

Coral Bleaching and Sea Surface Temperatures in The Philippines and Tobago



(Coral Cay Conservation 2008)

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Abstract

Coral bleaching is now a prevalent threat to the worlds coral reefs due to rising sea surface temperatures associated with climate change. This dissertation examines the relationship between the current rising sea surface temperatures (SST's) and coral bleaching in the locations of The Philippines and Tobago. It sets out to discover the similarities and differences between the bleaching trends at these sites over time and ascertains the reasons for this. To discover this, primary and secondary data in the form of chain transects, was used from the company Coral Cay Conservation. Furthermore, long term SST data was constructed from NASA, annual SST's from Bilko and bleaching decades and El Niño data from Reefbase.

Analysis of the data proved that over the past few decades SST's have continued to rise and as a result so has coral bleaching. When looking at this trend over the past decade, it seems that SST's of 26°C-30°C cause the highest counts of coral bleaching. Despite SST's of over 30°C, being recorded, they do not seem to have much of an impact on bleaching as they are too infrequent to cause the coral severe thermal stress. Furthermore it appears that Tobago sees higher counts of bleaching in El Niño years and The Philippines sees fewer counts of bleaching in La Niña years. Consequently, Tobago's reefs are at a higher risk than those of the Philippines. As SST's continue to rise, it seems imperative to understand the vulnerability of these fragile and important ecosystems.

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1. Introduction

“Bleaching episodes have apparently increased in their frequency and severity in the last 20 years (Glynn, 1993; Hoegh-Guldberg, 1999), initiating concern that, with maximum yearly temperatures increasing through the next century, thermal tolerance thresholds of corals throughout the world could be exceeded on an annual basis by 2030” (Coles et al 2003). Page 185.

The world’s coral reefs are now facing a crucial and novel challenge, coral bleaching (Glynn 1993). Coral reefs are highly important to many countries; they provide economic and environmental services to the millions of people living in coastal regions. In particular they help to establish an income from international, national and local fishing industries. Globally, in one year alone these ecosystems provide employment for millions and produce a fish catch size of six million metric tonnes (Bryant *et al.* 1998; Crabbe 2008; Hoegh-Guldberg 1999). In addition to this, they have immense biological wealth, with the reef creating a habitat for roughly 800 species of corals and over 4,000 species of fish (Bryant *et al.* 1998) and this does not begin to take into account the hundreds of thousands of species which are yet to be described or discovered (Hoegh-Guldberg 1999).

Economically the reefs additionally provide a tourism trade which generates billions of dollars. For example, annually the Caribbean reefs alone bring in up to US\$ 90 billion dollars for the Caribbean region (Hoegh-Guldberg 1999). The degeneration of coral reefs due to coral bleaching thus has considerable environmental, economic, social and biological concern and as a result, a significant body of research is needed in order to ensure their survival (Baker *et al.* 2008; Bryant *et al.* 1998).

Tobago and The Philippines are both situated within high risk bleaching areas and therefore are highly vulnerable to the loss of this ecosystem. This dissertation intends to determine whether the bleaching occurring at Charlotteville in Tobago

and at Southern Leyte in The Philippines is positively correlated to rising sea surface temperatures. Secondly by comparing the two sites over time, it will give a better understanding about if and why there are similar and differing bleaching trends throughout the tropics. The methods used to discover this consist of study sites, G.I.S maps, primary and secondary data and global databases. Examining and comparing different regions bleaching events has not received much research within the literature. Furthermore these two sites have yet to be compared making this dissertation original.

This dissertation consists of 7 chapters, with chapter 1 being this introduction. Chapter 2 reviews the current literature on coral bleaching which includes theories on El Niño and La Niña and thermal adaption. The third chapter focuses on the two chosen areas of study and chapter 4 looks at the methods used to collect and analyse the data. Chapter 5 consists of all the graphs and figures which represent the results of the data analysis. The sixth chapter analyses and discusses the results found and determines whether they support or reject the hypothesis and current literature. The final chapter summarises the results found throughout this research and concludes whether rising sea surface temperatures are causing an increase in bleaching events.

2. The Coral Reef ecosystem

“Bleaching episodes have resulted in a catastrophic loss of coral cover...with a potentially critical influence on the maintenance of biodiversity in marine tropics”
(Baker et al. 2008) Page 435.

2.1. Coral Bleaching:

Thermal bleaching, which occurs in corals, ensues when corals are exposed to above or below normal temperature conditions (Crabbe 2008). This bleaching becomes dangerous when the sea surface temperatures range from 28.2°C- 34.4°C, which causes depletion in the coral due to high energy demands leaving the coral vulnerable to disease and death, as well as causing a stunt in coral growth from which it may take decades to recover (Crabbe 2008; Eakin *et al* 2009). Tropical and sub-tropical waters are the primary location for a number of reef dwelling species, including corals, who are hosts to, ‘*dinoflagellate symbionts in the genus Symbiodinium*’ often known as zooxanthellae which provide a nutrient rich and therefore diverse marine life in an otherwise nutrient starved environment (Baker *et al.* 2008 page 436; Hoegh and Guldborg 1999; Stanley and Schootbrugge 2009). Coral bleaching is defined as occurring when the zooxanthellae- a single-celled photosynthetic algae which lives in the coral, is expelled due to cell damage from overproduction of oxygen (Baker *et al.* 2008; Stanley and Schootbrugge 2009). The overproduction of oxygen is caused by environmental extremes such as high sea surface temperatures, causing the white framework of the calcium carbonate coral to become exposed (Baker *et al.* 2008; Stanley and Schootbrugge 2009). The difference between a healthy coral and a bleached coral can be seen below in figures 2.1 and 2.2.

Figure 2.1. A healthy coral reef



(MacGillivray Freeman Films 2001)

Figure 2.2. A bleached coral reef.



(Ove Hoegh-Guldberg, Global Change Institute, The University of Queensland)

2.1.1. Symbiotic relationships of coral reefs

The zooxanthellae and the coral have a mutualistic symbiotic relationship, where both derive benefit (Hough-Guldberg 1999). The zooxanthellae use UV light to create the calcification needed to create the scleractinian¹ coral and its photosynthetic pigment gives the coral its colour, as well as contributing to the corals' energy budget (Baker *et al.* 2008; Van Oppen *et al.* 2005). This is done by,

“...translocating 95% of their photosynthetic production to it....selectively leak amino acids, sugars, complex carbohydrates and small peptide across the host-symbiont barrier.” (Hoegh-Guldberg 1999). Page 841.

The zooxanthellae in turn gains protection, essential nutrients (ammonia and phosphate) and a habitat (Stanley and Schootbrugge 2009; Hoegh-Guldberg 1999). The corals expel these algae when under stress producing a bleached facade often leading to disease and death of the coral (Stanley and Schootbrugge 2009).

2.2. Climate change, SST's and Coral Reefs:

Coral reefs are extremely sensitive and need a specific depth, UV penetration, location (25°N-25°S) and can tolerate temperatures of 18°C-30°C. They are particularly susceptible to climate change and changes in the physical environment (Baker *et al.* 2008; Crabbe 2008; Hoegh-Guldberg 1999). Figure 2.4 shows the vast number of processes which affect coral survival (Crabbe *et al.* 2008a and 2008b). Many academics have positively correlated increased bleaching with rising sea surface temperatures (SST's) which are currently having the largest impact on coral bleaching (Baker *et al.* 2008; Brown 1997a; Brown and Ogden 1993; Coles *et al.* 2003; Crabbe 2008; Eakin *et al.* 2009; Hoegh-Guldberg 1999; Jones *et al.* 1997; Van

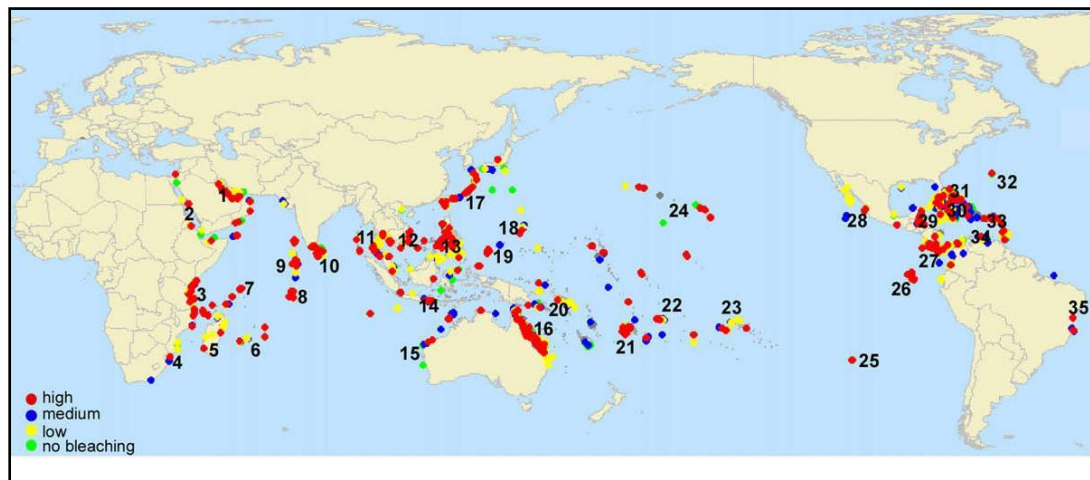
¹ Scleractinian corals are otherwise known as hard or stony corals.

Oppen *et al* 2005). This is occurring due to a shift to a warming climate which can be attributed to the concentration of the atmospheric greenhouse gas CO². It has risen by ~101ppm since 1979 (Van Oppen *et al* 2005) and the globally averaged SST has markedly increased in the last 1000 years and is expected to rise from 1.4-5.8°C by 2100 (Aronson 2007). Academics and scientists believe that warming sea surface temperatures will be commonplace in future decades (Baker *et al* 2008). This in turn leads to the coral reefs' sensitive environment becoming under threat, causing the reefs to undergo stress, which results in coral bleaching (Baker *et al.* 2008) and with the current enhanced greenhouse effect, this may only be expected to get worse (Brown 1997a; Goreau 1990; Glynn 1991). The current number of bleaching events can be seen in figure 2.3 below. It is now believed that the catastrophic bleaching of 1998 will become a frequent event within the next twenty years (Hoegh-Guldberg 1999) and Baker *et al.* (2008) continues to emphasize this point by stating that,

"The frequency and scale of coral bleaching events during the past few decades have been unprecedented with hundreds of reefs exhibiting bleaching at some point." Page 436.

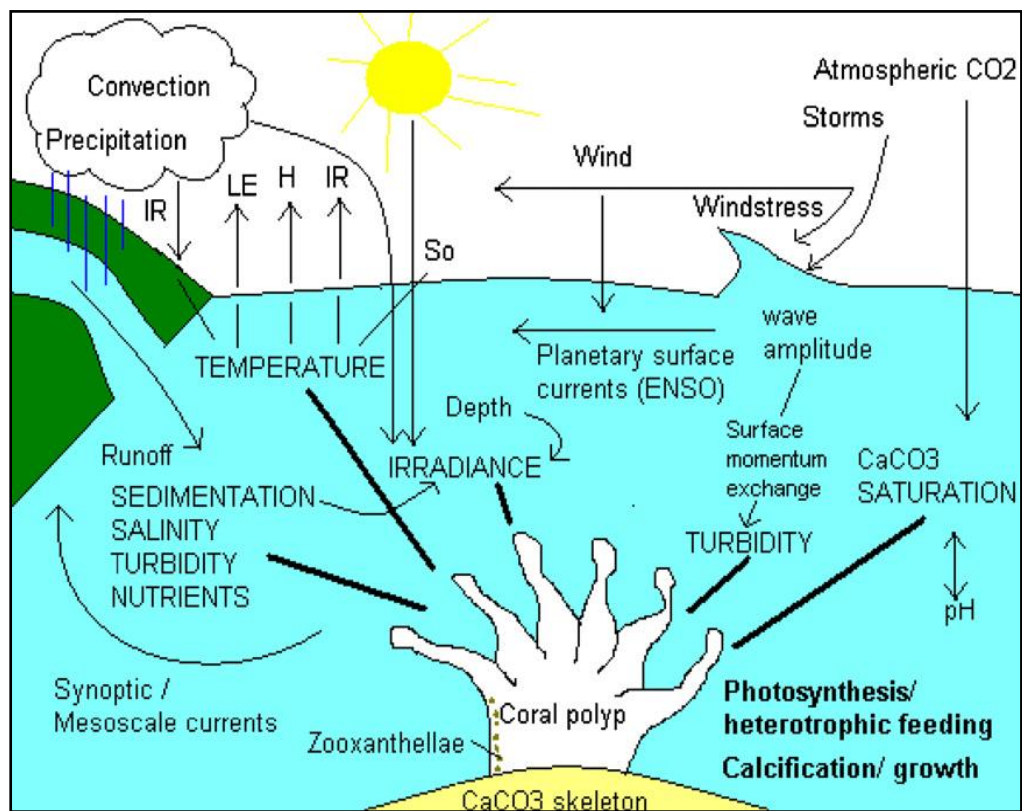
The relationship between rising SST's and bleaching can be clearly observed in the Caribbean in the 1980's- 1990's, where it was noted that a 0.1°C rise in sea surface temperatures led to a 35% increase in reported bleaching events and in addition to this a 0.2°C increase lead to mass bleaching (Baker *et al.* 2008).

Figure 2.3 Reef-base data of worldwide bleaching records-as of March 2008. Map from Reefbase, www.reefbase.org.



(Baker *et al.* 2008)

Figure 2.4. A schematic diagram summarising the key meteorological processes and coral requirements controlling calcification, photosynthesis and survival.



(Adapted from Crabbe *et al* (2008a) and Crabbe *et al* (2008b))

2.3. Other factors impacting bleaching

It would be difficult to deny that the most important driver in the bleaching of coral reefs is high sea surface temperatures and although UV penetration, nutrient leaching, acidity, increases in sedimentation all play a role, only a rise in sea surface temperatures have been the underlying factor of all reported bleaching episodes (Baker *et al.* 2008). This is validated by Van Woesik (2001) who declares that the zooxanthellae's photosynthetic effectiveness correlates to SST's rather than light or any other factor. Anthropogenic forces also impact on the bleaching of corals; however they are not included in this dissertation because no human driven factors acidity, sedimentation or U.V penetration have caused the same kind of reef losses in one year compared to damage caused by the rise of SST's (Rogers 2009).

There is a theory that since 1979 the only reason why coral bleaching appears to be rising is because it had simply been disregarded before 1979 and that coral bleaching is a natural process which is unconnected to climate change (Hoegh-Guldberg 1999). This can be discounted by looking at Thunnell *et al.* (1994), who proclaim that mean sea temperatures in tropical oceans may have varied by less than 2°C over the past 18,000 years. This shows the small variation in sea temperature in the past would not have been substantial enough to create widespread and frequent bleaching, which is why there are not many cases reported in the literature before 1979 and that the more recent climate change is the cause of the rise in SST's (Hoegh-Guldberg 1999). Finally to emphasize this point Hughes *et al* (2003) have stated:

"The link between increased greenhouse gases, climate change, and regional-scale bleaching of corals, considered dubious by many reef researchers only 10 to 20 years ago (Glynn 1993) is now considered incontrovertible". Page 929.

It is clear from this statement and the publications in section 2.3, that rising sea surface temperatures are the primary cause of bleaching (Eakin *et al* 2009).

2.3.1. The time it takes for corals to bleach

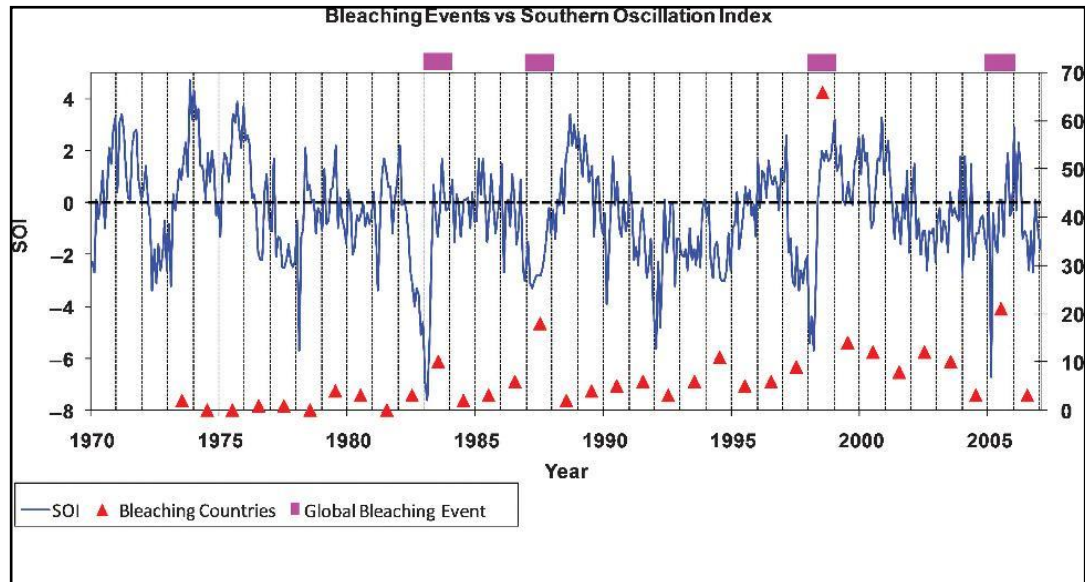
It has been argued that corals need to be subjected to high SST's for about 5-10 weeks in order for bleaching to impact on the corals (Christensen *et al* 2008; Glynn *et al* 1990). This theory depends however, on the type of coral being subjected to these rising SST's. Some may take only a few weeks to endure coral mortality and some may take months (Glynn *et al* 1990). If the SST is exceptionally higher than average, then immediate bleaching can take place (Christensen *et al* 2008). Additionally the 5-10 weeks the coral needs to be subjected to may not take place continuously. If the coral is subjected to an SST of over 30°C for enough weeks over the course of the year, then bleaching will occur from it (Glynn *et al* 1990). Furthermore as higher SST's are becoming more commonplace, it is more likely that the corals will now be subjected to them for enough weeks in the year to cause bleaching.

2.4. Coral Bleaching and El Niño

Glynn (1984) was the first to make the link between SST warming due to ENSO (El Niño-Southern Oscillation) events and the bleaching of corals (Aronson 2007). Although these events do not directly cause bleaching episodes, they create uncharacteristic warming of SST's in certain areas resulting in coral bleaching (Oliver *et al.* 2005). Evidence shows that zooxanthellae are not usually expelled due to seasonal changes. However, when these atmospheric and oceanic processes are enhanced by climate change, for example ENSO, bleaching often occurs (Hoegh-Guldberg 1999). The direct effect of this can be seen from the 1982-83 global and severe coral bleaching, which stemmed from an El Niño event causing abnormally high water temperatures (Bryant *et al.* 1998) and this strong link can clearly be seen in figure 2.5 below (Van Oppen *et al* 2005). It shows 5 distinct peaks of coral

bleaching, the worst of which was triggered by the 1997-98 El Niño event (Eakin, *et al* 2009).

Figure 2.5 Global bleaching events and the Southern Oscillation Index (SOI).



(Oliver *et al* 2005)

2.4.1. The 1998 global bleaching event

The most severe case of global El Niño bleaching was recorded in the 1997-8 ENSO event where 2,070 coral bleaching and mortality events were recorded (Aronson 2007).

“The mass coral bleaching event of 1998 is considered to be the most severe on record (NOAA 1998; ISRS 1998a), with bleaching affecting every geographic coral-reef realm in the world.” (Hoegh-Guldberg 1999). Page 844.

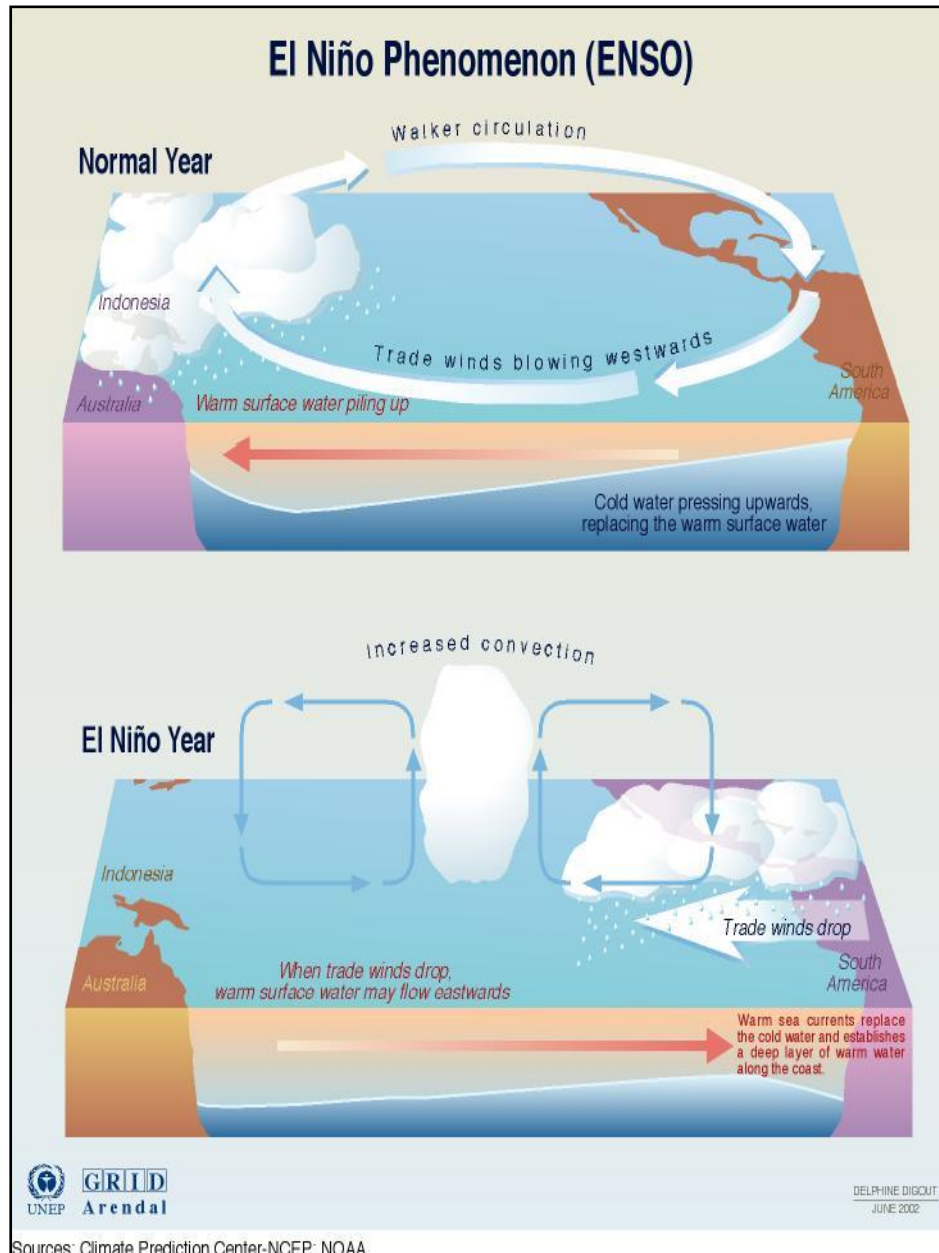
Since records began nearly 150 years ago, 1998 saw the warmest temperatures ever recorded and furthermore the strongest El Niño in history (Van Woesik 2001; Wilkinson *et al* 1999). The bleaching which occurred due to the 1998 El Niño was the most unprecedented, widespread and severe account of coral mortality ever recorded (Van Woesik 2001; Wilkinson 1998). Bleaching was reported in over 60 countries and was most severe in the Indian Ocean which recorded a mortality rate of over 70% (Global Warming 2003). Moreover, this was the first bleaching event in which severe bleaching was seen in water 50m deep (Global Warming 2003). Before this point bleaching was not seen below 15 metres. It is important to note that the severity of this event was not solely attributed to the 1998 El Niño event and was enhanced by the general rise in SST's over the past decade (Spalding *et al* 2002).

2.4.2 The El Niño process

Philander (1990) stated that the ENSO involves large scale changes in the Walker circulation (west to east atmosphere circulation) and the Hadley cells (North to South circulation of trade winds) in the Pacific Ocean region (Philander 1990). During the years of El Niño, the trade winds, which usually pile up warmer surface water in the equatorial Eastern pacific, weaken allowing the Walker circulation and pressure differences to change, allowing the Western Pacific (around Indonesia) to receive the warm water because of high pressure in the East and low pressure in the West (Aronson 2007). In the Eastern Pacific, neighbouring areas like the Caribbean, are then subjected to warmer waters and low cloud cover because the Australian thunderstorm belt can move into the Pacific due to the pressure change, causing coral bleaching, which then spreads through the whole Pacific (Aronson 2007). These areas often experience cooler conditions in La Niña and warmer conditions in El Niño and this is where we see the most dramatic El Niño bleaching (Oliver *et al*. 2005). These conditions tend to last for about a year (NOAA 2008). The El Niño process can be seen in figure 2.6. Sheppard (2003) believes that all the available evidence suggests that more similar ENSO bleaching events can be

expected in the future and it is therefore important to understand and monitor the current state of bleached corals to put into place possible techniques to preserve these biologically important and vulnerable ecosystems (Sheppard 2003).

Figure 2.6 El Niño-Southern Oscillation (ENSO) phenomenon.

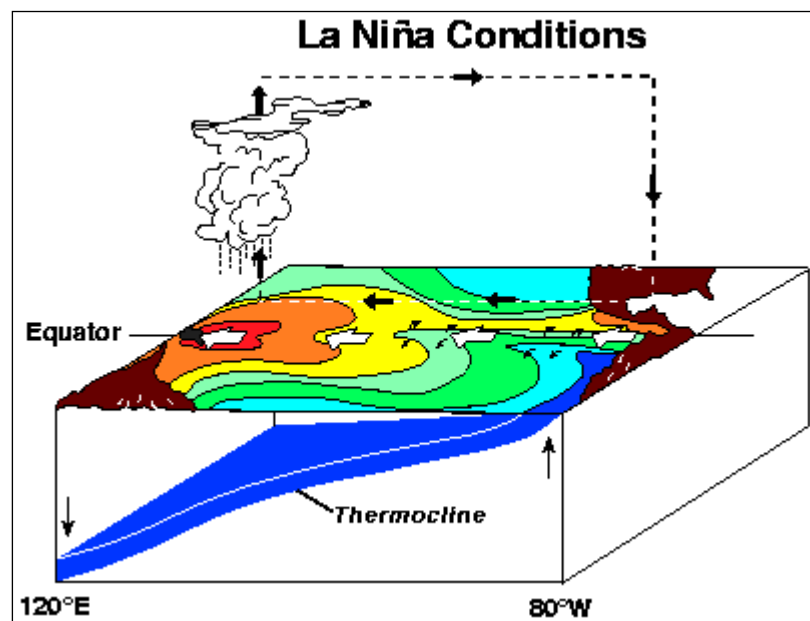


(UNEP 2009)

2.5. The La Niña process

Generally it is agreed that the impacts of La Niña seem to be the opposite of El Niño, with cooler than normal conditions appearing in the equatorial Pacific Ocean (NOAA 2008). Cold waters are pushed towards the equatorial Pacific by the strengthening westward trade winds (Tull 2007). The upwelling of cold waters along the West coast of South America and the equator strengthens causing SST's to drop up to 7°F (Tull 2007). This can be seen in figure 2.7 Indonesia and South Africa tend to experience heavy rains and areas such as Peru experience drought conditions (Glantz 2001). In the Southeast winter temperatures are warmer than expected and in the Northwest they are cooler than expected (NOAA 2008).

Figure 2.7. Diagram of La Niña Conditions



(Tull 2007)

It has been perceived that La Niña is not as severe as El Niño; however this has now been challenged by Stanley Changnon. In 1999 Changnon stated that La Niña impacts different regions than El Niño thereby making it seem less disastrous

(Glantz 2001). As a result of this, regions which may not experience bleaching from El Niño years may see bleaching in La Niña years. It is therefore important to understand the La Niña process in order to accurately analyse regions which are impacted by it.

2.6. Long term effects of Coral Bleaching

2.6.1. The food chain

The main problem with coral bleaching is that not only are there the initial effects but long term effects can last for months or even years (Baker *et al.* 2008). Long term effects are sometimes not as obvious as coral mortality, which generally has the biggest impact in smaller reef colonies and may lead to the complete demise of a reef community (Baker *et al.* 2008). Crustaceans living within the affected coral lose a habitat and a food source, often leading them to stray from the safety of the reefs resulting in a demise in these animals, which ultimately lead to impacts on the entire food chain (Baker *et al.* 2008).

2.6.2. *Acanthanster Planci*

More worryingly, however, is the abundance of *Acanthanster Planci* more commonly known as the 'Crown of Thorns' starfish, which has devastated reefs around the world. As mentioned earlier, after a bleaching event, many of the animals living on the reef abandon it and this results in less food for the *Acanthanster Planci* leading them to concentrate their eating habits on the coral itself (Baker *et al.* 2008). Finally, there is the issue of bioerosion-the breakdown of the limestone coral skeletons. This is usually not a problem in healthy reefs as the calcification often outweighs the bioerosion (Baker *et al.* 2008). Nonetheless in the reefs affected by bleaching events, the calcification is reduced or stopped altogether allowing the reef to slowly erode away (Baker *et al.* 2008).

Figure 2.8. Picture of *Acanthanster Planci* feeding on bleached coral.



(Greenreport 2008)

2.6.3. A reduction in fertility

In addition, the long term issues associated with coral bleaching are much more important to the corals' recovery after a bleaching event and one of the main issues is the reduction in reproduction (Baker *et al.* 2008). In the years following bleaching events, it has been noted that there is a reduction in the number of eggs per polyp, the number of fertile polyps, and the amount of sperm released which is most likely caused by the energy depletion caused from the bleaching (Baker *et al.* 2008; Coles *et al* 2003). From this the problems associated with bleaching events of the worlds' coral reefs becomes apparent, many of which affect the ecosystem for years after the bleaching.

2.7. The ABH theory

2.7.1. How corals are adapting?

A new theory called ABH (adaptive bleaching hypothesis) is currently beginning to emerge. It has been argued that corals are beginning to adapt to increasing sea surface temperatures (Van Woesik 2001 and Ware *et al* 1996). This is due to a

number of factors, one of which is 'Photo-protection'. This is when the algae expel the excess solar radiation into the ground. As this is occurring, the excess radiation is converted to heat via the 'xanthophyll cycle' (Demmig-Adams *et al* 1993). Another protective factor may be 'florescent coral pigments' which seem to reflect solar radiation (Salih *et al* 2000). These protective processes might be the key to the survival of thermally exposed corals. However it has been suggested that the algae needed for these protective processes can be altered by rising SST's, preventing them from defending the coral (Coles *et al* 2003).

