A SPATIAL ANALYSIS OF SHARK ATTACKS IN RELATION TO EL NINO-SOUTHERN OSCILLATION PHASE

THESIS

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CHAPTER I

INTRODUCTION

The purpose of this study is to determine if a linkage exists between El Nino-Southern Oscillation Phase (ENSO) and shark attacks. Between the years 1950-2000, over 1600 shark attacks have been recorded worldwide. In an average year, 25-30 shark attacks were reported. However, there were years with as few as 7 reported attacks and other years with as many as 77 reported attacks (International Shark Attack File 2001). Recent shark attacks in Florida have renewed interest in the mechanisms causing such attacks.

Also during the past fifty years, twelve El Nino and twelve La Nina events have occurred (Legler 2001). Although the meteorological aspects of the ENSO phenomenon have been the focus of many studies, to date none have attempted to determine the linkage between shark attacks and ENSO phase. It is not expected that ENSO phase will directly influence shark attacks but that the global impacts of El Nino/La Nina may trigger favorable conditions for such attacks in certain regions. Environmental Geography will serve as the underlying basis of this research. The human-environment interactions that define environmental geography are evident in the occurrence of shark attacks and the populations threatened by such attacks.

Problem Statement

As coastal populations grow, assessing the temporal and spatial movements of sharks is of interest worldwide. Reports of shark attacks have increased over the past fifty years, with about 5-15 fatalities annually (International Shark Attack File 2001). In addition to protecting human lives in the future, an inquiry into shark attacks may also be beneficial to various shark species. By putting the attacks into perspective, some of the hysteria in response to shark attacks may alleviate some of the "anti-shark" retaliation measures that often take place after an attack (Cliff 1991). Both ENSO and shark attacks can negatively affect human lives. A study of the two could lead to new understandings of shark migration dynamics and/or the effect of ENSO on different species of large vertebrates. With an increase in shark attacks caused by more human-shark interactions, it would be invaluable to be able to forecast trends in migration.

Hypothesis

H_0: The spatial patterns of worldwide shark attacks will not show a statistically significant relationship to the effects of El Nino-Southern Oscillation phase.

H_1: The spatial patterns of worldwide shark attacks will show a statistically significant relationship to the effects of El Nino-Southern Oscillation phase.

Additional Research Question: Do longitude and latitude have an effect on shark attacks or show interaction with ENSO phase?

Explanation of Hypothesis

It is expected that there will be a difference in the number of shark attacks by ENSO phase on a regional basis. However, the nature of that relationship is yet to be determined. El Nino affects sea surface temperature, sea level, coastal upwelling, nutrient supply, and phytoplankton, which in turn regulate the amount and distribution of marine organisms (Barber and Kogelschatz 1989). During the 1982-83 El Nino event, total primary production was estimated at 53% of normal while new primary production was at 26% of normal. While this regulation is mainly that of primary producers, higher trophic levels may be affected as interruptions in the food web cause mortality, poor growth, and reproductive failure (Barber and Kogelshatz 1989).

In other instances, the effects of ENSO can benefit certain species. Off the coast of Taiwan, it has been shown that the recruitment of larval anchovy fluctuates dependent on ENSO episodes, with higher recruitment during El Nino years (Tsai et al. 1997). The authors suggest that this may be due to changes in coastal upwelling and river discharge caused by ENSO. Additionally, the effects of ENSO on local weather may impact human activities, creating the opportunity for more human-shark interactions. The conflicting behavior of different species in response to ENSO episodes makes it difficult to predict how shark attacks may vary.

Definition of Terms

For the purpose of this study, a shark attack is defined as any recorded incident in which a shark comes into contact with a human. The location of the attack is the closest latitude and longitude for the site of the attack, using the most detailed information available (e.g. locality, county, state). ENSO phase as described by the Climate Prediction Center (CPC) seasonal scale and Japan Meteorological Agency Sea Surface Temperature Anomalies (JMA-SSTA) scale are designated only as cold, warm, or neutral regardless of the magnitude of an episode and a time lag associated with ENSO events is not considered. In accordance with the definition of ENSO year in the JMA-SSTA scale, shark attack years were defined as October to September.

CHAPTER II

LITERATURE REVIEW

Theoretical Framework

This study utilizes a positive empirical approach for conducting research and will use both the JMA-SST and CPC indices. The JMA-SST yearly index is determined by mean sea surface temperature anomalies of the tropical Pacific between 4° North and South and 150°-90° West over a five month period. El Nino years are designated by six consecutive months with index values greater than 0.5°C. La Nina years are indicated by six consecutive months with index values less than –0.5°C. All other years are designated as neutral (Legler 2001). The old CPC seasonal index was determined by a semi-subjective analysis of sea surface temperature, rainfall, and pressure oscillations during ENSO events (NOAA 2004). During the course of this study, the CPC developed a more accurate method for calculating ENSO phase. The new CPC seasonal index is based on a threshold of +/- 0.5°C for the Oceanic Nino Index (the 3 month running mean of ERSST.v3 SST anomalies between 5°N-5°S and 120°-170°W) for 5 consecutive over-lapping seasons (NOAA 2008).

A regional approach will be used to group areas of shark attacks that are affected similarly by ENSO phase. Amedeo and Golledge (1975) define a region as "an *area* that displays *some* degree of *homogeneity* with respect to the values on some characteristic(s), variables(s), or property(ies) occurring in it" (p144). The concept of an abstract region will be helpful in this study to associate areas that are affected in the same manner by ENSO phase with shark attacks. A worldwide study is not expected to show significant differences because ENSO is a regional phenomenon. Hagget (1990) provides five rationales for regional study: 1) regions serve as exemplars, 2) as anomalies, 3) as analogues, 4) as modulators, and 5) as covering sets. Of these rationales, three are relevant to this study. By serving as exemplars, regions "give local substance to generalization" (Haggett 1990 79). As analogues, regions match characteristics of one area of the world with other similar areas. This concept is particularly useful in dividing areas of shark attacks into like regions. As covering sets, regions meet the need to reduce large complex phenomena into smaller more understandable subsets. The mechanisms causing and caused by ENSO events are extremely complex lending validity to breaking down this phenomena into more easily studied regions.

Global Impacts of the ENSO Phenomenon

El Nino is defined by anomalously warm ocean waters in the eastern and central Pacific occurring in irregular intervals of approximately four years (Hansen 1989; Trenberth 1991). This results in unusual rainfall amounts in normally arid locations, due to an interruption of the cold-water upwelling caused by the Peru Current and the trade winds (Hansen 1989). Figure 1 illustrates several spatial and temporal characteristics of strong El Nino/La Nina episodes (Allen et al. 1996). Walker and Bliss (1932) first noted the "Southern Oscillation" comprising of the fluctuation of pressure over the southern

Pacific and Indian Oceans and the concurrent shift of rainfall in inverse proportion to the air pressure. The connection between EL Nino and the Southern Oscillation was first recognized by Bjerknes (1969). He noted that warm water in the tropical Pacific Ocean is normally driven westward by surface winds and that this warm water in the west promotes convective rainfall while the cold water in the east promotes stability. Therefore, if El Nino causes a shift in the ocean temperature, it affects the entire system (Hansen 1989).

For example, the warm water influx in Peru results from a decrease in the atmospheric pressure gradient between the eastern subtropical Pacific and Indonesia. This gradient change relaxes the trade winds and generates a gigantic Kelvin wave that crosses the Pacific in less than 2 months. When this wave reaches the South American coasts, the sea level rises, the thermocline is depressed, and the mixed surface layer becomes thicker. Coastal upwelling is warm and poor in nutrients. Phytoplankton, which is evenly distributed in the mixed layer, is directly affected by these changes. When the thermocline and the mixed layer are deep, the nutrients and light available for photosynthesis decrease. The resulting reduction in primary productivity causes proportional reductions in growth and the reproductive success of zooplankton, fish, and all other organisms in the higher trophic levels of the ecosystem. Fish that normally live near the surface stay down in cold subsurface waters below the thermocline to avoid the warm temperatures above (Trillmich et al. 1986).

Shark Attacks

While a change in the distribution of prey may in turn alter the distribution of sharks, it is also possible that ENSO may also alter human activities. Thus it is possible that weather associated with ENSO could draw more people to beaches and increase the likelihood of human-shark interactions, increasing the number of attacks independently of shark feeding patterns.

Langley and Morrow (1997) examined animal related fatalities reported in the Vital Statistics of the United States, which annually reports all human fatalities reported causes of death in the United States. During the period of 1979-1990, 1882 animal related deaths were reported with venomous animals causing 718 deaths and non-venomous animals causing 1164 deaths. Of non-venomous animals, the "other - specified category" caused an average of 66.33 deaths per year followed by dogs, which caused an average of 15.5 deaths per year. During the study period, three deaths were reported due to marine animal injury but the species of animals involved were not identified. According to the International Shark Attack File (2001) 174 shark attacks occurred during the years 1979-1990 in the United States, with seven fatalities and an average of approximately 15 attacks per year.

In a comprehensive review of 1165 worldwide shark attacks, Baldridge (1974) statistically evaluated several conditions present at the time of attack including: date and time, geographical considerations, meteorological and hydrographic factors, air and sea temperatures, attack sites, victim profiles, and attack outcomes, as well as other applicable information that was available. In regard to date and time, it was found that attacks are related closely with periods of time with an abundance of potential victims (e.g. weekends and holiday periods). Sixty five percent of the attacks between 1900-1968 occurred on weekends. With the exception of four provoked attacks, all attacks during the study period occurred between 47° S and 47° N. The geographic distributions for both the northern and southern hemispheres followed the same pattern: few attacks near the equator, most of the attacks occurring in the middle latitudes, and fewer attacks in the higher latitudes. This was attributed to the distribution of the human population.

Most of the data collected indicates that shark attacks are related to favorable conditions for human activities in the water. Greater than 90% of attacks occurred during the daylight hours but this cannot be considered a statistical conclusion as there are far more swimmers during the daytime than at night. The large majority of attacks occurred on sunny days, in calm water, with both warm air and sea temperatures- all favorable conditions for human recreation in the ocean. In fact, an attack is considered "very unlikely" below a temperature of 68-70° F as most humans do not spend much time in the water at that temperature. It was found that sharks do not feed in waters much warmer than 85° F so the prime time for attacks would be when the water temperatures are between 70-85° F. Regarding water temperature and the species of each shark involved in an attack, it was found that the species that span a wider range of water temperatures were the ones with the greatest number of attacks (Baldridge 1974).

Sixty-two percent of the attacks occurred in less than five feet of water within 100 feet of the shore. As a control study at Myrtle Beach, South Carolina showed, this is also where the greatest number of people tend to congregate along the beach. However, there does appear to be a very high ratio of male to female attack victims (10:1). This may be due to the fact that males are more likely to go further off shore or engage in activities such as spearfishing than females. However, in the 65 cases of attacks on females where depth of the victim was reported, no attacks were recorded below 5 feet from the surface. The authors speculate that this may be due to a different swimming style by female divers or an olfactory clue by which sharks differentiate between males and females. Overall, submerged divers were at greater risk for attack but had a significantly less chance of a lethal attack with a mortality rate of 12% as opposed to a 35% mortality rate for all victims (Baldridge 1974).

One of the most famous shark attacks occurred on the New Jersey coast in July of 1916. Within a period of one month, five attacks, including four that were fatal, negatively impacted the resort industry (Randall 1963). Once an 8.5 foot white shark was caught in the area, its stomach containing human remains, the attacks ceased. This series of attacks supports the "rogue shark" theory in which one shark goes on a rampage.

A pattern of white shark (*Carcharodon carcharias*) attacks on divers has been described along the Pacific Coast of North America. Collier (1992) determined that of 35 cases of white shark attack on divers, 69% occurred in six "attack prone" geographical regions. These regions were all similar in that they were populated by pinniped populations and contained a lack of canopy forming underwater vegetation. Underwater visibility did not appear to influence attack patterns as attacks occurred in both clear and murky waters.

Davies (1963) studied the relationships between shark attack and temperature, beach patronage, and seasonal abundance of various shark species along the Natal coast. This study supported Coppleson's hypothesis that 70°F is a critical temperature for shark attack. A high correlation coefficient was found between mean monthly temperatures and the number of shark attacks recorded for each month in the years 1940-61 as well as a positive correlation between increased beach patronage and incidence of attack. This is dramatically shown in the two years of polio outbreaks (1945, 1955) which had the lowest number of attacks on record. It was also found that there has been a steady increase in shark attacks along with the increased use of the ocean for recreational activities since 1940. Since 1952, many beaches in Natal have been netted, virtually eliminating attacks in those areas. The nets also allowed for identification of the most common sharks (11 species) in South African waters. The Zambezi River shark's population is most abundant during the months with the maximum number of attacks. The great white and mako sharks were found to rarely inhabit the inshore waters off Natal. The largest number of attacks took place between December and April.

Out of a total 103 attacks along the South African Coast between 1960-1990, 41% were swimmers, 41% were board riders, and 17% were divers (Cliff 1991). In Natal, the majority (73%) of events took place in turbid water while along the Cape only about half (46%) occurred in turbid water. The majority of attacks were attributed to the bull shark, *Carcharhinus leucas.* Other species involved included the ragged tooth shark, *Carcharhinus Taurus*, the tiger shark, *Galeocerdo cuvier*, and the blacktip shark, *Carcharhinus limbatus* (Cliff 1991).

Most of the incidents in Natal took place in the afternoon hours while along the Cape attacks were spread out throughout the day. The author suggests that this pattern is due to the fact that the majority of attacks along the Cape are by white sharks, which are more active during daylight hours than the other species that are predominant in Natal. While white shark catches are highest in winter, the majority of attacks in Natal took place in the summer. Also, a larger portion of the serious and fatal attacks took place in Natal rather than along the Cape, which the author speculates is due the influence of warmer water temperatures on shark behavior (Cliff 1991).

A review of shark attacks in South Africa, during the years 1980-1999, found 86 attacks with ten fatalities (Woolgar et al. 2001). The attack victims included surfers (54%), divers (25.5%), and swimmers (20%). The species of shark in most of the incidents was identified by bite wound characteristics, bite patterns on surfboards, tooth fragments, and eyewitness reports. *C. carcharias* caused the most attacks (34) and claimed 6 of the 10 fatalities. Other species involved included *C. Taurus*, with 17 attacks and minor injuries, *C. leucas*, with six attacks and one fatality, *G. cuvier*, with three attacks and one fatality, and *C. limbatus*, with one attack and minor injuries. The species of shark was not identified in 17 of the attacks (Woolgar et al. 2001). The sensation caused by shark attacks in South Africa has led to various efforts to reduce the occurrence of human-shark encounters. Cliff (1992) reviewed the efforts to protect beachgoers from shark attack between 1952-90.

In South Australian waters, sharks have attacked humans, horses, dogs, and boats. Sharks implicated in these attacks include whalers, tiger, nurse shark, and great whites, with few less than six feet in length. Most common hours for attack are the late afternoon hours, in about four feet of water, within 10-25 yards offshore. All sea and beach conditions have been found with solitary bathers more commonly attacked than groups. Clothed people were not attacked as often as those in bathing suits (Whitley 1963).

