Thesis for the Degree of Master of Fisheries Science

Relationship between climatic factors and distribution and abundance of skipjack tuna (*Katsuwonus pelamis)* and yellowfin tuna (*Thunnus albacares*) in the Western and Central Pacific Ocean

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중서부 태평양 가다랑어(*Katsuwonus pelamis)*와 황다랑어(*Thunnus albacares*) 의 분포 및 풍도와 기후요인과의 관계

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by

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ABSTRACT

Distribution and abundance of two commercial species skipjack (*Katsuwonus pelamis)* and yellowfin tuna (*Thunnus albacares)* are highly sensitive to environmental variances, in particular the rising sea surface temperatures and enhanced levels of CO_2 in the atmosphere. In order to ascertain a relationship between these factors, tuna catch data

were obtained from the Western & Central Pacific Fisheries Commission (WCPFC) during 1997 – 2007 to identify the relationship between the wild stock population of the two tuna species and environmental variability in particular Southern Oscillation Index (SOI), Pacific Decadal Oscillation (PDO), Aleutian Low Pressure Index (ALPI) and sea surface temperatures (SST). El Niño and La Niña events of 1997/1998 and 1998/1999 respectively were used, to evaluate the intensified climatic impacts on the fishery compared to that of a normal situation, which also leads to implications of ocean acidification and the prolonged changes over a period of time.

Evidently, climate indices SOI and ALPI were shown to be generally related and catch yields of both species were directly related to ocean temperatures, reaching 1.4 million MT, as opposed to 600,000 MT in unfavorable temperature ranges. Hence, an understanding of these causes and impacts is the key to better management and sustainability.

1. INTRODUCTION

1.1 Background

Species distribution and abundance are determined by their natural environment. Changes or variability of the environment are known to have a direct influence on the exploited fish stock populations. Each species has its optimal range of environmental condition and its tolerance limits, and any conditions outside this margin may cause tension, which can limit growth, reproduction or even threaten the survival of the population (Suarez-Sanchez, 2004).

The skipjack and yellowfin tuna species are geographically found within ranges of 40°N and 40°S; within sea water temperatures ranging from 18-31°C. Though the depth they reside varies according to life-stages, they are located mostly in surface layers of the ocean. However, they sometimes can reach 200 meters. Tuna are of the family Scombridae and quite unique to most other species of fish, such that they are fast swimming highly migratory fish species with the ability to maintain a body temperature significantly warmer than that of the ambient surrounding seawater temperature. Tuna are however not able to regulate their body temperature at a constant range. Lifespan is relatively short of a maximum 6-7 years, with a highly rapid growth rate at the early stages in life which gradually slows down with increasing development and age. In terms of reproductive maturity, both the males and females reach a length of approximately 2 meters which is around 2-3 years of age. They have a high fecundity with up to a million eggs per spawning episode, and are known to spawn all year round, within favorable water temperature conditions of around 24-25°C .

Tuna distribution and abundance have been shown to be sensitive to environmental variability. Tuna movement is linked to the horizontal displacement of SST isotherms and vertical changes in mixed layer depths that determine their surface habitat in particular. The El Niño Southern Oscillation (ENSO) appears to have important consequences both for spatial distributions and migrations of the tuna populations and for their level of recruitment and biomass (Suarez-Sanchez, 2004). Most notable is the sea surface temperature

(SST) which has been documented to have a direct influence on the stock status and level of catches within a given area.

Biological oceanographic processes in the surface currents and seawater properties such as seawater temperature and salinity play a vital role in determining the overall productivity of the tuna fishery. The ocean circulation and water movements are known to greatly affect biological activity by having an influence on the geographical distribution of fish species such as the tuna. For instance, within the Western and Central Pacific there is a unique system known as the cold tongue/warm pool area, such that an upwelling from the eastern Pacific generated by trade winds extends towards the western Pacific forming a zonal band referred to as the cold tongue, which is generally characterized by cold temperature and nutrient rich waters. On the other hand, the area west of approximately 160°E north of the equator is known to have the warmest (29°C) surface waters in all the world's oceans and is referred to as the "warm pool". Therefore the result of the meeting waters induces what is known as the convergence zone. Ocean-climate systems have been known to strongly influence tuna fisheries in the Western and Central Pacific Ocean (WCPO) at various spatio-temporal scales and in different ways (Bour *et al.,* 1981; Lehodey *et al.,* 2003).