Peter Glynn presented information at the Ninth International Coral Reef Symposium on the 23th to 27th October 2000. He stated that when comparing the 1982-1983 El Niño associated bleaching with the 1997-1998 El Niño bleaching, there was less recorded bleaching in some regions in the latter event (Van Woesik 2001). It was therefore concluded that for whatever reason, the zooxanthellae or corals had become more thermally tolerant (Van Woesik 2001). However, there was a lack of information on the solar radiation for these two events and as a consequence there is uncertainty about whether lower solar radiation caused the lower bleaching in 1997-1998 (Coles *et al* 2003). Therefore this theory cannot be validated.

Buddemeier *et al* (1993) suggests that there has been an underestimation of zooxanthellae adaptation. It has been suggested that the thermally resistant zooxanthellae will eventually displace the less resistant symbiotic algae (Buddemeier *et al* 1993). However Van Woesik (2001) argues,

"...is this displacement really adaptation, in a Darwinian sense, or is it merely the 'reshuffling' of a limited gene pool?" Page 120.

As bleaching causes a reduction in fertility within corals, species sensitive to bleaching are being eliminated from the coral population (Baker *et al.* 2008). If this is the case, there are many questions that need to be answered. If zooxanthellae are adapting then how are they passing on this genetic information through generations? As it is the coral polyps which sexually reproduce and not the zooxanthellae than this cannot be validated. (Coles *et al* 2003; Van Woesik 2001). Laboratory and field studies provide limited but inconclusive support for the ABH theory (Baker 2001). However this work has been criticised by Hoegh-Guldberg *et al* (2002) as researching corals at different depths created misinterpretations of the results. As a result there is still not a thorough enough understanding of zooxanthellae genotypes,

“Clearly, finer genetic differentiation will be required to understand not only the physiological tolerances of the algae but also their dynamics within the coral colony. Until this is achieved the case for or against the ABH will not be determined” (Coles *et al* 2003) Page 194.

2.7.2. Are corals adapting?

In light of this, it is clear that little is understood about corals’ ability to adapt to thermal stress. It has only been in the last century that corals have begun to be researched and the majority of discoveries about corals and their zooxanthellae have only been ascertained in the last 30 years (Coles *et al* 2003). Furthermore there has not been enough controlled research to establish the capacity of corals to adapt to thermal stress even on a short-term scale (Coles *et al* 2003; Van Woesik 2001). The most crucial question is can corals adapt rapidly enough to deal with rising sea surface temperatures and will their thermal tolerance be high enough to protect against the highest SST’s? (Coles *et al* 2003; Van Woesik 2001). Until more research is undertaken these questions cannot be answered and therefore the ABH theory is ambiguous.

2.8. Justification and Research objectives

This chapter has identified the reasons why this dissertation is worthwhile, for example the extent of bleaching worldwide and the high number of predicted future bleaching events (Baker *et al.* 2008; Crabbe 2008). The importance of the reefs currently at risk (Bryant *et al.* 1998), the factors impacting the reefs such as ENSO events and rises in sea surface temperatures due to climate change (Aronson 2007; Baker *et al.* 2008; Crabbe 2008; Philander 1990). It has also addressed the science behind coral bleaching (Baker *et al.* 2008; Crabbe 2008; Stanley and Schootbrugge 2005) and some of the theories which may impact the results (Glynn *et al.* 1990; Buddemeier *et al.* 1993; Christensen *et al.* 2008; Ware *et al.* 1996). From the literature, it is hypothesized that as SST's rise, then so should the number of bleaching events. Furthermore, there should be differences between the data in El Niño and La Niña years. Tobago should see more bleaching in El Niño years and less in La Niña years. The Philippines should see the opposite of this. This dissertation intends to ascertain the bleaching trends identified in the Philippines and Tobago and understand the causes behind them. In order to validate this hypothesis, the following research objectives have been created:

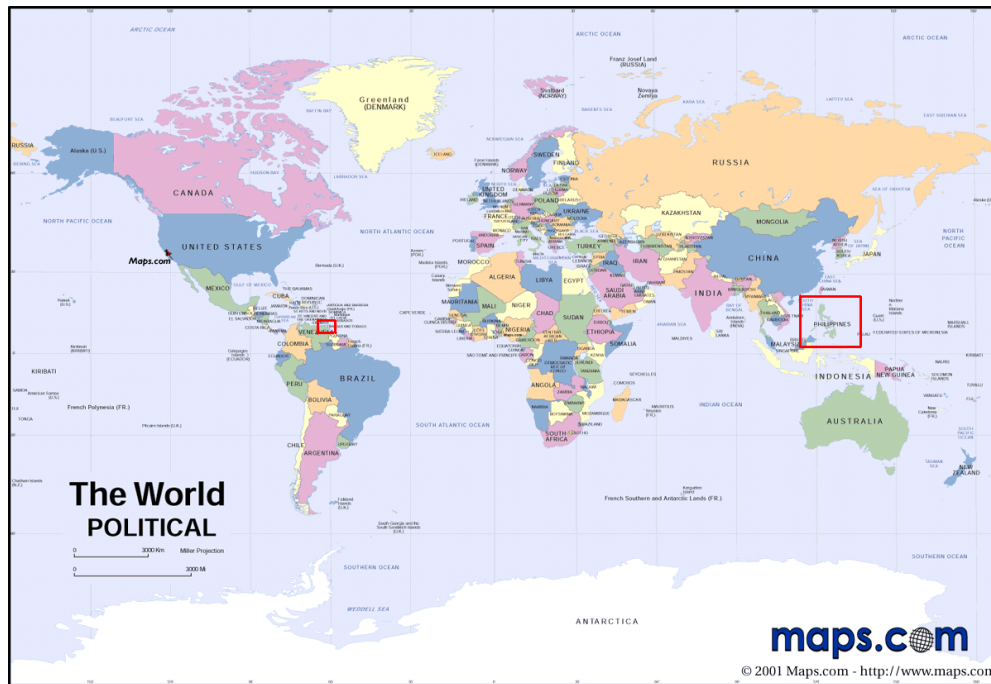
- 1) To what extent is coral bleaching in the reefs of the Philippines and Tobago, due to rising SST's (sea surface temperatures)?
- 2) What similarities and differences are found in the bleaching and SST trends from the reefs of the Philippines and Tobago?
- 3) What are the potential reasons for the similarities and differences in the data?

3. Study Area

3.1. The vulnerability of Tobago and The Philippines

The future number of bleaching events from potential future sea surface temperature rises has been predicted using four different general circulation models (GCM's) and the Integrated Global Ocean Services System (IGOSS) of coral thermal tolerance (Crabbe 2008). These models indicated that the frequency of coral reef bleaching is predicted to rapidly rise and in particular in the areas of South East Asia, the Caribbean and the Great Barrier Reef (Crabbe 2008). In addition, they also predict that bleaching events are set to become annual worldwide by 2040. More worryingly, the Caribbean (Tobago) and South- East Asia (The Philippines) are predicted to reach this point by 2020 (Crabbe 2008). Despite management and conservation efforts, in the Philippines at least half of the coral has died in 20% of 245 sites (Licuanan *et al* 2000). This puts into perspective how urgent the problem is. This dissertation will focus on two areas in these high risk regions, the Philippines in South East Asia and Tobago, an island in the Caribbean. The locations of these sites can be seen in figure 3.1 below.

Figure 3.1 World map showing the location of Tobago and The Philippines.



(Pakalert 2009, edited by Author)

3.2. Philippine site

The Philippines is located in South East Asia and is made up of over 7,000 tropical islands (The Lonely Planet 2009). Coral Cay's site in the Philippines is currently located in Sogod Bay. This is located in Southern Leyte and is one of 6 provinces in the Visayas (Coral Cay Conservation 2009). The exact location of this can be seen in figure 3.2 and 3.3 below.

Figure 3.2. Map of the Philippines

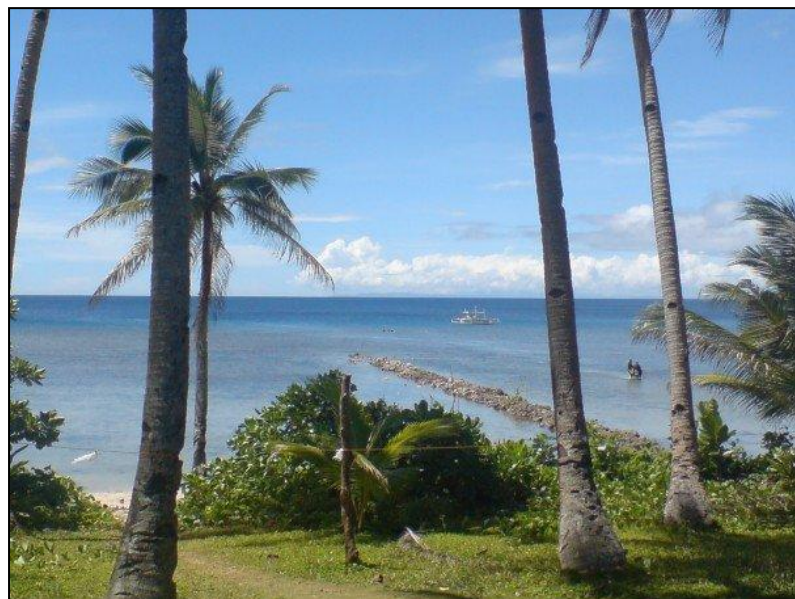
(Web-translations 2009, edited by author)

Figure 3.3 Map of Leyte



(DAR 2009, edited by Author)

Figure 3.4 Picture of Ampo Reef

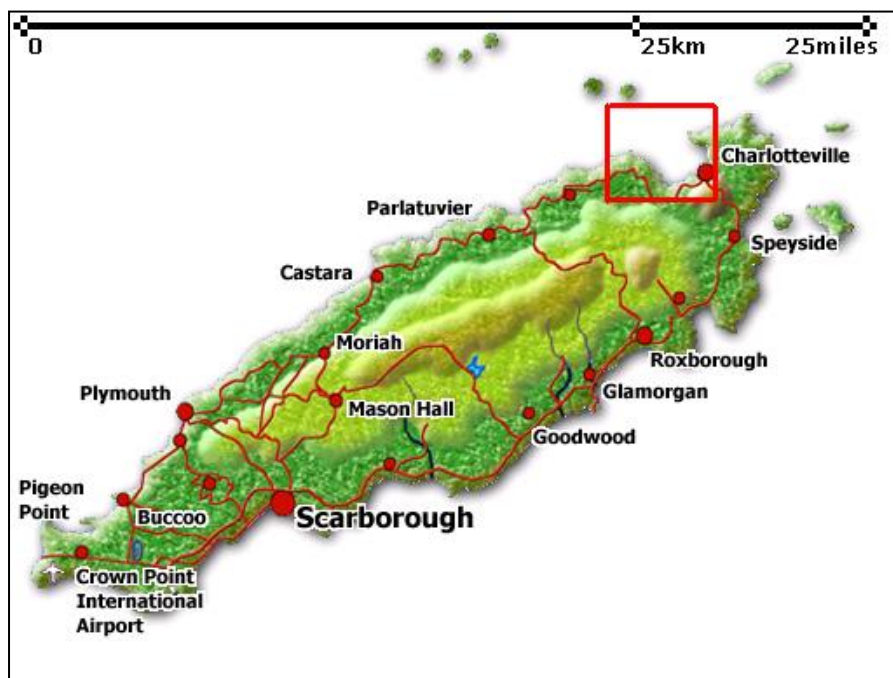


(Author 2007)

3.3 Tobago site

Tobago is situated in the Caribbean off the North-eastern coast of South America (Coral Cay Conservation 2009). The survey site at Tobago is situated on the North East coast in Charlotteville. The bay in which the surveying is undertaken is called the 'Man of War Bay' and this can be seen in figure 3.5.

Figure 3.5. Map of Tobago



(Ministry of Tourism 2010, edited by author)

3.4. Impacts of Oceanic and Atmospheric processes on the study sites

Both these regions will be impacted by oceanic and atmospheric processes such as El Niño and La Niña. However as declared by Aronson (2007) each event will effect each place differently². For this reason, these two globally contrasting sites were selected in order to gain a better understanding of the issue of coral bleaching in different regions and how the climate might affect them differently.

² See section 2.4.2.

3.5 How studying these sites adds to research previously undertaken

There seems to be a gap in the literature when researching these two sites. Although there are many worldwide case studies, there are not many which compare two sites. These two countries are found in opposite sides of the world and therefore it would be interesting to see if they are impacted differently by the rising sea surface temperatures. By comparing the results, the similarities and differences between these two sites should become apparent. One of the reasons why two sites were chosen in this dissertation is attributed to the argument made by Peter Glynn, in which he states that some regions do not see bleaching in high SST's (Van Woesik 2001). The reason for this may be due to the region experiencing an upwelling of cooler waters or that the coral species are less susceptible (Van Woesik 2001). Understanding why these regions may not experience bleaching will allow these regions to be used for coral refuges and nurseries in order to sustain the threatened reefs (West 2001).

4. Methodology

4.1. Sample techniques

The main practical sample techniques used when surveying coral reefs can be grouped into four areas; Quadrats, Chain transects, Photo Quads and Line Point transects (Stoddart *et al* 1978). All of these techniques have particular advantages and disadvantages and differ in suitability depending on the type of results being obtained from the survey. These can be seen in table 1 below.

Table 1. Advantages and disadvantages of coral survey techniques.

Survey Technique	Advantages	Disadvantages
Quadrats	Relatively Inexpensive Suitable for novices	Doesn't take into account structural complexity of corals. SCUBA ONLY
Chain transects	Estimates structural complexity Relatively Inexpensive Not as awkward as quadrats Suitable for novices	Time consuming SCUBA ONLY
Photo Quadrats	Visual Representation Can be archived so long-term analysis can re-analysis can be achieved.	Difficult to obtain good quality underwater photos Expensive Difficult to set up and destructive SCUBA ONLY
Line Point Transect	Suitable for novices Environmentally friendly Relatively quick Cost effective Most accurate Not as awkward as quadrats	Does not take into account structural complexity of corals. Does not indicate coral size Does not indicate coral density

(Edited from Nadon *et al* 2006; Dodge *et al* 1982; Ohlhorst *et al* 1988)

As a qualified advanced open water diver any of these techniques would be suitable for this research. Chain transects are the most accurate and detailed technique to use and furthermore they are used by Coral Cay Conservation (CCC), the organisation from which primary and secondary data was sourced from.

4.2. Data Collection in the field

4.2.1. Primary Data

The chain transect method was used for 8 weeks³ in the Philippines in 2007 at a reef called Ampo. This survey was started by finding the relevant GPS point and a bearing was taken with the wrist compass to gain the direction of the shore. This bearing was followed under the water to keep the correct direction. The diver must then descend to a depth of 30metres or where the last transect finished. An SMB (Safety Marker Buoy) was used to demonstrate to surrounding boats where you were and a GPS point is taken to mark the beginning of the transect. The 'buddy' took a 10 metre long tape measure and swam in the direction of the bearing until the tape is taut. This gave the correct length and direction the transect should be taking. The second diver swam along the tape measure, collected it in, and looked roughly 5 metres each side of the tape measure (this is represented by the dotted line in figure 4.2). Whilst doing this how much of each coral colony is bleached was recorded given a %. It was important to do this accurately, even if it meant not finishing a complete transect.

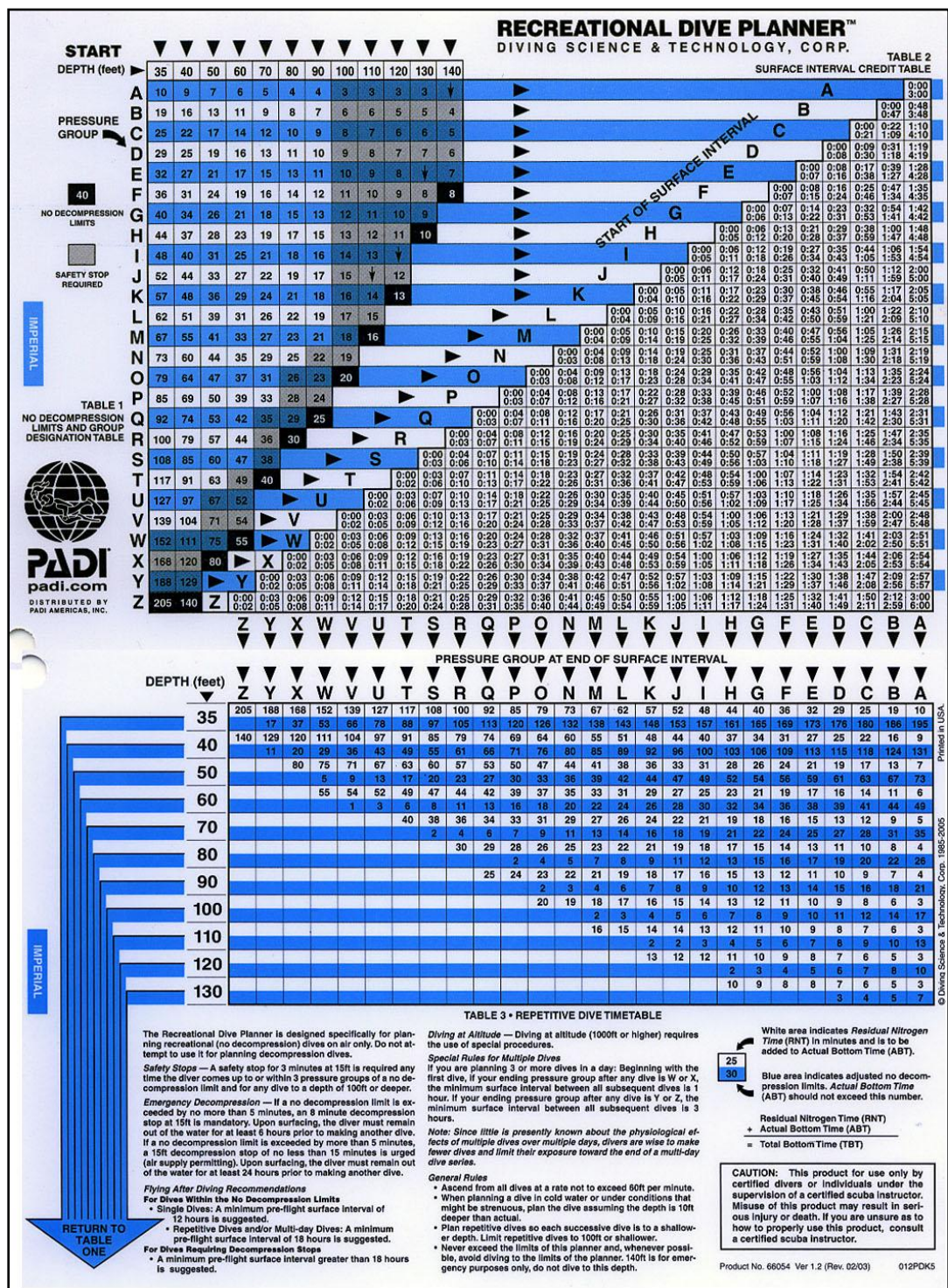
Before the dive, the temperature was taken using a digital thermometer on the surface. This recorded the SST's. The maximum time allowed under the water was calculated using a decompression table as seen in figure 4.1. When this was reached the divers began to surface. Most importantly, a safety stop was taken at 5

³ Conducted in January-March. I undertook 2 dives a day for 6 days of the week. The primary data can be found highlighted within appendix I.

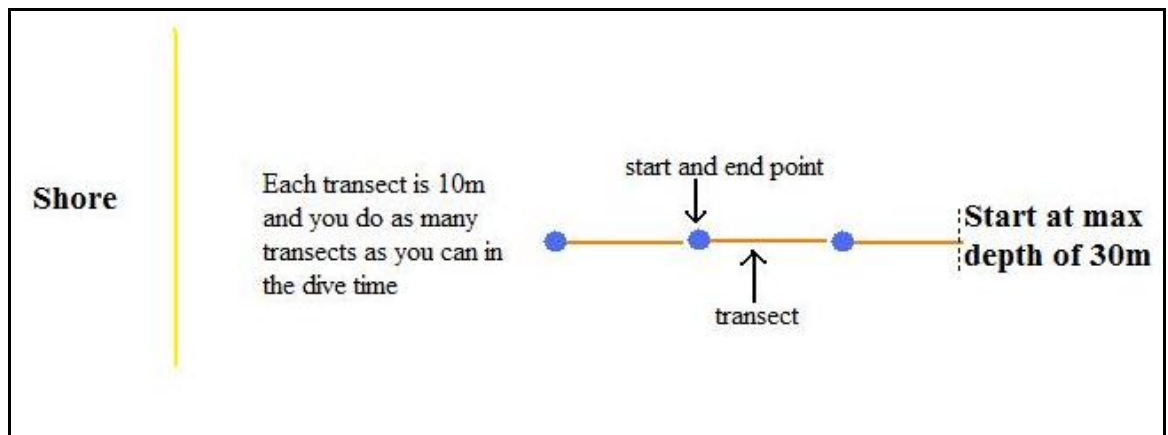
metres for 3 minutes to allow the nitrogen to safely work itself out of the body (at 30 metres the maximum dive time is 20 minutes). Another GPS point was taken where the transect finished, as three or four 10 metre transects may have been completed or one uncompleted. This allowed the survey to be restarted at the exact point it was finished before. This continued to the shore, or when there is no more coral left to survey⁴. The next transect is conducted 10 metres width away from the previous one because 5 metres each side was recorded. This covered the whole reef in the most productive and least time consuming way. This whole process can be seen in figure 4.2.

⁴ Coral Cay Conservation recorded many other aspects of the reefs in teams of 4, but only the relevant aspects of this dissertation are spoken about.

Figure 4.1. A PADI decomposition table.



(Maximum Scuba 2009).

Figure 4.2. Drawing of a chain transect (not to scale)

(Author 2009)

4.2.2. Equipment:

The equipment needed to undertake chain transects:

Wetsuit

Mask and Fins

Scuba Equipment

Dacor Pelagic wrist mounted compass and bezel

Hand mounted dive computer (analogue pressure gauge, digital depth gauge, thermometer, compass, calculates how long you have been underwater for, rapid ascent warning, depths and times for subsequent dives, various toxicity warnings.)

GPS

10 metre tape measure

SMB

Underwater tablet and pencil to record.

Underwater camera

(Scuba Diving info 2009)

4.2.3. Limitations encountered with this technique:

One of the problems associated with this kind of data is that it was subjective and what may have looked like bleaching to one person may have looked like white band disease to another. Additionally 5 metres may have looked differently to each person so some areas may be ignored and consequently bleached corals may be overlooked. Furthermore it was also up to the volunteer to make sure they looked under and closely at the corals to spot the small scale bleaching.

Working underwater on the tablets could be complicated which made it difficult to read the data written, therefore rendering some pieces unusable. Another problem encountered working underwater was jellyfish stings. For about a week there was a high volume of jellyfish in the water which caused very painful dives and may have resulted in some of the transects being completed quickly in order to get out of the water. It is important to remember this when the data is analysed as unprecedented results may be attributed to this⁵. Nonetheless, without data collected by (Coral Cay Conservation) CCC volunteers, the state of the reefs in the Philippines and Tobago would not be so extensively examined and the vulnerability of these reefs would be unknown. It is important to note that CCC had the highest of standards and therefore low quality surveys would be re-done.

4.3. Secondary data:

4.3.1 Coral Cay Conservation (CCC)

Much of the data used in this dissertation came from secondary data sources as the primary data was only from 8 weeks and one site. In order to get a better understanding of the relationship between rising SST's and bleaching, larger

⁵ See section 4.4.2 (Abouserie 1992- statistics should never be examined in isolation).

datasets were needed for the chosen sites. CCC kindly sent the rest of the datasets they had for The Philippines and Tobago. Coral Cay Conservation is a non-profit organisation and a registered charity which is invited by governments and local charities to assist with conservation (Coral Cay Conservation 2009). These datasets have been ongoing for a number of years and they proved invaluable to this dissertation as they were able to show the differences and similarities between bleaching on these two reefs.

4.3.2 Limitations with this data:

The limitations with this data was that the Tobago and Filipino data were not in the same format and therefore required reorganisation. This could have resulted in some of the data being missed out or deleted by accident. Additionally the datasets did not cover all the same years and only represented a few years. For this reason additional data was used.

4.3.3 NOAA data:

Since 1972, the federal agency NOAA (National Oceanic and Atmospheric Administration) has collected its sea surface temperatures (SST's) daily from polar orbiting satellites which gather infrared radiation from the ocean surface. The primary source of this data was compiled from an 'Advanced Very High Resolution Radiometer (AVHRR) located on all NOAA satellites (McClain *et al* 1985; Strong 1991; Strong *et al* 2000).

"AVHRR is a broad-band, four or five channel (depending on the model) scanner, sensing in the visible, near-infrared, and thermal infrared portions of the electromagnetic spectrum." (NOAA 2008).

Another form of satellite being used is the POES system which completed 14 polar-orbits daily giving everyday global coverage (McClain *et al* 1985; Strong 1991; Strong *et al* 2000). Finally buoys placed in strategic locations within the oceans are used to sustain SST accuracy from the satellites by compiling their own data, and therefore removing anomalies (McClain *et al* 1985; Strong 1990; Strong *et al* 2000). NOAA collates all this data and it is placed online for the general public's use. It was these records which provided these long-term and large scale datasets to create the Bilko maps, transects and Reefbase GIS maps.

4.3.4. Limitations

Many of these databases included thousands of pieces of data making it near impossible to originally decipher. Much time was spent on calculating a way to analyse it. Finally the software Bilko was chosen in order to take on this task.

4.3.5. Reefbase data

Bleaching events were compiled from Reefbase GIS (Geographical Information System) for bleaching decades and El Niño years. The Reefbase GIS maps are created from NOAA databases and represented bleaching events in Tobago and the Philippines in the quickest and most effective way. Bleaching events, the time span and the choice of region was selected and Reefbase created the maps.

4.3.6. Limitations

As the data is collected from NOAA weather stations, many small scale bleaching events are missed. This highlights how important it is to use the CCC data in order to understand what is happening on a local scale.

4.3.7. GHCN data

Long term SST maps were created from GHCN (Global Historical Climatology Network) data using the GISS (Goddard Institute of Science and Space) temperature analysis scheme. This was created in the late 1970's to compare one-dimensional global climate models (NASA Goddard Institute for Space Studies 2009). The maps were created by inputting the requirements into the database. This can be seen in figure 4.3. The data for these maps was created by Rayner (2000) for the years 1880-1981 and Reynolds *et al* (2002) for the years 1981-present.

Figure 4.3. Print screen of map creation from GHCN data

The screenshot shows the GISS Surface Temperature Analysis web interface. At the top is the NASA logo and the text 'Goddard Institute for Space Studies New York, N.Y.'. To the right are links to the NASA Portal, Goddard Space Flight Center, and GSFC Earth Sciences Division, along with a 'FIND IT @ NASA' search bar. Below this is a navigation bar with links: + RESEARCH, - DATA & IMAGES (selected), + PUBLICATIONS, + SOFTWARE, + EDUCATION, and + ABOUT GISS. The main heading is 'DATASETS & IMAGES'. Underneath is 'GISS Surface Temperature Analysis' and 'Global Maps from GHCN Data'. A paragraph explains that users can generate a surface temperature anomaly or trend map using the form, with a link to an explanation of input elements. A note states: 'Note: Generating figures takes 5-10 seconds. Please be patient.' The form itself has several sections: 'Data Sources' with dropdowns for 'Land: GISS analysis' and 'Ocean: none'; 'Map Type' with a dropdown for 'Anomalies'; 'Mean Period' with a dropdown for 'Nov'; 'Time Interval' with 'Begin' (1960) and 'End' (1970) fields; 'Base Period' with 'Begin' and 'End' fields; 'Smoothing Radius' with a dropdown for '1200 km'; and 'Projection type' with a dropdown for 'regular'. A 'Make Map' button is at the bottom of the form. Below the form are 'Notes concerning the maps:' and 'Input Elements:' sections with detailed footnotes.

Data Sources: Land: GISS analysis
Ocean: none

Map Type: Anomalies

Mean Period: Nov

Time Interval: Begin 1960 — End 1970

Base Period: Begin — End

Smoothing Radius: 1200 km

Projection type: regular

Make Map

Notes concerning the maps:

- * The number at the top right-hand corner is an estimate for the global mean. Missing data are replaced by the zonal mean to find that estimate.
- * The end points of the color bar are either -4.1 or +4.1 (new, it used to be +8,-8) or the minimum or maximum value of the data if it is outside that range.

Input Elements:

- * **Data Sources: Land**
 - * None: NO land temperature data are used
 - * **GHCN** unadjusted data (**through 1999 only**) (Peterson and Vose 1997)

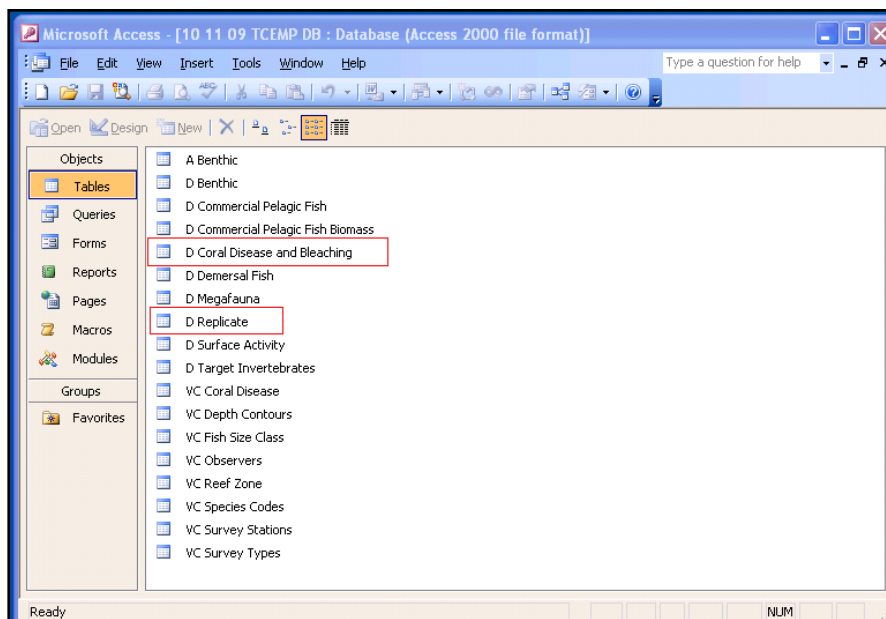
(NASA Godard Institute for Space Science 2009)

4.4. Data Analysis

4.4.1. Excel:

In order to undertake analysis, all the Coral Cay data was copied and pasted into excel spreadsheets and separated into years and date order. The Tobago and Filipino data is set out differently and therefore needed to be organized separately. The 'D replicate' sent by Coral Cay for the location of Tobago was opened in order to acquire the dates, SST's and RID (Survey number). The 'D coral bleaching and disease data' was opened to obtain the coral bleaching and their equivalent RID data. This can be seen in figure 4.4 below:

Figure 4.4. Print screen of D replicate, coral bleaching and disease data



In the 'Disease' variable there are all the diseases found on each survey which included CB (coral bleaching). There could therefore be numerous data for one RID. In order to align the data a new column was added called 'Bleaching' and each RID was looked at determining whether there was reported coral bleaching. When coral bleaching was prevalent, all the subsequent 'Disease' data was deleted. The

relevant RID in the D Replicate data was found, and in the 'Bleaching' column 'YES' was written. As this was a complicated process an example can be found in figures 4.5 and 4.6 below using RID 103.