Shark Behavior and Biology

Of 250 known species, approximately 27 have been known to attack humans. Most sharks are not dangerous to people until they reach 3-4 feet in length. Alternately, some of the largest species, such as the whale shark, pose no threat to human life (Garrick and Shultz 1963).

Shark fishermen in Florida have found fishing to be very poor in temperatures greater than 85°F and that sharks tend to leave shallow water in hot still weather. Tiger sharks are known to eat large conchs, horseshoe crabs, sea turtles, marine mammals, sea birds and large fish and tend to feed at night. Bull sharks eat small sharks and porpoises. They are often found in shallow water in the northern Gulf of Mexico and enter estuaries to give birth. Spinner sharks, blacktip and lemon sharks are common in southern Florida and feed mainly on fish and crustaceans. Dusky sharks, nurse sharks, and sand sharks are common as well (Springer 1963).

Much of the literature focuses on the events of shark attacks and the optimal conditions for such attacks. Many shark attack reports contain the location, time, and water temperature, which help to determine the species involved, as well as provide a detailed record of which parameters are preferred by various species (Nakaya 1993).

Results of a tagging study of Mako sharks in the Atlantic Ocean reveal a tendency for Mako sharks to prefer a temperature range of 17°-22° Celsius. In addition, large pelagic fishes often populate areas with strong surface-temperature gradients (Casey and Kohler 1992). One such distribution exists over much of the western portion of the Atlantic Ocean. A distribution of 18°C water forms a layer between the warm surface water and cold deeper water (Casey and Kohler 1992). If similar layers in the Pacific Ocean are affected by ENSO events, it could affect the migratory patterns of sharks, leading them toward warmer coastal waters.

A study of shark dynamics in Hawaii found an interannual pattern of shark sightings by lifeguards and from fishery bycatch reports but could not identify the cause (Parrish and Goto 1997). Comparisons with sightings were made with island runoff data, sea-surface temperature and El-Nino events. The study did note a drop in shark sightings during the 1986-87 ENSO events but not for the ENSO events of 1983 and 1992 (Parrish and Goto 1997). Previous studies have noted that ENSO events may affect interannual shark sightings (Chirions-Vildoso 1985) but this study did not confirm that concept. However, the difficulty in determining and quantifying the ENSO effects in the Hawaiian ocean precludes a full study. In addition, the authors do not state their method of comparison for the shark sightings and ENSO events.

In the waters off of New South Wales, Australia, temperature, proximity to deeper water, and presence of reefs have been significant factors in the spatial and seasonal variation of shark catches (Krough 1994). Following the implementation of netted beaches in an attempt to decrease numbers of attacks, higher catch rates of white sharks have been found at the edges of the netted regions in both South Africa and Australia (Cliff and Dudley 1992; Krough 1994).

ENSO Effects on Animals and Ecosystems

In addition to the many studies of the effect of the ENSO phenomena on meteorological conditions, ENSO has also been linked to such varied phenomena as African Horse Sickness in South Africa (Baylis et al. 1999) and rodent outbreaks in Chile (Lima and Jaksic 1999). For the most part, these studies relate the meteorological changes caused by ENSO to their effect on breeding, growth, and migration patterns.

While changes in tidepool fish habitat vary on a seasonal scale, the temperature and sea level changes caused by ENSO do not cause a change in habitat for four common species of tidepool fish (Davis 2000). However, certain populations do increase or decrease according to ENSO phase. This may be due to the changes in plankton populations offshore (Davis 2000).

There is a documented linkage between larval anchovy recruitment and ENSO episodes off southwestern Taiwan, with the possible explanation of altered coastal upwelling and river discharges (Tsai et al. 1997). It has also been suggested that cyclic meanders, at approximate intervals of five years, in the Kuroshio Current may be the result of an oscillation in the ENSO cycle (Tsai et al. 1997).

South American fur seals showed a marked decrease in pup viability during the 1982-83 El Nino event (Trillmich et al. 1986). Females spent markedly longer periods foraging at sea than during normal years expectedly due to the lack of availability of fish.

The poor body condition and high pup mortality is likely due to the fact that this type of seal is not adapted to long periods of the mother being away from the pup. This may be attributed to the fact that the mother must hunt further away as well as the increased energy demands of diving deeper to find food. 70% of pups were in poor condition (identified subjectively as protruding pelvic and shoulder girdle) and there was 42% mortality over the 22 day study period (Trillmich et al. 1986).

Methodologies

The previously mentioned studies indicate that although ENSO is a global phenomenon, ecosystem reactions vary by region. This is to be expected as ENSO creates diverse consequences for different regions of the world. A geographical study of the ENSO phenomenon as it relates to shark attacks may provide useful insights stemming from the discipline's focus on temporal and spatial patterns.

ENSO has been related to different environmental factors using various methods. While not all are specific to sharks, the methodology remains valid. Parish and Goto (1997) compared shark sightings to the El Nino events of 1983, 1986-1987, and 1992 but were not specific in their methods. It appears that the authors visually compared the number of shark sightings for El Nino years versus neutral years. A major depression in shark sightings was noted for 1986-87 but was lacking in the other two years. It must be noted that the authors did not supply statistical data for this small sample size. A problem of scale intervenes as well. Identifying the effects of ENSO is a difficult task that might be better analyzed in the context of larger regional similarities.

A study by Lehodey et al. (1997) correlates Skipjack tuna abundance with the location of the 29°C sea surface temperature (SST) isotherm and the Southern Oscillation Index (SOI). The 29°C SST isotherm was used because it is indicative of a convergence zone where plankton and other food sources are abundant. The SOI is the difference between the air pressures between sea level pressure at Darwin, Australia and Society Island, Tahiti. Negative values indicate a warm event while positive values reveal a cold event (Glantz 1991). This study indicated a strong positive correlation between the numbers of Skipjack Tuna caught and negative SOI values.

Monfredo (1999) summed SOI values for March through February to create a cumulative annual SOI. Regions in the Midwest were ranked according to the number of violent tornadoes that occurred from February to July. Using Spearman's nonparametric test for rank correlation, a significant correlation was found between the two factors. This method could be incorporated to involve rankings of regionalized shark attacks to a cumulative annual SOI and would support the notion of studying ENSO effects regionally.

Another method was used to determine a linkage between ENSO and African Horse Sickness (AHS) epizootics in South Africa. This involved averaging rainfall for three-month periods and then estimating the deviation from the mean rainfall in non-ENSO years (Baylis et al. 1999). These data were then compared with AHS epizootics using a Chi-square test. The authors found a significant link between El Nino years and AHS epizootics. This method could be used in studying shark attacks if done on a regional scale.

Dixon et al. (1999) compared avalanche records in Glacier National Park with the Japan Meteorological Agency Sea Surface Temperature (JMA-SST) scale that classifies each year as warm (El Nino), cold (La Nina), or neutral. Inferential statistics were used to test the mean number of avalanches per ENSO phase. ANOVA and Chi-Square tests were conducted and the authors found a significant tendency for fewer avalanches in El Nino years. A preliminary study comparing worldwide shark attacks to ENSO phase using the JMA-SST scale yielded no significant results. However, this is to be expected since as noted earlier, ENSO tends to be a regional phenomenon. The CPC data are available to break down each ENSO year into seasonal differences. In addition, a comparison of regional effects of ENSO with shark attacks may provide a clearer picture of a possible linkage.

CHAPTER III

METHODOLOGY

Preparation and Limitations of Data

Data from the International Shark Attack File from the University of Florida, listing all recorded shark attacks since 1950, were compared to the JMA-SST's determination of ENSO phase on a yearly basis and to the CPC's determination of ENSO phase on a seasonal basis. All ambiguous data points from the data set (e.g. non-specific locations – Open Ocean/Sea) were removed. Out of 1726 original data points, 1266 were used in the worldwide analysis and 1217 were used in the regional analysis. The longitude and latitude were determined for each location to the nearest known point (locality, county, or state) and further divided into two categories: East/West and North/South.

One limitation on the data set is that the number of shark attacks reported in less developed countries may be lower than the actual number of attacks. A lack of technology and communication systems may prevent all attacks from being reported. Likewise, more attacks may have been reported in recent years as awareness and communication systems have increased. Another limitation on the data is that many of the recorded attacks contain information on the state level rather than county or locality.

While this does not produce a major impact for a worldwide analysis, smaller regional analyses can be affected.

Regionalization

The shark attack data were broken into smaller regions and analyzed against ENSO phase. According to Abler et al. (1971) the simplest form of a spatial relationship is that if two objects or phenomena are often found together in a specific area, there is good reason to suspect a relationship between them. If the two phenomena are contained within a contiguous region, it is referred to as a specific regional system, as opposed to a general system that does not require locational proximity. In addition, the data were analyzed in a time space continuum, as the numbers of attacks are expected to vary by both season and ENSO phase. The regions were delineated as described below for the similarities in seasonal change of weather patterns, similar effects of ENSO along the coast, and general ocean characteristics.

The United States was separated into four regions: 1) the East Coast from Maine to Florida, 2) the West Coast from Oregon to California, 3) the Gulf of Mexico from Texas to Florida, and 4) the Hawaiian Islands. Florida was divided between the eastern and Gulf coasts at Monroe and Miami-Dade counties with Monroe County considered a part of the Gulf region and Miami-Dade County in the eastern region. Key West is considered part of the eastern coast of Florida for the purpose of this analysis. Data from Australia and New Zealand were combined to form a fifth region while all attacks in South Africa formed the sixth region. The eastern coast of South America forms the final region.

As shown in Figure 1, those areas receiving higher than usual precipitation during El Nino years include: Southeastern South America, western South America, Florida north and west of Cape Canaveral, the western cape of South Africa, Northern Africa, and Sri Lanka. Areas with lower than normal precipitation include: north-central and eastern South America, Eastern Australia, North Island of New Zealand, southeastern Africa including the eastern cape, Florida south and west of Regina Beach, Hawaii, Fiji, and Central America. All other areas are considered to not have higher or lower than usual precipitation during El Nino years (Allen et al. 1996).

Worldwide Statistical Analysis

Initially, the data were analyzed on a global scale. In preliminary analyses, using the JMA-SST yearly data (Legler 2001), descriptive statistics were obtained for shark attacks by ENSO phase. An ANOVA was performed to test for differences in the number of shark attacks per year (DV) in relation to ENSO phase (IV). A two way ANOVA was performed to test for differences in the number of shark attacks (DV) in relation to ENSO phase (IV) as well as the latitude of the attack (IV). The latitude was categorized as either North or South of the equator. The analysis was repeated for attacks within 30°N-30°S of the equator. Last, a two way ANOVA was performed to test for differences in the mean number of shark attacks (DV) in relation to ENSO phase (IV) as well as the longitude of the attack (IV). The longitude was categorized as East or West of the Prime Meridian.

Regional Statistical Analysis

The regional analysis focused on the East, West, and Gulf coasts of the United States, Hawaii, the eastern coast of South America, the South African Coast, and the Australia/New Zealand area. Using data from the international shark attack file (2001) the latitude and longitude was determined for each attack. ENSO phase was determined using both the old and new Climate Prediction Center's seasonal scales that divide each year into seasons (winter, spring, summer, fall) and list the ENSO phase for each season as either strong, moderate, or weak (NOAA 2008). For the purpose of this study, each season was classified as only warm, cold, or neutral without regard to the strength of an episode and where differences between the two scales occurred, the new scale was considered more accurate. The distribution of ENSO phases using both scales, listed by season, is shown in Table 1 for the years 1950-2000. Cold episodes were classified as –1, neutral episodes as 0, and warm episodes as +1. A table was set up for each region listing the year, the number of attacks for each season, and both the old and new ENSO phase for every season of the year (listed as +1, 0, or –1). An example is shown in Table 2.

ANOVAs were run for all three phases in each region. Two additional ANOVAs were performed for each region using warm vs. non-warm (i.e. cold or neutral phases) and cold vs. non-cold (warm or neutral phases) phases. Maps were created using ArcGIS to visually display the attacks for each region.

CHAPTER IV

RESULTS AND ANALYSIS

Global Results

The results of the descriptive statistics for worldwide shark attacks by ENSO phase are presented in Table 3. The sample size was small with 13 cold (La Nina) years, 12 warm (El Nino) years and 26 neutral years for a total of 51 attack years. There were a mean number of 22 attacks during both El Nino and La Nina years, 27 attacks during neutral years, with an overall mean of 24 attacks per year. A one-way ANOVA was conducted to test the hypothesis that the mean number of shark attacks is different for each ENSO phase. The result was not significant with an F ratio of .46 at $p = .64$.

Descriptive statistics for the number of shark attacks by geographic location are presented in Table 4. There were a mean number of 16 attacks per year north of the equator and 9 attacks south of the equator. A mean number of 9 attacks were recorded east of the Prime Meridian and 16 attacks were recorded west of the Prime Meridian each year.

The results of the two-way ANOVA for shark attacks by ENSO phase and latitude is summarized in Table 5. The main effect results showed that shark attacks are significantly different between latitudes ($F=11$, $p=.001$). The interaction between latitude and phase was not significant. As shown in Table 6, the two-way ANOVA was repeated for latitude and longitude, excluding those attacks that occurred farther than 30°N or 30°S of the equator. Again, the number of attacks were significantly different between latitudes ($F=5.6$, $p=.02$) and there was no significant interaction between phase and latitude.

The results for the two-way ANOVA for shark attacks by ENSO phase and longitude are shown in Table 7. The main effect results showed that shark attacks are significantly different between longitudes with an F ratio of 4.69 at $p= .03$. There was no significant interaction between longitude and ENSO phase.

Regional Results

It is not surprising that shark attacks were not shown to differ by ENSO phase on a worldwide basis, as ENSO affects different regions of the world in vastly different ways. The next step in the analysis was to compare shark attacks in different regions of the world to ENSO phase, to determine if a more localized effect exists. As shown in Table 8, the largest number of reported attacks occurred along the east coast of the United States for a total of 388 over a 50 year period. The Australia/New Zealand and South African regions each recorded approximately 150 attacks followed by the western coast of the United States with 117 attacks. The Gulf coast of the United States and South America recorded the fewest number of attacks with 65 and 66 respectively.

The rates of attacks per year in each region give an alternative method of considering the data. Tables 9-12 show the average number of attacks by season and

ENSO phase for each region. Using the new CPC scale, during JFM, Australia/New Zealand has the highest rate of attack followed by South Africa, with values ranging from .64 to .72 attacks per year during neutral phases. The Gulf coast of the United States had the lowest number of attacks, with values as low as .00 attacks per year during warm phases. In all other seasons, the east coast of the United States had the highest rate of attack per year with values ranging from .80 to 2.1, generally during neutral years. The most attacks occurred during the summer months for each region (i.e. JAS for the United States and JFM for Australia/New Zealand). The specifics for each region are detailed below.