Recently there have been speculations as to the impacts of ocean acidification upon tuna stock populations in terms of the different developmental stages within its life cycle. The rate of survival typically increases as fish develop and mature and the environmental processes which greatly affect recruitment of stocks act primarily upon early life history stages (Pepin, 1991). Generally it is expected within all species that only a subset of the total larval population can survive through to the stage of adulthood. Thus the consequences of an increased natural mortality rate may have a drastic effect on the adult population. Hence, enhanced temperature is expected to have a direct effect on the growth of fish (Thresher *et al.*, 2007). Aside from global warming effects on fish stocks, recently there have been speculations as to the impacts of ocean acidification upon fish populations. Especially, formation of calcium carbonate ($CaCO_3$) in fish tissue (i.e., bone, otolith, etc.) may be directly influenced by reduced pH condition in seawater. Otherwise, foodweb structure may be threatened by a decrease in zooplankton organisms which form exoskeleton with calcium carbonate.

1.2 Economic importance of tuna fishery for developing island nations

The tuna fishery is regarded as one of the most important natural resources in island nations of the Western and Central Pacific Ocean. This fishery supports the largest tuna fisheries in the World. In recent years an approximate 53% of the world's total tuna production was captured in that part of the ocean (ISSF, 2010).

The two main species captured within this region are the yellow fin and the skip jack tuna. Many Pacific Island countries depend on this fishery resource both as a source of income and food. Tuna fishery, for example in Papua New Guinea plays an important role to the economy in terms of the country's natural resources with a sizeable portion obtained from access and licenses fees to distant water fishing nations; and direct financial employment and other such benefits to the local communities. As tuna are a highly migratory species the management of this resource is generally undertaken regionally which may often causes improper management.

Economically, tuna fishery comprises a substantial amount of island nation's yearly revenue, which in many ways contributes to development and investments to many of these developing countries. In order to have a proper and efficient management of tuna populations in the Western and Central Pacific; the Western and Central Pacific Fisheries Commission (WCPFC) was established by the Convention for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean (WCPF Convention) which entered into force on 19 June 2004. It is comprised of Members and cooperating non-member countries include a majority of the following Pacific Island countries including Australia, EU, Japan , Korea, and the United States of America; Belize, Ecuador, El Salvador, Indonesia, Mexico, Senegal, Vietnam, Panama, Thailand and other participating territories, American Samoa, Commonwealth of the Northern

Mariana Islands, French Polynesia, Guam, New Caledonia, Tokelau, Wallis and Futuna.

1.3 Objectives

East-west movement of the warm pool and cold tongue in pelagic ecosystem is caused by ENSO episodes (Brained, 2007). Such that environmental data are very important to determine the location and effectiveness of purse seine fishery. The primary objective of this study was to identify the relationship between climatic factors in particular changing SSTs and the impacts on the state of the skipjack and yellow fin tuna productions. Especially, the catch locations of skipjack and yellowfin tuna were interpreted in relation to El Niño and La Niña events in 1997/1998 and 1998/1999.

2. METHODS AND DATA

2.1 Study site

The WCPFC statistical area is defined by the Western and Central Pacific Commission as follows (Fig. 1): from the south coast of Australia due south along the 141° meridian of east longitude to its intersection with the 55° parallel of south latitude; thence due east along the 55° parallel of south latitude to its intersection with the 150° meridian of east longitude; thence due south along the 150° meridian of east longitude to its intersection with the 60° parallel of south latitude; thence due east along the 60° parallel of south latitude to its intersection with the 130° meridian of west longitude; thence due north along the 130° meridian of west longitude to its intersection with the 4° parallel of south latitude; thence due west along the 4° parallel of south latitude to its 3 intersection with the 150° meridian of west longitude; thence due north along the 150° meridian of west longitude; and from the north coast of Australia due north along the 129° meridian of east longitude to its intersection with the 8° parallel of south latitude, thence due west along the 8° parallel of south latitude to the Indonesian archipelago; and from the Indonesian peninsula due east along the 2°30′ parallel of north latitude to the Malaysian peninsula (WCPFC, 2010).

