Atoll area and a linear regression line has been added to show if a trend between the two occur,

SPUE decreases with maximum people which is confirmed to be significant by the statistical analysis.

SPUE increases with SSTa which was confirmed by statistical analysis. This data was smoothed with a five day moving average for both SSTa and SPUE to remove inconsistencies before statistical analysis (The graph shows unsmoothed data).

It appears from the  $p$  and  $R^2$  values that maximum people has a very slightly larger influence on SPUE than SSTa.

### 3.5 Relationships between People and Behaviour

After discovering that maximum people in the water impacted whale shark sightings, behavioural changes with number of people in the water were investigated. The behaviour was divided into Cruising (C), Feeding (F), Evasive (E) and Inquisitive (I).

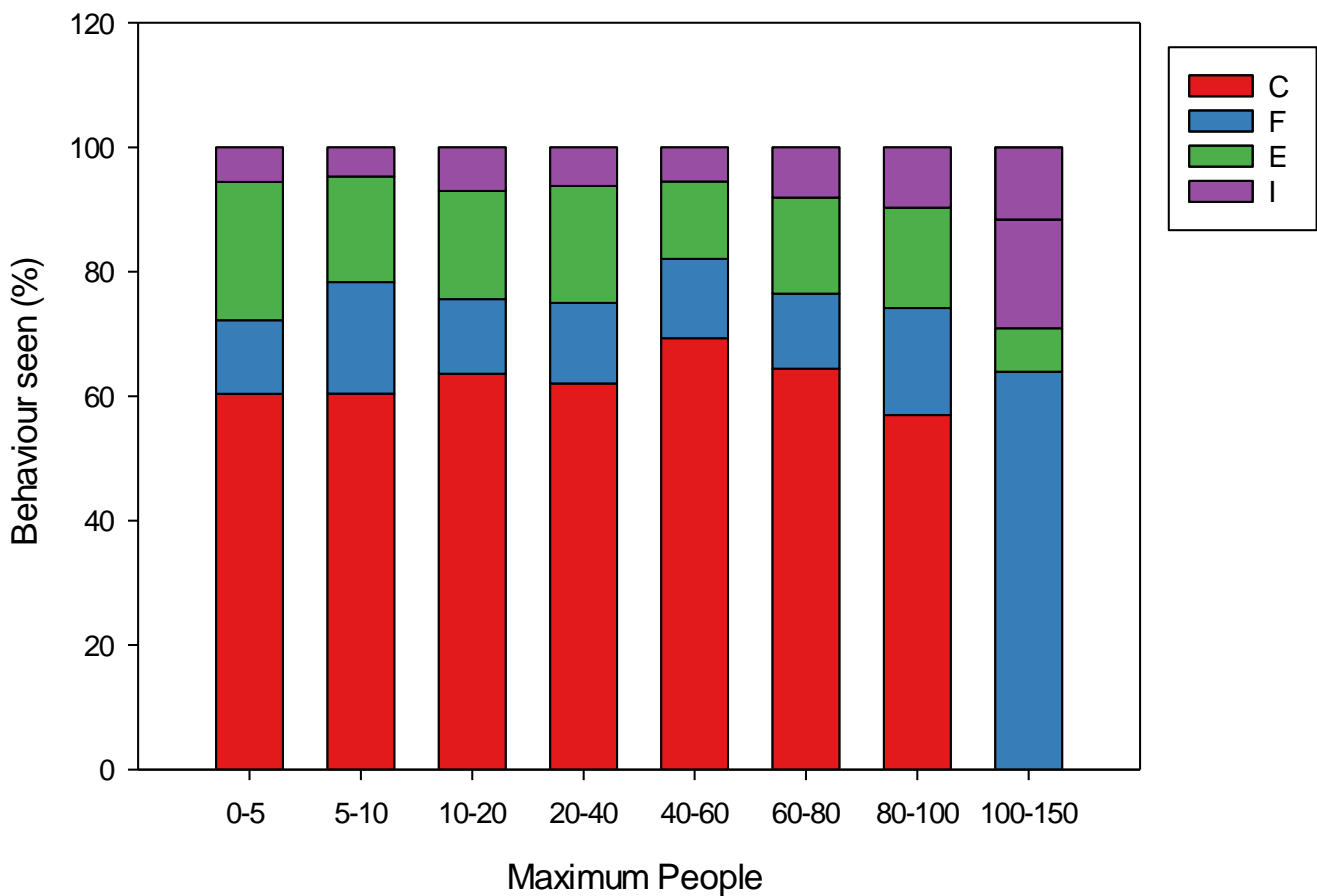


Figure 9: Stacked histogram showing the average percentage of each behaviour in each category of number of people over a 4 year period from January 2013 to December 2016 in the South Ari Atoll area.