South America

There were 89 reported shark attacks along the South American continent from 1950-2000 and 66 met the criteria for inclusion in the analysis. As shown in Figure 2, the majority of attacks took place along the eastern coast of the continent. Table 13 summarizes the numerical distribution of attacks and Figures 3 and 4 graphically display the location of attacks by ENSO phase and season. As expected, attacks tend to track from north to south with the change in season. For example, the majority of attacks took place in October through January, during the warmer seasons.

Figure 3 suggests that the majority of attacks occur during warm ENSO events. This trend is less obvious in Figure 4, which utilizes the new CPC scale. Using the old scale, the trend is verified statistically for the months of JFM at the p=.02 level. Using this scale, during JFM, there were a mean number of .02 attacks per year during cold phases, .10 attacks per year during neutral phases, and .28 attacks per year in warm phases. Using the new scale, the rate of attacks during cold phases remains the same, while the rate drops to .14 attacks per year during warm phases and increases to .24 attacks per year during neutral phases. There were no statistically significant differences using the new scale.

As shown in Table 14, the Tukey HSD multiple comparison test indicates that there is a significant difference between warm vs. cold and warm vs. neutral phases, using the old scale (p=.02 and .07). Further analysis using the old scale shows a significant difference between warm vs. non-warm phases (cold and neutral phases combined) at the p=.01 level. These statistics are summarized in Table 15. During JAS, a similar trend is found for warm vs. non-warm phases at the p=.04 level. There were no statistically significant differences in South America using the new scale.

Australia/New Zealand

There were 204 reported shark attacks in the Australia/New Zealand region between 1950-2000. Of these, 166 had specific dates associated with them and 157 had locations available for mapping. As shown in Figure 5, the majority of attacks took place along the southern and eastern coasts of Australia as well as being split evenly between the two coasts of New Zealand. Major clusters of attacks occurred near Adelaide, Perth, and Melbourne, Australia as well as Christchurch and Auckland, New Zealand.

As shown in Table 16, most attacks took place during neutral years during JFM. Figures 6 and 7 display this trend by ENSO phase and season but as shown in Figure 17, there were no significant differences between phases. Figures 6 and 7 also suggest that many of the attacks during warm events using the old scale were reclassified as neutral events using the new scale.

As shown in Table 18, there were significant differences between cold vs. other phases using both the old and new scales ($F=3.7/3.0$, $p=.06/.09$) during AMJ. There was also a significant difference between warm vs. other phases ($F=3.5$, $p=.07$) during AMJ using the old scale. During JAS, there was a significant difference between cold vs. other phases using both the old and new scales ($F=3.1/3.7$, $p=.08/.06$).

South Africa

There were 190 reported shark attacks in the Republic of South Africa between 1950-2000. Of these, 182 attacks had specific dates associated with them and 169 had recorded locations for analysis and mapping. As shown in Figure 8, the attacks tended to be spread evenly along the coast with the exception of any attacks along the Northern Cape. Most of the attacks occurred in the vicinity of Port Elizabeth, Cape Town, East London, and Durban.

As shown in Figure 9 and 10, the attacks do vary seasonally but not as much as in South America and Australia. Table 19 displays the numerical data for attacks and clearly shows that most attacks occurred during JFM for a total of 79 attacks. This is also reflected in the maps. There were no attacks in Natal during JAS.

As shown in Table 20, there were significant differences in attacks during OND during warm vs. neutral phases ($F=-.77$, $p=.09$) using the new scale. There were no significant differences using the old scale. Further analysis shows that there were also statistically different numbers of attacks during warm phases than in non-warm phases using both the old and new scales ($F=3.7/5.9$, $p=.06/.02$).

United States – East Coast

There were 423 recorded shark attacks along the east coast of the United States between 1950 and 2000. 385 had specific dates associated with them and 388 had recorded locations for analysis and mapping. Figure 11 shows the distribution of attacks along the eastern seaboard with the majority of attacks occurring in Florida. In fact, in a 50 year period, over 300 attacks took place in Florida. During the same time period, South Carolina had the second largest number of attacks with 22.

As shown in Figures 12 and 13, the attacks vary seasonally with almost no attacks occurring outside of Florida during the winter months. During the summer months, attacks occurred as far north as Massachusetts. Table 22 shows the numerical distribution of attacks by ENSO Phase and season. Again, it is apparent that most attacks take place during the summer months. It appears that the majority of attacks in the northern states occurred during cold phases but this trend was not verified statistically. As shown in Tables 23 and 24, there were no significant statistical findings for the number of attacks by ENSO phase for the east coast.

United States – Gulf Coast

There were 94 recorded shark attacks along the Gulf Coast of the United States between 1950-2000. Of these, 80 had specific dates associated with them and 65 had locations available for analysis and mapping. Figure 11 shows the distribution of attacks to be fairly evenly distributed along the coast with the exception of western Louisiana. Florida had the most attacks (39) with Texas following with 19. Louisiana and Alabama had three each while Mississippi had only one recorded attack in 50 years. Major clusters appear along the west coast and panhandle of Florida as well as most of the Texas coast.

Figures 12 and 13 show the seasonal variation of attacks by season and ENSO phase using the old and new scales. The maps show that the fewest attacks occur during the fall and winter months of October through March. Table 25 confirms this with a total of 7 attacks during these months as compared with 39 attacks during the summer months of July through September. As shown in Table 26, during AMJ there was a significant difference between cold and neutral phases using the old scale (p=.08). No other significant differences were found for the Gulf Coast.

United States – West Coast

There were 126 recorded shark attacks along the western coast of the United States between the years 1950-2000. Of these, 117 had specific dates associated with them and 117 had locations available for analysis and mapping. Figure 14 shows the distribution of attacks during this time period, with attacks spread evenly along the western coast. Washington proves to be the exception with only one attack recorded over the entire 50 year period while Oregon reported 13 attacks. Most of the attacks (103) took place along the California Coast, mainly within populated areas such as San Francisco, Los Angeles, and San Diego.

Figures 15 and 16 show the seasonal variation of attacks by ENSO phase. During the months of January through June, no attacks took place during neutral phases in the northern reaches of the coast. July through December show a fairly even distribution of attacks throughout all three phases. Table 28 summarizes the numerical distribution of attacks by ENSO phase and season and it is obvious that most of the attacks (55) take place during the months of JAS. The fewest attacks (14) took place during JFM. Again, the attacks are fairly evenly distributed between all three ENSO phases with slightly fewer during cold phases. Both the maps and table show that there were considerably fewer attacks during warm phases when using the new CPC scale. As shown in Tables 28 and 29, there were no significant statistical findings for the West Coast.

United States – Hawaii

There were a total of 82 reported shark attacks in the waters of Hawaii from 1950-2000. Of these, 76 had specific dates associated with them and 75 had locations available for analysis and mapping. Figure 17 shows the distribution of attacks and indicates that most took place on the islands of Oahu (27), Maui (21), and Kauai (14). The least number of attacks took place on the islands of Hawaii and Molokai with 9 and 4 attacks respectively over the 50 year period.

Figures 18 and 19 show the seasonal variation of attacks according to ENSO phase. The largest number of attacks (27) took place during the months of OND, while the fewest attacks (13) took place during JFM. There is no discernable pattern in the movement of attacks by season or ENSO phase. Table 31 summarizes the numerical distribution of attacks and highlights the difference in the number of warm phases between the old and new scales. As shown in Tables 32 and 33, there were no statistically significant findings for the state of Hawaii.

CHAPTER V

SUMMARY

Discussion

The results of this study indicated several significant linkages between ENSO phase and the number of reported shark attacks. On a global scale, attacks were significantly related to longitude and latitude but not to ENSO phase. South America showed higher numbers of attacks during warm phases using the old CPC scale. Australia/New Zealand showed higher numbers of attacks during warm vs. other and cold vs. other phases using both the old and new scales. Significantly more attacks were recorded in South Africa during warm phases, using both scales. The Gulf coast region had significantly more attacks during cold phases than neutral phases. The reasons why these regions were affected by ENSO while others were not are many and varied. Several possibilities are considered below.

Influence of Latitude and Longitude

On a global scale, there were significant differences in shark attacks between latitudes and longitudes but no differences in relation to phase. This is probably due to the distribution of human populations and human swimming habits. Studies have shown that an attack is considered very unlikely below a temperature of 68-70° F as most humans do not spend much time in the water at that temperature (Baldridge 1974). In the same study, almost all of the attacks occurred between 47° S and 47° N. The geographic distributions for both the northern and southern hemispheres followed the same pattern: few attacks near the equator, most of the attacks occurring in the middle latitudes, and fewer attacks in the higher latitudes. The authors attributed this to the distribution of the human population. In this study, all attacks occurred between 48°N and 47°S and tended to follow the same distribution of fewer attacks in the lowest and highest latitudes.

Increased Beach Attendance

As most of the significant differences in reported shark attacks occurred during warm phases, it is of primary importance to address the human-environment interaction. Warm phases of ENSO tend to cause lower than normal precipitation and higher than normal temperatures along the northeastern coast of South America, the eastern coast of Australia, New Zealand's North Island, and all of South Africa with the exception of the extreme northwestern portion of the country. This is particularly interesting as there was a marked decrease in shark attacks in northwestern South Africa.

Dry, sunny weather and warm temperatures are likely to cause a swell in beach attendance, hence the opportunity for more human-shark interactions. While this is not a direct effect on shark abundance or proximity, it shows an effect between humans and their environment. Further analysis is needed to quantify this effect in order to determine the extent that ENSO affects the spatial distribution of shark populations.

Changes in Sea Surface Temperature/Coastal Upwelling

In an upwelling ecosystem along the South American Coast, the warming effect of the 1982-83 El Nino caused the system to become more tropical, disrupting the food web and causing the migration or demise of many fish and invertebrates (Arntz and Tarazona 1989). However, this provided some benefits to the fisheries on the northern Peruvian coast, as certain species more tolerant of warm water moved into the area. At higher trophic levels, the effect was not as beneficial. Guano birds and seal populations dropped due to higher mortality levels and lower recruitment probably related to food scarcity. However, few long-term effects were reported after the end of the ENSO phase (Arntz and Tarazona 1989). In northern Chile, the effects of ENSO again appeared to alter the lower trophic levels first (seed bank and herb cover), which then caused changes in higher levels (hawks, owls, and foxes) (Jaksic et al. 1997). Skipjack tuna are known to migrate with the western equatorial Pacific warm pool and their populations experience large spatial shifts during ENSO events. This is likely in response to the effect of ENSO on plankton and other food sources (Tsai et al. 1997). All of these studies support the possibility that shark attack patterns may be related to an increase or decrease in their food supply, due to the effects of ENSO.

Decreased Precipitation/River Runoff

All three regions that had significantly more attacks during warm phases experienced a decrease in precipitation as well as decreased river runoff. It would be expected that attacks would decrease in less turbid waters. It is possible that changes in sea level may put humans closer to shark territory or conversely, bring sharks further inshore than when runoff is more powerful.

Differences Between the Old and New CPC Scales

Most of the changes between the two scales involve neutral episodes replacing warm episodes. The previous CPC scale was considerably more subjective in determining phase than the new scale so it can be assumed that the newer scale is more accurate. The change in scale affected different parts of the analysis in different ways. In some cases (South America, Gulf Coast) the change in scale resulted in changing the data from being significantly different to not being significantly different. In other cases (South Africa), the data changed from being not significant to significant. In other cases (Australia), the data became more or less significantly different depending on the scale. While not directly related to this study, previous studies using the old CPC scale may have different outcomes if they were conducted using the new scale.

Conclusion

In summary, the only global connections between reported shark attack patterns were due to latitude and longitude and not ENSO phase. However, on a regional basis, phase may have affected the number of attacks in South America, Australia/New Zealand, the Gulf Coast of the United States and South Africa. It is possible that these changes are related to increased beach attendance, changes in sea surface temperature and coastal upwelling, and decreased amounts of precipitation causing lower river runoff, all of which are evident during El Nino episodes in these regions. Differences between the old and new scales affected different regions in different ways. As reports of human-shark interactions increase, it is of importance to study all possible avenues in an effort to save both human and animal lives. This study can act as a starting point for such explorations.

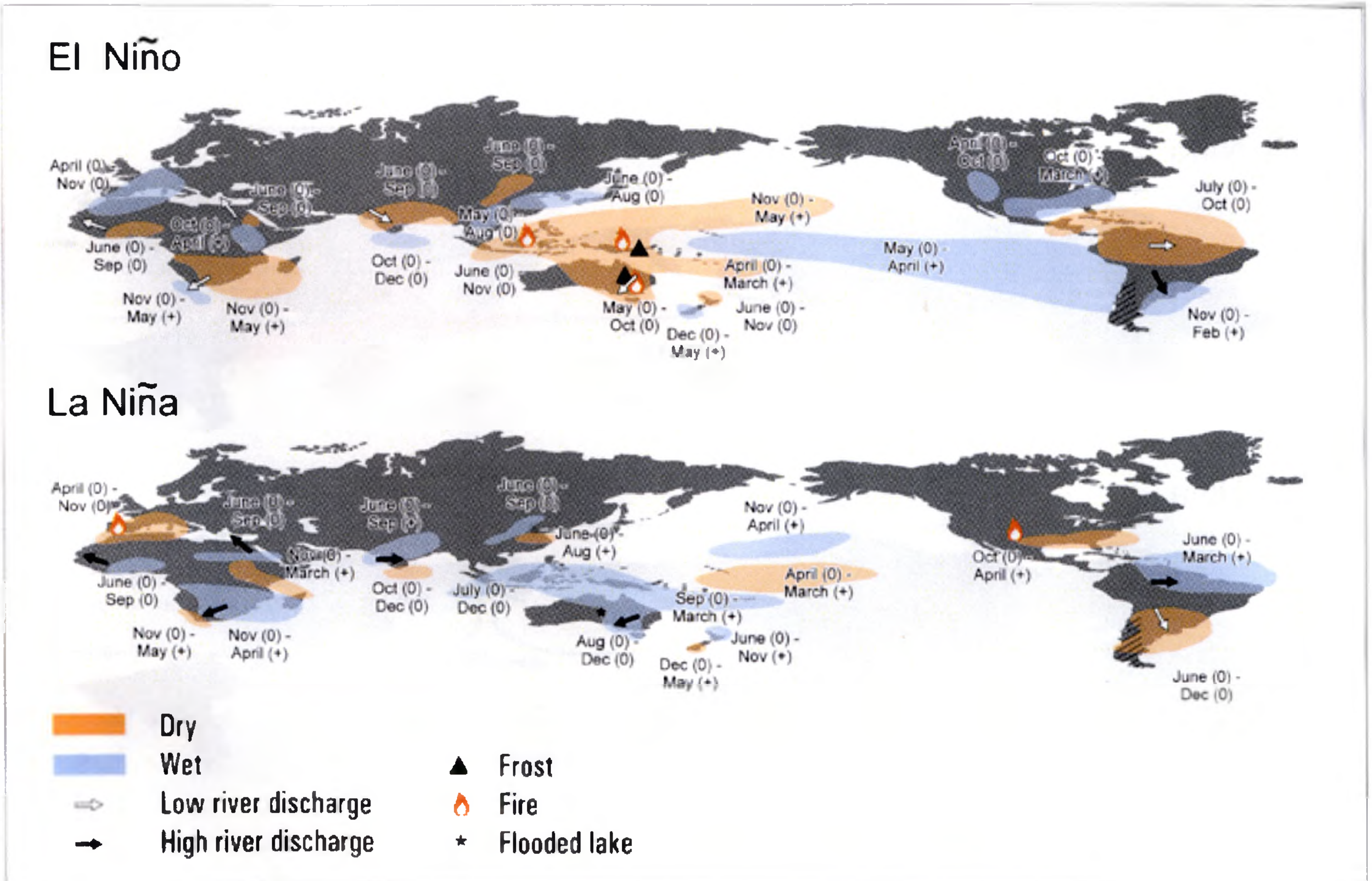

Figure 36: Schematics of the spatial and temporal responses of global hydro-climatological variables during strong El Niño and La Niña phases (From various sources detailed in the text).