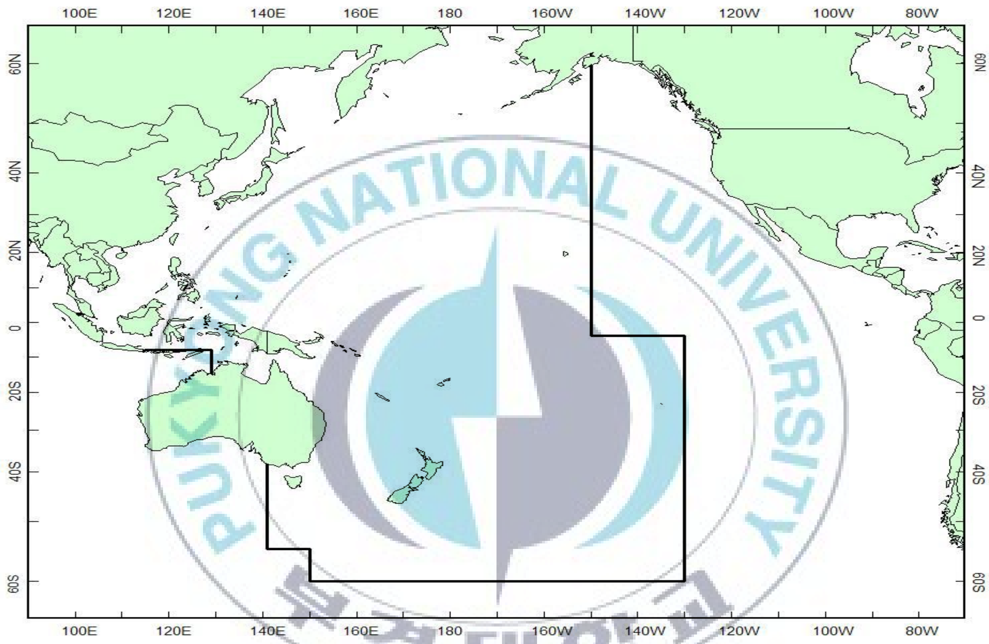


Fig. 1. Western and Central Pacific Fishery Commission statistical area in which the fishing and catches were carried out and recorded (WCPFC tuna yearbook 2010)

2.2 Data analysis

Both the yellowfin and skipjack tuna catch data and temperature data were obtained within the WCPFC statistical area within the Western and Central Pacific Ocean (Fig. 1). The purse seine fishery data from the Western and Central Pacific Ocean were collected and recorded in monthly-basis. The WCPFC has a compiled a public domain version of aggregated catch and effort data using operational, aggregate and annual catch estimates data provided by Commission Members (CCMs) and Cooperating Non-members (CNMs). The tuna catch aggregated data was compiled by the Western and Central Pacific Fisheries Commission (WCPFC), which were geo-referenced to 5-degree (longitude) x 5-degree (latitude). In addition the Southern Oscillation index (SOI) as an Index of ENSO was also collected over the same period.

The aggregated catch data used were spatially scattered and not evenly distributed; hence the annual Catch record was obtained through the "RAP requirements of the WCPFC, known as the "Rules and Procedures for the Protection, Access to, and Dissemination of Data Compiled by the

Commission" or whereby effort was calculated by means aggregated by year/month and 5°x5° grid. Annex 2 of the RAP indicates that public domain aggregated catch/effort data can be made available at a higher resolution (e.g. data with a breakdown by vessel nation, and aggregated by 1°x1° grids for surface fisheries)

The raw temperature data was utilized by means of a graphical illustration which identified the geographical locations of the catches, within the known El Niño and La Niña events of 1997 and 1999. Environmental data was recorded through monthly intervals, Sea surface temperature (SST) and the Nino 3.4 was obtained from (V2.2.4 by grid 0.5x0.5 degrees) over the period from January 1997- December 1999. Pearson's correlation was used to assess the annual averages of catches over January 1997- December 2007 in terms of climatic indices which included the following: the Aleutian Pressure index (ALPI), the Pacific Decadal Oscillation (PDO) and the Southern Oscillation Index (SOI) for a better representation.