Figure 4.5. Print screen on coral bleaching in RID 103

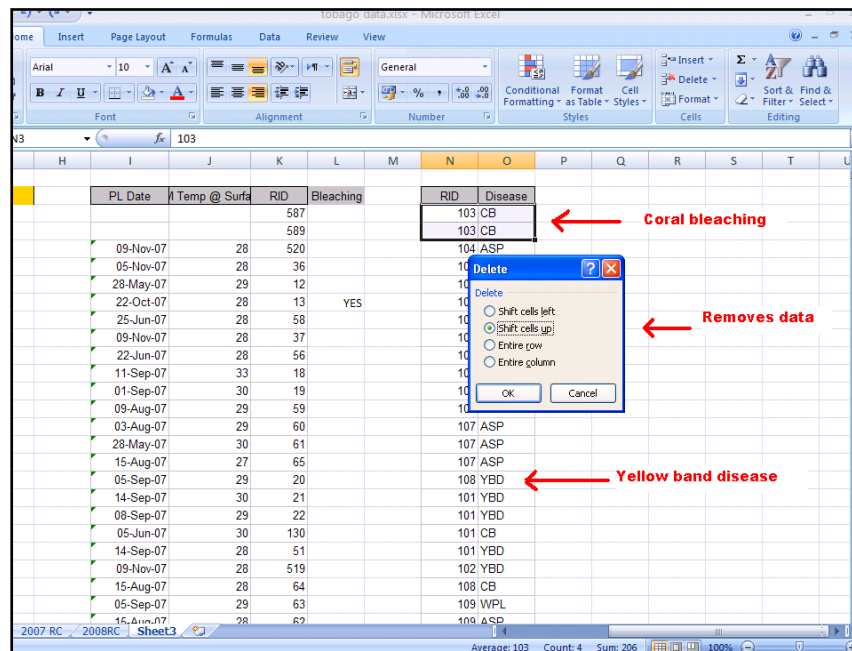
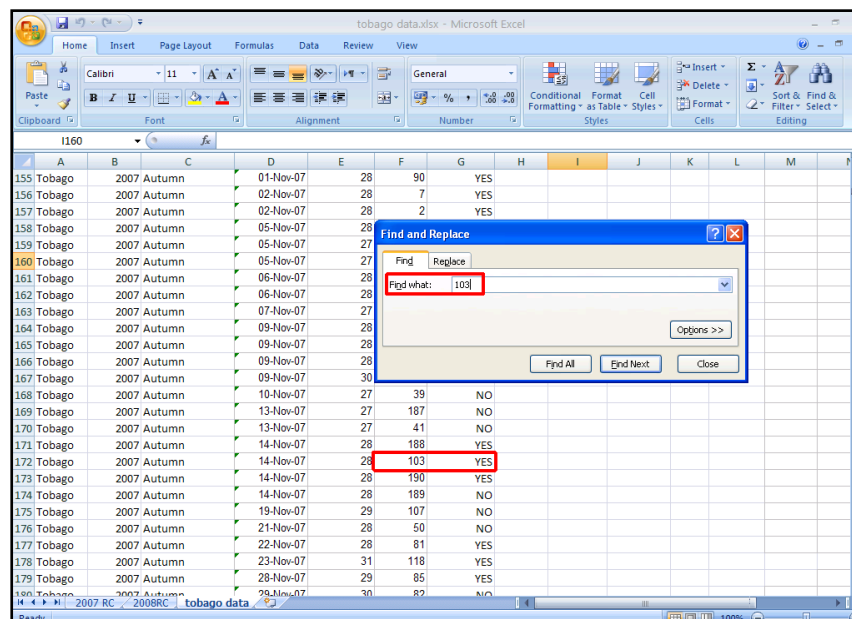


Figure 4.6. Print screen of finding RID 103 and entering bleaching data



If an RID did not demonstrate bleaching then the relevant RID was filled with 'NO' and if there was no data then it with 'NR' (Not Recorded). The Filipino data given to me by Coral Cay was slightly different as all the information was on one spreadsheet and therefore all the relevant data was copied and pasted in different spreadsheets depending on the year it was recorded (Figure 4.7). Once again they were organized in date order and then copied into one spreadsheet. The data for 2004 was unfortunately unusable as it did show any recordings for bleaching or disease. Once this was organized the data was inputted into SPSS.

Figure 4.7. All Philippine data in one spreadsheet; date and year order.

	A	B	C	D	E	F	G	H	I	J	K
	Location	Season	Year	LAT_ST	LAT_END	LON_ST	LON_END	DATE	M_BLEACH	S_TEMP	
1											
2	Philippines	Autumn	2005	718185	718235	1109786	1109801	04/01/2005		27	
3	Philippines	Autumn	2005	719127	719143	1109480	1109510	05/01/2005		28	
4	Philippines	Autumn	2005	719143	719159	1109510	1109528	05/01/2005		28	
5	Philippines	Autumn	2005	718231	718235	1109766	1109794	06/01/2005		27	
6	Philippines	Autumn	2005	719128	719113	1109585	1109591	06/01/2005		27	
7	Philippines	Autumn	2005	720151	720152	1108498	1108500	07/01/2005		27	
8	Philippines	Autumn	2005	720150	720161	1108518	1108531	10/01/2005		28	
9	Philippines	Autumn	2005	720626	720653	1107823	1107850	10/01/2005		28	
10	Philippines	Autumn	2005	720176	720209	1108528	1108541	11/01/2005		28	
11	Philippines	Autumn	2005	719317	719324	1109098	1109091	12/01/2005		27	
12	Philippines	Autumn	2005	718236	718245	1109798	1109849	12/01/2005		27	
13	Philippines	Autumn	2005	719315	719354	1109081	1109063	13/01/2005		28	
14	Philippines	Autumn	2005	719354	719363	1109063	1109104	13/01/2005		27	
15	Philippines	Autumn	2005	719444	719475	1109021	1109051	14/01/2005		29	
16	Philippines	Autumn	2005	728210	728155	1098060	1098065	17/02/2005		27	
17	Philippines	Autumn	2005	728207	728178	1097083	1097079	18/02/2005		27	
18	Philippines	Autumn	2005	728182	728169	1097011	1096999	21/02/2005		28	
19	Philippines	Autumn	2005	720374	720392	1108096	1108105	22/02/2005		27	
20	Philippines	Autumn	2005	720378	720398	1108107	1108116	23/02/2005		28	
21	Philippines	Autumn	2005	733740	733756	1113854	1113386	12/03/2005	NO	27	
22	Philippines	Autumn	2005	720632	720648	1107832	1107865	17/03/2005		28	
23	Philippines	Autumn	2005	720407	720420	1108068	1108072	17/03/2005		28	
24	Philippines	Autumn	2005	720420	720431	1108072	1108089	18/03/2005		27	
25	Philippines	Autumn	2005	728169	728138	1097095	1097095	18/03/2005		28	
26	Philippines	Autumn	2005	720455	720471	1108041	1108058	21/03/2005		27	
27	Philippines	Autumn	2005	728127	728090	1097115	1097130	21/03/2005		28	

4.4.2 SPSS:

Statistics often cause feelings of uncertainty especially when faced with large volumes of data such as this one (Abouserie 1992). However there are now software packages which can quickly and efficiently complete the necessary formulas for the users' data (Abouserie 1992). One such software is SPSS. Statistics can allow the user to see relationships, trends and distributions whilst organizing

and presenting the data logically and efficiently (Abouserie 1992). It is for this reason SPSS was chosen over Excel to represent the results.

The data was inputted into SPSS from excel and a new data source was opened. Then the chosen spreadsheet was selected, for example 'Tobago'. The variable names were changed to correspond with each column, such as bleaching or SST (sea surface temperatures). With the Filipino data, the date format was incorrect so the dates had to be entered manually, in order to make sure all the data matched up (Figure 4.8). This was exceptionally time-consuming and a problem which had not been predicted.

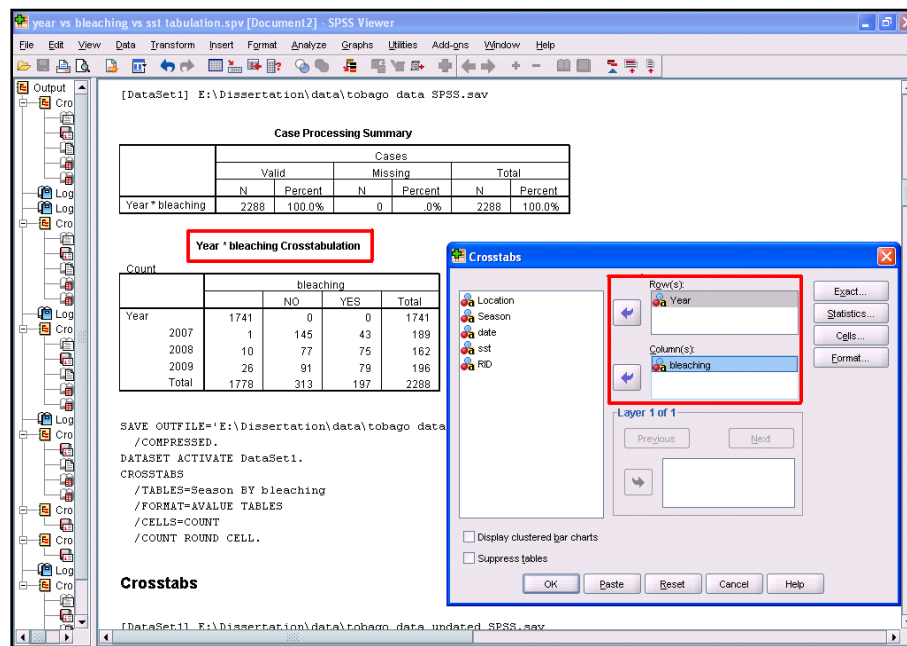
Figure 4.8. Print screen showing uncalibrated Philippine dates.

	Location	Season	Year	LAT_ST	LAT_END	LON_ST	LON_END	DATE	M_BLEACH	S_TEMP	VAR	YES
207	Philippines	Spring	2006	725780	725786	1101042	1101056	30/04/2006	YES	27		
208	Philippines	Spring	2006	721670	721657	1109862	1109848	01/05/2006	NO	27		
209	Philippines	Spring	2006	721848	721858	1115005	1115024	07/05/2005	NO	29		
210	Philippines	Spring	2006	721853	721851	1115024	1114984	07/05/2005	NO	29		
211	Philippines	Spring	2006	721807	721833	1114492	1114492	07/05/2005	NO	31		
212	Philippines	Spring	2006	721833	721790	1114492	1114409	07/05/2005	NO	29		
213	Philippines	Spring	2006	726942	726930	1094911	1094879	08/05/2006	YES	30		
214	Philippines	Spring	2006	727669	727639	1094686	1096654	08/05/2006	NO	28		
215	Philippines	Spring	2006	726746	726746	1101740	1101740	10/05/2006	NO	28		
216	Philippines	Spring	2006	728135	728045	1098291	1095291	38854	YES	29		
217	Philippines	Spring	2006	728118	728137	1095336	1095207	38854	YES	29		
218	Philippines	Spring	2006	728102	728109	1095553	1095621	38854	YES	29		
219	Philippines	Spring	2006	728070	728091	1095762	1095855	38856	NO	29		
220	Philippines	Spring	2006	728091	728045	1095855	1095056	38856	NO	29		
221	Philippines	Spring	2006	728105	728105	1095573	1095573	38856	NO	29		
222	Philippines	Spring	2006	728105	728108	1095573	1095743	38856	YES	29		
223	Philippines	Spring	2006	728006	727931	1095839	1095612	38860	NO	30		
224	Philippines	Spring	2006	728108	728138	1095743	1095733	38860	YES	29		
225	Philippines	Spring	2006	726701			1109516	38860	NO	29		
226	Philippines	Spring	2006	726834			1109515	38860	NO	29		
227	Philippines	Spring	2006	718067	717992	1109746	1109849	38869	NO	27		
228	Philippines	Spring	2006	727376	727336	1100222	1100245	38870	NO	28		
229	Philippines	Spring	2006	727303	727282	1100251	1100199	38870	NO	29		
230	Philippines	Spring	2006	721036	721019	1107286	1107347	38870	NO	29		
231	Philippines	Spring	2006	725681	725718	1101791	1101787	38871	YES	28		

Once all this data was correctly inputted it was checked to guarantee that only the variables which had been entered were being used. This was to ensure when analysing the data that SPSS only takes into consideration your data and not the whole spreadsheet. Once this was done, cross tabulations were chosen to analyze the data as it included descriptive data as well as nominal data. This meant that

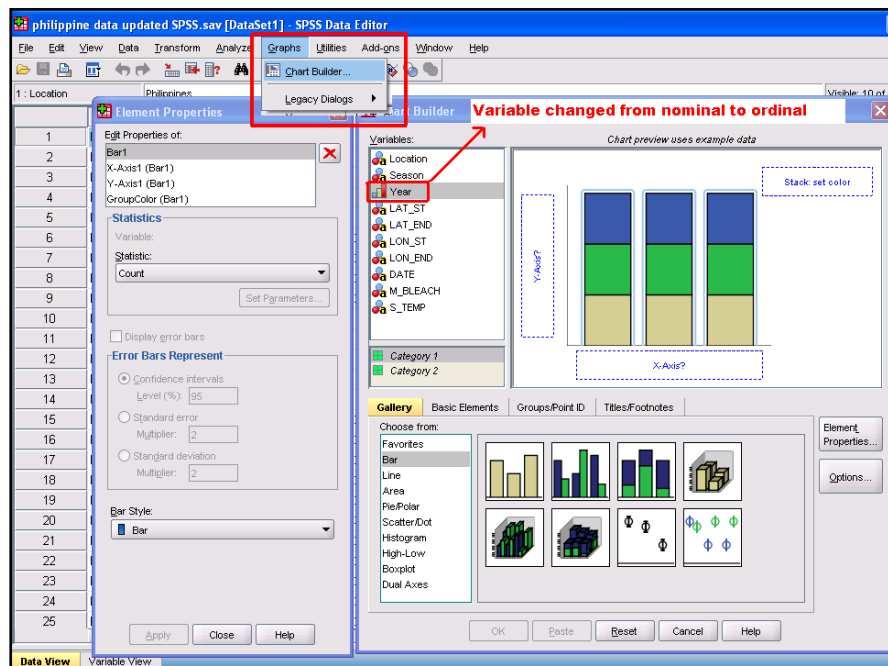
other statistics tests could not be used; nonetheless crosstabs are a quick and easy way to compare your results. They were created by choosing 'Analyze' in the SPSS toolbar (see figure 4.10), then 'Descriptive statistics' and finally 'Crosstabs'. The variables you want compared can then be selected. This grouped the data into a table allowing for easy comparison. An example of this can be seen in figure 4.9.

Figure 4.9. Print screen of cross tabulation process.



When all the relevant crosstabs had been produced, graphs were created to make the data look more aesthetically pleasing and to identify trends and differences quickly. 'Graphs' was selected on the toolbar and then 'Chart builder'. This brought up a window which can be seen in figure 4.10. It was important to remember to change the data from nominal to ordinal. This differentiated the variables and also created a rank ordering i.e. gives the 'Yes' and 'No' data meaning. This was done by right clicking on the 3 coloured circles next to the variables and clicking 'Ordinal'. To create the graph, the type of graph which best illustrated the data was dragged into the display window. The chosen variables of the graph were also dragged onto the x or y axis and the legend. Finally 'OK' was pressed to create the chosen graph.

Figure 4.10. Print screen showing Graph process



“Statistics should never be presented or interpreted in isolation without due regard for the method of data collection, the natures of the sample and the situation of the study.” (Abouserie 1992) Page 1.

It was vital when undertaking the analysis of these statistics to take into consideration this advice. It was for this reason why the long term and global data was created and used. By taking into consideration that the sites may be impacted by other factors it seemed sensible to check the Tobago and Filipino data against what was occurring globally and over a longer time-frame. This was carried out by using software called Bilko.

4.4.3. Bilko

Bilko is a 16- bit image processing software designed to work on home computers and which goes hand-in-hand with the UNESCO (United Nations Educational,

Scientific and Cultural Organisation) project created in 1987⁶ (UNESCO 2003). It is used worldwide and the users range from laboratories, educational establishments and individual users (UNESCO 2003). It came with seven computer-based learning modules to take the user through the processes they need (UNESCO 2003). The reason why Bilko was used in this dissertation is due to the fact that it can create yearly temperature transects and maps. It used NOAA data and therefore it was recognized as using up to date, accurate and extensive data. In addition to this it used the same data as the Reefbase GIS maps creating consistency throughout this dissertation.

Bilko was downloaded along with the tutorials to create temperature maps from long term data off the NOAA website and yearly data from National Oceanic and Atmospheric Administration Coral Reef Watch (NOAA CRW) which began in 2001 and currently end in 2008. In order to create the mean maximum sea surface temperature for each month needed to be calculated, applied and merged into one map. This was achieved by opening the climatology stack on the desktop and choosing the file type 'SETS'. This opened the monthly climatology dataset. 'ALL' was then selected so it calculated the maximum mean sea surface temperature for each month in the chosen year. The 'CRW_SST' palette was then dragged on the map, which downloaded with the software onto the desktop and gave the greyscale map the correct consecutive colours. 'SST_convert' which was also found on the desktop was opened and the formula was copied and pasted onto the colour map to convert the actual SST's to degree Celsius.

Finally a transect which showed this data in graphical form was able to be created. This was done by right clicking on the mean maximum sea surface temperature map and 'new' was selected. This brought up a number of options of which 'transect' was chosen and 'apply stretches to new documents' was deselected. 'OK'

⁶ Created in order to develop people's ability in remote sensing.

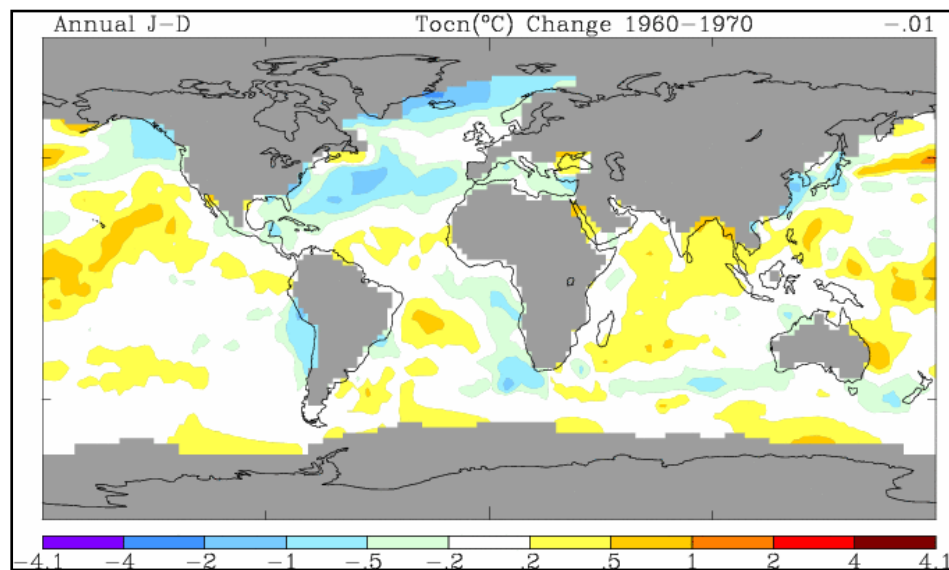
was selected and the program created a transect to show the mean maximum sea surface temperatures as a line graph. This enhanced the map, as it allowed the trend throughout the year to be more obvious and allowed the years to be compared with each other quickly and efficiently. Furthermore the maps did not have a scale as they were simply meant to compare the colour change, therefore the transect allowed for a more accurate comparison of SST change. By using global averages it removed the local processes which may be affecting the CCC and Reefbase data, allowing for a more accurate idea about what was happening to sea surface temperatures throughout the decade.

5. Results

5.1. Global and long term data results

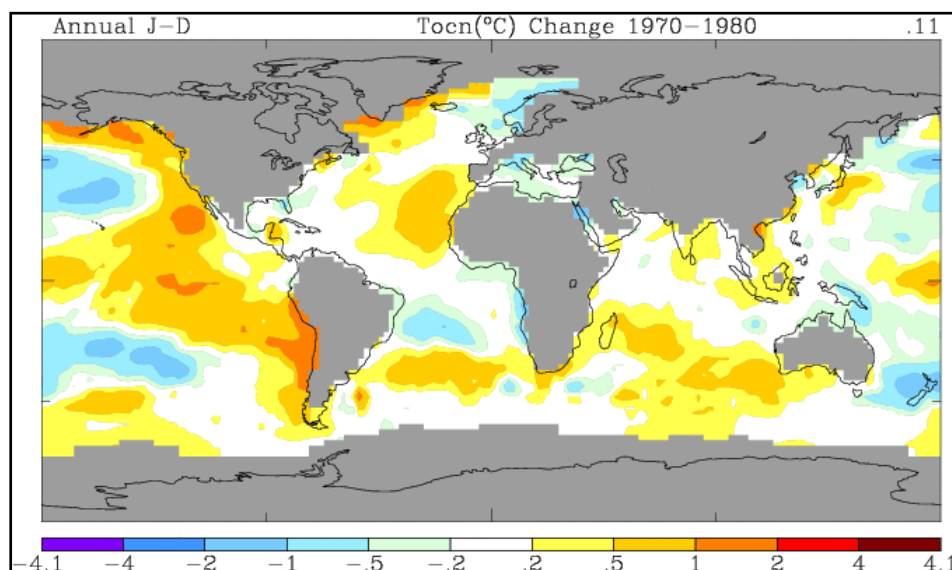
Colour bar at the bottom of the maps represents average °C change throughout the decades. Maps are not to scale.

Figure 5.1.1 Map illustrating SST change from 1960-1970



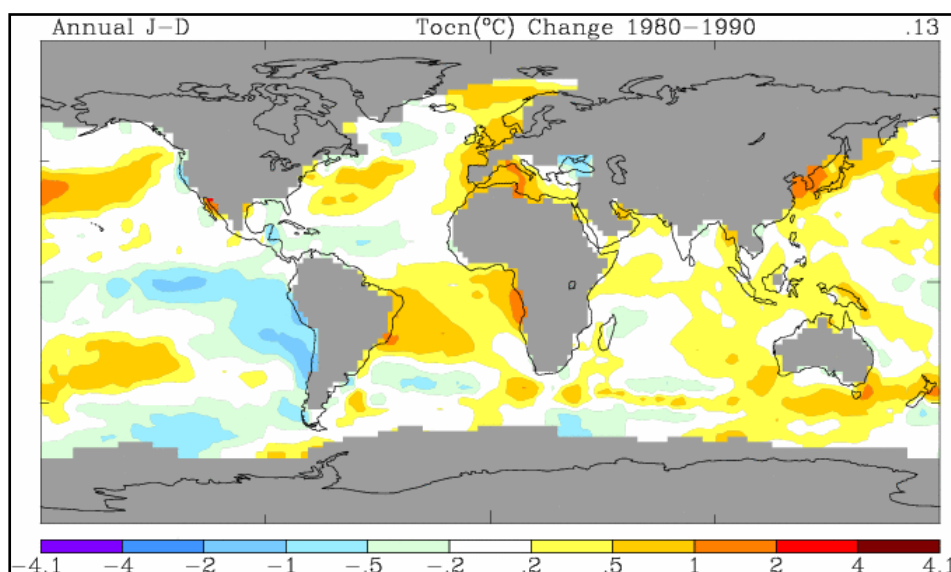
(NASA 2009)

Figure 5.1.2 Map illustrating SST change from 1970-1980



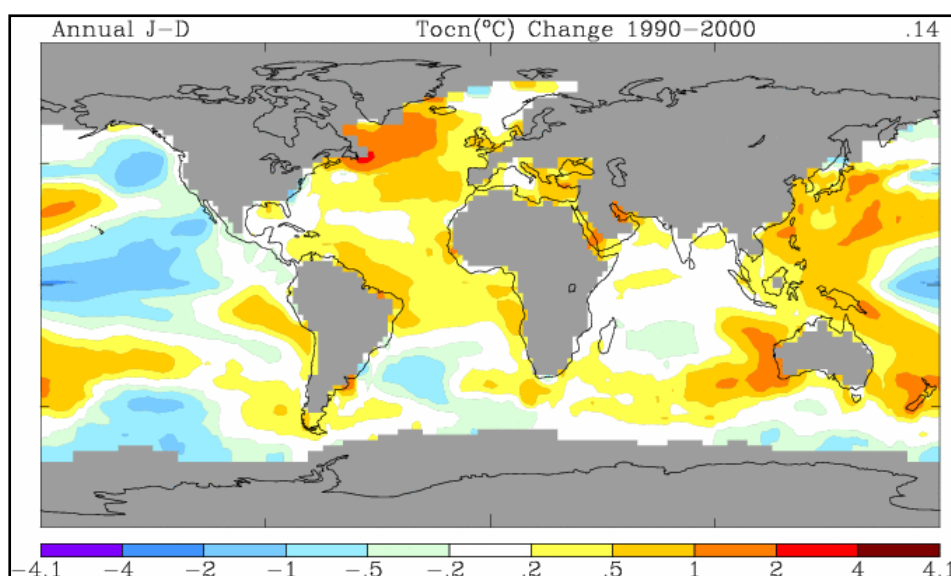
(NASA 2009)

Figure 5.1.3 Map illustrating SST change from 1980-1990



(NASA 2009)

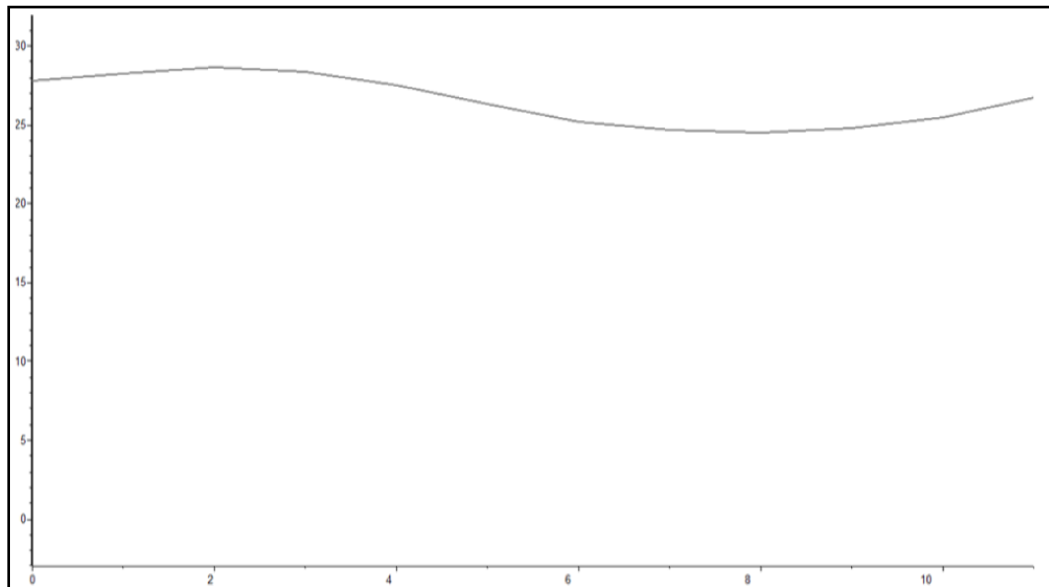
Figure 5.1.4. Map illustrating SST change from 1990-2000



(NASA 2009)

Scales at the bottom of the Bilko maps can be translated to degrees using the formula: 'pixel no' $\div 3 \times 0.15$. E.g. 180 = 26.55°C (UNESCO 2009).