Figure 1. Phenomena Associated with ENSO (Allen et al. 1996)

Figure 2. Recorded South American Shark Attacks 1950-2000

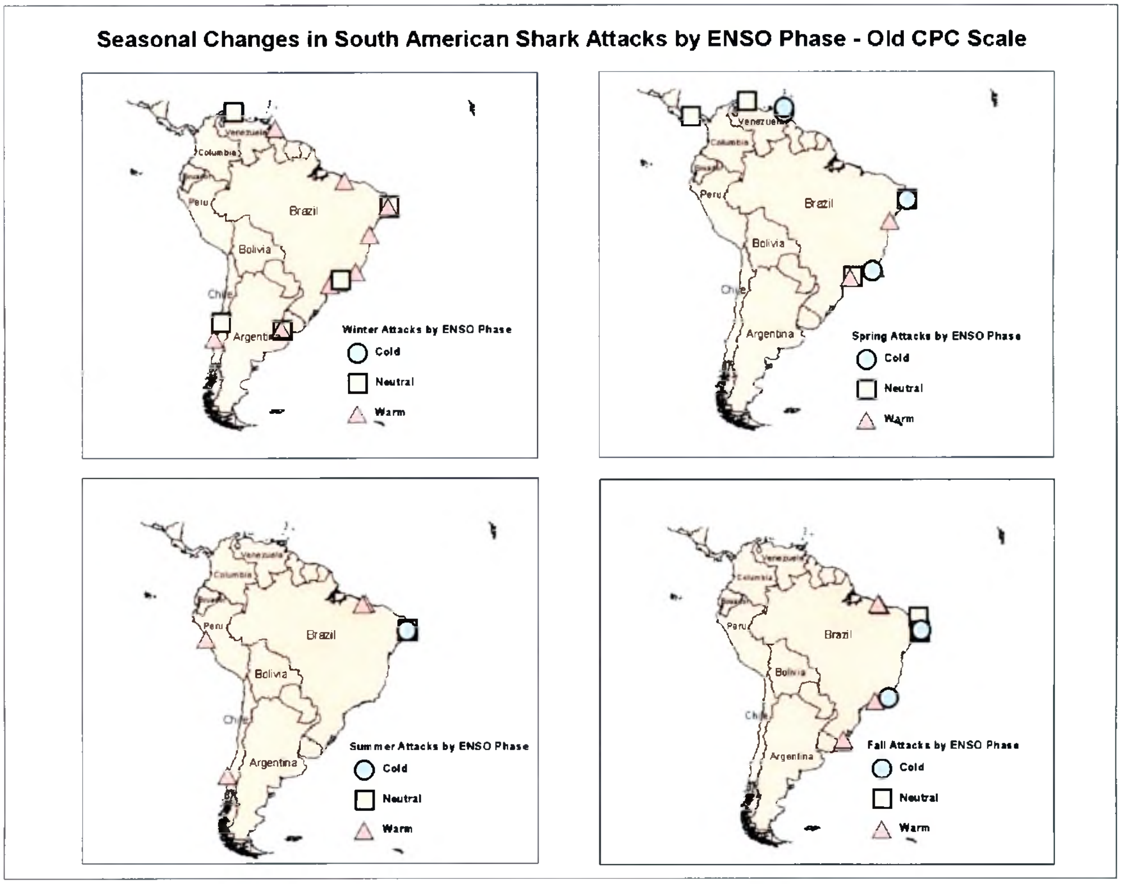

Figure 3. Seasonal Changes in South American Shark Attacks by ENSO Phase – Old CPC Scale

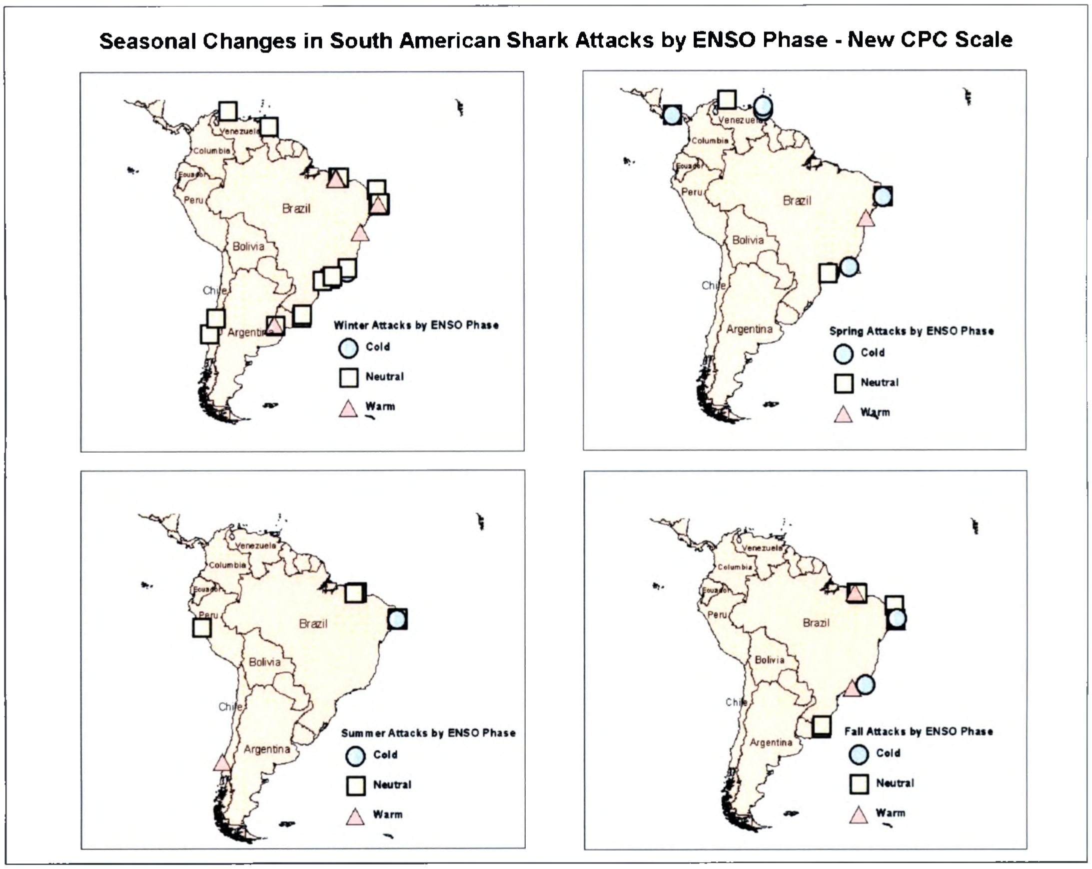

Figure 4. Seasonal Changes in South American Shark Attacks by ENSO Phase – New CPC Scale

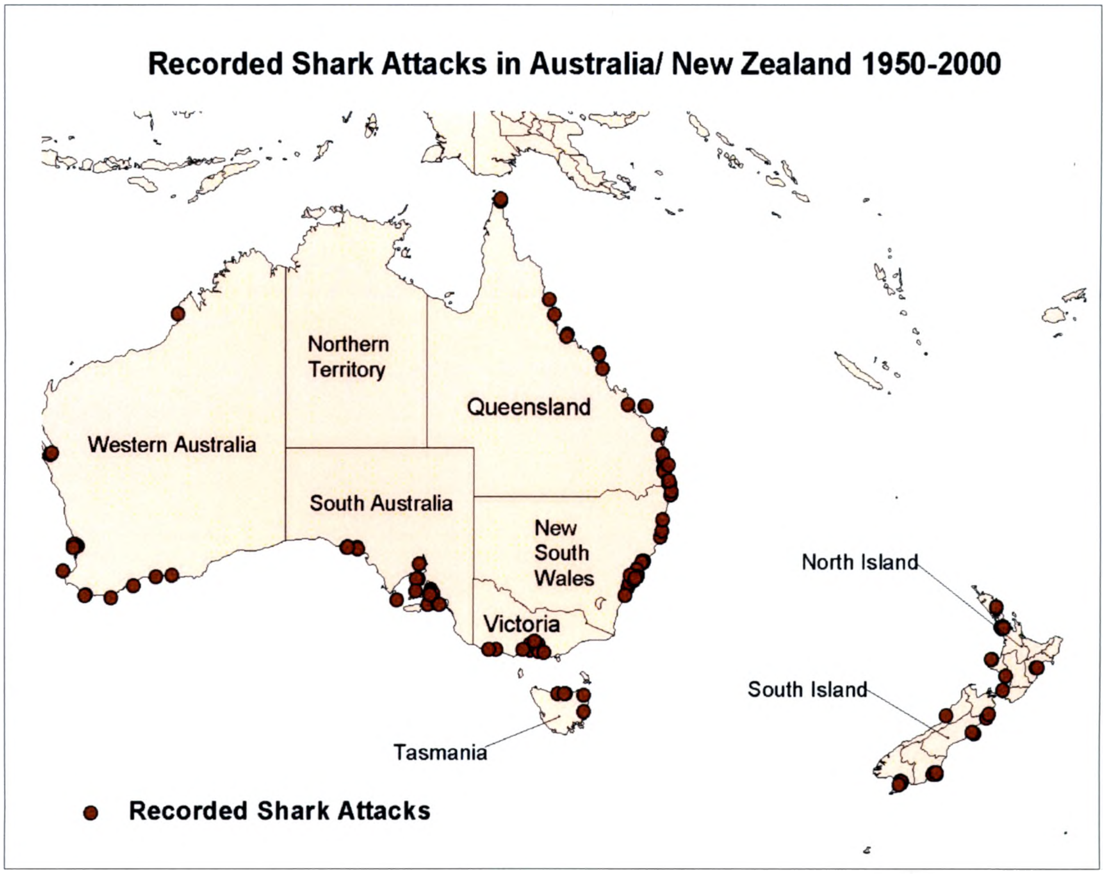

Figure 5. Recorded Shark Attacks in Australia/New Zealand 1950-2000

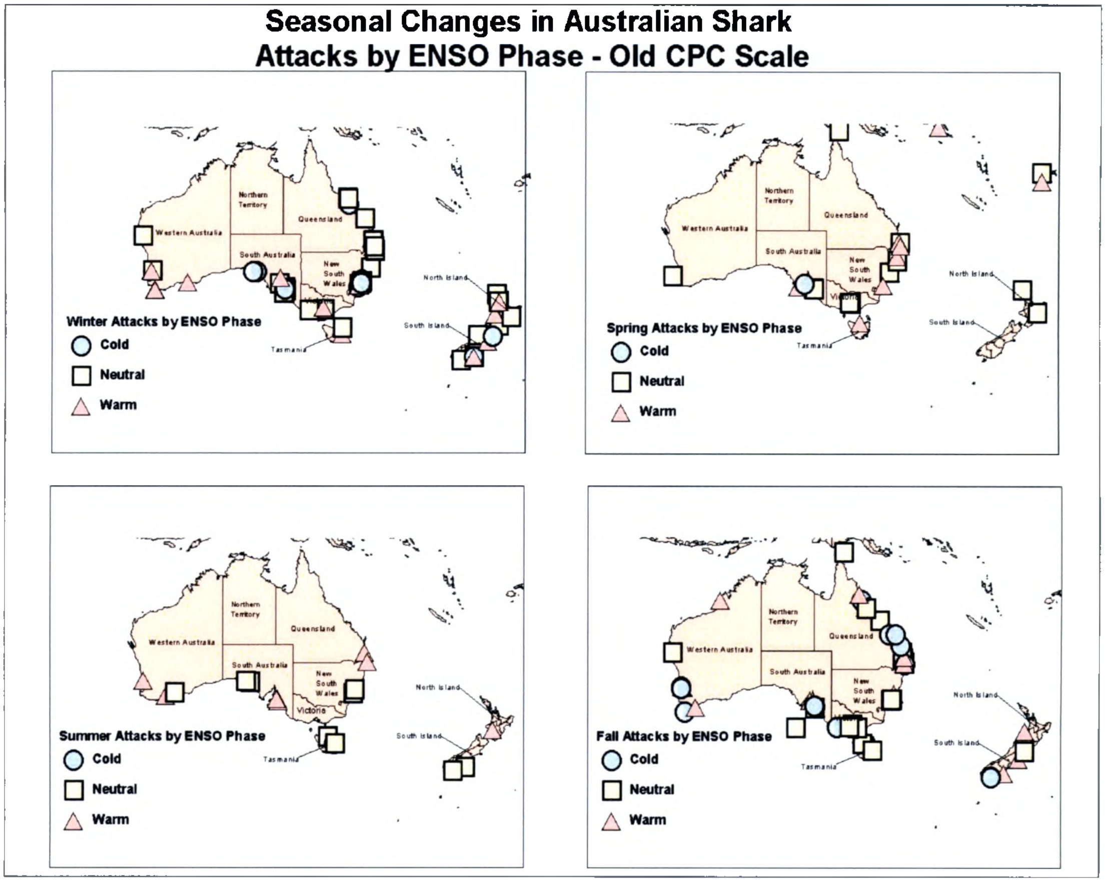

Figure 6. Seasonal Changes in Australian Shark Attacks by ENSO Phase – Old CPC Scale