The graph shows that Cruising is the most prominent behaviour and seems fairly uniform despite the number of people in the water at the encounter. Feeding also appears to be fairly uniform as does evasive behaviour. Inquisitive behaviour is the only one that appears to change, increasing with number of people.

## **Discussion**

### **4.1 Seasonality**

This study showed there is no difference between any months in the four years of data tested. Therefore it can be assumed in this case that there is no seasonal influence on whale shark numbers in the South Ari Atoll. The whale shark population appears to be more or less consistent throughout the year, indicating that there is a subpopulation of whale sharks which remain in or near the South Ari Atoll throughout the year that are loyal to the area as also found by Rowat (2007). This membership behaviour has been seen in other areas such as Ningaloo reef, the Seychelles and Djibouti with varying average membership years (Meekan, 2006) (Rowat *et al.*, 2011). Donati *et al.* (2016) found singularly high numbers of site fidelity and residency in the South Ari Atoll compared to other similar aggregations. They also saw no seasonal peak in sightings which is in line with the findings in this study. It was considered that these aggregations are occurring due to responses to external drivers.

The results here give rise to the thought that there is a somewhat resident population that stay within the Maldivian area although more research would be needed to confirm this. It would also seem that the fluctuations in aggregation abundance is caused by these sharks moving into the South Ari Atoll when environmental variables favour this area as opposed to any set seasonal movement.

### **4.2 Variables influence on whale shark abundance**

#### *Sea Surface Temperature*

Sea surface temperature was shown to increase over the 4 year period from January 2013 to December 2016. Although this may be an indication of global warming, it is too short a time frame to attribute this increase solely to climate change (Robinson, 2009) and is more likely due to natural variation. It appeared to stay fairly constant throughout the year only varying slightly which is consistent with what is expected in the South Ari Atoll and Maldives region.

SSTa (Sea surface temperature anomaly) is the difference between daily SST and average SST for the four year study period. SSTa appeared to have a positive significant correlation ( $p=0.026$ ) and linear regression ( $p=0.026$ ) with SPUE on a local scale meaning that when it increases, so do sightings. This appears consistent with other literature and studies that found SST and SSTa influence migration patterns as well as local scale sightings.

Abundance was shown to weakly correlate with Sea Surface Temperature in Ningaloo reef by Wilson *et al.* (2001). This was thought to be due to sharks being restricted to warmer water masses by thermal boundaries. Wilson *et al.* (2006) found that sharks tagged at Ningaloo Reef experienced temperature ranges from 4.2- 28.7. Similar temperature range of 3.4–29.9° C were also found in the Western Indian Ocean by Brunnschweiler *et al.* (2009) who also gave evidence of deep diving behaviour of up to 1,200m in *R.tpyus*. It is thought that the purpose of this vertical migration may be to gain information for navigational purposes or more likely for feeding. A study in the Indian Ocean by Sequeira *et al.* (2011) found that 65% of whale shark sightings occurred in waters between just 27.5 and 29 °C, and 90% between 26.5 and 30 °C. This shows that although they can tolerate a very wide range of temperatures they prefer to stay within a narrow range to avoid metabolic limitation in temperatures below this range as well as elevated metabolic rates and increased prey demand in temperatures above the band. They have been observed leaving this range, however this is most likely only temporarily for feeding or other essential activities. This behaviour is consistent with other large sharks such as white sharks (Boustany *et al.*, 2002). Wilson *et al.* (2006) also found that temperature can be used as a main predictor of distributions, showing that with climate change increasing aggregation locations could shift. Hacohe-Domené *et al.* (2015) found their data collected in the Mexican Caribbean showed an increase in SST also caused an increase in sightings. Hilbourne (2014) found a positive correlation of abundance with SSTa and attributed it to the fact that sharks wish to stay within a temperature range that benefits them metabolically. Anfonso (2014) studied the presence of whale sharks in the Azores, a fringe habitat, and found that increasing ocean temperatures were causing them to move further North. The study overall stated that SST was a main predictor of whale shark abundance in the area. Off the coast of Tofo in Mozambique, Sea Surface Temperature was measured and

although expected to have a significant effect on sightings, did not. However the researchers claimed this could be due to the remotely sensed surface temperature data they collected not being adequate (Rohner *et al.*, 2013).