Figure 5.1.5. Bilko transect of annual maximum SST's in 2003



(x axis: January-December and y axis: °C)

Figure 5.1.6. Map illustrating annual maximum SST's in 2003

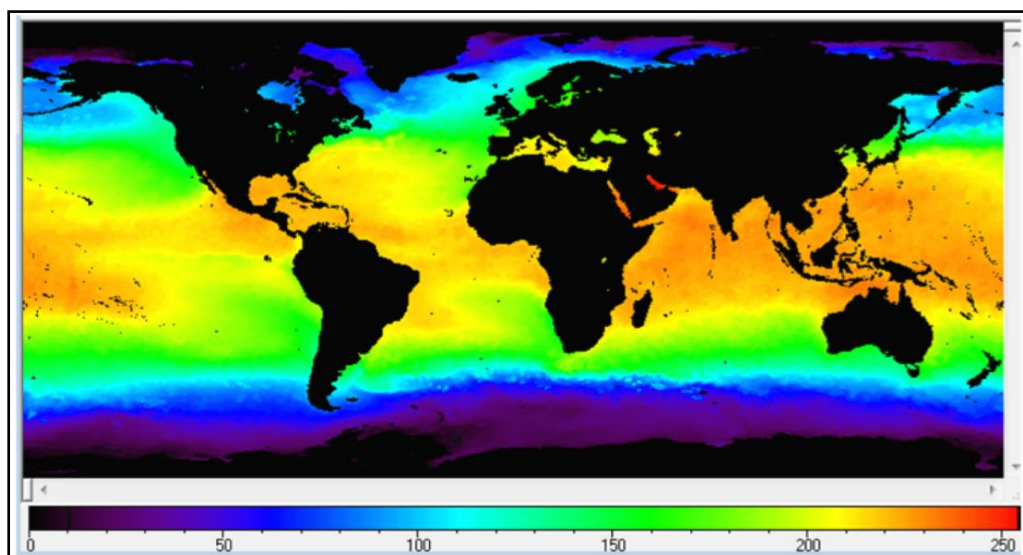
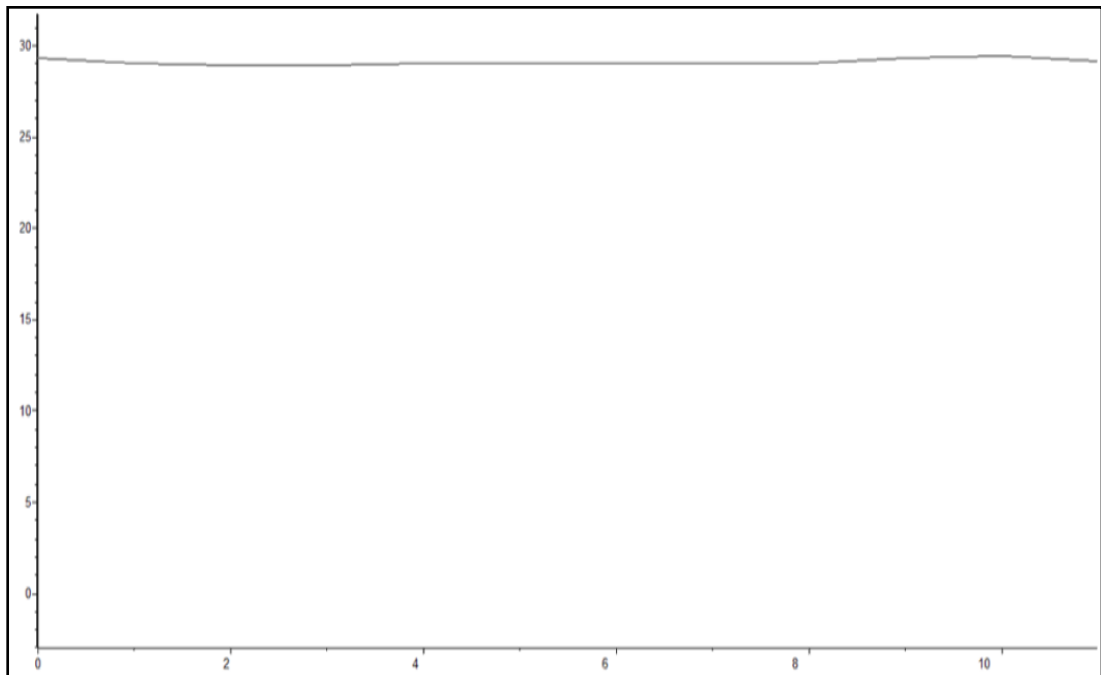


Figure 5.1.7. Bilko transect of annual maximum SST's in 2004



(x axis: January-December and y axis: °C)

Figure 5.1.8. Map illustrating annual maximum SST's in 2004

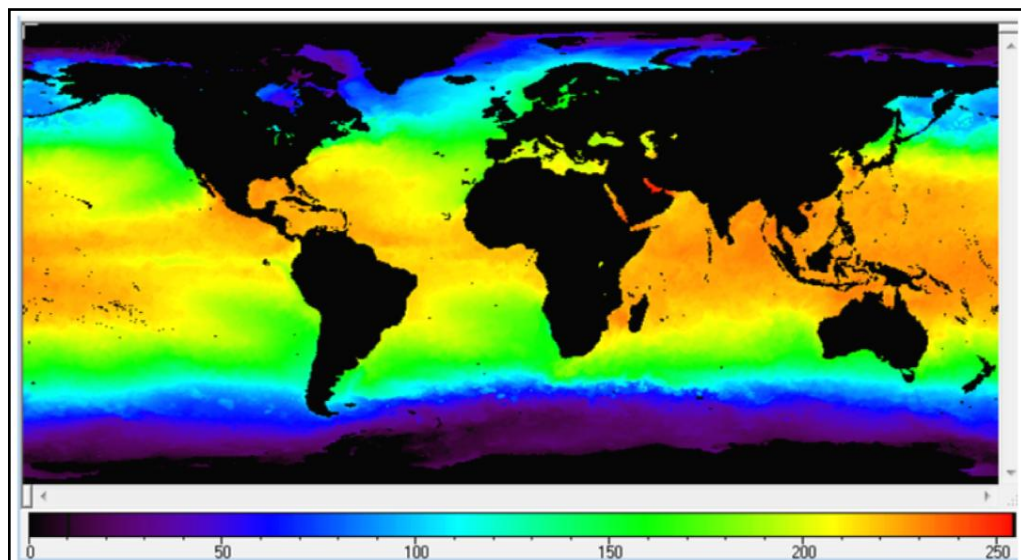
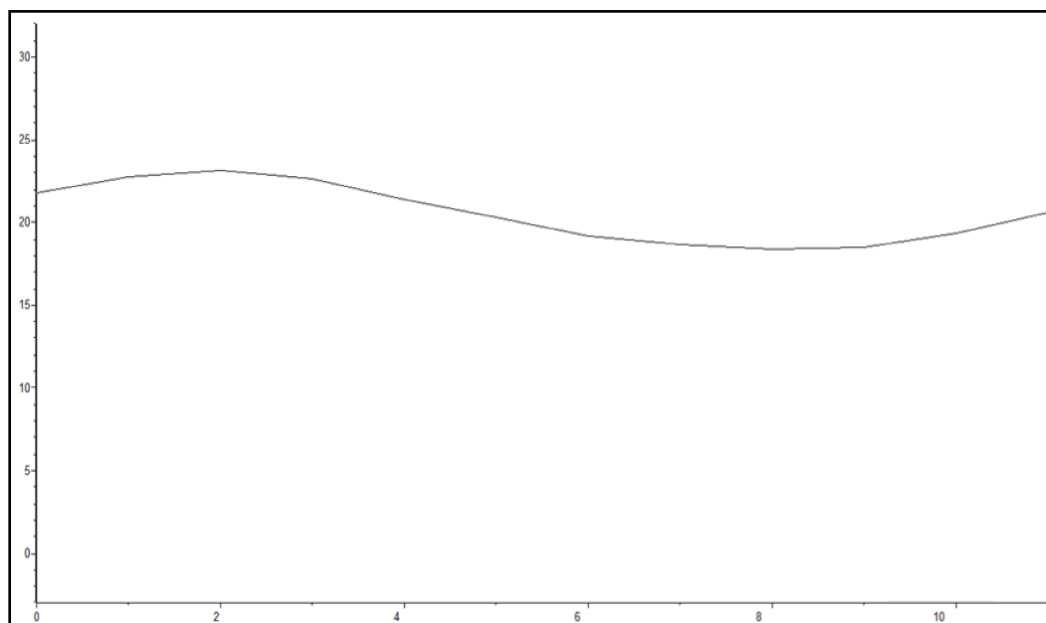


Figure 5.1.9. Bilko transect of annual maximum SST's in 2005



(x axis: January-December and y axis: °C)

Figure 5.1.10. Map illustrating annual maximum SST's in 2005

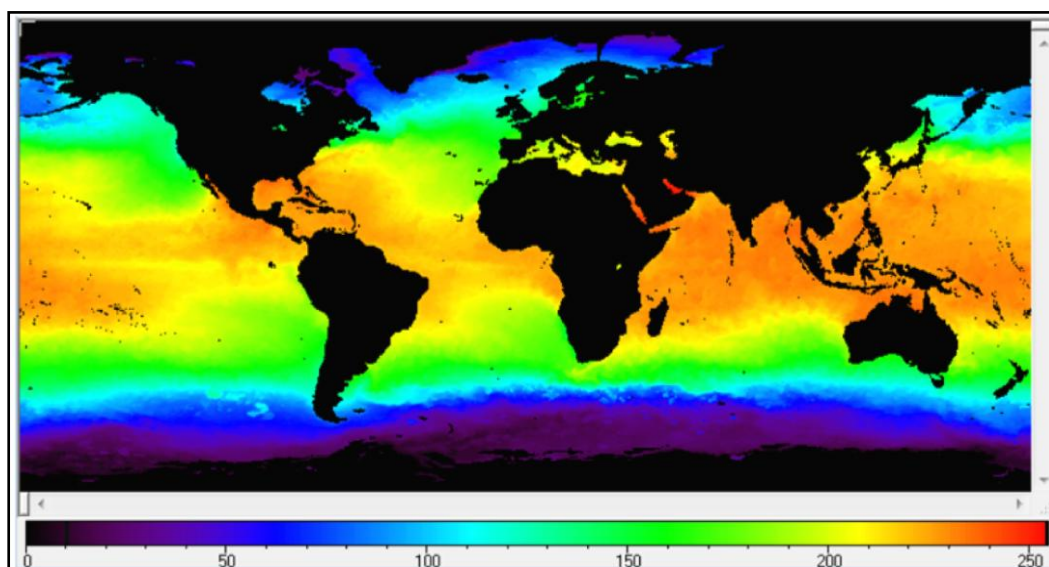
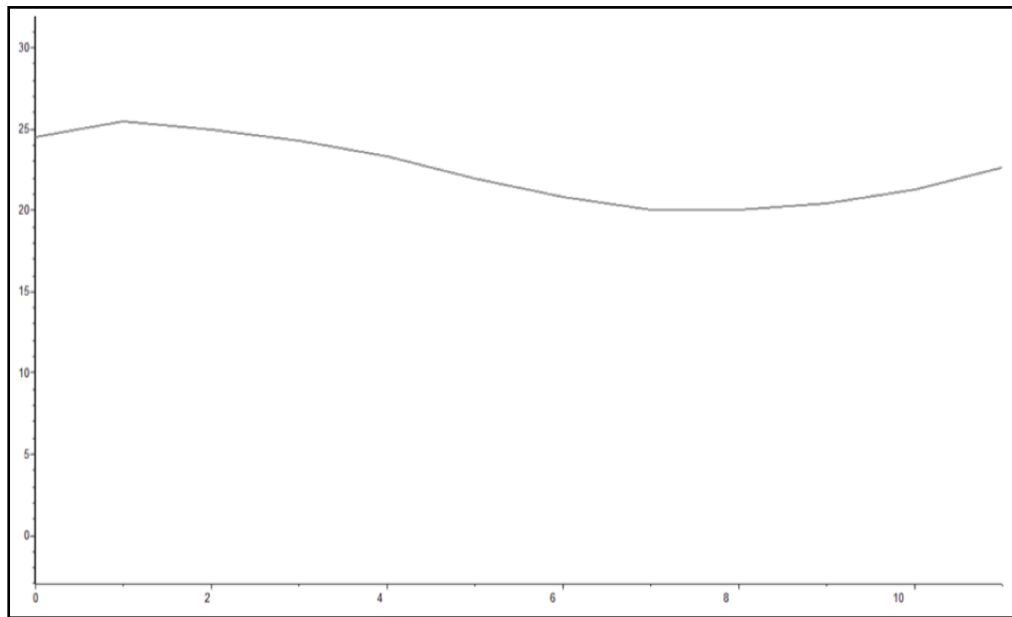


Figure 5.1.11. Bilko transect of annual maximum SST's in 2006



(x axis: January-December and y axis: °C)

Figure 5.1.12. Map illustrating annual maximum SST's in 2006

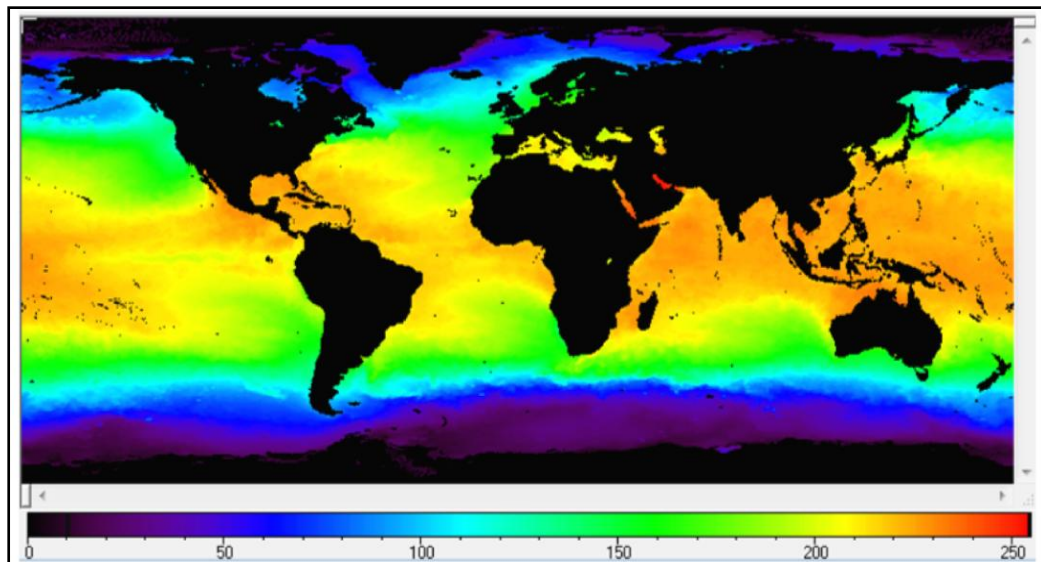
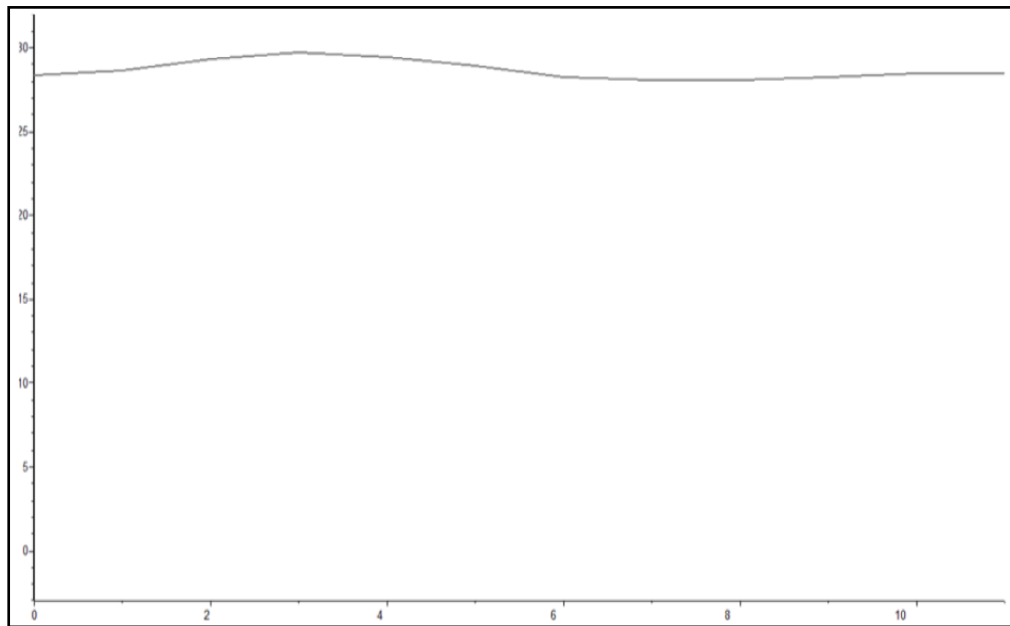


Figure 5.1.13. Bilko transect of annual maximum SST's in 2007



(x axis: January-December and y axis: °C)

Figure 5.1.14. Map illustrating annual maximum SST's in 2007

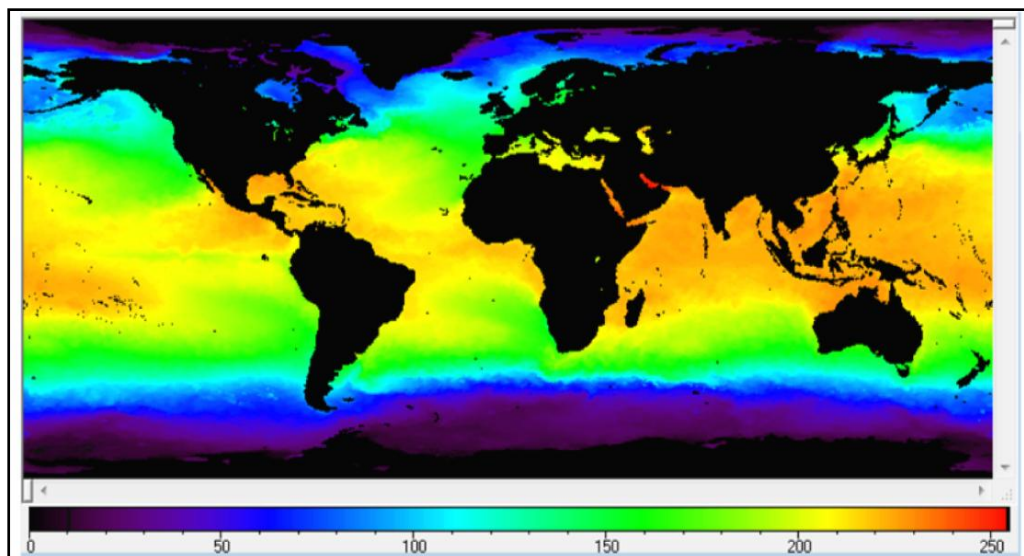


Figure 5.1.15. Bilko transect of annual maximum SST's in 2008

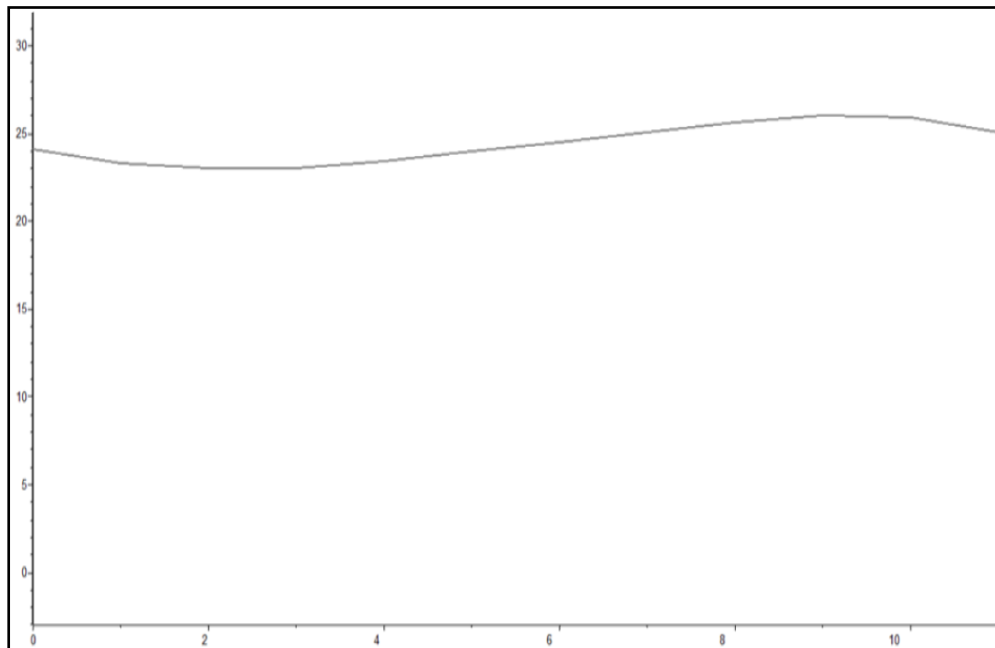
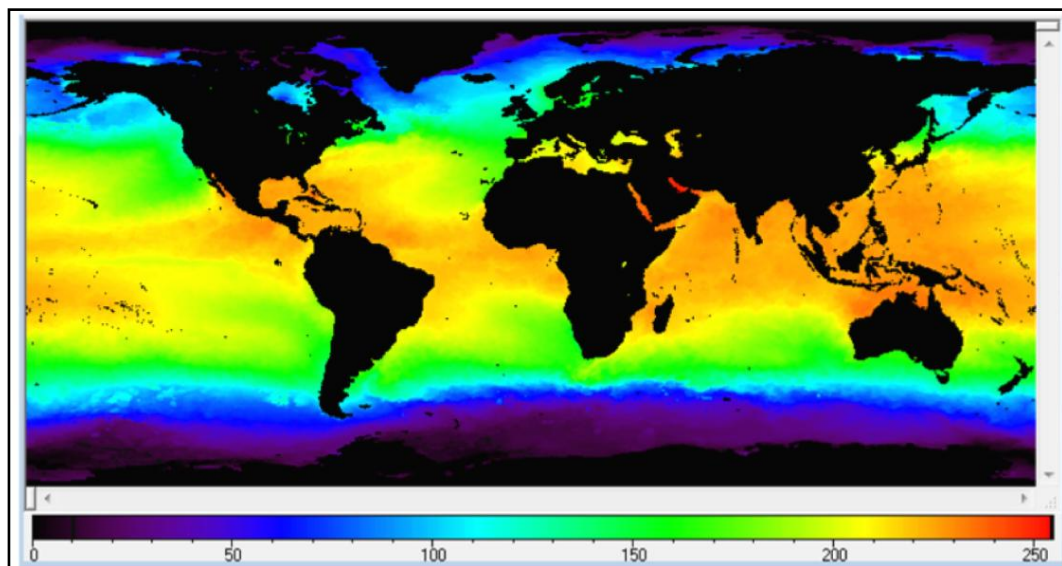


Figure 5.1.16. Map illustrating annual maximum SST's in 2008



5.2. Tobago results

Figure 5.2.1 Graph illustrating Bleaching vs. Year

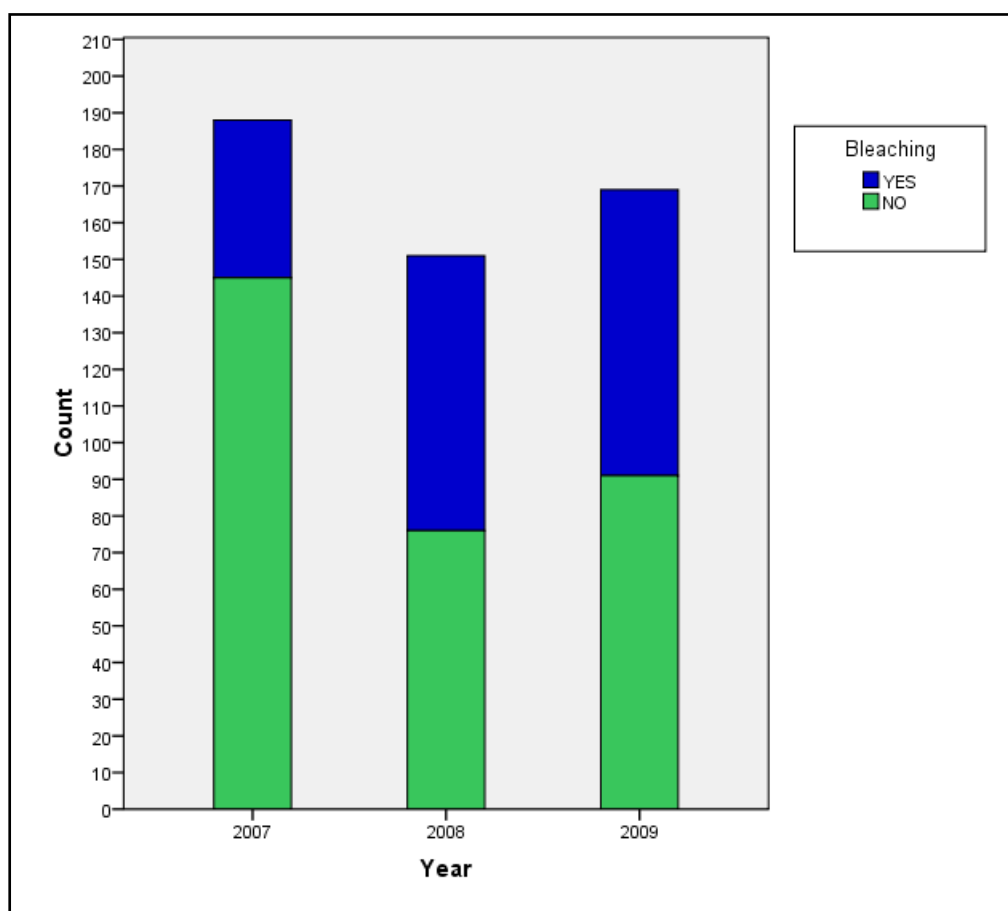


Figure 5.2.2. Cross-Tabulation illustrating Bleaching vs. Year

		Year			
		2007	2008	2009	Total
Bleaching	NO	145	76	91	312
	NR	1	11	27	39
	YES	43	75	78	196
	Total	189	162	196	547

Figure 5.2.3. Graph illustrating Bleaching vs. Season

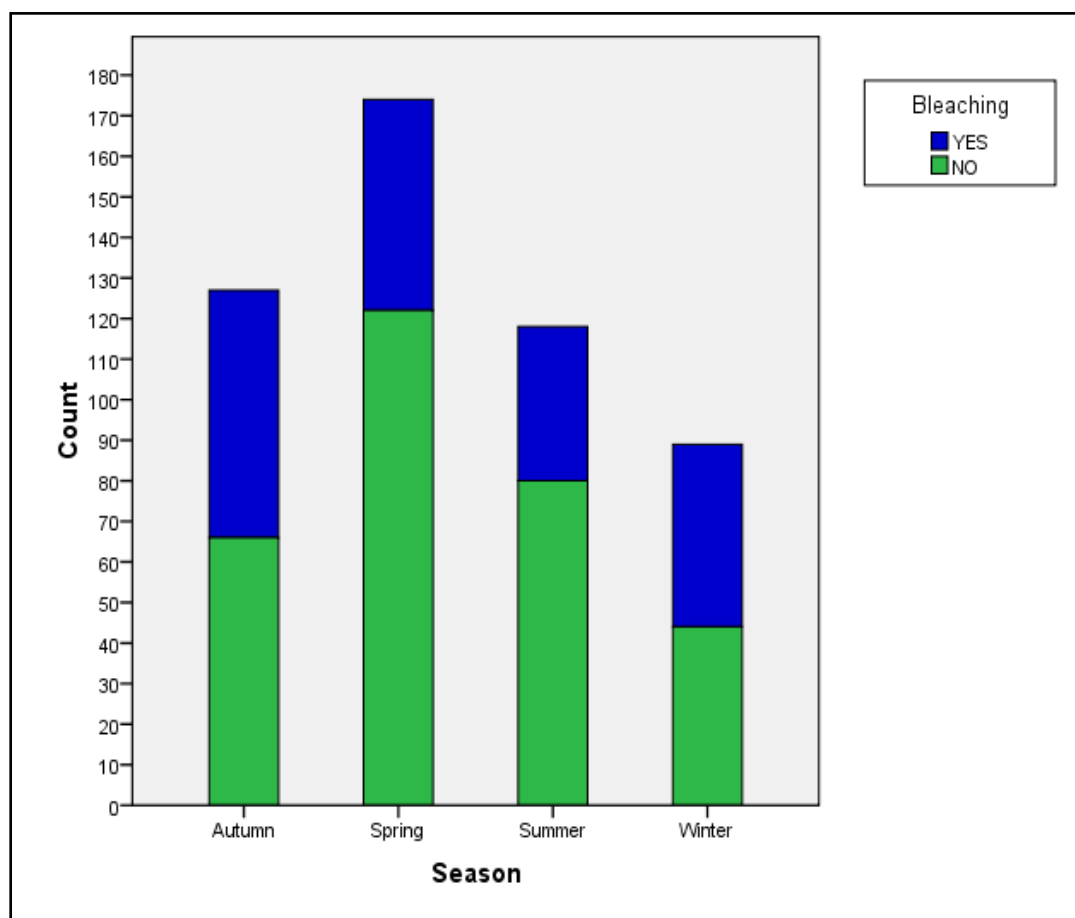
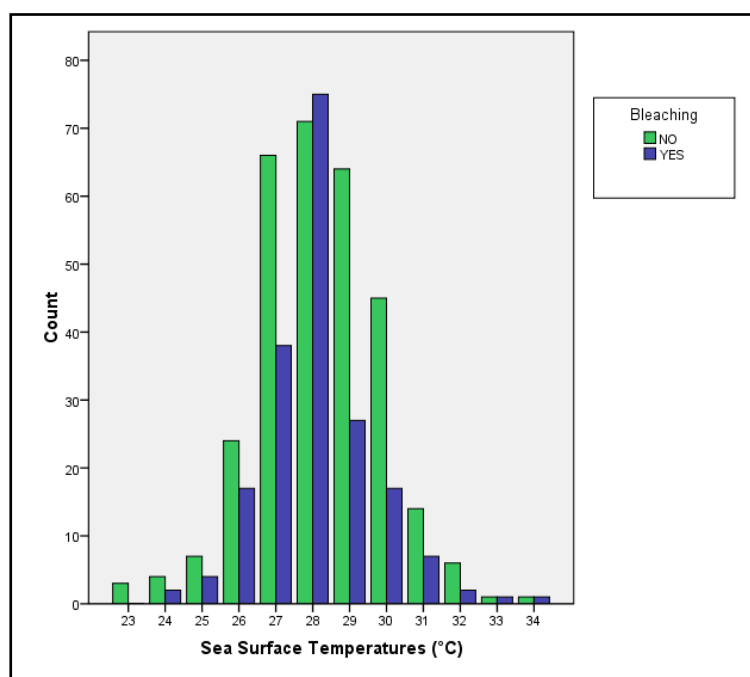


Figure 5.2.4. Cross-Tabulation illustrating Bleaching vs. Season

		Season				
		Autumn	Spring	Summer	Winter	Total
Bleaching	NO	66	122	80	44	312
	NR	8	15	7	9	39
	YES	61	52	38	45	196
	Total	135	189	125	98	547

Figure 5.2.5. Graph illustrating Bleaching vs Sea Surface Temperature**Figure 5.2.6. Cross-Tabulation illustrating Bleaching vs. SST**

	Bleaching			
	NR	NO	YES	Total
SST	5	6	5	16
23	0	3	0	3
24	0	4	2	6
25	1	7	4	12
26	9	24	17	50
27	13	66	38	117
28	6	71	75	152
29	0	64	27	91
30	3	45	17	65
31	3	14	7	24
32	0	6	2	8
33	0	1	1	2
34	0	1	1	2
Total	40	312	196	548