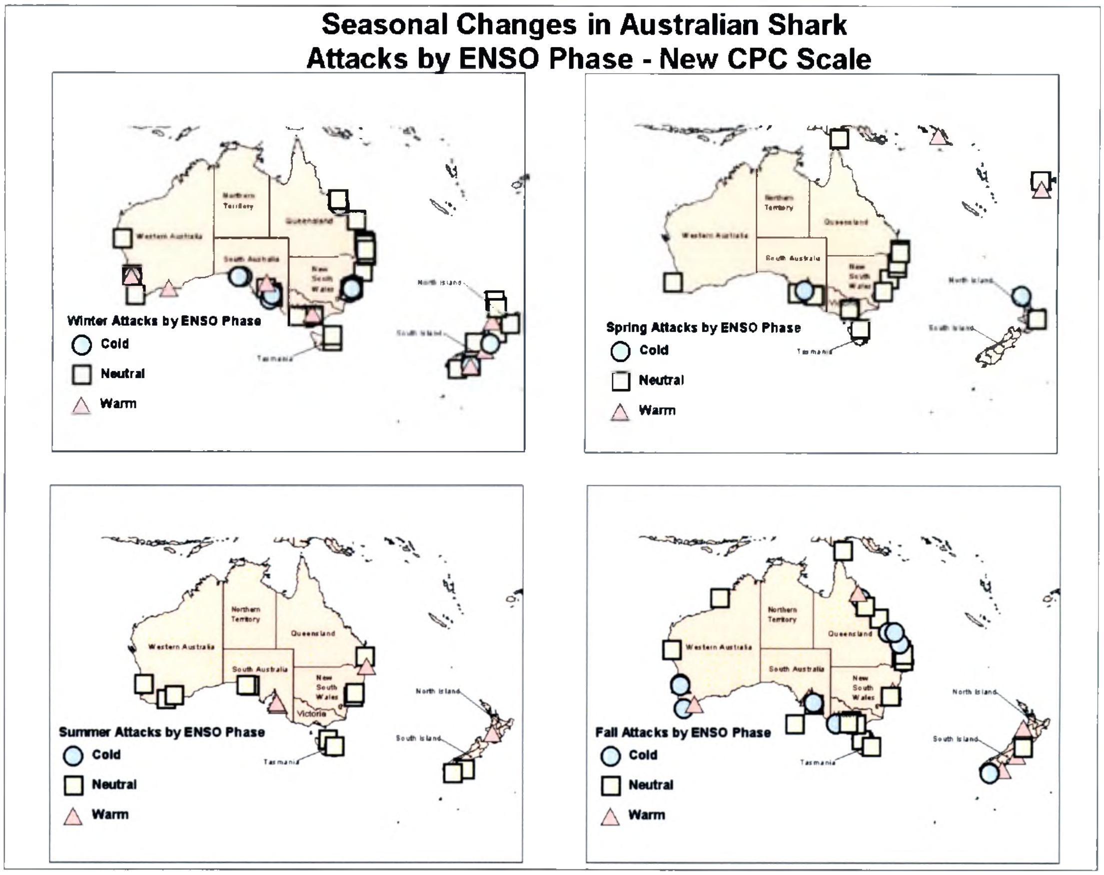

Figure 7. Seasonal Changes in Australian Shark Attacks by ENSO Phase – New CPC Scale

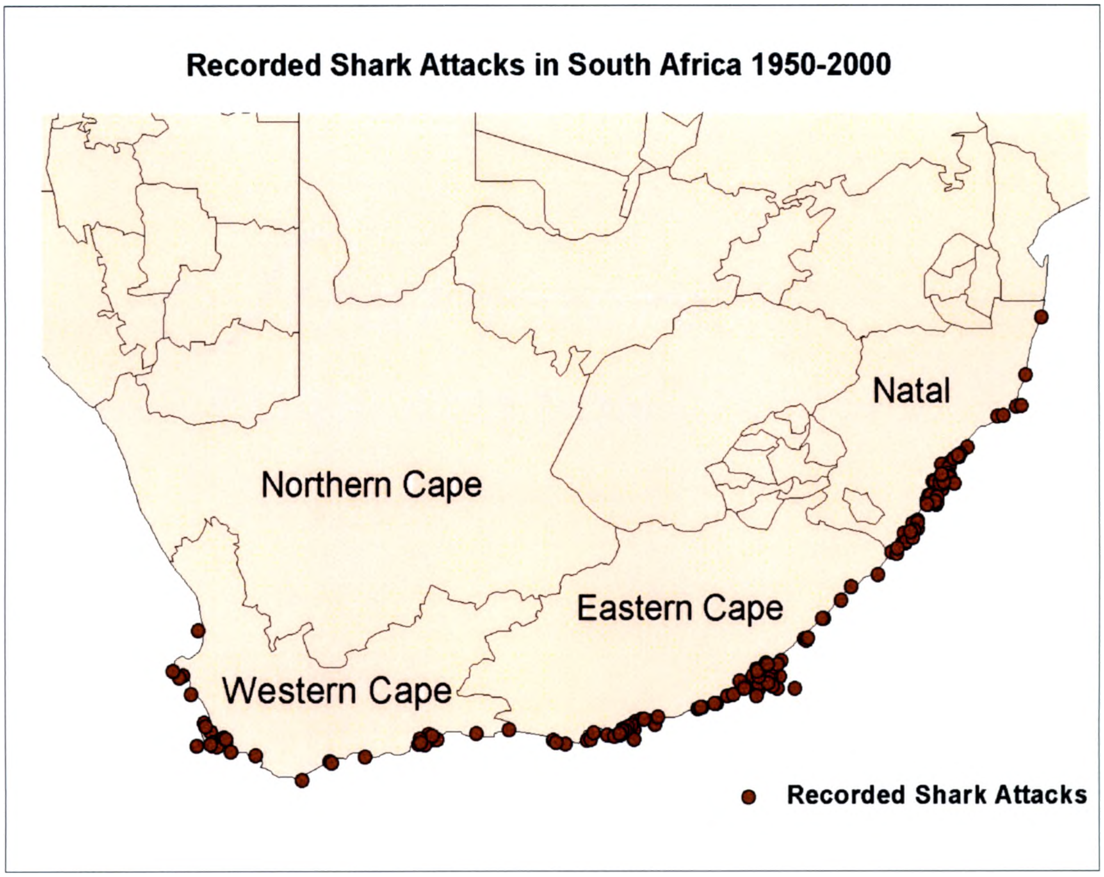

Figure 8. Recorded Shark Attacks in South Africa 1950-2000

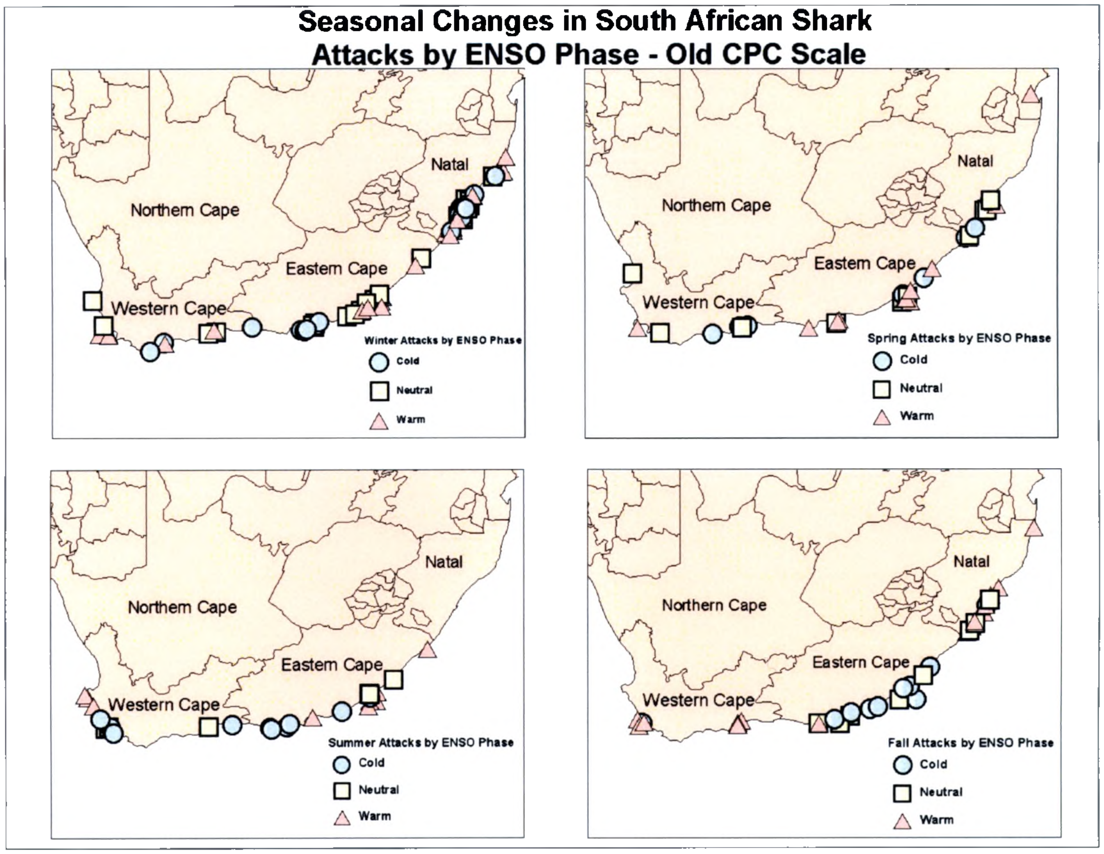

Figure 9. Seasonal Changes in South African Shark Attacks by ENSO Phase – Old CPC Scale

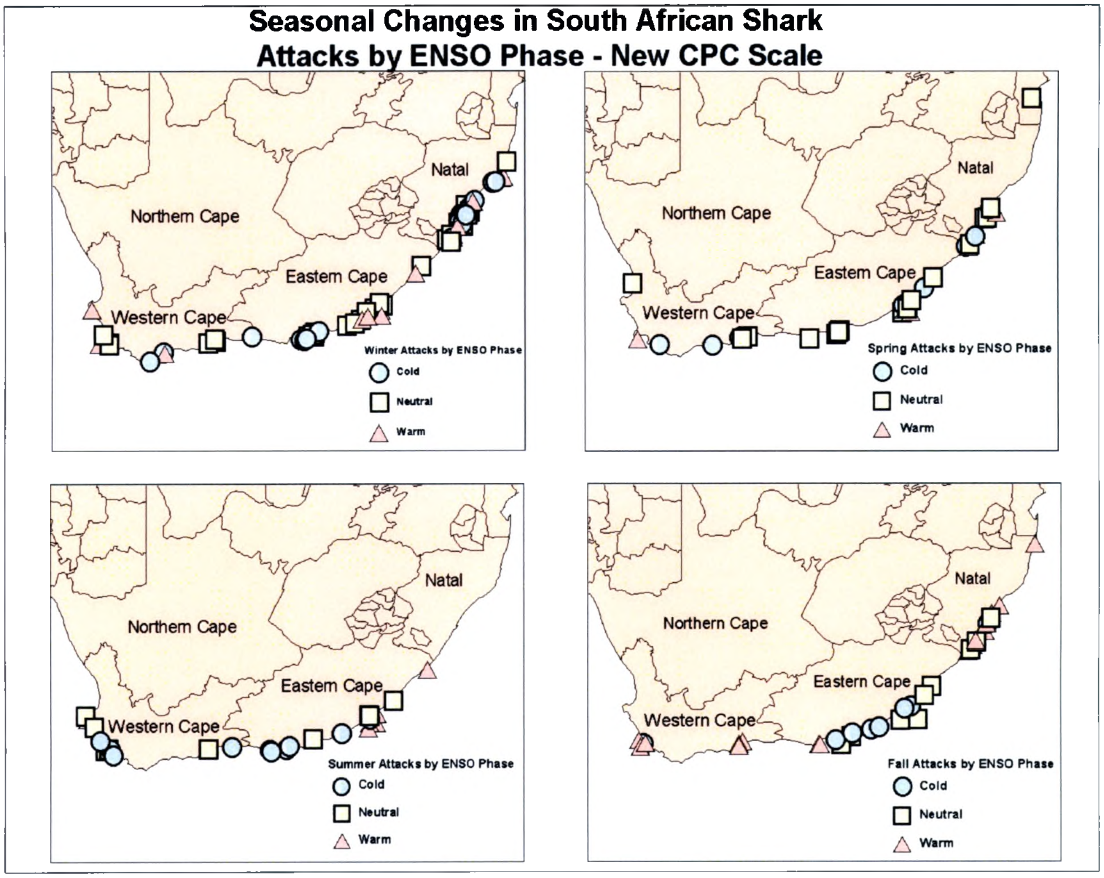

Figure 10. Seasonal Changes in South African Shark Attacks by ENSO Phase – New CPC Scale

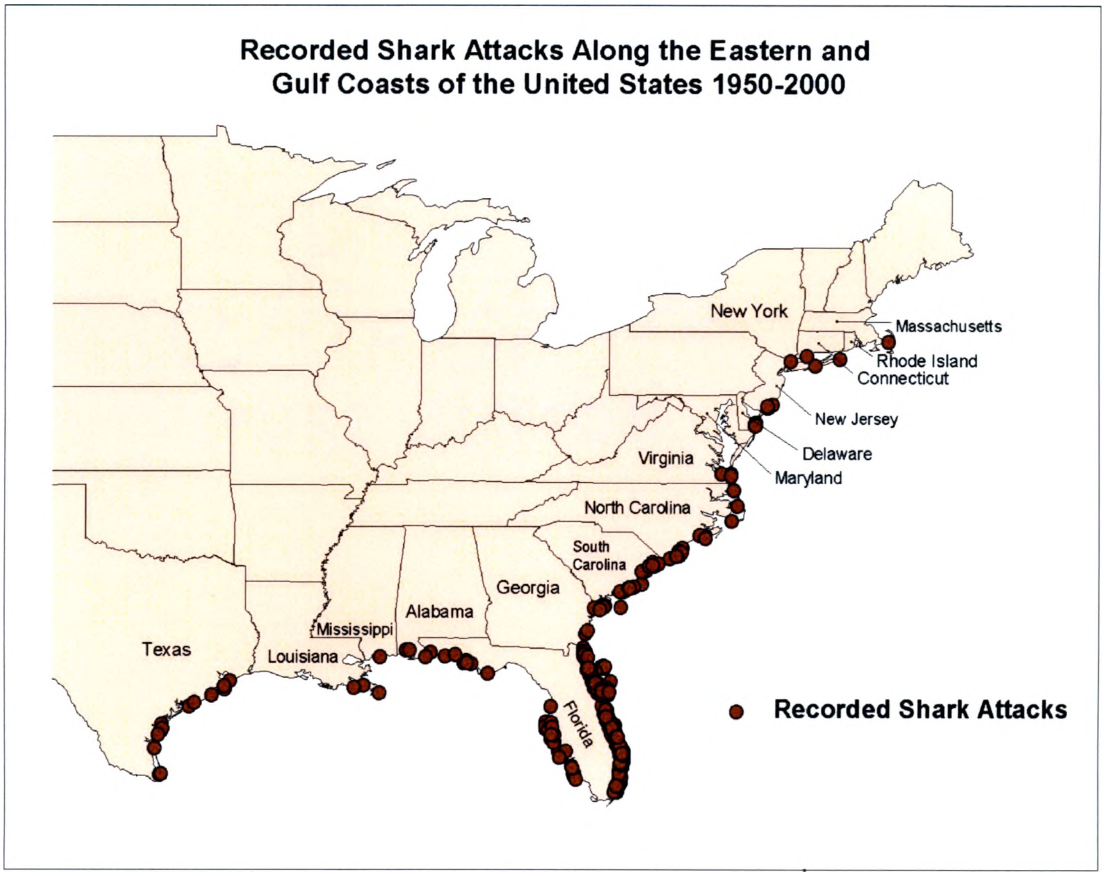

Figure 11. Recorded Shark Attacks Along the Eastern and Gulf Coasts of the United States 1950-2000