SSTa is a proxy for SST and was most likely to show a correlation while SST didn't because of the small differences and also due to the fact SSTa was smoothed with a moving average. We can assume however that SSTa equates to SST and that the other studies finding SST to be a factor in whale shark abundance are applicable here.

SSTa correlating positively on a local scale with whale shark abundance in the South Ari Atoll is most likely due to the sharks preferring to stay within a specific temperature range that they can function best in metabolically. It could also be attributed to stratification being more prominent at higher temperatures allowing for increased primary production and therefore higher prey abundance. Food availability has already been seen to be a factor in whale shark aggregations in Mexico and the Caribbean (Hacohen-Domené *et al.*, 2015) (Cárdenas-Palomo *et al.*, 2014). Finally however it has been suggested by the MWSRP that the sharks found in the area are deep diving for feeding as many other papers have found in other areas as mentioned above. This correlates with data they found that only 15.99% of sharks encountered on the S.A. MPA have shown any feeding behaviour meaning they are indeed most likely undergoing vertical migration to find prey. During these deep dives it has been found that whale sharks will encounter much lower temperatures (Brunnschweiler *et al.*, 2009). Therefore the MWSRP have suggested that whale sharks are using the shallow S.A. MPA area for thermal regulation in order to warm up their bodies after these dives (Maldiveswhalesharkresearch.org, 2017).

### *Wind Speed*

Wind speed is measured by the Beaufort scale and appeared to be very slightly higher in the July-August months, which is also the monsoon season. This aligns with the fact that wind is likely to change in direction and strength over the monsoon season (Anderson *et al.*, 2011). However these observed changes are very small and there is high variation especially in January months so the pattern is hard to

distinguish.

There appeared to be no interaction between wind speed and whale shark sightings in this study. Other research such as Sleeman (2010) found that wind shear, a proxy for wind speed and direction, affected abundance positively at Ningaloo Reef. This could be due to the fact it causes upwelling thus increasing food for *R. typus*. Rowat *et al.* (2009) also found a correlation between wind speed and abundance during aerial surveys in the Seychelles however this was negative. It was thought in this case that higher wind speed would cause surface disturbance and therefore alter the sharks' behaviour. It was also suggested that more disturbed surface conditions would affect the viewer's ability to spot sharks. There is evidence that wind direction and speed changing due to season can cause sharks to migrate from one side of the atoll to the other (Anderson and Ahmed, 1993) showing it's part in local migration. This study found no relationship between wind speed and whale shark abundance. This could be due to data collection limitations however it is more likely that the wind speed had no effect on abundance in this case.

### *Visibility*

Visibility appears to slightly decrease in around May time. This would perhaps coincide with spring bloom time which is known to reduce water visibility due to increased organisms in the water. It may also be due to increased sediment movement due to varying wind directions after the monsoon seasons.

Visibility seemed to increase over the 4 years of data; this may be due to decreasing plankton in the water making the oceans clearer. Despite increasing SST usually increasing primary production, climate change is affecting blooms and plankton in different ways and therefore this is plausible.

Rohner *et al.* (2013) looked at how surface conditions can influence sightings and found a smaller wave size correlated with increased sightings. It is unknown whether this is because of behavioural change in the sharks; such as them swimming lower in rough conditions or if it is due to calmer conditions increasing visibility for the people spotting (Rowat *et al.*, 2009). In this case there was no pattern between visibility and whale shark sightings however it is likely it would still be impacting whether sharks are being spotted.

## *Tourism*

There are lower numbers of boats and people present at encounters during monsoon months, most likely due to decreased tourism. There appears to be a decrease around May – July which is consistent with lower tourism season. There is, however, a peak around December which is consistent with the high tourism season due to Christmas holidays and good weather.

In this case it was found that the average number of people in the water per day negatively correlated with the number of sightings that day significantly ( $p=0.0224$ ) however boats in the water did not. There was also a significant negative linear regression ( $p=0.010$ ) showing that number of people were affecting the sightings. It was thought that these two factors would have the same effect however this is not the case. There have been other studies into the effect of tourism on whale sharks and other species.