Figure 5.2.7. Graph illustrating Bleaching vs Year vs Sea Surface Temperature

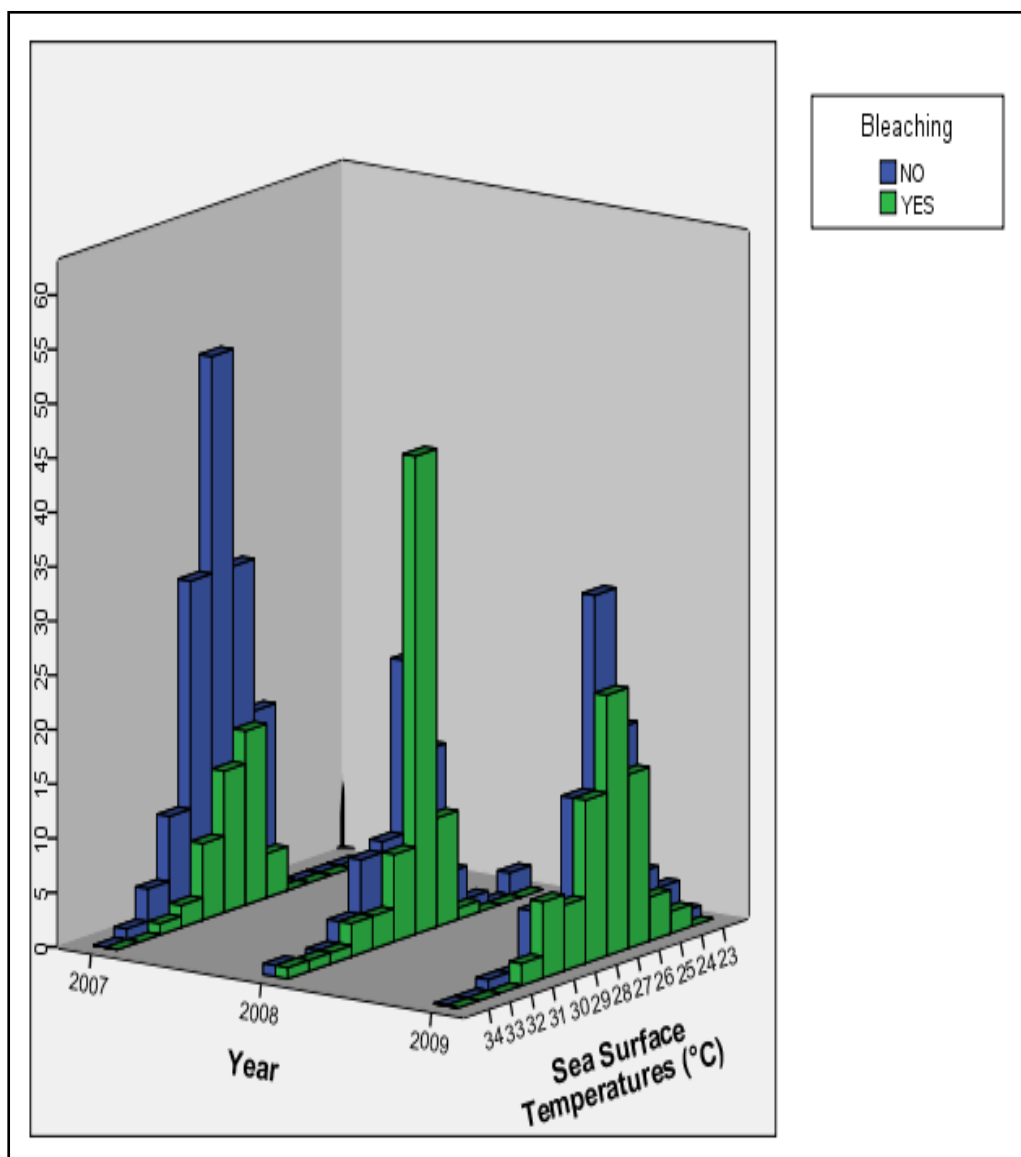
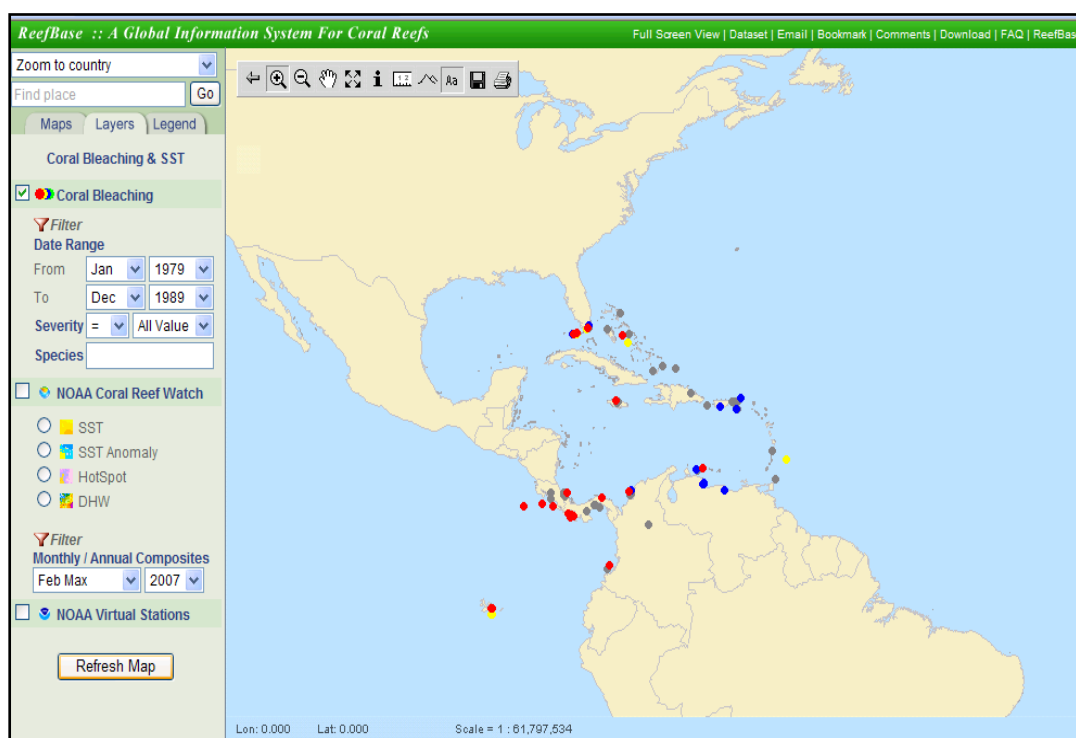


Figure 5.2.8. Cross-Tabulation illustrating Bleaching vs. Year vs. SST

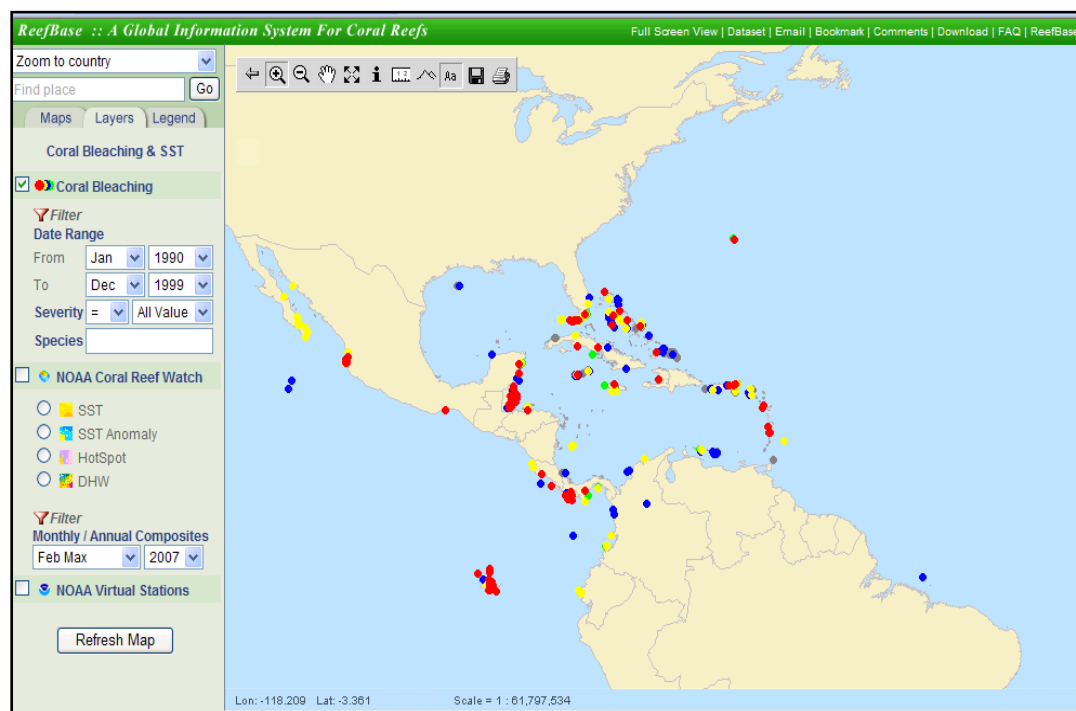
Year			Bleaching			
			NO	NR	YES	Total
2007	SST	27	17	0	4	21
		28	31	0	16	47
		29	51	0	13	64
		30	31	1	7	39
		31	10	0	2	12
		32	4	0	1	5
		33	1	0	0	1
		Total	145	1	43	189
2008	SST		6	2	3	11
		23	2	0	0	2
		25	1	0	0	1
		26	4	0	1	5
		27	16	2	10	28
		28	25	3	44	72
		29	9	0	8	17
		30	8	1	3	12
		31	3	3	3	9
		32	1	0	1	2
		33	0	0	1	1
		34	1	0	1	2
		Total	76	11	75	162
2009	SST		0	2	2	4
		23	1	0	0	1
		24	4	0	2	6
		25	6	1	4	11
		26	20	9	16	45
		27	33	11	24	68
		28	15	3	15	33
		29	4	0	6	10
		30	6	1	7	14
		31	1	0	2	3
		32	1	0	0	1
		Total	91	27	78	196

Figure 5.2.9. Map illustrating bleaching in years 1980-1989



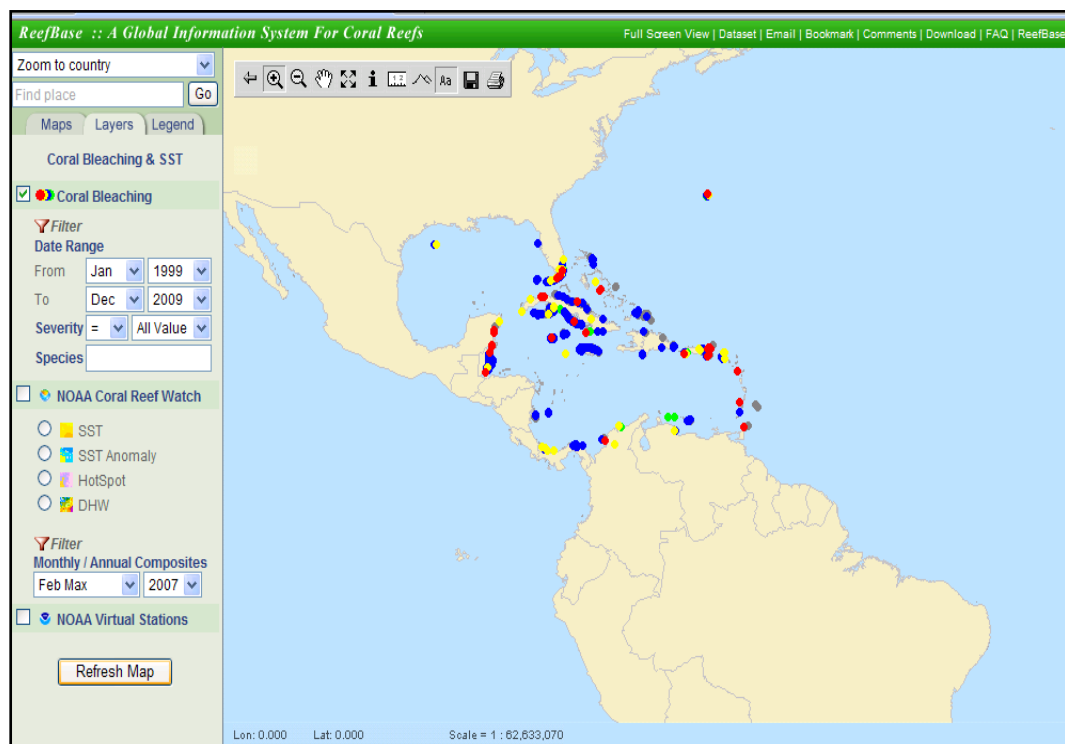
(Reefbase 2009)

Figure 5.2.10. Map illustrating bleaching in years 1989-1999



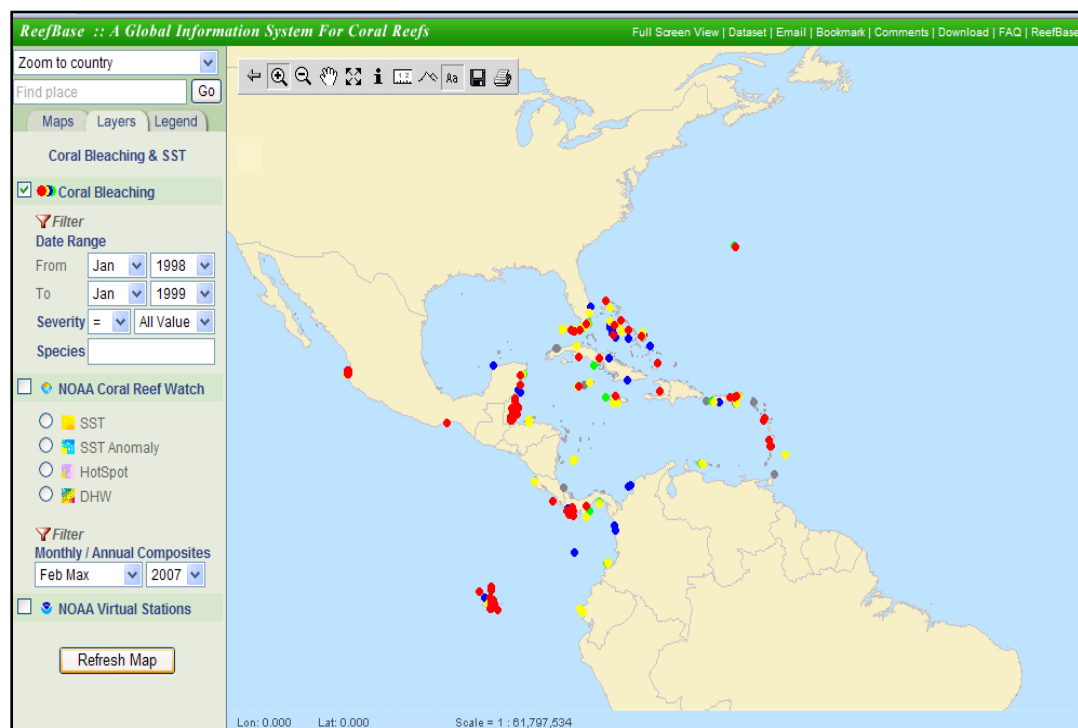
(Reefbase 2009)

Figure 5.2.11. Map illustrating bleaching in years 1999-2009



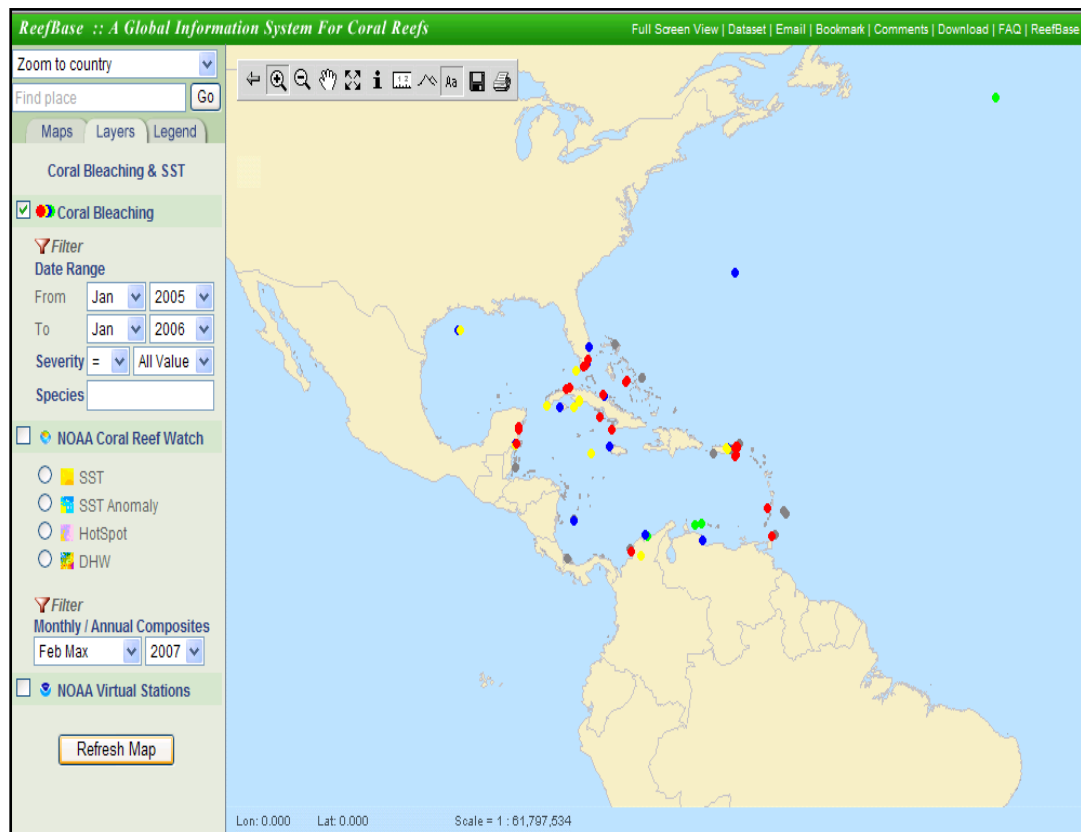
(Reefbase 2009)

Figure 5.2.12. Map illustrating bleaching in El Niño year 1998



(Reefbase 2009)

5.2.13. Map illustrating bleaching in El Niño year 2005



(Reefbase 2009)

5.3 Philippine results

Figure 5.3.1. Graph illustrating Bleaching vs Year

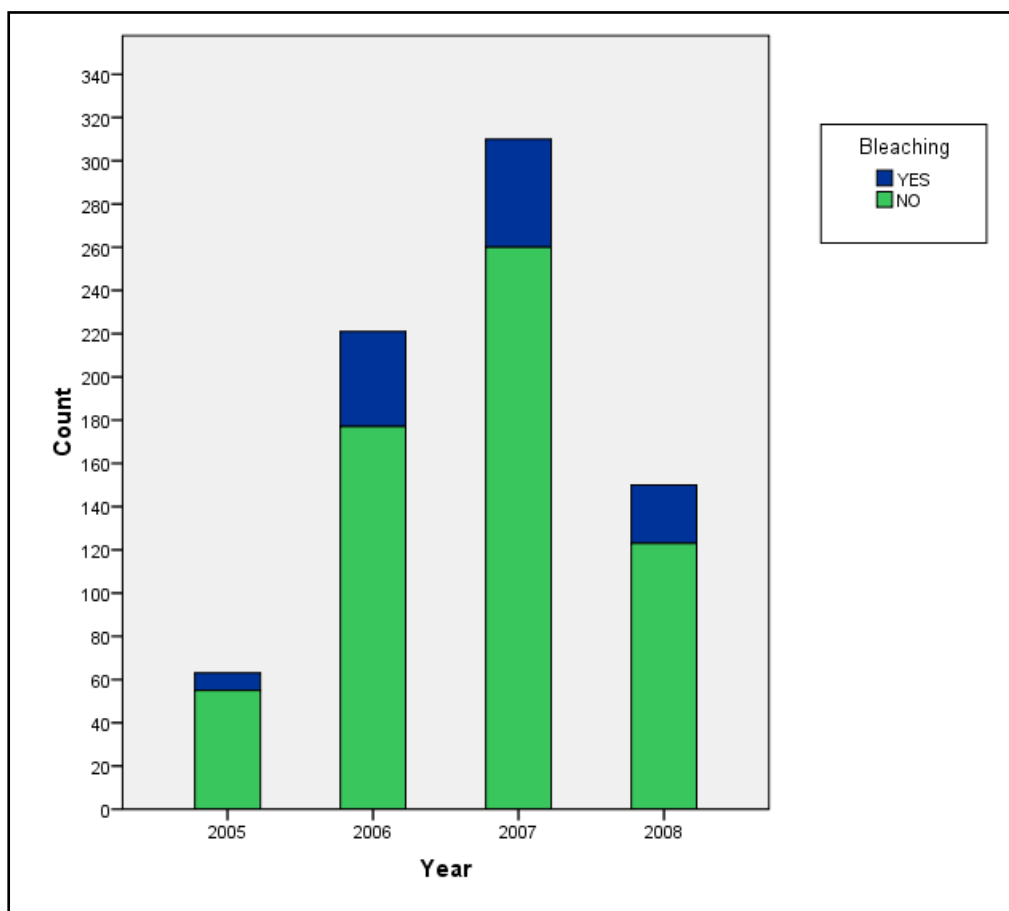
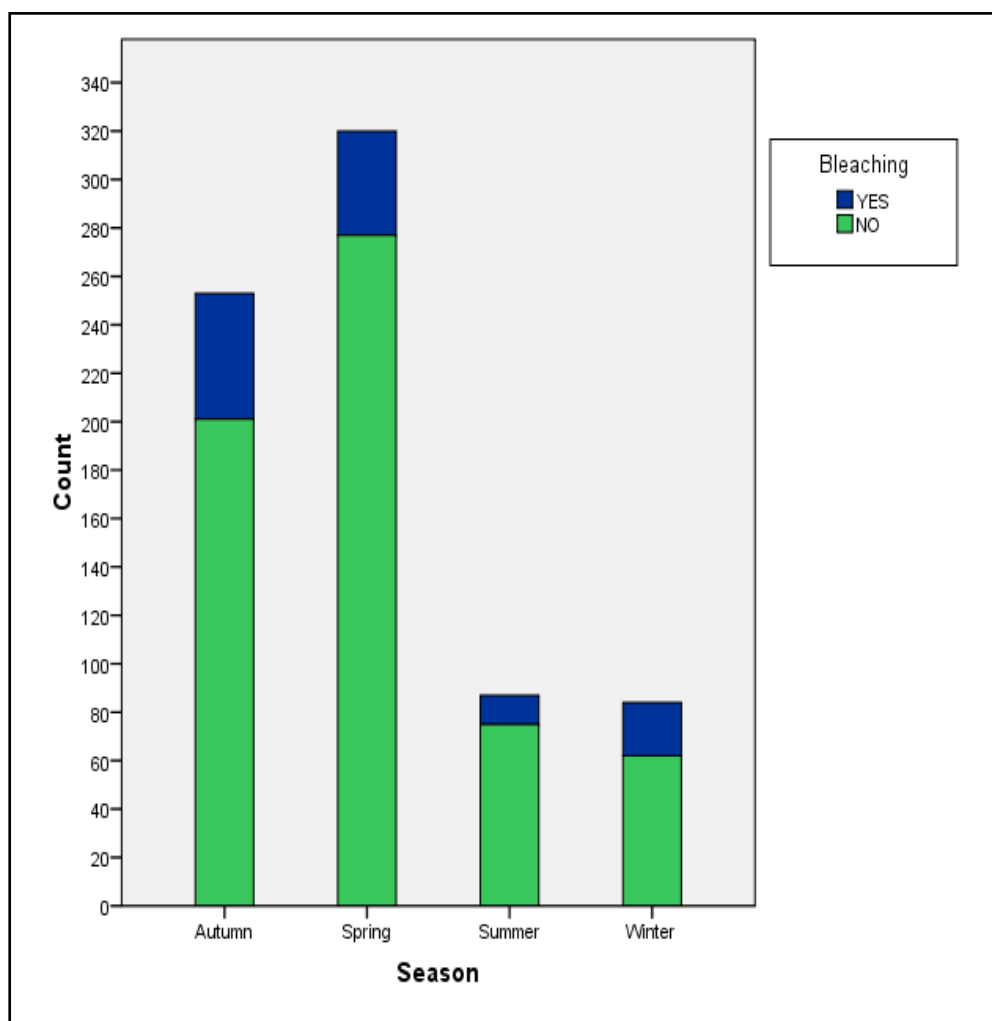
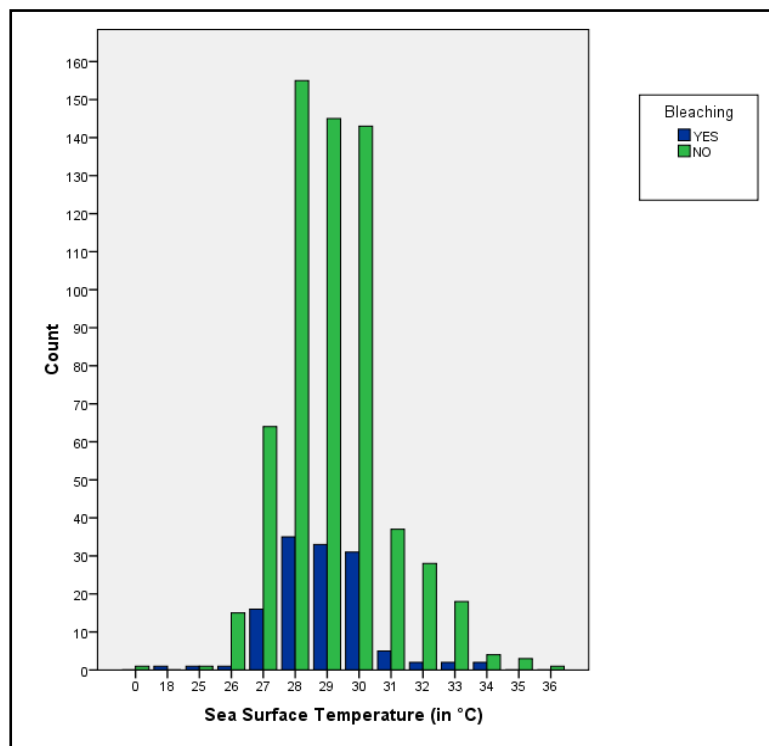


Figure 5.3.2. Cross-Tabulation illustrating Bleaching vs. Year

		Year				
		2005	2006	2007	2008	Total
Bleaching	NO	55	177	260	123	615
	NR	29	0	0	0	29
	YES	8	44	50	27	129
	Total	92	221	310	150	773

Figure 5.3.3. Graph illustrating Bleaching vs Season**Figure 5.3.4. Cross-Tabulation illustrating Bleaching vs. Season**

		Bleaching			
		NR	NO	YES	Total
Season	Autumn	29	201	52	282
	Spring	0	277	43	320
	Summer	0	75	12	87
	Winter	0	62	22	84
	Total	29	615	129	773

Figure 5.3.5. Graph illustrating Bleaching vs Sea Surface Temperatures**Figure 5.3.6. Cross-Tabulation illustrating Bleaching vs. SST**

	Bleaching			
	NR	NO	YES	Total
SST	0	1	0	1
18	0	0	1	1
25	0	1	1	2
26	0	15	1	16
27	15	64	16	95
28	13	155	35	203
29	1	145	33	179
30	0	143	31	174
31	0	37	5	42
32	0	28	2	30
33	0	18	2	20
34	0	4	2	6
35	0	3	0	3
36	0	1	0	1
Total	29	615	129	773

Figure 5.3.7. Graph illustrating Bleaching vs Sea Surface Temperatures vs Year

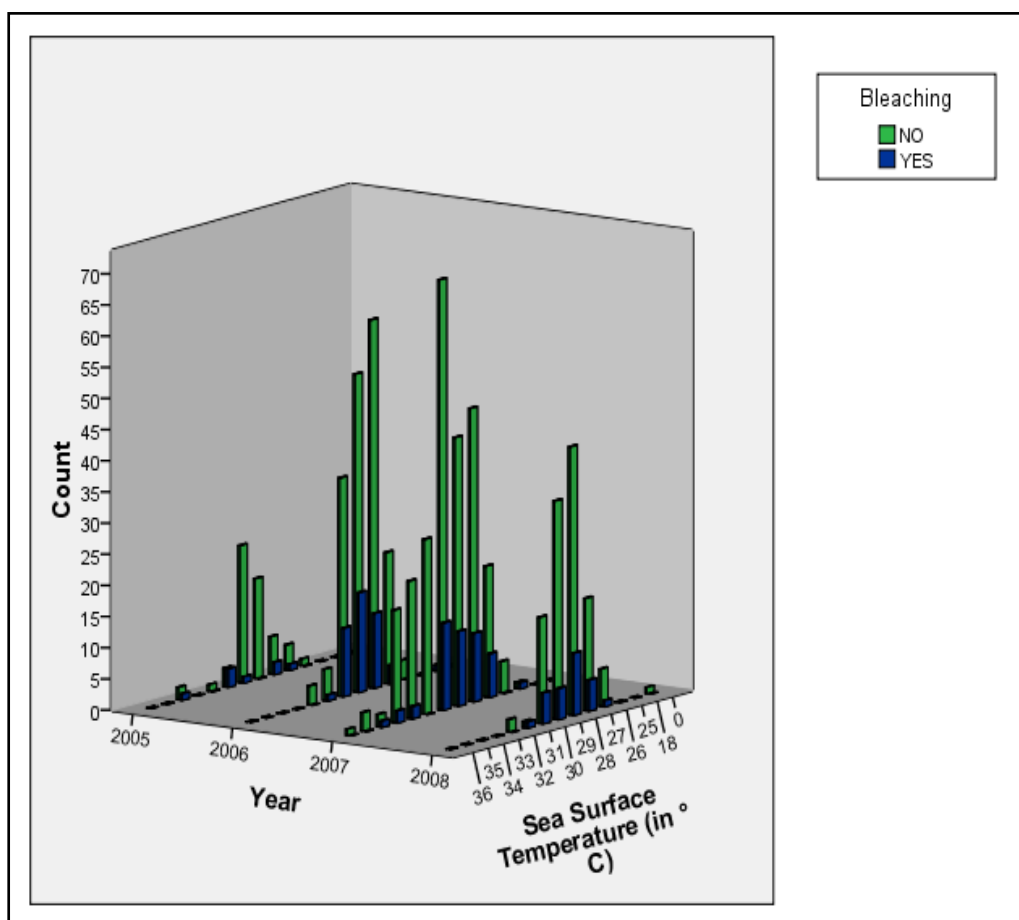
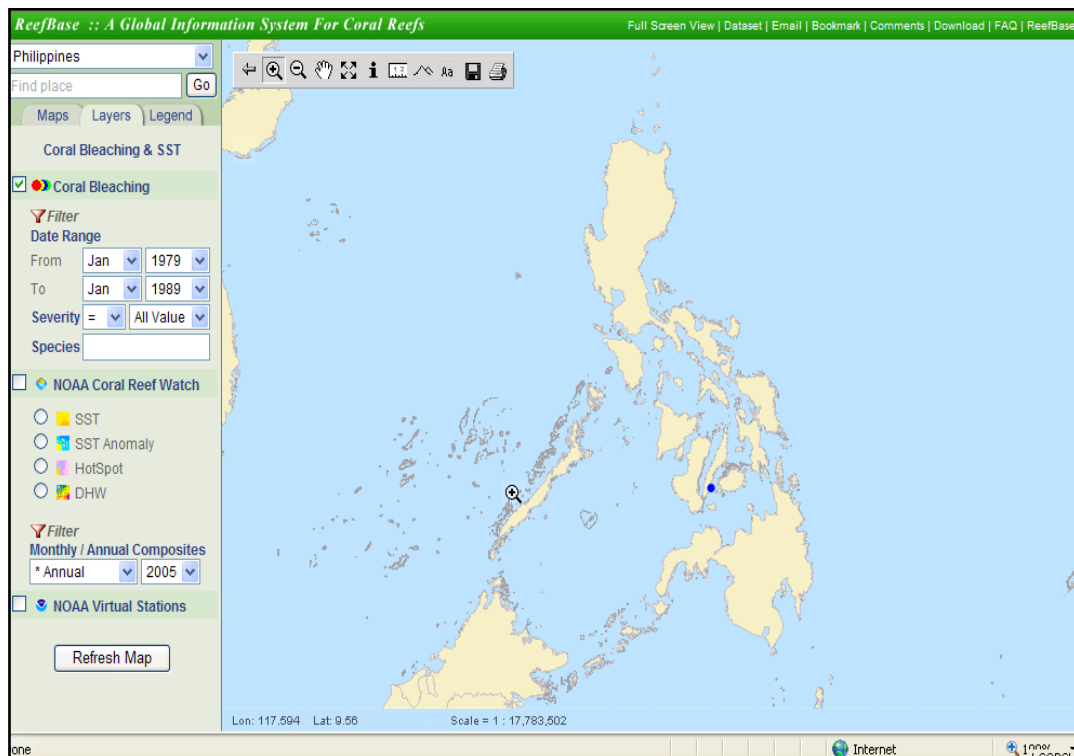