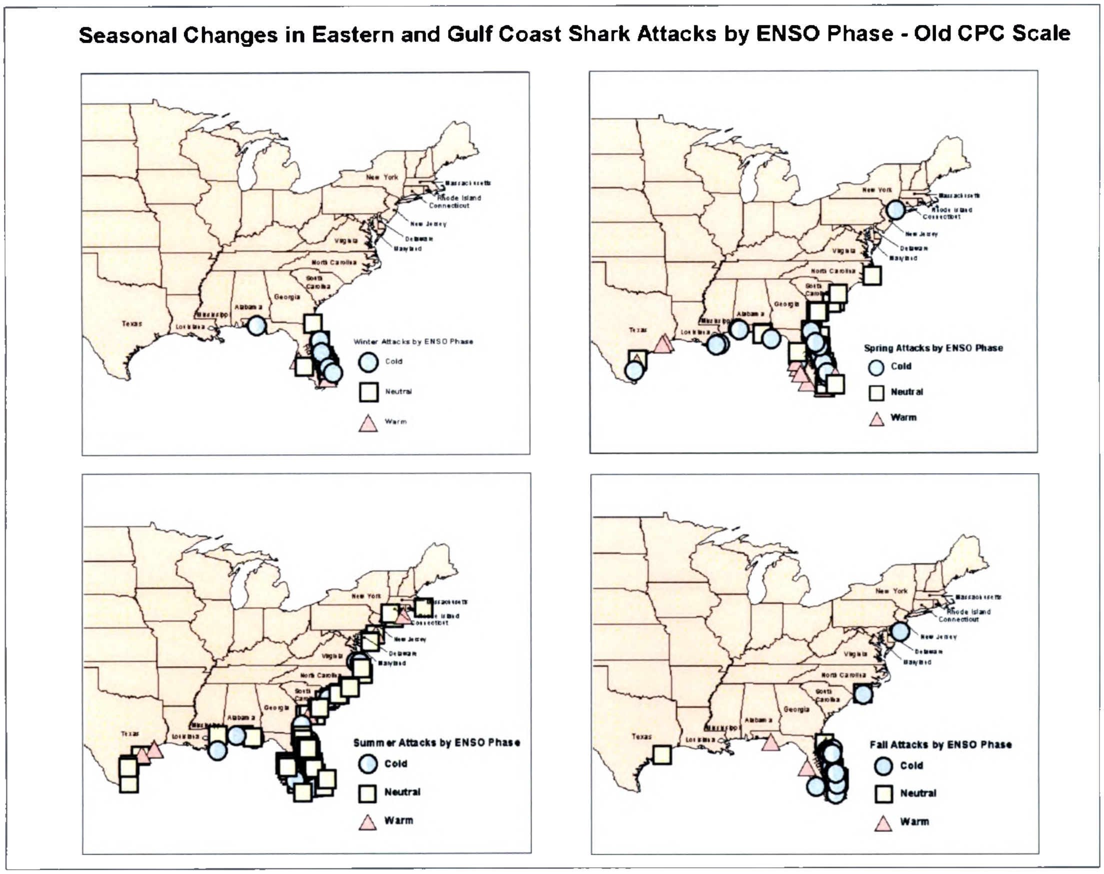

Figure 12. Seasonal Changes in Eastern and Gulf Coast Shark Attacks by ENSO Phase - Old CPC Scale

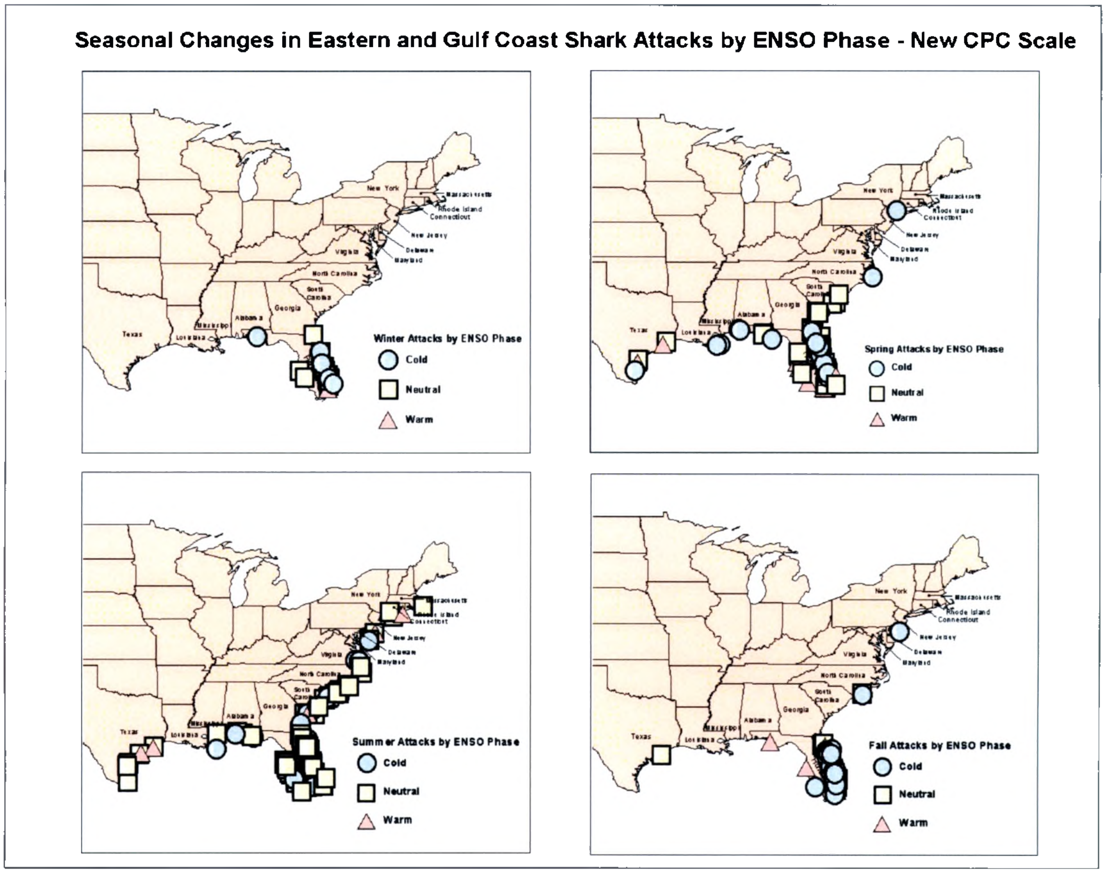

Figure 13. Seasonal Changes in Eastern and Gulf Coast Shark Attacks by ENSO Phase - New CPC Scale

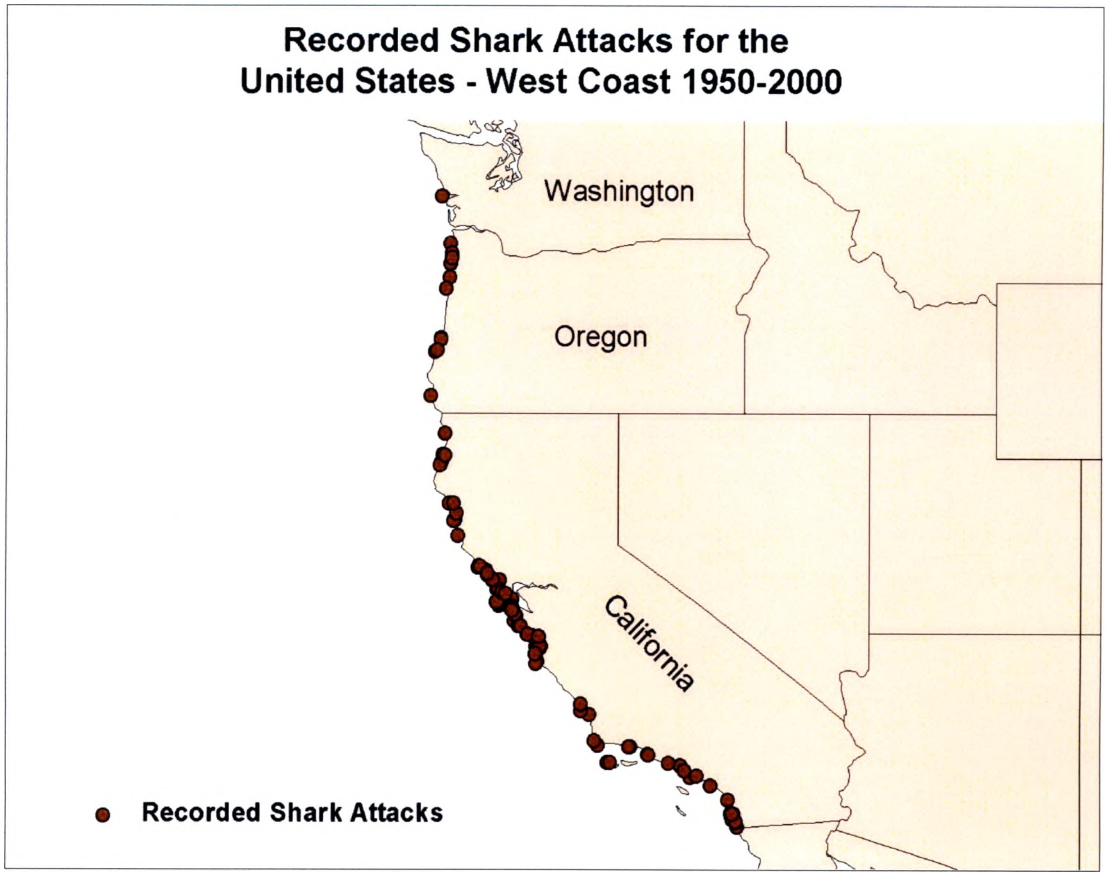

Figure 14. Recorded Shark Attacks for the United States – West Coast 1950-2000

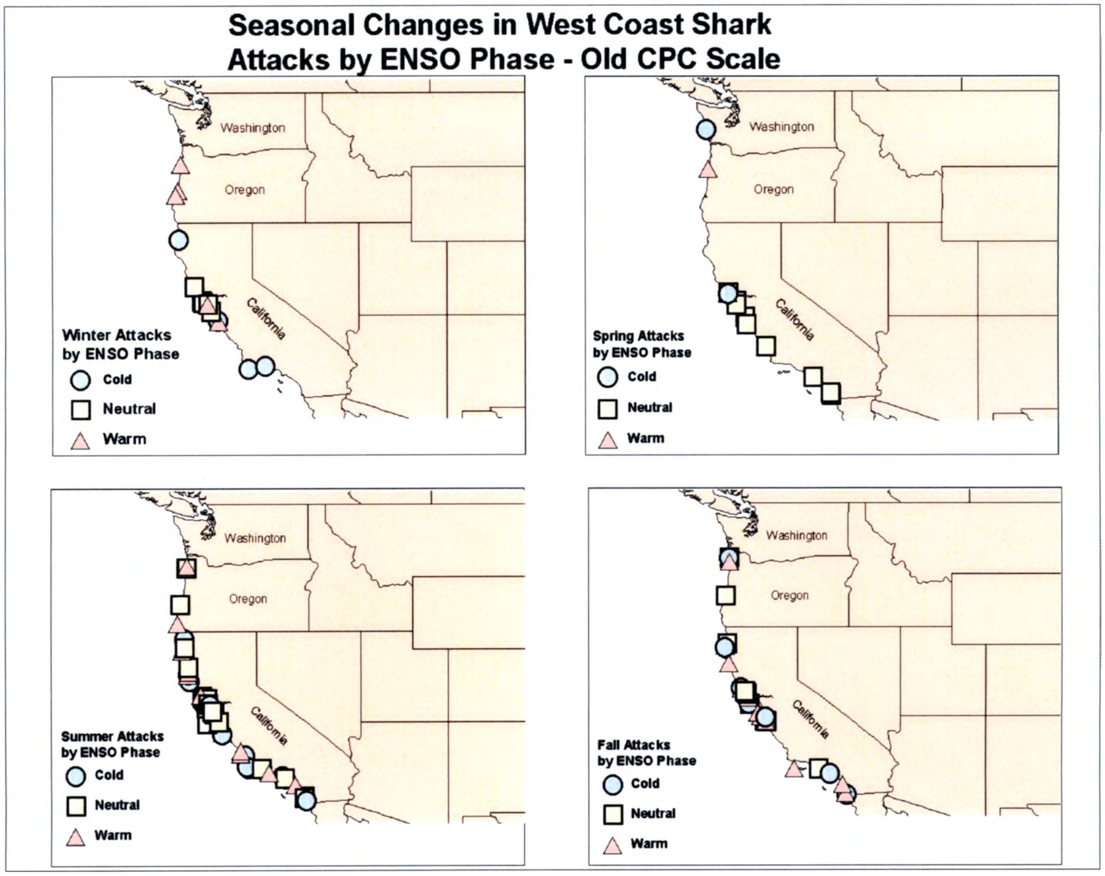

Figure 15. Seasonal Changes in West Coast Shark Attacks by ENSO Phase – Old CPC Scale