Speed *et al.* (2008) found whale sharks in the Indian Ocean are often seen with boat strike injuries such as lacerations from propellers and blunt force trauma from the bow of boats. There are also amputations that appear to be caused by vessels. The most common area of injury in this case was the caudal fin. Whilst in the 20<sup>th</sup> century deaths by boat strike were fairly common they appear to be rarely fatal nowadays, however this could be due to under recording and the corpses sinking too fast. It would be expected that boats would therefore be avoided by whale sharks; however it was not seen in this study.

Bejder *et al.* (2006) found that dolphin abundance in a tourist populated area decreased, most likely due to sensitivity to human interactions driving them away from the area. In the Philippines whale sharks have been known to make abrupt direction changes if humans are present while they are feeding, meaning that human presence is disturbing their basic natural behaviours (Quiros, 2007). They have also been seen to change course in order to swim around or away from humans (Martin, 2007).

When analysing the behaviours displayed by sharks the opposite of the expected occurred, it appeared that inquisitive behaviour actually increased with number of people in the water while all other behaviours remained fairly constant. There could

be several explanations for this. Firstly the sharks may be more inquisitive about large groups compared to smaller groups, however this doesn't seem to align with other research. It is more likely that the number of people doesn't directly cause stress but instead the people's behaviour on the encounter. Quiros (2007) found that in the Philippines, sharks behaviour was affected by people's proximity, touching, flash photography and obstruction. Although it would be expected that in groups of more people there would be more code of conduct violations it is not necessarily the case. Watkins (1986) found that in several species of whales behaviour changed greatly, but gradually after human presence. Sorice *et al.* (2003) also suggested a similar idea that implications of ecotourism on wildlife are not always identified due to the reactions not being immediate (Catlin and Jones, 2010). This may have been the case in this study, the sharks behaviour does not change instantaneously on human presence however it is likely to avoid the reef when there are many people present in the future. This is also reinforced by the fact that whale sharks have long lifespans meaning that these animals may not show these effects on site but an avoidance response may develop over time.

In this case due to the sampling area of the S.A. MPA being fairly small, it is likely if lots of people are swimming on the reef, possibly even on whale shark encounters, then sharks are more likely to avoid moving onto the reef that day. It may not necessarily be that the shark wishes to avoid higher numbers of people but just people in general. It is possible the increased potential of seeing people or the increased noise when there are higher numbers of people in the water better alerts the sharks to their presence. In other studies it is seen that whale sharks will avoid people, although mostly this has been during an encounter when the sharks deep dive or bank away on being approached by people. Perhaps this study shows that the sharks actively avoid people before even being approached or seen by them.

#### *Further factors to consider*

Additional factors to look at would have been global scale factors such as Southern Oscillation Index (SOI), El Nino Southern Oscillation (ENSO) or ONI (Oceanic Nino Index) which all give indication of El Nino and La Nina events occurring. SOI was found to correlate with shark abundance at Ningaloo Reef by Sleeman (2010) and

Wilson *et al.* (2001) while ONI was found to correlate negatively with abundance in Hilbourne (2014). It was thought by Wilson *et al.* (2001) that abundance was higher in La Nina events than El Nino however this pattern could not be confirmed. Hacothen-Domené *et al.* (2015) and Cárdenas-Palomo *et al.* (2014) also suggested that aggregations, at least around Mexico and the Caribbean, may depend on food availability and that areas with high productivity had high abundances of sharks due to higher levels of zooplankton. Sleeman *et al.* (2007) found chlorophyll *a* to be a factor on whale shark abundance at Ningaloo reef. Therefore looking at Chlorophyll *a* as a proxy for productivity may have shown whether this has any influence on whale shark abundance in the South Ari Atoll.

Other studies on similar aggregations appeared to find that code of conduct violations have a negative impact on behaviour (Quiros, 2007). Therefore it would be useful to see whether this is the case in the South Ari Atoll and whether whale shark behaviour changes with the close proximity of people, contact with people, flash photography and being obstructed by people.

Looking at boat numbers in South Ari in relation to the effect on numbers and types of injuries in sharks would be beneficial as it would show the extent of both fatal and non-fatal boat strikes in the area.