Figure 5.3.8. Cross-Tabulation illustrating Bleaching vs. Year vs. SST

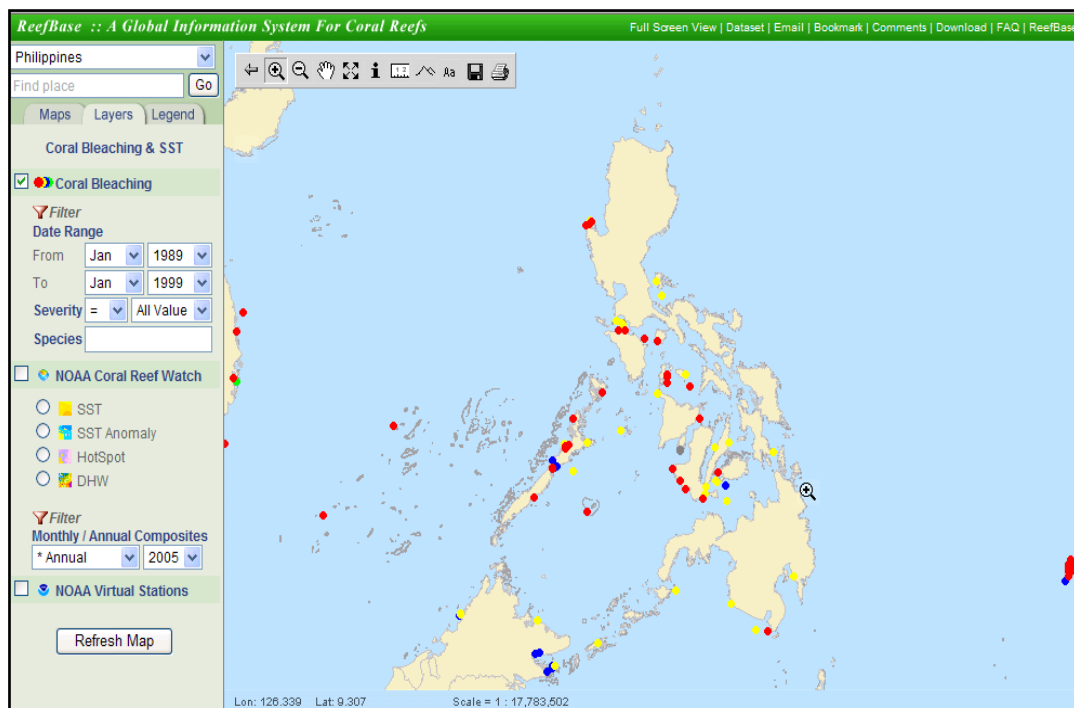
Bleaching			Year				
			2005	2006	2007	2008	Total
NO	SST	0	0	0	0	1	1
		25	0	0	1	0	1
		26	1	3	5	6	15
		27	4	21	21	18	64
		28	6	59	47	43	155
		29	16	51	43	35	145
		30	22	35	69	17	143
		31	3	5	28	1	37
		32	1	3	22	2	28
		33	0	0	18	0	18
		34	2	0	2	0	4
		35	0	0	3	0	3
		36	0	0	1	0	1
		Total	55	177	260	123	615
NR	SST	27	15				15
		28	13				13
		29	1				1
		Total	29				29
YES	SST	18	0	1	0	0	1
		25	0	0	1	0	1
		26	0	0	0	1	1
		27	1	3	7	5	16
		28	2	12	11	10	35
		29	0	16	12	5	33
		30	1	11	14	5	31
		31	3	1	0	1	5
		32	0	0	2	0	2
		33	0	0	2	0	2
		34	1	0	1	0	2
		Total	8	44	50	27	129

Figure 5.3.9. Map illustrating bleaching in 1979-1989



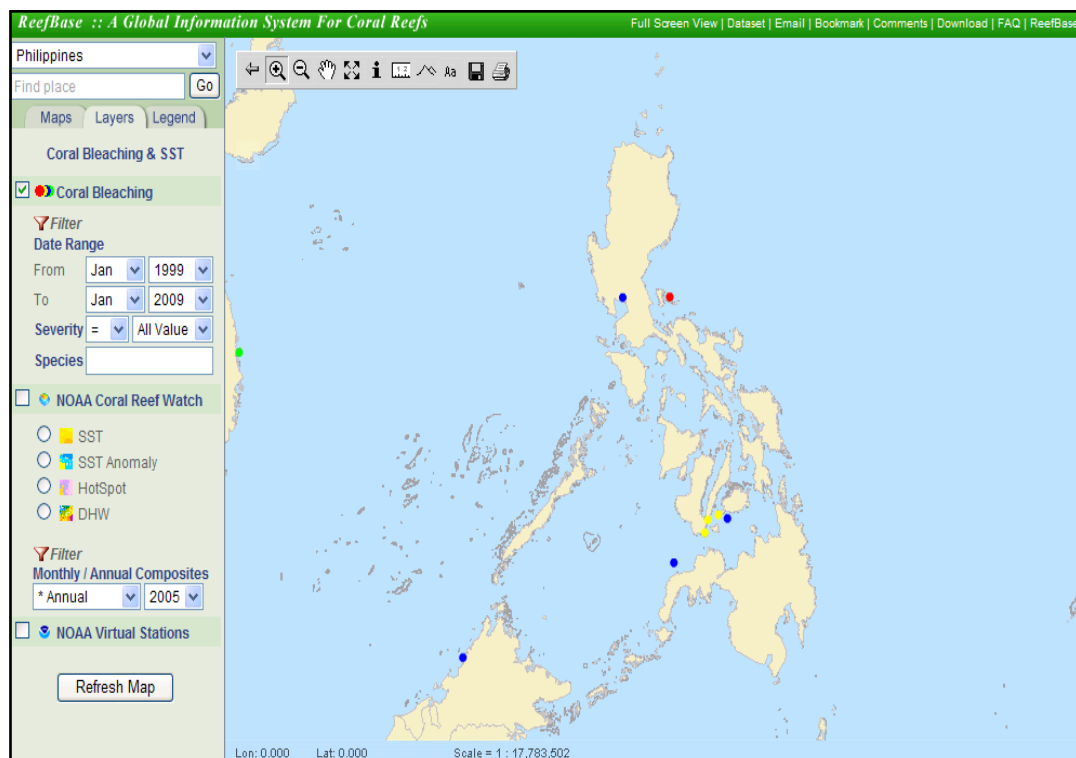
(Reefbase 2009)

Figure 5.3.10. Map illustrating bleaching in 1989-1999



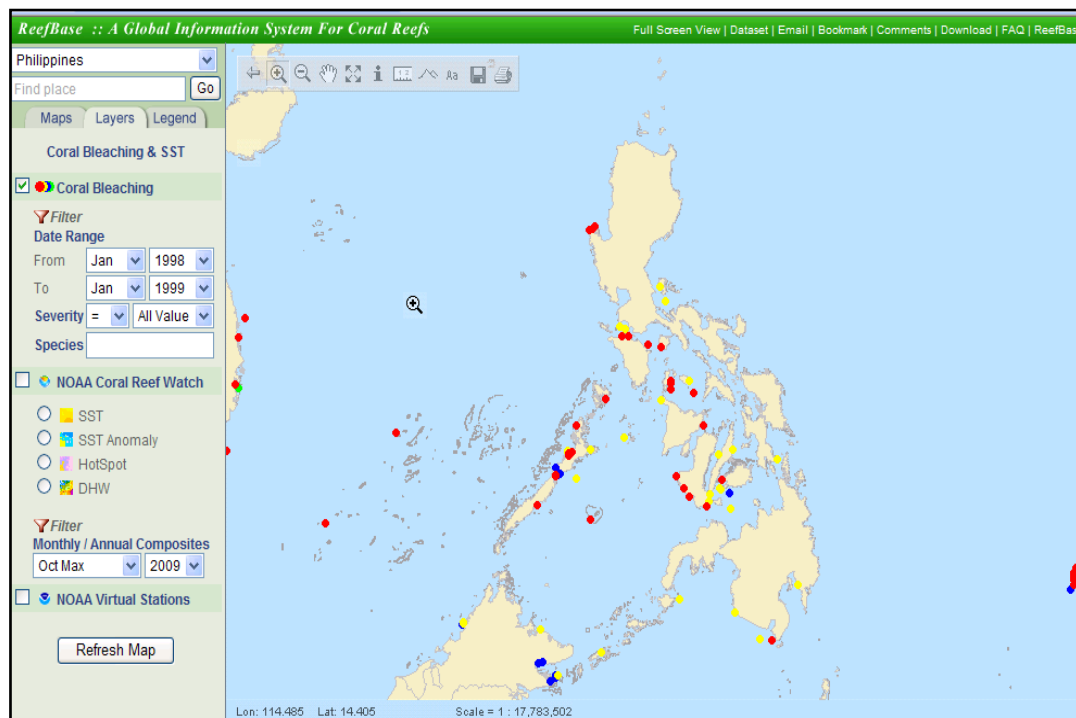
(Reefbase 2009)

Figure 5.3.11. A map illustrating bleaching in 1999-2009



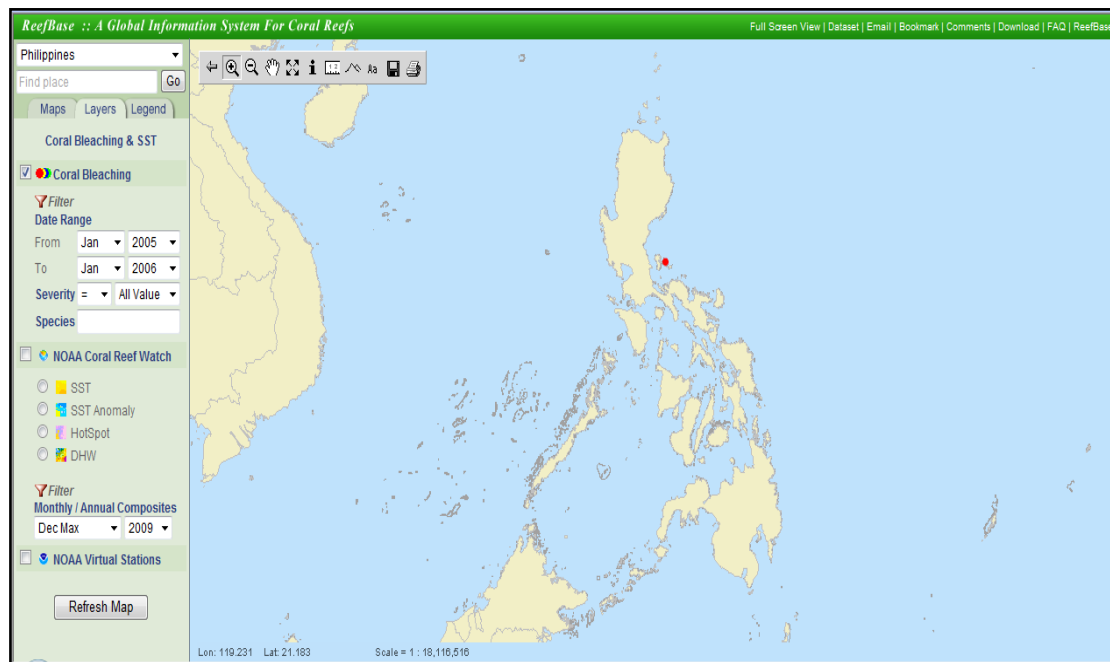
(Reefbase 2009)

Figure 5.3.12. Map illustrating bleaching in El Niño year 1998



(Reefbase 2009)

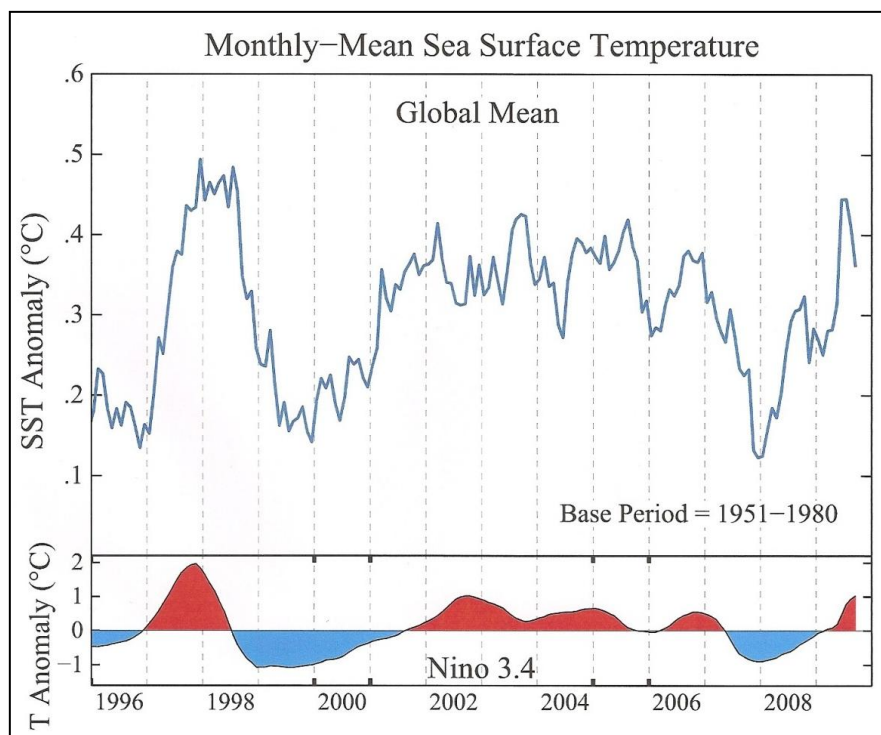
Figure 5.3.13. Map illustrating bleaching in El Niño year 2005.



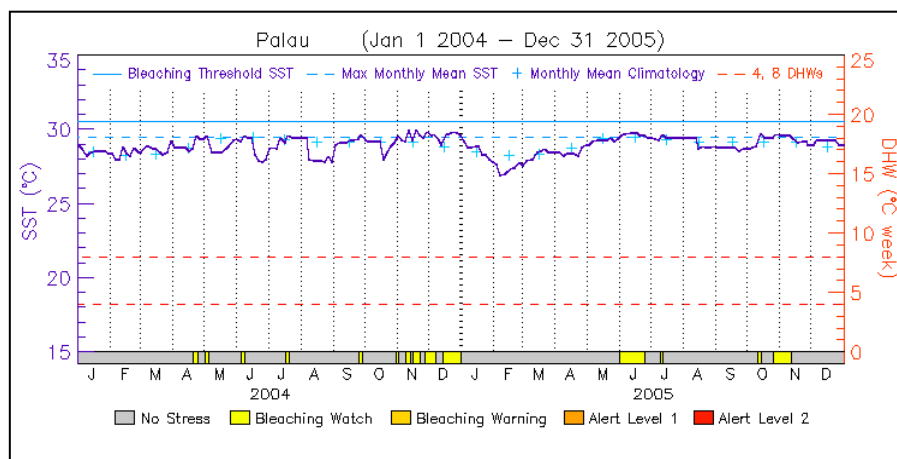
(Reefbase 2009)

5.4. El Niño

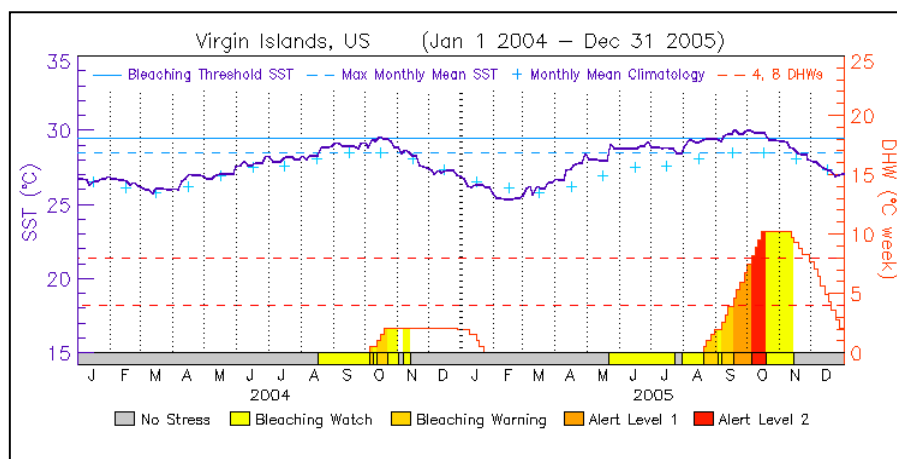
Figure 5.4.1. Graph illustrating SST anomalies associated with El Niño



(Sato 2009)

Figure 5.4.2. Map illustrating 2005 El Niño effect from Palau NOAA station (Philippines)

(Reefbase 2009)

Figure 5.4.3. Map illustrating El Niño effect from US Virgin Island NOAA station (Tobago)

(Reefbase 2009)

6. Analysis and Discussion

6.1 Global and long term data

6.1.2 Decadal change in Sea Surface Temperatures (SST's)

Coral Reefs are generally located within the tropics and therefore this analysis will primarily focus on this region when looking at SST change. As expected when examining figures 5.1.1-5.1.4, a general trend of increasing (SST's) over the decades is identified.

Inspecting figures 5.1.5- 5.1.16, illustrates that sea surface temperatures are not rising year upon year in a regimented pattern. It demonstrates that the highest SST's are recorded in 2007, which therefore suggests that the higher temperatures are being recorded later in the decade. The drop in temperature illustrated in 2008 (see figure 5.1.15) can be attributed to an oceanic and atmospheric process. The Met Office confirms that 2008 sees a strong La Niña and although it still makes 2008 0.37°C higher than the long-term average, it is the coldest year since 2000 (Met Office 2008).

Despite 2003 and 2006 producing lower than expected temperatures, they still hit high SST's at their SST maximums of 26°C and 29 °C confirming that in this decade SST's are higher than previous decades. From figure 5.1.9, it can be seen that 2005 has a very surprising temperature range of 19-23°C, which is the lowest for the decade and unprecedented as this is meant to be an El Niño year. In order to understand this it is important to remember that the transect is a global mean and it takes into consideration all ocean temperatures. When comparing this with the Bilko maps (figures 5.1.6, 5.1.8, 5.1.10, 5.1.12, 5.1.14, and 5.1.16) the Arctic Ocean seems to be colder this year and the colder temperatures seem to cover a much

larger area, which would impact the global mean temperatures and is most likely the cause of the generally lower temperatures in this year. The 2005 global cooler temperature should not impact the Tobago and Filipino data as the tropics still see a general warming of sea surface temperatures associated with El Niño. Other global temperatures may have an effect on the Filipino and Tobago data and therefore are important to know and understand.

6.2 TOBAGO

6.2.1 Year vs. Bleaching

From figure 5.2.1 and figure 5.2.2, it is clear that the number of coral bleaching events has risen consecutively each year, with the most significant rise occurring between 2007 and 2008. Here there is a substantial increase of 32 bleaching events. There is then a small increase of 4 reported cases from 2008 to 2009. However it must be noted that the data from 2009 was not complete and therefore there may have been more bleaching cases. Figure 5.2.3 illustrates that winter produces more bleaching events than summer and as the 2009 data finished in early November; the complete dataset for 2009 will contain more than 79 cases.

From the literature it is accepted that rising SST's are the primary cause of coral bleaching (Eakin *et al* 2009, section 2.2). Therefore it would seem that the SST's in 2008 should be warmer than 2007. From figure 5.2.5 and the transects (figures 5.1.13 and 5.1.15) it is clear that this is not the case. This is due to a very strong La Niña year in 2008. However there are still high counts of bleaching in 2008 which could be accountable to La Niña having a lesser impact on Tobago. It may also be that the high temperatures in 2007 could be the cause of the bleaching in 2008. If this is the case then these results prove the theory that corals need to be subjected to high SST's for a number of weeks or months before there is reported bleaching as stated by Christensen *et al* (2008) and Glynn *et al* (1990). It is most likely that it is a combination of these reasons that are the cause of the high bleaching in 2008.

6.2.2 Season vs. Bleaching

The season versus bleaching data provides some interesting results as the highest season for coral bleaching in Tobago seems to be autumn, which boasts 61 reported cases compared with the lowest of 45 reported in summer (see figure 5.2.3). This is very interesting as the highest temperatures seem to be found in summer and it has been stated by Christensen *et al* (2008) this is meant to be the Caribbean's highest bleaching season. These results clearly show this is not the case.

From Hoegh-Guldberg's (1999) argument in section 2.4, it states that it may be possible that the reasons for a particularly high number of reported cases in autumn could be due to an oceanic or atmospheric process. However it was not due to an El Niño, as the last reported El Niño was in 2005.

6.2.3 Sea Surface Temperatures vs. Bleaching

The relationship between coral bleaching and rising SST's can be proven when looking at figure 5.2.5 and 5.2.6. At 23°C there are absolutely no reported cases of coral bleaching which proves that at this low temperature corals' are not under any thermal stress and therefore no bleaching occurs. There is then a small increase in bleaching events up to 25°C, but it is at 26°C, 27°C and 28°C where there is the most significant rises in the number of recorded events. It peaks at 28°C with 75 recorded bleaching events. Despite the number of bleaching events starting to decline marginally after this, there seem to be large numbers of reported bleaching events up to 30°C. Furthermore the highest reported SST was 34.2°C, which was only ever recorded once was associated with coral bleaching.

It is interesting that there is a decline in bleaching events after 28°C. From the literature it is expected that the number of bleaching events would continue to rise.

The reason for inverse correlation can be attributed to the fact that as the SST's rise over 28°C they begin to become less frequent (see figure 5.2.5). This in turn results in less opportunity for the corals to be subjected to temperatures over 28°C and become bleached. These high SST's are too infrequent at the moment to cause bleaching (see section 2.3.1; Christensen *et al* 2008; Glynn *et al* 1990). This theory holds the strongest argument for explaining this trend; still there may be other or a combination of factors impacting these results.

One of these could be inconsistent data as only a couple of transects were being recorded by volunteers each day and so much of the coral bleached by these high temperatures may be attributed to other temperatures. Furthermore Van Woesik (2001) and Ware *et al* (1996) note, corals may be adapting to a life in high SST's and although this is not proven, it may be the cause of a lack of bleaching at higher SST's. This does not explain why bleaching is still occurring at lower temperatures if corals have adapted to surviving in higher temperatures and therefore Van Woesik (2001) and Ware *et al* (1996) theory can be questioned. In light of this, the data supports Coles *et al* (2003), Hoegh-Guldbergs' (2002) and Van Woesik (2001) criticism that this theory is not yet validated.

Despite these slightly unpredicted results, it is apparent that coral bleaching in Tobago is most common around 26-28°C and that there is a significant rise in bleaching compared to the lower temperatures of 23-25°C. Therefore there is sufficient evidence to support the literature and the hypothesis that coral bleaching in Tobago is becoming more common due to rising sea surface temperatures, even if it is not in a perfect positive correlation.

6.2.4 Sea surface temperatures vs. bleaching vs. Year

When comparing bleaching and SST's against year from figures 5.2.6, the temperatures of 26°C, 27°C and 28°C illustrate the highest numbers of bleaching events for all years. In 2008 there is the largest range of temperatures. It holds the highest recorded SST of 34°C as well as the highest recording of the low SST 23°C. This is due the oceanic or atmospheric process, La Niña creating cooler temperatures in this year⁷. However 2008 does not hold the lowest number of SST recordings for 27°C-29°C and records the highest SST within this dataset. Furthermore it only has one extra count of 23°C than 2009. Clearly the La Niña did not have a severe impact on the SST's and therefore bleaching of Tobago.

In figure 5.2.7 it is clear that in 2009 there is a lower SST range and fewer high SST's such as 30°C-34°C, recorded as in previous years; however there is a higher number of bleaching events within these lower temperatures. At 26°C there is a bleaching increase of 15 events compared with 2008 and at 27 °C there is an increase of 14 events. Furthermore these 2 SST's appear more frequently in 2009. Evidently the corals have more exposure to these SST's⁸ and in Tobago 26°C is a high enough SST to cause bleaching. It may seem that bleaching is increasing as SST's are falling which does not correspond with the current literature. However the SST's that causes bleaching in Tobago (26°C-30°C) are not impacted by the drop in SST range and consequently coral bleaching continues to rise.

26-30°C are the most frequent sea surface temperatures within this data, nonetheless there does not seem to be an increase in SST's throughout the consecutive years. In fact from figure 5.2.6, the SST's seem to be getting lower. This may be because the data is on too small a scale and unfortunately this kind of

⁷ This is confirmed by the Met Office.

⁸ Christensen *et al* (2008) and Glynn *et al* (1990) theory

bleaching monitoring has only begun in recent years for these more remote locations. Additionally when looking at a small location, there may be anomalies caused by aquatic pollution, run-off and anthropogenic activities. The most appropriate explanation seems to be that 2008 records the largest temperature ranges due to the La Niña. Furthermore it is also the only complete dataset. As previously mentioned a complete 2009 dataset would hold a higher volume of bleaching and warmer SST's and a complete 2007 would see cooler temperatures. This would create a trend of SST's rising annually.

The global data illustrates that there is an increase in SST's over the past few decades. Nonetheless SST's are not rising annually in this region. Clearly the relationship between bleaching and SST's is not as simple as previously thought as it does not show a perfect positive correlation. Any SST over 26°C proves to be a threat to coral reefs in this region, and at this moment in time it is the SST's which range from 26°C-29°C which are the most frequent and therefore causing the most damage. In the future as SST's such as 30°C+ become more frequent than these will also prove to be a threat to coral reefs.

6.2.5 Bleaching Decades:

When examining figures 5.2.8- 5.2.10, it can be seen that there is large scale bleaching in this region in 1979-1989, with maximum recordings in 1989-1999 and a large number frequenting in 1999-2009. This is unanticipated as it is expected that as global SST's are continuing to rise⁹ than so should the number of global bleaching events and therefore 1999-2009 should hold the most bleaching events.

⁹ See section 2.2. Baker *et al* (2008)

However when examining the El Niño data this can begin to be explained. El Niño causes high SST anomalies¹⁰ and this can be seen in figure 5.4.1, which illustrates a high peak in SST anomalies whenever there is an El Niño event. As previously mentioned in section 2.4.1, it was noted by Hoegh-Guldberg (1999) that 1998 saw the worst El Niño event on record. It produced SST anomalies of around 4.8°C higher than the average SST (figure 5.4.1). Therefore it is unsurprising that we see a high volume of ‘severe’ bleaching in 1998 and consequently in the 1989-1999 Caribbean bleaching data. The bleaching in 1998 is somewhat of an exception to the 1989-1999 data and therefore it may look differently when discarding coral bleaching associated with the El Niño.

When analysing the 1989-1999 data without the bleaching in 1998, less than 20 new bleaching events are identified and only 3 of which were classed as ‘severe’ (Comparing figure 5.2.10 with figure 5.2.12). In order to compare this with the 1999-2009 data, the bleaching associated with the 2005 El Niño event must also be discounted. Most of the bleaching within this decade was not associated with the SST anomalies in 2005¹¹ and as a result there is an increase in bleaching events in 1999-2009 compared with 1989-1999. As far as the Caribbean, and equally Tobago is concerned, this corresponds with the literature already available (see section 2.2). It is clear that as SST’s are generally rising so are the number of recorded bleaching events, thus proving the threat posed to coral reefs from rising sea surface temperatures.

¹⁰ See section 2.4. Oliver *et al* 2005

¹¹ Statement hypothesized by comparing figure 5.2.10 and 5.2.12

6.3. Philippines

6.3.1 Bleaching vs. Year

Figures 5.3.1 and 5.3.2, demonstrate an increase in bleaching events as the years increase suggesting a positive correlation. In 2008 there is a decrease of almost half the number of bleaching events. Additionally it is important to note that in 2008 there is also almost a decrease of half in the total number of recorded records. This could hinder the 2008 data as it has been surveyed less and therefore a smaller area may have been covered and as a result less bleaching could have been recorded. Hypothetically if we doubled the 2008 data to give it similar levels of surveying as the other years, there would be 54 reported bleaching events and as a result it would be higher than 2007. However this is just hypothetical. What is known is that when analysing figure 5.1.13 and 5.1.15, 2008 appears much cooler than 2007. As previously mentioned, 2008 is a La Niña year and this could be the reason for the low bleaching count as the SST's may have been lower than expected in this region. These results therefore suggest that La Niña events have a large impact on the Philippines.

Despite these cooler temperatures in 2008 there are still accounts of coral bleaching which begins to reiterate how important SST's are to coral reefs. Clearly the SST's have risen enough that bleaching is occurring in La Niña years and the corals have already been exposed to high enough SST's to create long term bleaching.

2005 was an El Niño year and so it is expected that there would be more bleaching in 2005 than 2006. 2005 holds the lowest recorded bleaching (8 events) within the whole dataset. The reason for this is may be that it was not until the end of March that bleaching was being recorded. This means that the 2005 data is incomplete and may not show the full extent of the bleaching in 2005 as the most bleaching occurs within January-March. It may also show that the Philippines are less affected

by an El Niño event. When looking at figure 5.4.2, it is clear that in 2005 there is no stress or bleaching watch recorded. Figures 5.3.1 and 5.3.2, display an increase of 36 bleaching events from 2005 - 2006, which is the largest increase within the data and clearly shows that 2005 did not cause the corals as much thermal stress as consecutive years. This evidently illustrates that the lack of bleaching in The Philippines in 2005 was caused by a lesser impact from El Niño, rather than being associated with an incomplete dataset.