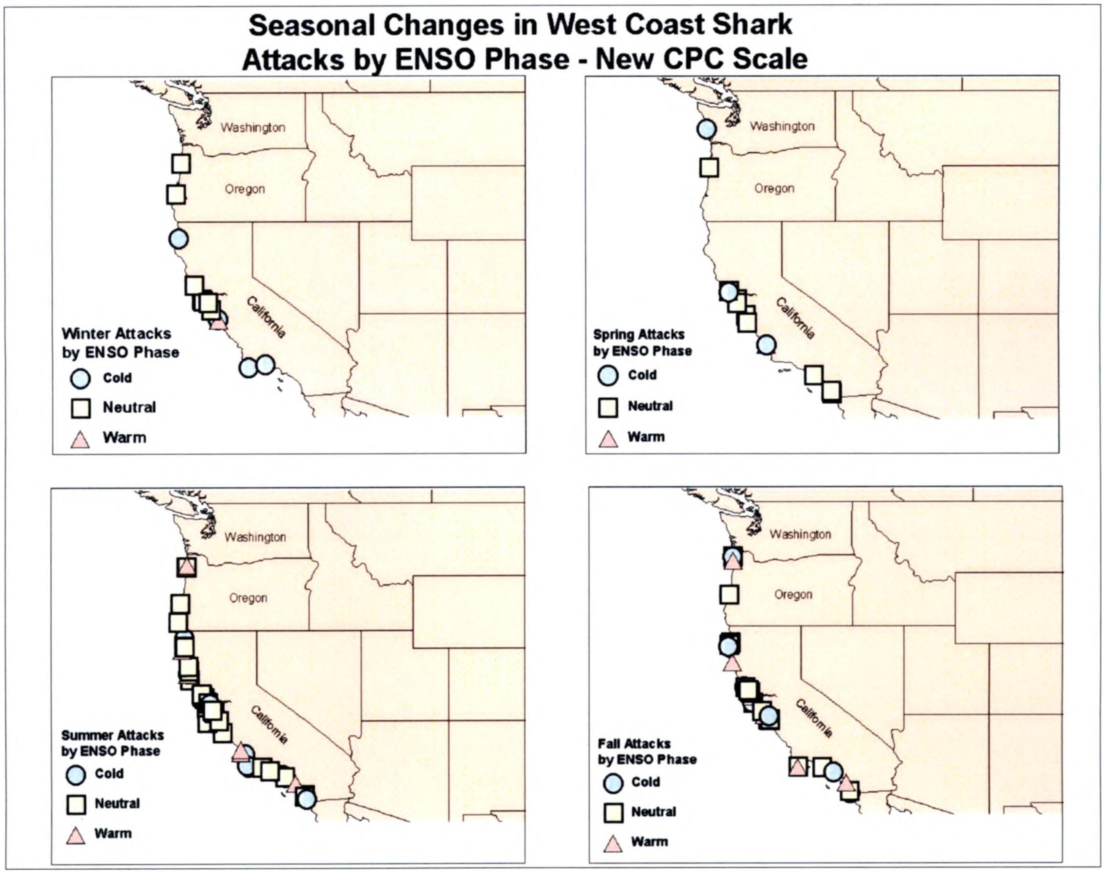

Figure 16. Seasonal Changes in West Coast Shark Attacks by ENSO Phase – New CPC Scale

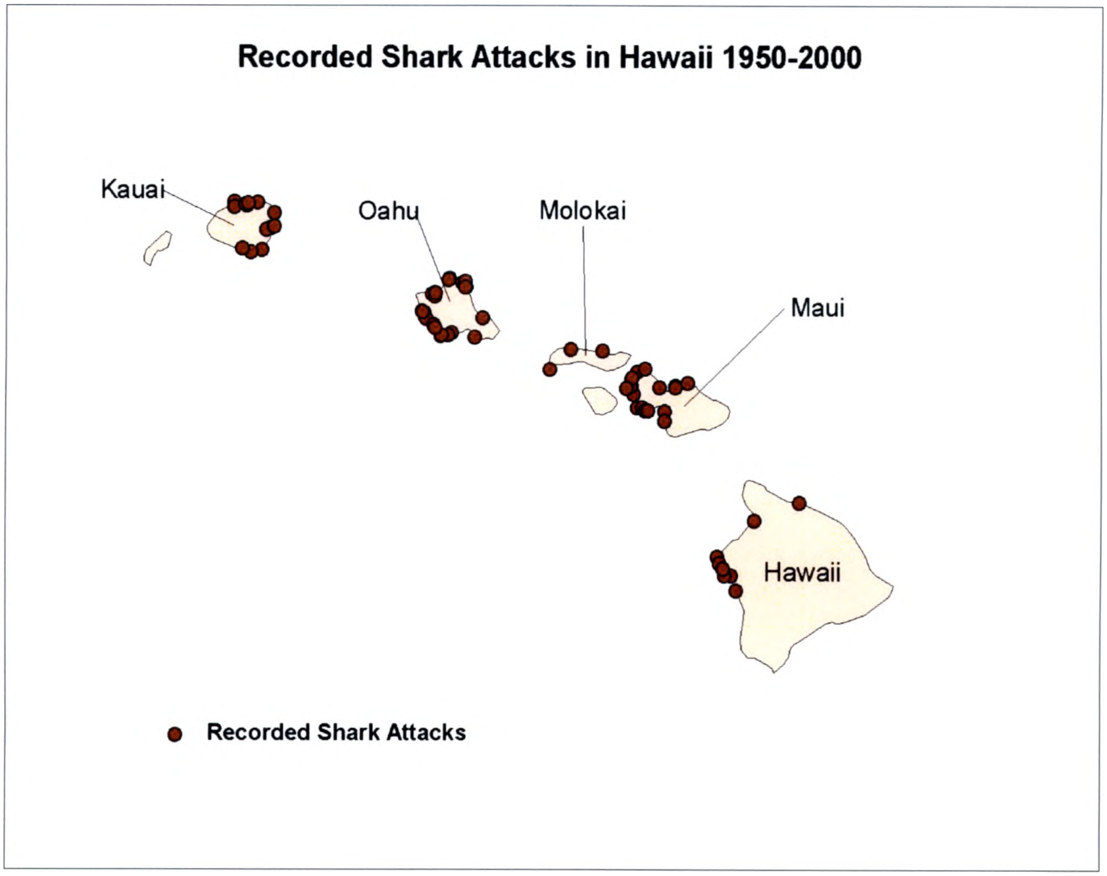

Figure 17. Recorded Shark Attacks in Hawaii 1950-2000

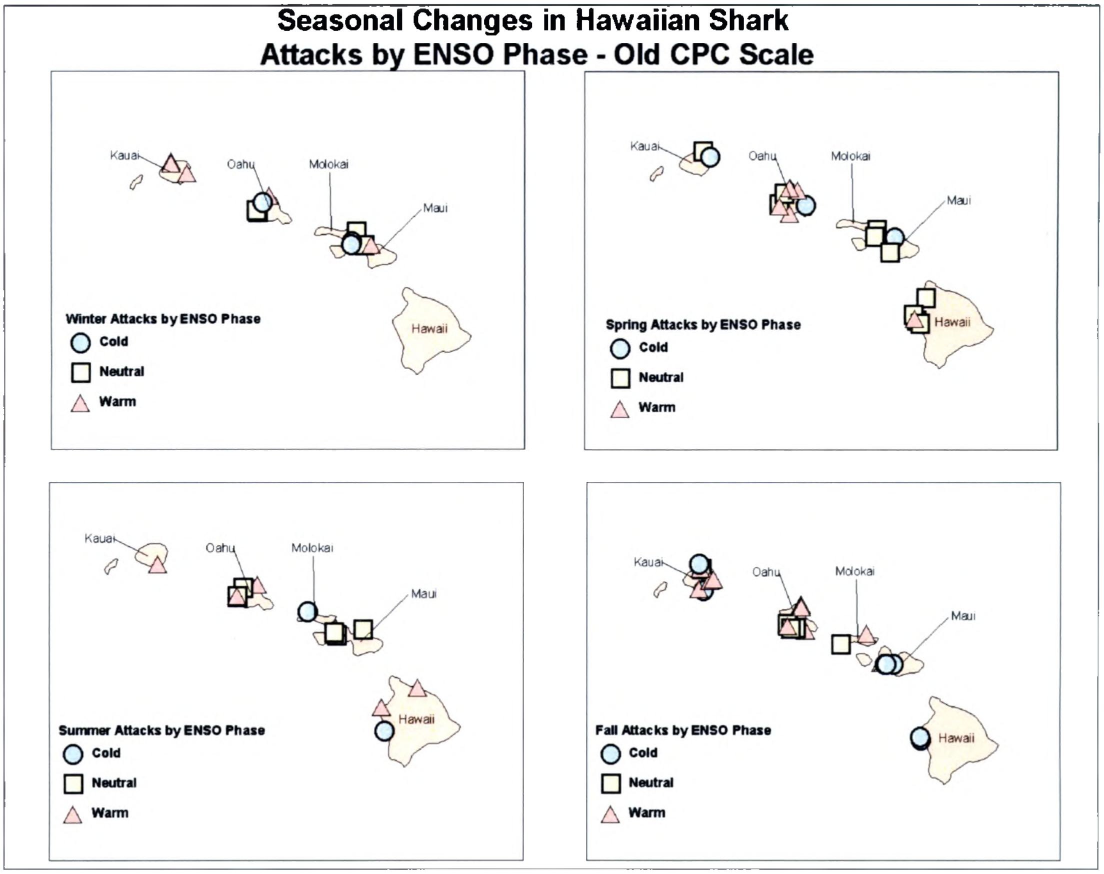

Figure 18. Seasonal Changes in Hawaiian Shark Attacks by ENSO Phase – Old CPC Scale

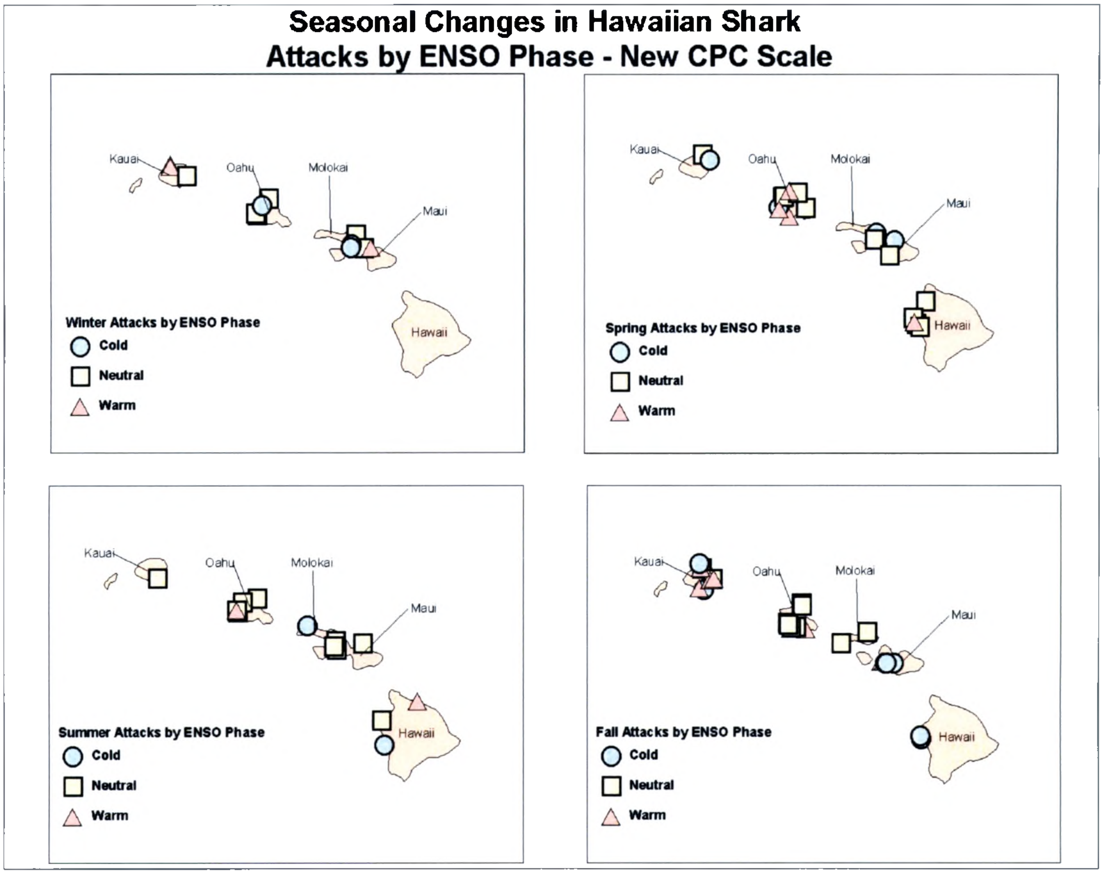

Figure 19. Seasonal Changes in Hawaiian Shark Attacks by ENSO Phase – New CPC Scale

Table 1. Number of ENSO Phases Per Season 1950-2000

	JFM (Old/New)	AMJ (Old/New)	JAS (Old/New)	OND (Old/New)	Total (Old/New)
Warm	16/12	14/15	17/10	19/15	66/52
Neutral	20/24	26/26	22/28	15/20	83/98
Cold	15/15	11/10	12/13	17/16	55/54

Table 2. Example of Data Table

Year	Number of Attacks in Winter	Winter ENSO Phase (Old)	Winter ENSO Phase (New)	Cold Only	Warm Only
1950	0	-1	-1	1	0
1951	2	1	0	0	1
1952	0	0	0	0	0
1953	0	0	0	0	0
1954	2	0	0	0	0
1955	3	-1	-1	1	0
1956	2	-1	-1	1	0
1957	0	0	0	0	0
1958	0	1	1	0	1
1959	4	1	0	0	1

Table 3. Descriptive Statistics - Number of Worldwide Shark Attacks by ENSO Phase

Phase	Cold	Warm	Neutral	All
Mean	22	22	27	24
Standard Deviation	18	14	19	17
Minimum	6	7	7	6
Maximum	67	50	77	77
N	13	12	26	51

Table 4. Descriptive Statistics - Number of Worldwide Shark Attacks by Location

Location:	North of Equator	South of Equator	East of Greenwich	West of Greenwich	N30°	S30°
Mean	16	9	9	16	11	4
Standard Deviation	13	5 7	5.2	15	10	3 7
Minimum	1	0	0	1	1	0
Maximum	61	22	22	61	45	16
N	51	51	51	51	51	51
Total	808	458	440	826	554	207

Table 5. Two-way ANOVA - Number of Shark Attacks by ENSO Phase and Latitude

Variable	F	Significance
Phase	.84	.44
Latitude	11	**.001***
Phase x Latitude	.07	.93

Table 6. Two-way ANOVA - Number of Shark Attacks by ENSO Phase Occurring Between 30°N and 30°S of Equator

Variable	F	Significance
Phase	.86	.39
Latitude	5.6	**.02***
Phase x Latitude	.09	.90

Table 7. Two-way ANOVA - Number of Shark Attacks by ENSO Phase and Longitude

Variable	F	Significance
Phase	.74	.48
Longitude	4.7	**.03***
Phase x Longitude	.12	.89

Table 8. Available Shark Attack Data 1950-2000

Region	Total Number of Attacks	Attacks with Dates	Attacks with Locations
Worldwide	1726	1410	1217
South America	89	71	66
Australia/New Zealand	204	166	157
South Africa	190	182	169
U.S. - East Coast	423	385	388
U.S. - West Coast	126	117	117
U.S. - Gulf Coast	94	80	65
U.S. - Hawaii	82	76	75
U.S. - Total	729	660	645

Table 9. Winter Rates of Attacks by ENSO Phase

Region	Cold (Old/New)	Warm (Old/New)	Neutral (Old/New)
South America	.02/.02	.28/.14	.10/.24
Australia/New Zealand	.30/.34	.34/.22	.64/.72
South Africa	.44/.48	.54/.38	.52/.64
U.S. - East Coast	.22/.26	.18/.16	.28/.26
U.S. - Gulf Coast	.02/.02	.02/.00	.02/.04
U.S. - West Coast	.08/.08	.10/.04	.10/.16
U S. - Hawaii	08/.08	.10/.06	.08/.12