Finally in order to reinforce the fact that there is a subpopulation of sharks remaining in the South Ari atoll it may be interesting to look at whether the same individuals were returning to the reef in repeated years. This was looked at by Riley *et al.* (2010) who found that over 6 years the same individuals continued returning to the reef. With the great improvement of individual identification since the creation of I3S software (Arzoumanian *et al.*, 2005) it may be beneficial to use this to give further evidence of a resident shark subpopulation.

### **4.3 Limitations of Data Collection and Analysis**

There are many issues with data collection being unreliable and inaccurate.

Firstly visibility is quantified using a Secchi disk; this equipment is objective and therefore could be judged differently by different people. It also only has a scale of 1 (poor) to 3 (good) which is not very specific.

Wind speed is collected using an anemometer, although this kit should give accurate

readings it is not as accurate as desired. There were also issues with other groups contributing to data using mph as opposed to the Beaufort scale. Although this was corrected for there still could be data missed.

SST undergoes very small changes in this area which aren't as well seen with unprecise measurements taken with a thermometer. NASA MODIS Aqua SST data uses more refined equipment and is carried out by professionals. It may have been more accurate to use this in replacement of the in situ data however there was very small difference and a strong correlation between the two data types. This means that the in situ data is valid. Being as a thermometer is how the MWSRP collects SST it was beneficial to see whether this could be used in analysis. It may have also been better to calculate SSTa using MODIS Aqua satellite due to this accounting for 24 hour SST whereas the data in this report only accounts for SST collected during the day when temperatures are higher, however this would have meant it wouldn't have corresponded with the data collected in situ and therefore wasn't used. The SSTa 5 day moving average was used to remove inconsistencies in the data, however instead can make the data skewed. Boats and especially people are difficult to count when in the water, often people are diving below the surface during the count or sometimes fins can be mistaken for a second person. There is also a high error of counting the same person repeatedly. Behaviours are measured using four 'types'. In reality this does not cover enough breadth and depth of real life behaviours. It is also difficult for even experienced staff to understand and recognise some of these behaviours.

Finally one of the largest errors is that the MWSRP use volunteers aboard their searching boat who are very involved in data collection. This means that objective variables such as visibility are most likely being taken by a different person every single time. It also means that usually environmental, human and shark variables are being recorded by people who have only just been taught how to carry it out. Due to this there is a likelihood of high error from the methodology being carried out or results being recorded incorrectly. To improve this there could be a training programme for volunteers, however due to the short time some volunteers are present this may be difficult. Although data is approved before being added to the MWSRP database it may be an idea to add an increased level of auditing as well.

There are other issues aside from problems with data collection and accuracy. Spotting whale sharks is dependent on a number of factors. Firstly it is fairly difficult to spot sharks from the surface if unaware of how the shadow looks especially when there are many reefs that can be misinterpreted as shark shadows. This means that the likelihood of spotting sharks is equal to the ability of volunteers and staff on board. Weather also plays a role in spotting sharks; when very overcast and cloudy it is much more difficult to see shadows in the water. Therefore on days with these conditions there is a high chance that sharks are present but not visible. This was countered by comparing visibility with SPUE however there was no significant effect of visibility on sightings, so perhaps is not as important as initially perceived.

There may also be associative relationships between other megafauna species and whale shark presence. For instance it has been noticed by MWSRP workers in previous years that if killer whales are spotted around the South Ari Atoll area, whale sharks will rarely be seen in the following weeks. This aligns with findings of orca attacks on *R.typos* (O'Sullivan, 2000).

Due to the Maldives being a hot spot for whale shark tourism there are many private and tourist boats that are out searching for sharks in the same places and at the same time as the MWSRP. Due to this high volume of human presence and from the pattern seen with a decrease in sightings with people in the water it is clear that the sharks will usually make an effort to avoid people. This means that if other companies are spotting and swimming with sharks they may leave the reef before the MWSRP have a chance to record their presence. Although some of the companies patrolling the area will take measurements and give them to the MWSRP this is not always the case, meaning that there are encounters occurring that are not being recorded. Finally the MWSRP don't carry out as much field work in July, August, December and January, although SPUE was used this could still have influenced the seasonality results.