Glynn *et al* 1990 and Christensen *et al* 2008 theory¹² may be applicable here. As the warmer SST's associated with the El Niño will be less frequent in this region. Therefore it may take the whole 12 months of the El Niño event for the corals to be subjected to the anomalously high SST's frequently enough to cause bleaching. This may result in records in 2006 being attributed to the 2005 El Niño. Therefore it seems likely that the combination of this theory and the weak impact El Niño has on this region is the cause of this trend.

6.3.2 Season vs. bleaching

From figures 5.3.3 and 5.3.4 it is autumn that holds the most frequent number of bleaching events at 52, despite spring having the largest total number of recorded events. Furthermore, summer has the fewest recorded bleaching events at 12 without having the lowest total number of recorded events (winter). Both summer and winter have very low total recorded events, however the autumn bleaching events are significantly larger than summer and therefore cannot be discounted due to its larger number of recorded events.

These numbers may be accounted for when the temperature and climate data for the Philippines is examined. In the Philippines the hottest month is May and the

¹² Corals must be subjected to high SST's for a number of weeks before bleaching.

coldest January. This could help explain the high amount of bleaching within the spring. Furthermore in the months of July and August the lowest numbers of sunlight hours (4.3) are recorded (climatetemp.info 2008). This could be the reason why the lowest amount of bleaching is in summer-it does not have the highest temperatures and has the lowest amount of sunlight hours within the year.

6.3.3 Sea surface temperatures vs. bleaching

Figures 5.3.5 and 5.3.6, demonstrate the most frequent SST's range from 27°C - 30°C. The amount of reported events more than doubles from 27°C to 28°C (16-35) which is the most frequently recorded temperature, the same is seen in the Tobago data. Once again like Tobago the frequency of the temperatures declines after 28°C, initially by small numbers and then more dramatically when they reach 31°C. At 35°C and 36°C there is no bleaching recorded, which is surprising. The same reasons applied to Tobago can be applied to the Philippines for this unforeseen trend. The very high SST's temperature are only experienced a couple of times a year (see figure 5.3.5) and therefore there is not enough exposure at this temperature for it to cause bleaching. It is the more frequent high SST's of 27°C-30°C, which are causing the bleaching through more long term exposure. This once again gives validation to the theory by Glynn *et al* (1990) and Christensen *et al* (2008). For the same reasons as in the Tobago data, the theory of coral adaptation may also be discarded (see section 6.2.3 Coles *et al* 2003; Hoegh-Guldberg 2002; Van Woesik 2001).

Although a perfect positive correlation was expected within this graph, it does not mean that rising SST's are not causing bleaching. Clearly the same trend is occurring in both locations which suggest that this could be occurring globally. When considering the global data (figures 5.1- 5.4.), there is a general rise in sea surface temperatures. Taking this into consideration, the most common SST for past

decades would be lower than 28°C and consequently removed the threat of bleaching from the coral reefs in this region.

6.3.4 Sea surface Temperatures (STT's) vs. Bleaching vs. Year:

When analysing the SST versus bleaching versus year for the Filipino data it is clear that it follows the same trend as in section 6.3.3. Additionally it can decipher whether the higher temperatures are becoming more frequent as the years go on. The lowest temperature noted is 18°C recorded in 2006. What is perhaps most interesting is that bleaching was recorded for this temperature. This is unexpected as bleaching is not usually associated with such a low temperature. The reason for this may be a misinterpretation of bleaching with white band disease. It may also be due to the coral which was bleached having a lower thermal tolerance level and therefore being affected by the lower temperature or that the SST was so cold it caused bleaching (Crabbe 2008 section 2.1; Van Woesik 2007 section 3.5). Unfortunately as this dissertation is not analysing what coral is bleached it causes uncertainty about whether this is the case and consequently all that can be done is to speculate. Interestingly this temperature is not associated with the coldest year. It may be that it is simply an inaccurate reading

The temperatures 33°C, 35°C and 36°C are only recorded in 2007, which is the warmest year globally (figure 5.1.13) and the warmest year in the Philippines (figure 5.3.7). This confirms the idea that the highest SST's are being seen in the latter years. Unpredictably these high temperatures are not strongly associated with bleaching but as has been frequently discussed throughout this analysis, the corals have not been subjected to these temperatures long enough for them to cause bleaching (Christensen *et al* 2008; Glynn *et al* 1990; section 2.3.1). These high SST's are not found in the 2008 dataset¹³; however from the Bilko data, it is

¹³ 2008's SST's finish being recorded at 31°C.

apparent that this year was surprisingly cooler due to a La Niña event and furthermore bleaching events also decreased. This confirms a positive correlation between SST's and bleaching and validates that the Philippines are strongly affected by La Niña events.

The temperature of 34°C is recorded in 2007 and 2005, however if it was not recorded in 2005, then the temperature range of 33°C-36°C would only be recorded in 2007. This would give more evidence to the idea that the higher temperatures are being recorded later in the decade. 2005 was an El Niño year which explains why higher SST's are recorded (31°C- 6; 32°C-1 and 34°C-3) however only 34°C shows a case of bleaching. Despite this, 2005 does not record many of the SST's associated with high levels of bleaching 27°C-30°C, which once again proves that The Philippines is not severely impacted by El Niño.

Evidently this dataset shows that in the case of the Philippines, coral bleaching is impacted by rising SST's. The combination of how ENSO impacts on this region and how long the corals are subjected to high SST's, provide the best explanation of the trends seen within this data.

6.3.5 Bleaching Decades

From figure 5.3.12, it is clear that there are no recorded bleaching events in the El Niño years of 1982-1983. Contrastingly in 1998 there are high volumes of 'severe' bleaching throughout the country (see figure 5.3.12) and this is the highest count of bleaching we see in the Philippines in the El Niño years¹⁴. This is unsurprising as it has been accepted that the 1998 El Niño event was catastrophic for coral reefs (see section 2.4.1 Wilkinson *et al* 1999). Interestingly there is only one count of 'severe'

¹⁴ Statement compiled from comparing figures 5.3.12 and 5.3.13.

bleaching in the El Niño year of 2005 (see figure 5.3.13) despite high SST's anomalies, which proves that The Philippines may be less affected by El Niño than previously thought. The 1998 bleaching is a 'one-off' as the event was so severe that even areas which are less impacted by El Niño were badly affected.

The 1989-1999 bleaching map, figure 5.3.10, has the largest volume of bleaching records out of all the decades. This can be credited to the 1998 El Niño event. When closely comparing figures 5.3.10 and 5.3.13, there is only one reported case of bleaching not in association with the 1998 El Niño event and the severity of this case is unknown. When examining the 1999-2009 data it would seem that there is less bleaching in this decade. However by examining figures 5.3.11 and 5.3.13, there are 4 'mild' bleaching cases not associated with the 2005 El Niño event which is slightly higher than bleaching in 1989-1999. Although there is not a significant increase within the decades, there is a small increase showing that bleaching is increasing in this region even if it is on a small scale.

This is surprising as from the Coral Cay data and figures 5.3.1 and 5.3.2, it is clear that there are many bleaching events within this data which should be recorded in the 1999-2009 Reefbase GIS maps. As a result despite a trend of rising SST's and bleaching events, the Reefbase data gives the impression that in the Philippines, coral bleaching is less affected by rising SST's. This highlights how important the work Coral Cay Conservation is undertaking as without their monitoring of the reefs, this relationship could be misunderstood. Clearly the Reefbase bleaching data is too general and does not take into account local and small-scale bleaching and different sources of data are needed when analysing this very complex issue.

6.4 Similarities and Differences between Tobago and the Philippines

6.4.1 Bleaching

Tobago is experiencing more counts of bleaching than the Philippines, highlighting that it is a more high risk area. However Leyte may be an area which experiences an upwelling of cooler water, which may not show on the SST data but will keep the area around the corals cooler (Van Woesik 2001). This would make the corals less susceptible to bleaching and may be why there are less bleaching events than Tobago. If this is the case then Leyte may provide a possible solution to areas with high levels of coral mortality (see section 3.5 West 2001). The whole of the Philippines is not a region which experiences upwelling as it was stated by Licuanan *et al* (2000) in section 3.1 that despite management efforts coral was still dying in managed site. However specific areas may experience upwelling such as Southern Leyte.

Nonetheless as sea surface temperatures continue to rapidly raise both these locations, which rely on the reefs for socio-economic reasons, are in danger of losing these invaluable ecosystems.

6.4.2 El Niño

The main difference between the two locations is the impact which El Niño has. In both locations there is 'severe' bleaching in 1998; however this has been accepted as one of the worst El Niño events so it is unsurprising that this kind of bleaching is recorded as it had a worldwide impact. Generally El Niño tends to have a more adverse effect on Tobago than the Philippines. This can be seen in the comparison of the effects of the bleaching years in Tobago (figures 5.2.12 and 5.3.13) and The Philippines (figure 5.3.12 and 5.3.13). Their locations are the reason for this as El Niño impacts these regions very differently (section 2.4.2; Aronson 2007). The higher anomalous SST's associated with an El Niño may be less common in the

Philippines, as the affects are lesser and as a result the bleaching is less frequent. The best example of this can be seen in the differences from the 2005 El Niño as seen in figures 5.4.2 and 5.4.3. Despite little Reefbase data for The Philippines it is clear from the CCC data, that bleaching is more common in 'normal' years, such as 2007.

6.4.3 La Niña

Like El Niño, both these locations are affected by the colder 2008 La Niña year. Tobago and The Philippines see a decrease in the most frequent bleaching SST's of roughly 26°C -30°C in 2008 compared to 2007. In Tobago there is a decrease from 171-135 and in The Philippines there is a decrease from 229-130¹⁵. Regardless of this, Tobago still has a high SST range in 2008 so clearly La Niña does not cool this region down as much as expected. This is further validated when it is noted that there is a smaller decrease in these temperatures in Tobago compared to the Philippines. Interestingly there is a drop in bleaching events in the Philippines from 2007-2008 (50-27) but an increase in Tobago (43-75). La Niña clearly cools The Philippines to a greater extent than Tobago and furthermore the Tobago reefs seem to be more susceptible to bleaching at these lower temperatures than The Philippines. In light of this, when analysing coral bleaching and SST's it seems imperative to take into consideration what is happening globally in order to understand what is happening locally.

6.4.4 Sea Surface Temperatures

In both locations the same trend is occurring in reference to the rise in SST's and coral bleaching. There is an exponential rise in bleaching events and SST's up to 28°C, after which there is an inverse correlation. This was unexpected, however the

¹⁵ This is calculated by adding the total number of recorded SST's 26°C and 27°C in 2007 and 2008.

fact that it happened in both regions clearly shows that this is not happening in isolation. The theory that this may be due to anomalous results as the data was collected subjectively¹⁶ can now be dismissed. By taking a look at all the CCC data and observing the same trend each year and in each location, it becomes apparent that it cannot be attributed to anomalous data. When referring back to literature (section 2.3.1) and taking into consideration that the statistics must not be analysed in isolation, it seems clear that the reason for this trend was that corals were not being exposed to the higher temperatures for a long enough time period to cause bleaching. Once again this validates Christensen *et al* (2008) and Glynn *et al* (1990) theory, which is clearly vital to consider when analysing this hypothesis and without which could result in misinterpretation of coral bleaching and rising SST data.

¹⁶ See section 4.2.3

7. Conclusion

From the current academic literature and this dissertations' hypothesis, the data collected from Tobago and The Philippines should show that there is a positive correlation between SST rise and coral bleaching. Conclusions drawn from the analysis illustrate that this is not the case. In both locations bleaching increases as the SST's rise to 28°C, but after this point bleaching begins to subside despite the SST's continuing to rise. However this can be accounted for upon referring back to the literature and taking into account Christensen *et al* (2008) and Glynn *et al* (1990) theory that corals need to be subjected to high SST's for roughly 5-10 weeks before bleaching occurs. The higher SST's (30°C+) are too infrequent to cause bleaching and subsequently this results in fewer bleaching events being associated with them. In reference to what effect rising SST's has on coral bleaching in Tobago, it can be stated from the CCC data that as the SST range declines annually, bleaching events increase, creating an inverse correlation. Upon further examination of the SST data, it becomes clear that the SST's most associated with bleaching (26°C - 30°C) are not impacted by the SST range decrease. They are in fact increasing in frequency, resulting in increased recorded bleaching and consequently validates the hypothesis that as SST's are rising so are bleaching events. The cause of this SST range decrease is attributed to the data being on too small a scale. In the Philippines, there is a much stronger link between rising SST's and bleaching. Up to the year 2008, both the SST's and coral bleaching rise. In 2008 there is a reduction in SST's and consequently a reduction in the number of bleaching events. Evidently the relationship between bleaching and rising SST's does not always show a perfect positive correlation and is not as simple as once assumed. It can be concluded that it is the impact of variations within the most common SST's (26°C- 30°C) that affect the relationship between SST's and coral bleaching. What is worrying is that the most common SST's have now reached a temperature which causes coral bleaching.

The conclusion above also explains the similarity seen in the general trend of SST and coral bleaching, however there are differences identified between the two datasets such as a reduction in bleaching in 2008 in The Philippines and not Tobago. This can be attributed to the atmospheric and oceanic process La Niña. In light of this, it becomes clear that Tobago's common SST's are not being cooled by La Niña resulting in a lack of reduced bleaching in 2008. This therefore disproves the hypothesis that La Niña would have a more severe impact on Tobago. Additionally Tobago appears to be more impacted by the increase in the common SST's and SST anomalies associated with El Niño. This explains why more bleaching is seen in 1998 and 2005 when compared to The Philippines. Furthermore the corals in Tobago appear to be more susceptible to lower temperatures as more bleaching is associated with the temperature of 26°C than in The Philippines. It can therefore be concluded that the corals of Tobago are at a higher risk than the corals of The Philippines.

The reason for these differences lies in the location of these two regions. Tobago is in a region which experiences the high SST's from El Niño and The Philippines is in a region which experiences a reduction in SST's from La Niña. This therefore establishes that within the tropics, variations occur with bleaching and consequently each area needs its own analysis to understand the threat of rising SST's to the coral.

In order to better understand these variations, further study is needed. Southern Leyte may be an area which experiences an upwelling of cooler water which could be the reason why Tobago reefs are experiencing higher counts of bleaching. In a future study, information on upwelling could be included to determine whether this is the cause of the higher susceptibility of the Tobago reefs. Furthermore there were some anomalous counts of bleaching associated with lower SST's than expected. The cause of this may be attributed to the fact that each coral species has a different susceptibility to coral bleaching. The CCC data included coral species and

in a future study it would be interesting to determine which species were the most or least vulnerable. By understanding these aspects, it can aid coral management policy. Understanding which areas and species are least vulnerable to coral bleaching, can allow the creation of coral sanctuaries. The sanctuaries can grow corals which are least susceptible to bleaching which can then be moved to areas with corals which are more prone to coral bleaching. Further study of the ABH theory, will allow the future of coral reefs to become clearer which can once again aid the management of the protection of coral reefs.

In conclusion, the similar and differing relationship of rising SST's and coral bleaching seems to originate from a combination of Christensen *et al* (2008) and Glynn *et al* (1990) theory and the impact of El Niño and La Niña. Therefore it is important not to look at SST's and coral bleaching in isolation and use relevant global and long term data in order to gain a full understanding of this complex relationship. To conclude, today's coral reefs are being stretched to their limits as SST's continue to rise due to the rising CO² within the atmosphere. As a consequence these invaluable ecosystems are becoming more vulnerable every year.

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Appendix I

The dates for when I was collecting data are highlighted in blue.

Location	Season	Year	DATE	M_BLEACH	S_TEMP
Philippines	Autumn	2005	04/01/2005		27
Philippines	Autumn	2005	05/01/2005		28
Philippines	Autumn	2005	05/01/2005		28
Philippines	Autumn	2005	06/01/2005		27
Philippines	Autumn	2005	06/01/2005		27
Philippines	Autumn	2005	07/01/2005		27
Philippines	Autumn	2005	10/01/2005		28
Philippines	Autumn	2005	10/01/2005		28
Philippines	Autumn	2005	11/01/2005		28
Philippines	Autumn	2005	12/01/2005		27
Philippines	Autumn	2005	12/01/2005		27
Philippines	Autumn	2005	13/01/2005		28
Philippines	Autumn	2005	13/01/2005		27
Philippines	Autumn	2005	14/01/2005		29
Philippines	Autumn	2005	17/02/2005		27
Philippines	Autumn	2005	18/02/2005		27
Philippines	Autumn	2005	21/02/2005		28
Philippines	Autumn	2005	22/02/2005		27
Philippines	Autumn	2005	23/02/2005		28
Philippines	Autumn	2005	12/03/2005	NO	27
Philippines	Autumn	2005	17/03/2005		28
Philippines	Autumn	2005	17/03/2005		28
Philippines	Autumn	2005	18/03/2005		27
Philippines	Autumn	2005	18/03/2005		28
Philippines	Autumn	2005	21/03/2005		27
Philippines	Autumn	2005	21/03/2005		28
Philippines	Autumn	2005	22/03/2005		27
Philippines	Autumn	2005	22/03/2005		27
Philippines	Autumn	2005	23/03/2005		28
Philippines	Autumn	2005	23/03/2005		27
Philippines	Spring	2005	12/05/2005	NO	29
Philippines	Spring	2005	12/05/2005	NO	29
Philippines	Spring	2005	16/05/2005	NO	28
Philippines	Spring	2005	16/05/2005	NO	28
Philippines	Spring	2005	16/05/2005	NO	27
Philippines	Spring	2005	19/05/2005	NO	29
Philippines	Spring	2005	19/05/2005	NO	29
Philippines	Spring	2005	02/06/2005	NO	30
Philippines	Spring	2005	02/06/2005	NO	30

Philippines	Spring	2005	07/06/2005	NO	29
Philippines	Spring	2005	08/06/2005	NO	29
Philippines	Spring	2005	08/06/2005	NO	30
Philippines	Spring	2005	08/06/2005	NO	30
Philippines	Spring	2005	09/06/2005	NO	30
Philippines	Spring	2005	09/06/2005	NO	30
Philippines	Spring	2005	09/06/2005	NO	30
Philippines	Spring	2005	09/06/2005	NO	30
Philippines	Spring	2005	09/06/2005	NO	29
Philippines	Summer	2005	01/07/2005	NO	30
Philippines	Summer	2005	11/07/2005	NO	30
Philippines	Summer	2005	11/07/2005	YES	31
Philippines	Summer	2005	12/07/2005	NO	30
Philippines	Summer	2005	12/07/2005	NO	31
Philippines	Summer	2005	12/07/2005	NO	30
Philippines	Summer	2005	13/07/2005	NO	30
Philippines	Summer	2005	13/07/2005	NO	31
Philippines	Summer	2005	13/07/2005	YES	30
Philippines	Summer	2005	13/07/2005	NO	30
Philippines	Summer	2005	13/07/2005	NO	30
Philippines	Summer	2005	13/07/2005	NO	30
Philippines	Summer	2005	15/07/2005	NO	30
Philippines	Summer	2005	15/07/2005	NO	30
Philippines	Summer	2005	15/07/2005	NO	30
Philippines	Summer	2005	05/08/2005	NO	30
Philippines	Summer	2005	08/08/2005	NO	29
Philippines	Summer	2005	08/08/2005	NO	29
Philippines	Summer	2005	09/08/2005	NO	29
Philippines	Summer	2005	09/08/2005	NO	29
Philippines	Summer	2005	11/08/2005	NO	29
Philippines	Summer	2005	11/08/2005	NO	29
Philippines	Summer	2005	02/09/2005	NO	29
Philippines	Summer	2005	02/09/2005	NO	29
Philippines	Summer	2005	05/09/2005	NO	28
Philippines	Summer	2005	06/09/2005	NO	29
Philippines	Summer	2005	06/09/2005	NO	30
Philippines	Summer	2005	12/09/2005	NO	30
Philippines	Winter	2005	24/11/2005	YES	34
Philippines	Winter	2005	25/11/2005	NO	32
Philippines	Winter	2005	28/11/2005	NO	28
Philippines	Winter	2005	29/11/2005	YES	31
Philippines	Winter	2005	29/11/2005	YES	31
Philippines	Winter	2005	05/12/2005	NO	34
Philippines	Winter	2005	05/12/2005	NO	34

Philippines	Winter	2005	23/12/2005	NO	27
Philippines	Winter	2005	23/12/2005	NO	26
Philippines	Winter	2005	27/12/2005	YES	27
Philippines	Winter	2005	27/12/2005	NO	28
Philippines	Winter	2005	28/12/2005	NO	28
Philippines	Winter	2005	28/12/2005	YES	28
Philippines	Winter	2005	29/12/2005	NO	31
Philippines	Winter	2005	29/12/2005	NO	27
Philippines	Winter	2005	30/12/2005	YES	28
Philippines	Autumn	2006	5/1/2006	NO	28
Philippines	Autumn	2006	20/01/2006	NO	28
Philippines	Autumn	2006	20/01/2006	NO	28
Philippines	Autumn	2006	19/01/2006	NO	27
Philippines	Autumn	2006	20/01/2006	NO	28
Philippines	Autumn	2006	23/01/2006	NO	27
Philippines	Autumn	2006	23/01/2006	YES	28
Philippines	Autumn	2006	24/01/2006	NO	29
Philippines	Autumn	2006	24/01/2006	YES	28
Philippines	Autumn	2006	25/01/2006	NO	30
Philippines	Autumn	2006	25/01/2006	NO	26
Philippines	Autumn	2006	26/01/2006	NO	28
Philippines	Autumn	2006	26/01/2006	NO	29
Philippines	Autumn	2006	27/01/2006	YES	29
Philippines	Autumn	2006	27/01/2006	NO	28
Philippines	Autumn	2006	31/01/2006	NO	29
Philippines	Autumn	2006	01/02/2006	YES	27
Philippines	Autumn	2006	01/02/2006	YES	28
Philippines	Autumn	2006	02/02/2006	NO	27
Philippines	Autumn	2006	02/02/2006	NO	28
Philippines	Autumn	2006	08/02/2006	YES	30
Philippines	Autumn	2006	08/02/2006	NO	28
Philippines	Autumn	2006	08/02/2006	NO	28
Philippines	Autumn	2006	08/02/2006	YES	29
Philippines	Autumn	2006	13/02/2006	YES	28
Philippines	Autumn	2006	14/02/2006	NO	27
Philippines	Autumn	2006	14/02/2006	NO	27
Philippines	Autumn	2006	16/02/2006	NO	27
Philippines	Autumn	2006	16/02/2006	NO	27
Philippines	Autumn	2006	16/02/2006	NO	28
Philippines	Autumn	2006	17/02/2006	NO	28
Philippines	Autumn	2006	17/02/2006	NO	28
Philippines	Autumn	2006	23/02/2006	NO	26
Philippines	Autumn	2006	27/02/2006	NO	30
Philippines	Autumn	2006	28/02/2006	NO	28

Philippines	Autumn	2006	28/02/2006	NO	28
Philippines	Autumn	2006	01/03/2006	NO	27
Philippines	Autumn	2006	01/03/2006	NO	27
Philippines	Autumn	2006	01/03/2006	NO	30
Philippines	Autumn	2006	01/03/2006	NO	27
Philippines	Autumn	2006	02/03/2006	NO	28
Philippines	Autumn	2006	02/03/2006	NO	28
Philippines	Autumn	2006	02/03/2006	NO	28
Philippines	Autumn	2006	02/03/2006	NO	28
Philippines	Autumn	2006	02/03/2006	NO	28
Philippines	Autumn	2006	04/03/2006	NO	27
Philippines	Autumn	2006	04/03/2006	NO	28
Philippines	Autumn	2006	04/03/2006	YES	28
Philippines	Autumn	2006	07/03/2006	NO	27
Philippines	Autumn	2006	08/03/2006	NO	29
Philippines	Autumn	2006	08/03/2006	NO	29
Philippines	Autumn	2006	13/03/2006	NO	28
Philippines	Autumn	2006	14/03/2006	NO	27
Philippines	Autumn	2006	15/03/2006	NO	28
Philippines	Autumn	2006	16/03/2006	NO	28
Philippines	Autumn	2006	16/03/2006	NO	28
Philippines	Autumn	2006	17/03/2006	NO	28
Philippines	Autumn	2006	17/03/2006	NO	28
Philippines	Autumn	2006	17/03/2006	NO	26
Philippines	Autumn	2006	17/03/2006	NO	28
Philippines	Autumn	2006	20/03/2006	NO	27
Philippines	Autumn	2006	20/03/2006	NO	27
Philippines	Autumn	2006	21/03/2006	NO	28
Philippines	Autumn	2006	21/03/2006	NO	29
Philippines	Autumn	2006	21/03/2006	YES	28
Philippines	Autumn	2006	21/03/2006	YES	28
Philippines	Autumn	2006	21/03/2006	NO	28
Philippines	Autumn	2006	21/03/2006	NO	28
Philippines	Autumn	2006	22/03/2006	NO	27
Philippines	Autumn	2006	22/03/2006	NO	28
Philippines	Autumn	2006	22/03/2006	NO	27
Philippines	Autumn	2006	22/03/2006	NO	27
Philippines	Autumn	2006	22/03/2006	NO	28
Philippines	Autumn	2006	23/03/2006	YES	27
Philippines	Autumn	2006	23/03/2006	NO	29
Philippines	Autumn	2006	23/03/2006	NO	29
Philippines	Autumn	2006	23/03/2006	NO	28
Philippines	Autumn	2006	30/03/2006	NO	32
Philippines	Autumn	2006	31/03/2006	NO	28

Philippines	Spring	2006	01/04/2006	NO	28
Philippines	Spring	2006	4/4/2006	NO	28
Philippines	Spring	2006	4/4/2006	NO	30
Philippines	Spring	2006	4/4/2006	NO	28
Philippines	Spring	2006	11/04/2006	NO	32
Philippines	Spring	2006	11/04/2006	NO	30
Philippines	Spring	2006	11/04/2006	NO	30
Philippines	Spring	2006	11/04/2006	NO	30
Philippines	Spring	2006	12/04/2006	NO	28
Philippines	Spring	2006	12/04/2006	NO	30
Philippines	Spring	2006	17/04/2006	NO	30
Philippines	Spring	2006	17/04/2006	NO	30
Philippines	Spring	2006	18/04/2006	NO	29
Philippines	Spring	2006	18/04/2006	NO	29
Philippines	Spring	2006	18/04/2006	NO	29
Philippines	Spring	2006	18/04/2006	NO	29
Philippines	Spring	2006	19/04/2006	YES	29
Philippines	Spring	2006	19/04/2006	YES	29
Philippines	Spring	2006	20/04/2006	YES	29
Philippines	Spring	2006	20/04/2006	NO	29
Philippines	Spring	2006	20/04/2006	YES	29
Philippines	Spring	2006	21/04/2006	NO	28
Philippines	Spring	2006	21/04/2006	NO	28
Philippines	Spring	2006	21/04/2006	NO	27
Philippines	Spring	2006	21/04/2006	YES	18
Philippines	Spring	2006	24/04/2006	NO	28
Philippines	Spring	2006	24/04/2006	NO	28
Philippines	Spring	2006	24/04/2006	NO	28
Philippines	Spring	2006	24/04/2006	NO	28
Philippines	Spring	2006	25/04/2006	NO	28
Philippines	Spring	2006	25/04/2006	YES	28
Philippines	Spring	2006	25/04/2006	NO	28
Philippines	Spring	2006	26/04/2006	NO	28
Philippines	Spring	2006	27/04/2006	NO	30
Philippines	Spring	2006	27/04/2006	NO	29
Philippines	Spring	2006	30/04/2006	YES	27
Philippines	Spring	2006	01/05/2006	NO	27
Philippines	Spring	2006	07/05/2006	NO	29
Philippines	Spring	2006	07/05/2006	NO	29
Philippines	Spring	2006	07/05/2006	NO	31
Philippines	Spring	2006	07/05/2006	NO	29
Philippines	Spring	2006	08/05/2006	YES	30
Philippines	Spring	2006	08/05/2006	NO	28
Philippines	Spring	2006	10/05/2006	NO	28

Philippines	Spring	2006	17/05/2006	YES	29
Philippines	Spring	2006	17/05/2006	YES	29
Philippines	Spring	2006	17/05/2006	YES	29
Philippines	Spring	2006	19/05/2006	NO	29
Philippines	Spring	2006	19/05/2006	NO	29
Philippines	Spring	2006	19/05/2006	NO	29
Philippines	Spring	2006	19/05/2006	YES	29
Philippines	Spring	2006	23/05/2006	NO	30
Philippines	Spring	2006	23/05/2006	YES	29
Philippines	Spring	2006	23/05/2006	NO	29
Philippines	Spring	2006	23/05/2006	NO	29
Philippines	Spring	2006	01/06/2006	NO	27
Philippines	Spring	2006	02/06/2006	NO	28
Philippines	Spring	2006	02/06/2006	NO	29
Philippines	Spring	2006	02/06/2006	NO	29
Philippines	Spring	2006	03/06/2006	YES	28
Philippines	Spring	2006	05/06/2006	NO	29
Philippines	Spring	2006	06/06/2006	NO	30
Philippines	Spring	2006	06/06/2006	YES	29
Philippines	Spring	2006	06/06/2006	YES	29
Philippines	Spring	2006	07/06/2006	NO	29
Philippines	Spring	2006	07/06/2006	NO	29
Philippines	Spring	2006	07/06/2006	NO	30
Philippines	Spring	2006	07/06/2006	NO	29
Philippines	Spring	2006	07/06/2006	NO	29
Philippines	Spring	2006	07/06/2006	NO	31
Philippines	Spring	2006	08/06/2006	YES	29
Philippines	Spring	2006	08/06/2006	NO	29
Philippines	Spring	2006	08/06/2006	NO	29
Philippines	Spring	2006	08/06/2006	NO	29
Philippines	Spring	2006	08/06/2006	NO	29
Philippines	Spring	2006	09/06/2006	NO	30
Philippines	Spring	2006	09/06/2006	NO	29
Philippines	Spring	2006	09/06/2006	YES	28
Philippines	Spring	2006	09/06/2006	NO	29
Philippines	Spring	2006	11/06/2006	NO	30
Philippines	Spring	2006	12/06/2006	NO	29
Philippines	Spring	2006	13/06/2006	NO	30
Philippines	Spring	2006	13/06/2006	YES	30
Philippines	Spring	2006	13/06/2006	NO	29
Philippines	Spring	2006	13/06/2006	NO	29
Philippines	Spring	2006	13/06/2006	NO	29
Philippines	Spring	2006	14/06/2006	NO	30
Philippines	Spring	2006	15/06/2006	NO	30