Table 10. Spring Rates of Attacks by ENSO Phase

Region	Cold (Old/New)	Warm (Old/New)	Neutral (Old/New)
South America	.08/.12	.10/.06	.04/.04
Australia/New Zealand	.02/.04	.18/.08	.22/.30
South Africa	.16/.16	.26/.14	.22/.34
U.S. - East Coast	.32/.46	.46/.38	.86/.80
U.S. - Gulf Coast	.16/.16	.14/.10	.08/.12
U.S. - West Coast	.04/.06	.06/.04	.22/.22
U.S. - Hawaii	.06/.08	.16/.12	.20/.22

Table 11. Summer Rates of Attacks by ENSO Phase

Region	Cold (Old/New)	Warm (Old/New)	Neutral (Old/New)
South America	.02/.02	.26/.16	.08/.18
Australia/New Zealand	.02/02	.16/.10	.20/.26
South Africa	.20/.20	.18/.12	.12/.18
U.S. - East Coast	.72/.86	.96/.62	1.9/2.1
U.S. - Gulf Coast	.12/.12	.24/.08	.42/.58
U.S. - West Coast	.32/.22	.38/.22	.40/.66
U.S. - Hawaii	.04/.04	.14/.20	.10/.04

Table 12. Fall Rates of Attacks by ENSO Phase

Region	Cold (Old/New)	Warm (Old/New)	Neutral (Old/New)
South America	.06/.06	.20/.12	.08/.16
Australia/New Zealand	.34/.34	.28/.22	.44/.50
South Africa	.20/.16	.36/.38	.18/.20
U.S. - East Coast	.80/.70	.82/.56	.26/.62
U.S. - Gulf Coast	.02/.02	.04/.04	.02/.02
U.S. - West Coast	.14/.14	30/.18	.20/.32
U.S. - Hawaii	.14/.14	.28/.16	.12/.24

Table 13. Reported Shark Attacks in South America by ENSO Phase and Season

Season	Cold (Old/New)	Warm (Old/New)	Neutral (Old/New)	Total
JFM	1/1	14/7	5/12	20
AMJ	4/6	5/3	2/2	11
JAS	1/1	13/8	4/9	18
OND	3/3	10/6	4/8	17
Total	9/11	42/24	15/31	66

Table 14. Results of South American Analysis (p =.10)

Season	Phase	Mean Difference (Old/New)	Significance (Old/New)
JFM	Cold vs. Neutral	-.18/-.43	.79/.29
	Cold vs. Warm	-.81/-.52	**.02***/ 28
	Warm vs. Neutral	.63/-.08	**.07***/.96
AMJ	Cold vs. Neutral	.29/.32	35/.20
	Cold vs. Warm	.01/.10	1.0/.90
	Warm vs. Neutral	-.28/-.22	.31/.55
JAS	Cold vs. Neutral	-.10/-.24	0.96/.73
	Cold vs. Warm	-.68/-.72	.15/.19
	Warm vs. Neutral	-.58/-.48	0.15/.38
OND	Cold vs. Neutral	.09/-.21	.97/.81
	Cold vs. Warm	-.35/-.21	.55/.82
	Warm vs. Neutral	-.26/.00	.74/1.0

Table 15. Results of South American ANOVA (p =.10)

Season	Phase	F (Old/New)	Significance (Old/New)
JFM	Cold vs. Other	1.3/.36	.26/.70
	Warm vs. Other	8.5/.75	**.01***/.39
AMJ	Cold vs. Other	.92/2.2	.34/.14
	Warm vs. Other	1.2/.26	.29/.61
JAS	Cold vs. Other	.69/1.4	.41/.24
	Warm vs. Other	4.4/2.7	**.04***/.11
OND	Cold vs. Other	.15/.50	.70/.48
	Warm vs. Other	.69/.09	.41/.76

Table 16. Reported Shark Attacks in Australia/New Zealand by ENSO Phase and Season

Season	**Cold (Old/New)**	**Warm (Old/New)**	**Neutral (Old/New)**	**Total**
JFM	15/17	17/11	32/36	64
AMJ	1/2	9/4	11/15	21
JAS	1/1	8/5	10/13	19
OND	17/17	14/11	22/25	53
Total	34/37	48/31	75/89	157

Table 17. Results of Australia/New Zealand Analysis (p =.10)

Season	**Phase**	**Mean Difference (Old/New)**	**Significance (Old/New)**
JFM	Cold vs. Neutral	-.48/-.25	.65/.84
	Cold vs. Warm	.00/.28	.90/.86
	Warm vs. Neutral	.49/.54	.56/.53
AMJ	Cold vs. Neutral	-.33/-.44	.43/.17
	Cold vs. Warm	-.55/-.27	.17/.66
	Warm vs. Neutral	-.21/.18	.65/ 80
JAS	Cold vs. Neutral	-.37/-.39	.27/.19
	Cold vs. Warm	-.39/-.42	.27/.28
	Warm vs. Neutral	.02/-.03	1.0/.99
OND	Cold vs. Neutral	-.47/-.23	.52/.83
	Cold vs. Warm	.26/.39	.79/.64
	Warm vs. Neutral	.73/.63	.20/.29

Table 18. Results of Australia/New Zealand ANOVA (p =.10)

Season	Phase	F (Old/New)	Significance (Old/New)
JFM	Cold vs. Other	.17/.03	.68/.86
	Warm vs. Other	.78/.92	.38/.34
AMJ	Cold vs. Other	3.7/3.0	**.06*/.09***
	Warm vs. Other	3.5/.00	**.07***/.96
JAS	Cold vs. Other	3.1/3.7	**.08*/.06***
	Warm vs. Other	.55/.46	.46/.50
OND	Cold vs. Other	.00/.01	1.0/.93
	Warm vs. Other	2.7/2.0	.11/.16

Table 19. Reported Shark Attacks in South Africa by ENSO Phase and Season

Season	Cold (Old/New)	Warm (Old/New)	Neutral (Old/New)	Total
JFM	22/24	27/19	26/32	75
AMJ	8/8	13/7	11/17	32
JAS	10/10	9/6	6/9	25
OND	10/8	18/19	9/10	37
Total	50/50	67/51	52/68	169

Table 20. Results of South Africa Analysis (p =.10)

Season	Phase	Mean Difference (Old/New)	Significance (Old/New)
JFM	Cold vs. Neutral	.17/.27	.94/.84
	Cold vs. Warm	-.22/.02	.90/1.0
	Warm vs. Neutral	-.39/-.25	70/.87
AMJ	Cold vs. Neutral	.30/-.12	.71/.94
	Cold vs. Warm	-.20/-.17	.89/.93
	Warm vs. Neutral	-.51/-.05	.34/.99
JAS	Cold vs. Neutral	.48/.37	.39/.52
	Cold vs. Warm	.22/.09	.83/.97
	Warm vs. Neutral	-.26/-.28	.71/.74
OND	Cold vs. Neutral	.06/.00	.99/1.0
	Cold vs. Warm	-.41/-.77	.49/.11
	Warm vs. Neutral	-.47/-.77	.43/**.09***

Table 21. Results of South Africa ANOVA (p =.10)

Season	Phase	F (Old/New)	Significance (Old/New)
JFM	Cold vs. Other	.00/.18	.96/.68
	Warm vs. Other	.44/.10	.51/.75
AMJ	Cold vs. Other	.07/.16	.79/.69
	Warm vs. Other	1.3/.06	.27/.82
JAS	Cold vs. Other	.67/.84	.42/.36
	Warm vs. Other	.36/.20	.55/.66
OND	Cold vs. Other	.44/1.0	.51/.32
	Warm vs. Other	3.7/5.9	**.06*/.02***

Table 22. Reported Shark Attacks in U.S. – East Coast by Phase and Season

Season	**Cold (Old/New)**	**Warm (Old/New)**	**Neutral (Old/New)**	**Total**
JFM	11/13	9/8	14/13	34
AMJ	16/23	23/19	43/40	82
JAS	36/43	48/31	94/104	178
OND	40/35	41/28	13/31	94
Total	103/114	121/86	164/188	388

Table 23. Results of United States East Coast Analysis (p =.10)

Season	**Phase**	**Mean Difference (Old/New)**	**Significance (Old/New)**
JFM	Cold vs. Neutral	.03/.32	1.0/.60
	Cold vs. Warm	.23/.28	.81/.76
	Warm vs. Neutral	.20/-.04	.83/.99
AMJ	Cold vs. Neutral	-.20/-.01	.96/1.0
	Cold vs. Warm	-.19/-.37	.97/.90
	Warm vs. Neutral	-.01/-.36	1.0/.89
JAS	Cold vs. Neutral	-1.3/-.41	.78/.97
	Cold vs. Warm	.18/.21	1.0/1.0
	Warm vs. Neutral	-1.4/.61	.67/.95
OND	Cold vs. Neutral	1.5/.64	.20/.73
	Cold vs. Warm	.20/.32	.97/.93
	Warm vs. Neutral	1.3/ 32	.29/.93

Table 24. Results of United States East Coast ANOVA (p =.10)

Season	Phase	F (Old/New)	Significance (Old/New)
JFM	Cold vs. Other	.01/.99	.93/.32
	Warm vs. Other	.18/.06	.67/ 81
AMJ	Cold vs. Other	.08/.03	.78/.87
	Warm vs. Other	.01/.25	.94/.62
JAS	Cold vs. Other	.13/.02	.72/.89
	Warm vs. Other	.40/.07	.53/.79
OND	Cold vs. Other	1.4/.45	.24/.51
	Warm vs. Other	.35/.00	.56/.97

Table 25. Reported Shark Attacks in U.S. – Gulf Coast by ENSO Phase and Season

Season	Cold (Old/New)	Warm (Old/New)	Neutral (Old/New)	Total
JFM	1/1	1/0	1/2	3
AMJ	8/8	7/5	4/6	19
JAS	6/6	12/4	21/29	39
OND	1/1	2/2	1/1	4
Total	16/16	22/11	27/38	65

Table 26. Results of United States Gulf Coast Analysis (p =.10)

Season	Phase	Mean Difference (Old/New)	Significance (Old/New)
JFM	Cold vs. Neutral	.02/.02	.98/.98
	Cold vs. Warm	.00/.07	1.0/.76
	Warm vs. Neutral	.01/.08	.99/.59
AMJ	Cold vs. Neutral	.57/.30	**.08***/ 43
	Cold vs. Warm	.23/.03	.72/.99
	Warm vs. Neutral	-.35/-.27	.33/.60
JAS	Cold vs. Neutral	-.45/-.57	.47/.24
	Cold vs. Warm	-.21/.06	.87/.99
	Warm vs. Neutral	.25/.64	.76/.24
OND	Cold vs. Neutral	.01/.01	1.0/1.0
	Cold vs. Warm	-.05/-.07	.87/.75
	Warm vs. Neutral	-.04/-.08	.91/.65

Table 27. Results of United States Gulf Coast ANOVA (p =.10)

Season	Phase	F (Old/New)	Significance (Old/New)
JFM	Cold vs. Other	.56/.02	.45/.88
	Warm vs. Other	.05/.96	.82/.33
AMJ	Cold vs. Other	1.5/.98	.22/.33
	Warm vs. Other	.32/.36	.58/.55
JAS	Cold vs. Other	.91/1.4	.35/.24
	Warm vs. Other	.61/1.5	.44/.23
OND	Cold vs. Other	.13/.05	.72/.82
	Warm vs. Other	.29/.81	.59/.37

Table 28. Reported Shark Attacks in U.S. – West Coast by ENSO Phase and Season

Season	Cold (Old/New)	Warm (Old/New)	Neutral (Old/New)	Total
JFM	4/4	5/2	5/8	14
AMJ	2/3	3/2	11/11	16
JAS	16/11	19/11	20/33	55
OND	7/7	15/9	10/16	32
Total	29/25	42/24	46/68	117

Table 29. Results of United States West Coast Analysis (p =.10)

Season	Phase	Mean Difference (Old/New)	Significance (Old/New)
JFM	Cold vs. Neutral	.02/-.07	1.0/.93
	Cold vs. Warm	-.05/.10	.97/.88
	Warm vs. Neutral	.06/.17	.94/.66
AMJ	Cold vs. Neutral	-.24/-.22	56/.55
	Cold vs. Warm	-.03/.00	.99/1.0
	Warm vs. Neutral	-.21/.22	.60/.63
JAS	Cold vs. Neutral	.51/.08	.49/.98
	Cold vs. Warm	.30/.05	.80/.99
	Warm vs. Neutral	-.21/-.03	.86/1.0
OND	Cold vs. Neutral	-.25/-.36	.70/.46
	Cold vs. Warm	-.38/-.16	.42/.87
	Warm vs. Neutral	.12/.20	.92/.79

Table 30. Results of United States West Coast ANOVA (p =.10)

Season	Phase	F (Old/New)	Significance (Old/New)
JFM	Cold vs. Other	.01/.01	.95.95
	Warm vs. Other	.12/.64	.73/.43
AMJ	Cold vs. Other	.58/.65	.45/.42
	Warm vs. Other	.45/.38	.51/.54
JAS	Cold vs. Other	.67/.04	.42/.85
	Warm vs. Other	.03/.00	.87/1.0
OND	Cold vs. Other	1.5/1.1	.23/.31
	Warm vs. Other	1.0/.02	.32/.89

Table 31. Reported Shark Attacks in U.S. – Hawaii by ENSO Phase and Season

Season	Cold (Old/New)	Warm (Old/New)	Neutral (Old/New)	Total
JFM	4/4	5/3	4/6	13
AMJ	3/4	8/6	10/11	21
JAS	2/2	7/2	5/10	14
OND	7/7	14/8	6/12	27
Total	16/17	34/19	25/39	75

Table 32. Results of United States Hawaii Analysis (p =.10)

Season	Phase	Mean Difference (Old/New)	Significance (Old/New)
JFM	Cold vs. Neutral	.06/.02	.93/1.0
	Cold vs. Warm	-.05/.02	.97/1.0
	Warm vs. Neutral	.11/.00	.80/1.0
AMJ	Cold vs. Neutral	-.11/-.16	.87/.71
	Cold vs. Warm	-.30/-.33	.45/.38
	Warm vs. Neutral	-.19/-.18	.62/.72
JAS	Cold vs. Neutral	-.06/-.20	.95/.54
	Cold vs. Warm	-.25/-.04	.50/.98
	Warm vs. Neutral	.18/.15	.58/.74
OND	Cold vs. Neutral	.01/-.16	1 0/.86
	Cold vs. Warm	-.33/-.10	.53/.96
	Warm vs. Neutral	.34/.06	.53/.98

Table 33. Results of United States Hawaii ANOVA (p =.10)

Season	Phase	F (Old/New)	Significance (Old/New)
JFM	Cold vs. Other	.01/.01	.92/.92
	Warm vs. Other	.28/.00	.60/.97
AMJ	Cold vs. Other	.61/1.2	.44/.27
	Warm vs. Other	2.0/1.2	.17/.28
JAS	Cold vs. Other	.56/.78	.46/.38
	Warm vs. Other	1.5/.21	.23/.65
OND	Cold vs. Other	.43/.24	.52/.63
	Warm vs. Other	1.6/.00	.21/.98

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