#### **4.4 Implications of this report and future application**

This study has highlighted the drivers of aggregations in the South Ari atoll as well as insight into possibly larger global scale drivers as well. These drivers are useful for

understanding where and why whale sharks sometimes move such large distances while remaining in the same place in other instances. These influential drivers are also useful in understanding the implications of increasing human pressures on the ocean as there is high chance of these factors changing. In the future it will be important to understand the impact of these changes on *R.typus* and how these effects can be reduced.

Ecotourism is seemingly beginning to have a negative impact on *R.typus* and is becoming ever still more popular throughout the world's oceans. In this study it appears that the more people in the water per day resulted in more whale sharks avoiding the reef. Quiros (2007) showed that breaking the code of conduct could vastly affect behaviour, especially feeding. Norman (2005) even suggested that this avoidance behaviour could go as far as leading the sharks to drastically change their migration patterns thus excluding them from vital feeding and mating areas. The ramifications of ecotourism are still unknown and therefore should be researched further in more aggregation sites with varying levels of tourism. It also means that code of conducts should be enforced better by trip coordinators and operators. In Western Australia a limit has been set on the number of whale shark tourist boats in order to attempt to combat these negative effects. These limits were also set in Belize once whale shark sightings per trip began to decrease (Quiros, 2005). Many studies showed that tourists often had issues with the overcrowding of sharks and number of boats in the water in Mexico and at Ningaloo reef (Ziegler *et al.*, 2012) (Catlin and Jones, 2010). In the South Ari Atoll therefore it may be worth considering a stricter code of conduct as well as boat number regulations in order to reduce the negative effects of tourism on the sharks and preserve the experience for tourists.

Due to the vulnerability of the species, the effects of climate change are likely to have a negative impact. This study has shown that whale sharks are affected by SST and therefore as it increases, the sharks behaviours and movements are likely to change. Migratory species are also known to be vulnerable to increased SST from climate change due to the change in food availability, trophic mismatch of blooms and loss of habitat (Robinson *et al.*, 2009). It is thought that global climate change may affect size and distribution of whale sharks in the future (Hacohen-Domené *et al.*, 2015). There have been cases of whale sharks decreasing in size in Australia and although this was associated with overfishing it may also be affected

by climate change (Bradshaw *et al.*, 2008). A future global distribution model constructed by Sequeira *et al.* (2014) predicted a pole-ward shift of whale sharks in future years as well as a reduction in suitable habitat area, particularly within the equatorial region of the Atlantic and Indian Oceans. These habitat shifts are expected, as warming often increases metabolic rates in terrestrial ectotherms (Makarieva *et al.*, 2005) which may in turn increase food requirements. Although this may be avoided by deep diving behaviour it is not a long term solution for a variety of reasons and the sharks may instead have to shift their habitats in order to find high prey availability (Sequeira *et al.*, 2014). There are already cases of sharks moving further North into the Bay of Fundy, Canada (Turnbull and Randell, 2006) and into the Azores due to increasing SST in the region from climate change (Anfonso, 2014).

*R. typus* is vital ecologically and economically for the South Ari Atoll as well as all other regions it resides in. Silas (1986) suggested that whale sharks may be indicators of overall ocean health due to their reliance on plankton and association with larger fish such as tuna. This shows that their presence is important and that their loss could impact the ocean. The ecological role of whale sharks is another area that should be researched further into facing the inevitable threats to the species. Whale shark tourism brings in huge amount of money and allows for many jobs including SCUBA dive instructors, boat drivers and guides. In just the South Ari Marine Protected Area alone, whale shark tourism brought in \$9.4 million US dollars in 2013 (Cagua *et al.*, 2014). The removal of the whale sharks therefore would likely cause a reduction in tourism in these areas and certainly a dwindle in people wishing to participate in SCUBA and snorkel trips.

Future studies should look into migration patterns further. Although the leap in individual identification have allowed assessment of aggregations to be better , creating tags that retain within the skin for longer would allow an assessment of the movements between these aggregation sites. This would allow movement patterns over an entire life span to be seen which would be especially beneficial in females in order to understand their life histories better. As seen in other studies boat strike injuries are prominent in the Indian Ocean (Speed *et al.*, 2008) however the extent of this is unknown. By researching more into boat injuries and numbers in the South Ari Atoll it would give an idea into how much of a threat boats, especially from increasing

tourism are. By combining this information with an understanding of aggregation sites and movement patterns it may even be possible to reduce these strikes by adjusting boat routes around main aggregation sites. More research should also be taken into the effects of environmental variables on these movement patterns on both a local and global scale to understand these drivers better. Finally the implications of eco-tourism and human presence should be looked into over longer time scales rather than just observations on an encounter. In order to do this a clearer way to distinguish and elaborate on whale shark behaviours would be useful.