Philippines	Spring	2006	15/06/2006	NO	29
Philippines	Spring	2006	15/06/2006	NO	29
Philippines	Spring	2006	16/06/2006	NO	30
Philippines	Spring	2006	16/06/2006	NO	30
Philippines	Spring	2006	16/06/2006	NO	30
Philippines	Spring	2006	19/06/2006	NO	30
Philippines	Spring	2006	19/06/2006	NO	30
Philippines	Spring	2006	20/06/2006	NO	30
Philippines	Spring	2006	21/06/2006	NO	30
Philippines	Spring	2006	21/06/2006	NO	30
Philippines	Spring	2006	22/06/2006	NO	30
Philippines	Summer	2006	4/7/2006	NO	29
Philippines	Summer	2006	4/7/2006	YES	28
Philippines	Summer	2006	06/07/2006	YES	29
Philippines	Summer	2006	06/07/2006	YES	30
Philippines	Summer	2006	07/07/2006	NO	31
Philippines	Summer	2006	07/07/2006	NO	30
Philippines	Summer	2006	10/07/2006	YES	29
Philippines	Summer	2006	10/07/2006	NO	29
Philippines	Summer	2006	11/07/2006	YES	30
Philippines	Summer	2006	11/07/2006	NO	30
Philippines	Summer	2006	13/07/2006	NO	30
Philippines	Summer	2006	14/07/2006	NO	31
Philippines	Summer	2006	14/07/2006	NO	31
Philippines	Summer	2006	4/9/2006	NO	29
Philippines	Summer	2006	10/09/2006	NO	28
Philippines	Winter	2006	03/10/2006	NO	29
Philippines	Winter	2006	5/10/2006	NO	28
Philippines	Winter	2006	05/10/2006	NO	29
Philippines	Winter	2006	05/10/2006	NO	28
Philippines	Winter	2006	5/10/2006	NO	28
Philippines	Winter	2006	06/10/2006	YES	30
Philippines	Winter	2006	10/10/2006	YES	30
Philippines	Winter	2006	10/10/2006	NO	29
Philippines	Winter	2006	26/10/2006	NO	30
Philippines	Winter	2006	27/10/2006	YES	30
Philippines	Winter	2006	27/10/2006	NO	30
Philippines	Winter	2006	03/11/2006	NO	29
Philippines	Winter	2006	06/11/2006	YES	30
Philippines	Winter	2006	06/11/2006	NO	30
Philippines	Winter	2006	07/11/2006	YES	30
Philippines	Winter	2006	08/11/2006	NO	29
Philippines	Winter	2006	08/11/2006	YES	30
Philippines	Winter	2006	09/11/2006	YES	31

Philippines	Winter	2006	13/11/2006	NO	28
Philippines	Winter	2006	15/11/2006	YES	28
Philippines	Winter	2006	18/11/2006	NO	29
Philippines	Winter	2006	23/11/2006	NO	30
Philippines	Winter	2006	23/11/2006	NO	32
Philippines	Winter	2006	04/12/2006	NO	28
Philippines	Winter	2006	05/12/2006	NO	28
Philippines	Winter	2006	05/12/2006	NO	29
Philippines	Winter	2006	05/12/2006	NO	28
Philippines	Winter	2006	06/12/2006	NO	28
Philippines	Autumn	2007	02/03/2007	NO	29
Philippines	Autumn	2007	05/03/2007	NO	28
Philippines	Autumn	2007	06/03/2007	YES	29
Philippines	Autumn	2007	08/03/2007	YES	29
Philippines	Autumn	2007	08/03/2007	YES	30
Philippines	Autumn	2007	09/03/2007	NO	30
Philippines	Autumn	2007	09/03/2007	NO	32
Philippines	Autumn	2007	09/03/2007	NO	32
Philippines	Autumn	2007	06/03/2007	NO	28
Philippines	Autumn	2007	02/03/2007	NO	29
Philippines	Autumn	2007	05/03/2007	YES	34
Philippines	Autumn	2007	06/03/2007	NO	32
Philippines	Autumn	2007	07/03/2007	NO	30
Philippines	Autumn	2007	16/01/2007	NO	36
Philippines	Autumn	2007	16/01/2007	NO	29
Philippines	Autumn	2007	12/03/2007	YES	29
Philippines	Autumn	2007	18/01/2007	NO	26
Philippines	Autumn	2007	07/01/2007	NO	29
Philippines	Autumn	2007	07/01/2007	NO	28
Philippines	Autumn	2007	01/02/2007	YES	27
Philippines	Autumn	2007	22/01/2007	YES	27
Philippines	Autumn	2007	03/01/2007	NO	27
Philippines	Autumn	2007	05/01/2007	NO	28
Philippines	Autumn	2007	08/01/2007	NO	30
Philippines	Autumn	2007	08/01/2007	NO	30
Philippines	Autumn	2007	16/01/2007	NO	28
Philippines	Autumn	2007	18/01/2007	YES	30
Philippines	Autumn	2007	26/01/2007	NO	27
Philippines	Autumn	2007	30/01/2007	NO	30
Philippines	Autumn	2007	07/01/2007	NO	27
Philippines	Autumn	2007	07/01/2007	NO	26
Philippines	Autumn	2007	01/02/2007	YES	27
Philippines	Autumn	2007	02/02/2007	NO	26
Philippines	Autumn	2007	19/02/2007	NO	28

Philippines	Autumn	2007	22/02/2007	NO	33
Philippines	Autumn	2007	22/02/2007	YES	29
Philippines	Autumn	2007	23/02/2007	NO	28
Philippines	Autumn	2007	26/02/2007	NO	33
Philippines	Autumn	2007	01/03/2007	NO	33
Philippines	Autumn	2007	23/02/2007	YES	28
Philippines	Autumn	2007	19/02/2007	NO	27
Philippines	Autumn	2007	22/02/2007	YES	28
Philippines	Autumn	2007	26/02/2007	NO	31
Philippines	Autumn	2007	27/02/2007	YES	29
Philippines	Autumn	2007	28/02/2007	YES	25
Philippines	Autumn	2007	28/02/2007	NO	31
Philippines	Autumn	2007	07/02/2007	YES	30
Philippines	Autumn	2007	02/02/2007	YES	27
Philippines	Autumn	2007	05/02/2007	NO	27
Philippines	Autumn	2007	05/02/2007	NO	26
Philippines	Autumn	2007	06/02/2007	YES	27
Philippines	Autumn	2007	07/02/2007	NO	27
Philippines	Autumn	2007	21/02/2007	NO	27
Philippines	Autumn	2007	07/01/2007	NO	30
Philippines	Autumn	2007	07/01/2007	NO	32
Philippines	Autumn	2007	22/01/2007	YES	28
Philippines	Autumn	2007	02/07/2007	NO	27
Philippines	Autumn	2007	21/02/2007	NO	26
Philippines	Autumn	2007	07/02/2007	NO	31
Philippines	Autumn	2007	28/02/2007	NO	29
Philippines	Autumn	2007	01/03/2007	NO	32
Philippines	Autumn	2007	02/03/2007	NO	29
Philippines	Autumn	2007	05/03/2007	NO	32
Philippines	Autumn	2007	28/02/2007	NO	33
Philippines	Autumn	2007	15/02/2007	NO	31
Philippines	Autumn	2007	28/02/2007	NO	29
Philippines	Autumn	2007	01/03/2007	NO	32
Philippines	Autumn	2007	05/03/2007	NO	32
Philippines	Autumn	2007	02/03/2007	YES	29
Philippines	Autumn	2007	15/02/2007	NO	31
Philippines	Autumn	2007	07/02/2007	NO	28
Philippines	Autumn	2007	28/02/2007	NO	33
Philippines	Autumn	2007	01/03/2007	NO	30
Philippines	Autumn	2007	01/03/2007	YES	30
Philippines	Autumn	2007	15/02/2007	NO	31
Philippines	Autumn	2007	16/02/2007	NO	28
Philippines	Autumn	2007	16/02/2007	NO	27
Philippines	Autumn	2007	01/03/2007	NO	32

Philippines	Autumn	2007	12/03/2007	YES	33
Philippines	Autumn	2007	14/03/2007	NO	31
Philippines	Autumn	2007	14/03/2007	NO	30
Philippines	Autumn	2007	15/03/2007	NO	29
Philippines	Autumn	2007	16/03/2007	NO	27
Philippines	Autumn	2007	13/03/2007	NO	31
Philippines	Autumn	2007	14/03/2007	NO	31
Philippines	Autumn	2007	14/03/2007	NO	29
Philippines	Autumn	2007	04/03/2007	YES	30
Philippines	Autumn	2007	16/03/2007	NO	27
Philippines	Autumn	2007	16/03/2007	NO	28
Philippines	Autumn	2007	16/03/2007	NO	28
Philippines	Autumn	2007	15/03/2007	YES	30
Philippines	Autumn	2007	15/03/2007	NO	32
Philippines	Autumn	2007	16/03/2007	NO	27
Philippines	Autumn	2007	20/03/2007	NO	27
Philippines	Autumn	2007	20/03/2007	NO	28
Philippines	Autumn	2007	22/03/2007	NO	28
Philippines	Autumn	2007	23/03/2007	YES	27
Philippines	Autumn	2007	26/03/2007	NO	28
Philippines	Autumn	2007	27/03/2007	NO	28
Philippines	Autumn	2007	20/03/2007	NO	28
Philippines	Autumn	2007	15/03/2007	NO	32
Philippines	Autumn	2007	16/03/2007	NO	28
Philippines	Autumn	2007	20/03/2007	YES	28
Philippines	Autumn	2007	20/03/2007	YES	28
Philippines	Autumn	2007	22/03/2007	NO	28
Philippines	Autumn	2007	23/03/2007	NO	28
Philippines	Autumn	2007	23/03/2007	YES	27
Philippines	Autumn	2007	26/03/2007	YES	28
Philippines	Autumn	2007	28/03/2007	NO	29
Philippines	Autumn	2007	20/03/2007	NO	27
Philippines	Autumn	2007	22/03/2007	NO	30
Philippines	Autumn	2007	23/03/2007	NO	28
Philippines	Autumn	2007	27/03/2007	NO	27
Philippines	Autumn	2007	28/03/2007	NO	28
Philippines	Autumn	2007	29/03/2007	NO	28
Philippines	Spring	2007	03/04/2007	NO	27
Philippines	Spring	2007	11/05/2007	NO	28
Philippines	Spring	2007	16/05/2007	NO	29
Philippines	Spring	2007	17/05/2007	NO	30
Philippines	Spring	2007	18/05/2007	NO	30
Philippines	Spring	2007	11/05/2007	NO	31
Philippines	Spring	2007	16/05/2007	NO	31

Philippines	Spring	2007	17/05/2007	NO	31
Philippines	Spring	2007	18/05/2007	NO	29
Philippines	Spring	2007	21/05/2007	NO	30
Philippines	Spring	2007	21/05/2007	NO	29
Philippines	Spring	2007	17/04/2007	NO	29
Philippines	Spring	2007	17/04/2007	NO	29
Philippines	Spring	2007	18/04/2007	YES	28
Philippines	Spring	2007	19/04/2007	YES	29
Philippines	Spring	2007	18/04/2007	NO	29
Philippines	Spring	2007	17/04/2007	NO	28
Philippines	Spring	2007	18/04/2007	YES	28
Philippines	Spring	2007	19/04/2007	NO	28
Philippines	Spring	2007	19/04/2007	NO	29
Philippines	Spring	2007	20/04/2007	NO	28
Philippines	Spring	2007	24/04/2007	NO	28
Philippines	Spring	2007	26/04/2007	NO	30
Philippines	Spring	2007	16/05/2007	NO	30
Philippines	Spring	2007	18/04/2007	NO	28
Philippines	Spring	2007	17/04/2007	NO	27
Philippines	Spring	2007	18/04/2007	NO	28
Philippines	Spring	2007	19/04/2007	NO	29
Philippines	Spring	2007	20/04/2007	NO	29
Philippines	Spring	2007	24/04/2007	NO	28
Philippines	Spring	2007	26/04/2007	NO	28
Philippines	Spring	2007	26/04/2007	NO	30
Philippines	Spring	2007	11/05/2007	NO	29
Philippines	Spring	2007	16/05/2007	NO	31
Philippines	Spring	2007	17/05/2007	NO	30
Philippines	Spring	2007	18/05/2007	NO	30
Philippines	Spring	2007	20/04/2007	NO	29
Philippines	Spring	2007	17/04/2007	NO	28
Philippines	Spring	2007	19/04/2007	NO	28
Philippines	Spring	2007	19/04/2007	NO	30
Philippines	Spring	2007	20/04/2007	NO	29
Philippines	Spring	2007	24/04/2007	NO	30
Philippines	Spring	2007	26/04/2007	NO	28
Philippines	Spring	2007	26/04/2007	NO	30
Philippines	Spring	2007	27/04/2007	YES	29
Philippines	Spring	2007	17/05/2007	YES	32
Philippines	Spring	2007	19/04/2007	NO	28
Philippines	Spring	2007	26/04/2007	NO	28
Philippines	Spring	2007	27/04/2007	NO	30
Philippines	Spring	2007	07/05/2007	NO	32
Philippines	Spring	2007	11/05/2007	NO	29

Philippines	Spring	2007	18/05/2007	NO	30
Philippines	Spring	2007	27/04/2007	NO	29
Philippines	Spring	2007	10/04/2007	NO	28
Philippines	Spring	2007	11/04/2007	YES	28
Philippines	Spring	2007	22/06/2007	NO	32
Philippines	Spring	2007	06/06/2007	NO	33
Philippines	Spring	2007	03/06/2007	NO	32
Philippines	Spring	2007	06/06/2007	NO	30
Philippines	Spring	2007	08/06/2007	NO	30
Philippines	Spring	2007	14/06/2007	NO	33
Philippines	Spring	2007	13/06/2007	NO	33
Philippines	Spring	2007	06/06/2007	NO	30
Philippines	Spring	2007	08/06/2007	NO	30
Philippines	Spring	2007	08/06/2007	NO	35
Philippines	Spring	2007	13/06/2007	NO	31
Philippines	Spring	2007	14/06/2007	NO	30
Philippines	Spring	2007	14/06/2007	NO	33
Philippines	Spring	2007	19/06/2007	NO	30
Philippines	Spring	2007	13/06/2007	NO	33
Philippines	Spring	2007	06/06/2007	NO	35
Philippines	Spring	2007	08/06/2007	NO	31
Philippines	Spring	2007	13/06/2007	NO	32
Philippines	Spring	2007	14/06/2007	NO	32
Philippines	Spring	2007	13/06/2007	YES	33
Philippines	Spring	2007	13/06/2007	NO	30
Philippines	Spring	2007	14/06/2007	NO	32
Philippines	Spring	2007	14/06/2007	NO	33
Philippines	Spring	2007	18/06/2007	NO	33
Philippines	Spring	2007	20/06/2007	NO	30
Philippines	Spring	2007	15/06/2007	NO	30
Philippines	Spring	2007	20/06/2007	NO	30
Philippines	Spring	2007	20/06/2007	NO	30
Philippines	Spring	2007	15/06/2007	NO	30
Philippines	Spring	2007	15/05/2007	NO	29
Philippines	Spring	2007	22/05/2007	NO	30
Philippines	Spring	2007	24/05/2007	NO	30
Philippines	Spring	2007	12/06/2007	NO	33
Philippines	Spring	2007	15/06/2007	NO	30
Philippines	Spring	2007	12/06/2007	NO	33
Philippines	Spring	2007	12/06/2007	NO	30
Philippines	Spring	2007	12/06/2007	NO	31
Philippines	Spring	2007	15/06/2007	NO	32
Philippines	Spring	2007	15/06/2007	NO	34
Philippines	Spring	2007	21/06/2007	NO	30

Philippines	Spring	2007	23/04/2007	NO	28
Philippines	Spring	2007	25/04/2007	NO	30
Philippines	Spring	2007	01/05/2007	NO	30
Philippines	Spring	2007	15/05/2007	YES	29
Philippines	Spring	2007	24/05/2007	YES	30
Philippines	Spring	2007	23/04/2007	YES	30
Philippines	Spring	2007	24/04/2007	NO	28
Philippines	Spring	2007	01/05/2007	NO	29
Philippines	Spring	2007	10/05/2007	NO	30
Philippines	Spring	2007	30/04/2007	NO	30
Philippines	Spring	2007	01/05/2007	NO	29
Philippines	Spring	2007	03/05/2007	NO	30
Philippines	Spring	2007	03/05/2007	NO	30
Philippines	Spring	2007	15/05/2007	YES	30
Philippines	Spring	2007	10/05/2007	NO	30
Philippines	Spring	2007	30/04/2007	NO	30
Philippines	Spring	2007	01/05/2007	NO	29
Philippines	Spring	2007	03/05/2007	NO	29
Philippines	Spring	2007	03/05/2007	NO	30
Philippines	Spring	2007	04/05/2007	NO	29
Philippines	Spring	2007	04/05/2007	NO	30
Philippines	Spring	2007	10/05/2007	NO	29
Philippines	Spring	2007	15/05/2007	NO	30
Philippines	Spring	2007	22/05/2007	NO	31
Philippines	Spring	2007	05/06/2007	NO	30
Philippines	Spring	2007	15/05/2007	NO	29
Philippines	Spring	2007	22/05/2007	NO	31
Philippines	Spring	2007	12/06/2007	NO	35
Philippines	Spring	2007	12/06/2007	NO	34
Philippines	Spring	2007	07/04/2007	NO	30
Philippines	Spring	2007	23/04/2007	NO	30
Philippines	Spring	2007	23/04/2007	NO	29
Philippines	Spring	2007	30/04/2007	NO	28
Philippines	Spring	2007	18/06/2007	NO	33
Philippines	Spring	2007	23/04/2007	NO	30
Philippines	Spring	2007	30/04/2007	NO	32
Philippines	Spring	2007	23/04/2007	NO	30
Philippines	Spring	2007	23/05/2007	NO	30
Philippines	Spring	2007	23/05/2007	NO	30
Philippines	Spring	2007	23/05/2007	YES	30
Philippines	Spring	2007	18/06/2007	NO	30
Philippines	Spring	2007	16/04/2007	NO	28
Philippines	Spring	2007	08/05/2007	YES	30

Philippines	Summer	2007	07/08/2007	NO	31
Philippines	Summer	2007	07/08/2007	NO	29
Philippines	Summer	2007	09/08/2007	YES	29
Philippines	Summer	2007	13/08/2007	NO	29
Philippines	Summer	2007	07/08/2007	NO	30
Philippines	Summer	2007	07/08/2007	NO	30
Philippines	Summer	2007	07/08/2007	YES	30
Philippines	Summer	2007	03/07/2007	YES	30
Philippines	Summer	2007	03/07/2007	NO	30
Philippines	Summer	2007	03/07/2007	NO	29
Philippines	Summer	2007	02/08/2007	NO	27
Philippines	Summer	2007	02/09/2007	NO	33
Philippines	Summer	2007	06/07/2007	NO	31
Philippines	Summer	2007	09/08/2007	NO	30
Philippines	Summer	2007	09/08/2007	NO	30
Philippines	Summer	2007	09/08/2007	NO	31
Philippines	Summer	2007	09/08/2007	NO	31
Philippines	Summer	2007	10/08/2007	NO	31
Philippines	Summer	2007	09/08/2007	NO	31
Philippines	Summer	2007	09/08/2007	NO	32
Philippines	Summer	2007	09/08/2007	NO	30
Philippines	Summer	2007	06/08/2007	NO	30
Philippines	Summer	2007	06/07/2007	NO	30
Philippines	Summer	2007	06/07/2007	NO	30
Philippines	Summer	2007	06/07/2007	NO	31
Philippines	Summer	2007	10/08/2007	NO	32
Philippines	Winter	2007	04/12/2007	NO	28
Philippines	Winter	2007	08/10/2007	NO	28
Philippines	Winter	2007	04/11/2007	NO	28
Philippines	Winter	2007	04/12/2007	YES	28
Philippines	Winter	2007	23/10/2007	NO	29
Philippines	Winter	2007	24/10/2007	NO	31
Philippines	Winter	2007	27/12/2007	NO	29
Philippines	Winter	2007	03/12/2007	NO	29
Philippines	Winter	2007	04/10/2007	YES	29
Philippines	Winter	2007	04/12/2007	NO	32
Philippines	Winter	2007	02/12/2007	NO	31
Philippines	Winter	2007	02/12/2007	NO	31
Philippines	Winter	2007	04/12/2007	YES	32
Philippines	Winter	2007	04/12/2007	YES	28
Philippines	Winter	2007	26/10/2007	YES	30
Philippines	Winter	2007	30/10/2007	YES	29
Philippines	Winter	2007	25/10/2007	NO	29
Philippines	Winter	2007	02/10/2007	NO	28

Philippines	Winter	2007	04/10/2007	NO	28
Philippines	Winter	2007	20/10/2007	NO	29
Philippines	Winter	2007	23/10/2007	NO	29
Philippines	Winter	2007	26/10/2007	NO	29
Philippines	Winter	2007	01/10/2007	NO	27
Philippines	Winter	2007	01/11/2007	NO	27
Philippines	Winter	2007	01/12/2007	NO	27
Philippines	Winter	2007	01/11/2007	NO	25
Philippines	Winter	2007	08/10/2007	NO	33
Philippines	Winter	2007	09/10/2007	NO	28
Philippines	Winter	2007	08/10/2007	NO	33
Philippines	Winter	2007	09/10/2007	NO	30
Philippines	Autumn	2008	09/02/2018	NO	28
Philippines	Autumn	2008	02/01/2008	NO	28
Philippines	Autumn	2008	10/03/2008	NO	27
Philippines	Autumn	2008	10/03/2008	NO	28
Philippines	Autumn	2008	11/03/2008	YES	27
Philippines	Autumn	2008	12/03/2008	NO	28
Philippines	Autumn	2008	13/03/2008	NO	26
Philippines	Autumn	2008	13/03/2008	NO	28
Philippines	Autumn	2008	14/02/2008	NO	26
Philippines	Autumn	2008	14/02/2008	NO	27
Philippines	Autumn	2008	14/03/2008	YES	27
Philippines	Autumn	2008	14/03/2008	NO	28
Philippines	Autumn	2008	14/03/2008	YES	27
Philippines	Autumn	2008	15/02/2008	NO	29
Philippines	Autumn	2008	15/02/2008	NO	26
Philippines	Autumn	2008	17/03/2008	YES	27
Philippines	Autumn	2008	17/03/2008	NO	27
Philippines	Autumn	2008	17/03/2008	NO	29
Philippines	Autumn	2008	17/03/2008	NO	27
Philippines	Autumn	2008	19/02/2008	NO	30
Philippines	Autumn	2008	19/02/2008	NO	27
Philippines	Autumn	2008	19/02/2008	NO	27
Philippines	Autumn	2008	19/02/2008	NO	27
Philippines	Autumn	2008	20/03/2008	YES	26
Philippines	Autumn	2008	20/03/2008	NO	27
Philippines	Autumn	2008	20/03/2008	NO	28
Philippines	Autumn	2008	20/03/2008	YES	28
Philippines	Autumn	2008	21/02/2008	NO	28
Philippines	Autumn	2008	21/02/2008	YES	30
Philippines	Autumn	2008	22/02/2008	NO	28
Philippines	Autumn	2008	22/02/2008	YES	30
Philippines	Autumn	2008	22/03/2008	NO	27

Philippines	Autumn	2008	22/03/2008	YES	28
Philippines	Autumn	2008	22/03/2008	NO	26
Philippines	Autumn	2008	22/03/2008	NO	26
Philippines	Autumn	2008	22/03/2008	NO	28
Philippines	Autumn	2008	22/03/2008	YES	27
Philippines	Autumn	2008	23/01/2008	NO	28
Philippines	Autumn	2008	24/03/2008	NO	28
Philippines	Autumn	2008	25/02/2008	NO	28
Philippines	Autumn	2008	25/02/2008	NO	26
Philippines	Autumn	2008	25/02/2008	NO	28
Philippines	Autumn	2008	26/02/2008	NO	27
Philippines	Autumn	2008	26/02/2008	NO	27
Philippines	Autumn	2008	26/02/2008	NO	27
Philippines	Autumn	2008	26/03/2008	YES	28
Philippines	Autumn	2008	26/03/2008	YES	28
Philippines	Autumn	2008	27/02/2008	NO	27
Philippines	Autumn	2008	27/02/2008	NO	27
Philippines	Autumn	2008	27/03/2008	NO	28
Philippines	Autumn	2008	27/03/2008	NO	28
Philippines	Autumn	2008	27/03/2008	NO	29
Philippines	Autumn	2008	28/03/2008	NO	28
Philippines	Autumn	2008	28/03/2008	NO	30
Philippines	Autumn	2008	28/03/2008	NO	28
Philippines	Autumn	2008	30/01/2008	NO	28
Philippines	Autumn	2008	30/01/2008	NO	29
Philippines	Autumn	2008	31/01/2008	NO	28
Philippines	Spring	2008	22/05/2008	NO	29
Philippines	Spring	2008	22/05/2008	NO	30
Philippines	Spring	2008	22/05/2008	NO	28
Philippines	Spring	2008	22/05/2008	NO	28
Philippines	Spring	2008	02/04/2008	NO	30
Philippines	Spring	2008	06/06/2008	NO	29
Philippines	Spring	2008	06/06/2008	NO	29
Philippines	Spring	2008	10/06/2008	NO	29
Philippines	Spring	2008	10/06/2008	NO	28
Philippines	Spring	2008	15/04/2008	NO	30
Philippines	Spring	2008	15/04/2008	NO	28
Philippines	Spring	2008	15/04/2008	NO	29
Philippines	Spring	2008	15/04/2008	NO	29
Philippines	Spring	2008	06/05/2008	YES	28
Philippines	Spring	2008	06/05/2008	YES	29
Philippines	Spring	2008	20/05/2008	NO	30
Philippines	Spring	2008	09/05/2008	NO	0
Philippines	Spring	2008	09/05/2008	YES	31

Philippines	Spring	2008	10/06/2008	YES	30
Philippines	Spring	2008	09/05/2008	YES	29
Philippines	Spring	2008	15/05/2008	NO	30
Philippines	Spring	2008	15/05/2008	NO	28
Philippines	Spring	2008	20/05/2008	YES	29
Philippines	Spring	2008	10/06/2008	NO	29
Philippines	Spring	2008	16/05/2008	NO	29
Philippines	Spring	2008	15/05/2008	NO	29
Philippines	Spring	2008	16/05/2008	NO	28
Philippines	Spring	2008	06/06/2008	NO	29
Philippines	Spring	2008	23/05/2008	NO	29
Philippines	Spring	2008	26/05/2008	NO	28
Philippines	Spring	2008	06/06/2008	NO	30
Philippines	Spring	2008	12/06/2008	NO	30
Philippines	Spring	2008	12/06/2008	NO	29
Philippines	Spring	2008	12/06/2008	NO	29
Philippines	Spring	2008	23/04/2008	NO	29
Philippines	Spring	2008	24/04/2008	NO	28
Philippines	Spring	2008	24/04/2008	NO	28
Philippines	Spring	2008	29/04/2008	YES	28
Philippines	Spring	2008	14/04/2008	YES	28
Philippines	Spring	2008	21/04/2008	YES	29
Philippines	Spring	2008	21/04/2008	YES	28
Philippines	Spring	2008	14/04/2008	NO	28
Philippines	Spring	2008	23/04/2008	YES	29
Philippines	Spring	2008	07/05/2008	NO	28
Philippines	Spring	2008	14/04/2008	NO	28
Philippines	Spring	2008	25/04/2008	NO	27
Philippines	Spring	2008	25/04/2008	NO	29
Philippines	Spring	2008	14/04/2008	NO	27
Philippines	Spring	2008	07/05/2008	NO	29
Philippines	Spring	2008	07/05/2008	NO	29
Philippines	Spring	2008	11/06/2008	NO	31
Philippines	Spring	2008	11/06/2008	NO	29
Philippines	Spring	2008	11/06/2008	NO	29
Philippines	Spring	2008	05/06/2008	NO	29
Philippines	Spring	2008	05/06/2008	NO	29
Philippines	Spring	2008	11/06/2008	NO	30
Philippines	Spring	2008	08/05/2008	NO	28
Philippines	Spring	2008	08/05/2008	NO	29
Philippines	Spring	2008	13/05/2008	NO	28
Philippines	Spring	2008	13/05/2008	NO	30
Philippines	Spring	2008	13/05/2008	NO	28
Philippines	Spring	2008	13/05/2008	NO	28

Philippines	Spring	2008	13/05/2008	NO	28
Philippines	Spring	2008	13/05/2008	NO	28
Philippines	Summer	2008	07/07/2008	NO	29
Philippines	Summer	2008	09/07/2008	NO	30
Philippines	Summer	2008	09/07/2008	NO	30
Philippines	Summer	2008	30/07/2008	NO	29
Philippines	Summer	2008	07/07/2008	NO	29
Philippines	Summer	2008	07/07/2008	NO	29
Philippines	Summer	2008	07/07/2008	NO	29
Philippines	Summer	2008	31/07/2008	NO	29
Philippines	Summer	2008	31/07/2008	NO	30
Philippines	Summer	2008	01/09/2008	NO	30
Philippines	Summer	2008	01/09/2008	NO	32
Philippines	Summer	2008	02/09/2008	NO	30
Philippines	Summer	2008	10/07/2008	NO	32
Philippines	Summer	2008	30/07/2008	NO	30
Philippines	Summer	2008	10/07/2008	YES	30
Philippines	Summer	2008	08/07/2008	NO	29
Philippines	Summer	2008	11/07/2008	NO	29
Philippines	Summer	2008	08/07/2008	YES	30
Philippines	Winter	2008	20/11/2008	NO	28
Philippines	Winter	2008	22/12/2008	NO	28
Philippines	Winter	2008	22/12/2008	NO	28
Philippines	Winter	2008	20/11/2008	NO	28
Philippines	Winter	2008	03/12/2008	NO	27
Philippines	Winter	2008	03/12/2008	YES	28
Philippines	Winter	2008	03/11/2008	YES	28
Philippines	Winter	2008	10/10/2008	NO	28
Philippines	Winter	2008	02/11/2008	NO	27
Philippines	Winter	2008	10/10/2008	NO	29

Appendix II

Date: Fri, 8 Jan 2010 10:16:38 +1000 [08/01/2010 00:16 GMT]

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Subject: RE: coral bleaching- dissertation

I would be very happy to use the picture for your thesis. Credit it as follows: Ove Hoegh-Guldberg, Global Change Institute, The University of Queensland.

Good luck with your thesis.

Regards,

Ove

Ove Hoegh-Guldberg: Director, Global Change Institute (and Centre for Marine Studies); Smart State Premier's Fellow (2008-2013); Reviewing Editor for Science magazine; Deputy Director, ARC Centre for Excellence in Coral Reef Studies; Chair, Bleaching Working Group, CRTR project.
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