#### **4.5 Conclusion**

This study has shown that there is no seasonal movement of whale sharks into the South Ari atoll and there is in fact a likely somewhat resident subpopulation that remains within the area. Sea Surface Temperature Anomaly has a positive influence on whale shark abundance in the South Ari Atoll reef, most likely due to the sharks following the temperature range that their metabolism functions most optimally within. An increased number of people in the water per day has a negative influence on whale shark abundance in the South Ari Atoll reef, most likely due to the prolonged exposure to humans from SCUBA and snorkelling experiences causing them to have an avoidance behaviour when they can sense people on the reef. Overall it is likely the sharks aggregate into the South Ari Atoll area based on Sea Surface Temperature primarily. Once in the area it is also likely that they will avoid moving onto the shallow reef when they can sense people are in the water, which will be easier when there are increased numbers of people. This however doesn't mean they aren't in the area offshore simply avoiding moving into the shallows. This study along with further research would allow insight into the drivers of global movements and aggregations. It will also be useful in showing the effects on global populations from increasing temperature; an influencing factor as climate change worsens as well as the impact on behaviour as ecotourism continues to rise.

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# Appendices

## Pearson Product Moment Correlation

Wednesday, March 01, 2017, 14:53:01

Data source: Data 15 in Diss2

Cell Contents:  
Correlation Coefficient  
P Value  
Number of Samples

|           |             |
|-----------|-------------|
|           | <b>SSTa</b> |
| Sightings | 0.0803      |
|           | 0.0260      |
|           | 768         |

SSTa

The pair(s) of variables with positive correlation coefficients and P values below 0.050 tend to increase together. For the pairs with negative correlation coefficients and P values below 0.050, one variable tends to decrease while the other increases. For pairs with P values greater than 0.050, there is no significant relationship between the two variables.

## Linear Regression

Wednesday, March 01, 2017, 14:54:23

Data source: Data 8 in Diss2

Sightings = 2.945 + (0.131 \* SSTa)

N = 768      Missing Observations = 32

R = 0.0803      Rsqr = 0.00645      Adj Rsqr = 0.00515

Standard Error of Estimate = 1.352

|          | <b>Coefficient</b> | <b>Std. Error</b> | <b>t</b> | <b>P</b> |
|----------|--------------------|-------------------|----------|----------|
| Constant | 2.945              | 0.0488            | 60.322   | <0.001   |
| SSTa     | 0.131              | 0.0589            | 2.230    | 0.026    |

Analysis of Variance:

|            | <b>DF</b> | <b>SS</b> | <b>MS</b> | <b>F</b> | <b>P</b> |
|------------|-----------|-----------|-----------|----------|----------|
| Regression | 1         | 9.091     | 9.091     | 4.973    | 0.026    |
| Residual   | 766       | 1400.185  | 1.828     |          |          |
| Total      | 767       | 1409.276  | 1.837     |          |          |

Normality Test (Shapiro-Wilk)      Failed (P = <0.001)

Constant Variance Test:      Passed (P = 0.736)

Power of performed test with alpha = 0.050: 0.605

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**Pearson Product Moment Correlation**

Wednesday, February 22, 2017, 22:28:26

Data source: Data 9 in Notebook1

Cell Contents:  
Correlation Coefficient  
P Value  
Number of Samples

|           | Temp                   | Wind                        | Boats                    | People                     | Current                    | Vis                          |
|-----------|------------------------|-----------------------------|--------------------------|----------------------------|----------------------------|------------------------------|
| Sightings | 0.0651<br>0.120<br>571 | -0.0454<br>0.274<br>582     | -0.00348<br>0.926<br>715 | -0.0859<br>0.0224<br>707   | -0.0620<br>0.131<br>597    | 0.0417<br>0.268<br>709       |
| Temp      |                        | -0.308<br>2.425E-012<br>494 | -0.0446<br>0.295<br>552  | -0.0765<br>0.0746<br>544   | -0.188<br>0.0000221<br>501 | 0.255<br>0.0000000101<br>557 |
| Wind      |                        |                             | -0.107<br>0.0102<br>578  | -0.0825<br>0.0499<br>565   | 0.321<br>5.048E-014<br>523 | -0.198<br>0.00000171<br>577  |
| Boats     |                        |                             |                          | 0.605<br>8.717E-070<br>686 | -0.0382<br>0.355<br>588    | -0.00620<br>0.871<br>688     |
| People    |                        |                             |                          |                            | -0.0499<br>0.232<br>576    | -0.0688<br>0.0747<br>671     |
| Current   |                        |                             |                          |                            |                            | -0.0862<br>0.0358<br>593     |
| Vis       |                        |                             |                          |                            |                            |                              |

**Multiple Linear Regression**

Wednesday, February 22, 2017, 22:29:10

Data source: Data 6 in Notebook1

$$\text{Sightings} = 5.190 - (0.0445 * \text{Temp}) - (0.0637 * \text{Wind}) + (0.0513 * \text{Boats}) - (0.0184 * \text{People}) - (0.251 * \text{Current}) + (0.371 * \text{Vis})$$

N = 439      Missing Observations = 360

R = 0.182      Rsqr = 0.0332      Adj Rsqr = 0.0198

Standard Error of Estimate = 2.776

|          | Coefficient | Std. Error | t      | P     | VIF   |
|----------|-------------|------------|--------|-------|-------|
| Constant | 5.190       | 4.388      | 1.183  | 0.238 |       |
| Temp     | -0.0445     | 0.149      | -0.299 | 0.765 | 1.184 |
| Wind     | -0.0637     | 0.0874     | -0.729 | 0.467 | 1.264 |
| Boats    | 0.0513      | 0.0593     | 0.865  | 0.387 | 1.912 |
| People   | -0.0184     | 0.00712    | -2.589 | 0.010 | 1.921 |
| Current  | -0.251      | 0.189      | -1.330 | 0.184 | 1.165 |
| Vis      | 0.371       | 0.238      | 1.560  | 0.120 | 1.109 |

Analysis of Variance:

|            | DF  | SS       | MS     | F     | P     |
|------------|-----|----------|--------|-------|-------|
| Regression | 6   | 114.493  | 19.082 | 2.476 | 0.023 |
| Residual   | 432 | 3328.951 | 7.706  |       |       |
| Total      | 438 | 3443.444 | 7.862  |       |       |

Figure A1: Sigma Plot screenshots of statistical tests on environmental and anthropogenic variables (SST, Wind, Boats, People, Visibility, SSTa. Current was removed from the study after analysis).

Student No. 26873451

### Risk Assessment

| Activity  |                | Location   |                 |                 |     | Are additional Control Measures Needed (Y or N) |
|---|----------------|--|-----------------|-----------------|-----|---|
| Third year project on whale shark migration in the Maldives.  |                | Department/Unit  | Room / Building | Campus/Location |     |   |
| Having referred to the College risk assessment guidance and evaluated the overall level of risk, please tick the appropriate box below: |                | Very High  | High            | Medium          | Low | Insignificant                                   |
|   |                |  |                 |                 |     | <input checked="" type="checkbox"/>             |
| Hazards and Harm  | Who is At Risk | How Are Risks Currently Controlled   |                 |                 |     |   |
| Harmful local wildlife encountered while snorkelling  | Sophie Gibson  | Snorkelling with experienced team who know area and wildlife well. Safety briefing on arrival. Wearing fins to protect from stinging corals etc. |                 |                 |     | N   |
| Snorkelling - Drowning  | Sophie Gibson  | Snorkelling with experienced team. Have undergone sea survival courses/personal survival sessions.   |                 |                 |     | N   |
| Slips, trips + falls. On and off boat   | Sophie Gibson  | Slippery surfaces on boat avoided if possible, wearing gripped shoes. Being aware.   |                 |                 |     | N   |
| Heatstroke / Sunburn  | Sophie Gibson  | Wear suncream (high factor), hat, sunglasses, keep hydrated.   |                 |                 |     | N   |
| Awareness of local cultures to avoid problems with government   | Sophie Gibson  | Don't bring banned items (pork products/alcohol) through customs. Stay covered from knees to shoulders when in local area.                       |                 |                 |     | N   |

Figure A2: Risk assessment form for data collection in the South Ari Atoll with the MWSRP.