3. RESULTS

3.1 Catch and distribution

The purse seine annual average catches of tuna in metric tons (MT) over a ten year period from 1997 to 2007 were fairly uniform with yellowfin tuna showing a steady yield of 200,000~250,000 MT (Fig. 2). However, the catch of skipjack tuna was approximately 600,000 in 1997, and stable at about 900,000 MT until the early 2000s. Skipjack tuna catch was continuously increasing and reached the historic highest, about 1.4 million MT in 2007. The catches were generally caught within the known fishing locations as a means to determine the effort put into the fishery.

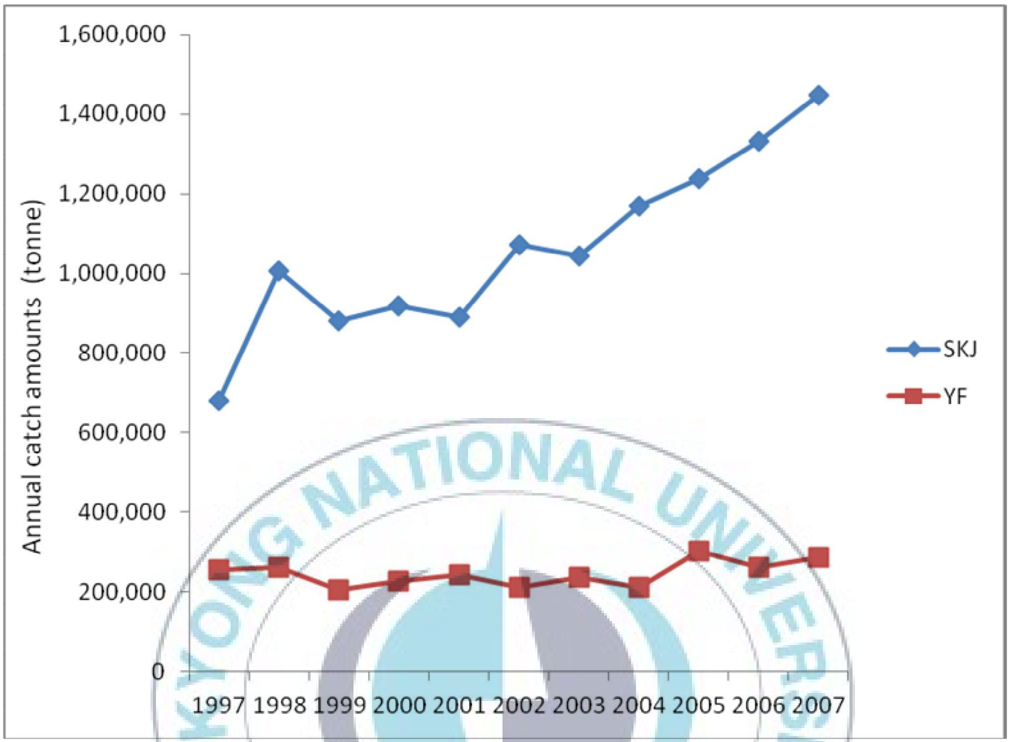
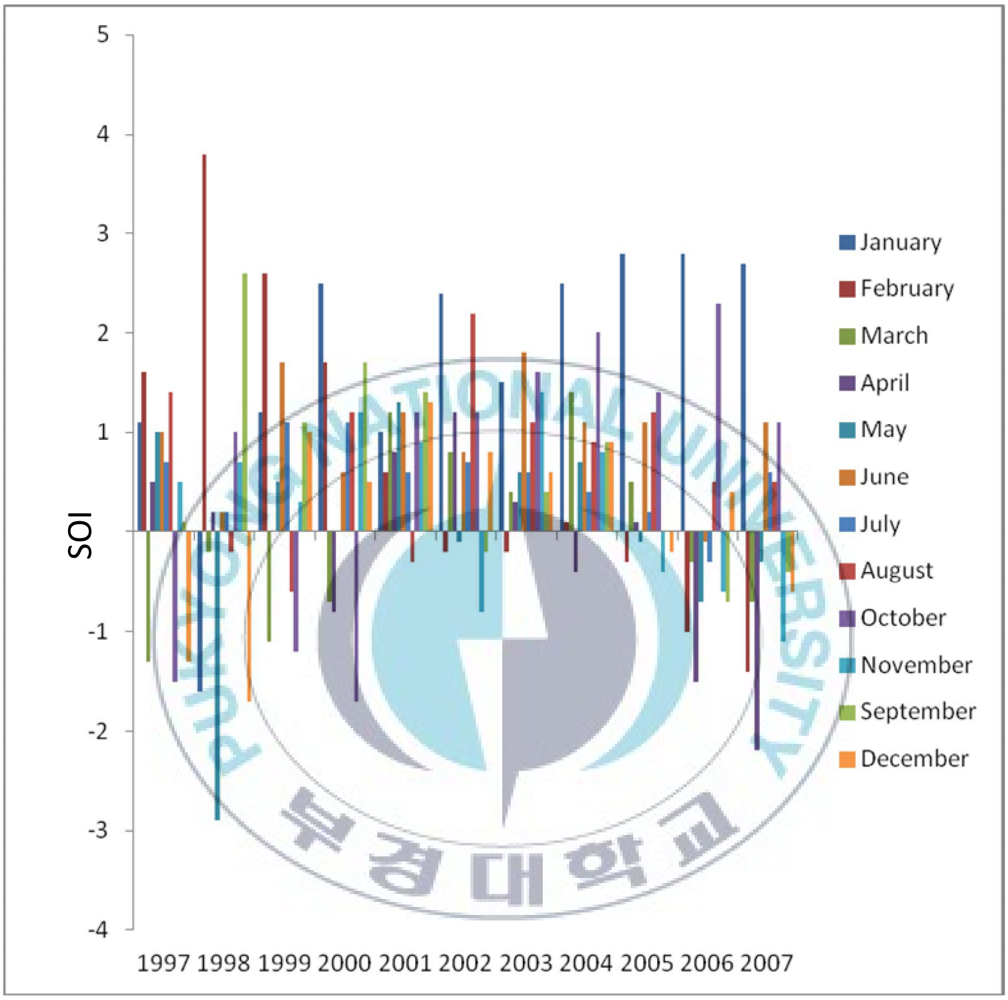


Fig. 2. Total Annual catch of skipjack (SKJ) and yellowfin (YF) tuna from 1997-2007

3. 2 Climatic indices

The El Niño- Southern Oscillation (ENSO) phenomenon is generally related to the major changes within the wind driven air pressures; which in turn influences the direction of the currents. The Southern Oscillation Index (SOI), which shows the El Niño when SOI is a negative value and La Niña when SOI is positive. The changes in SOI were shown in El Nino in 1997, and La Niña in 1999, respectively (Fig. 3a). Other climatic indices such as Pacific Decadal Oscillation (PDO) and the Aleutian Low Pressure Index (ALPI) which are generally co- related, with PDO representing a shifting phase on a decadal time scale influenced by ENSO; which is also significant to the variability's of ALPI. There was a strong shift from positive known to be warmer periods to negative or cooler, during 1997-1999 (Fig.3b). However, a relationship for PDO is best represented over greater locations and longer periods. Within the ten year period ALPI values (Fig. 3c) are shown to be strongly related to the monthly variations in the ENSO (Fig. 3a). In addition, there is also a significant shift from an intense period 1997/1998 to a very low period in 1999.

a)


SOI
5
4
3
2
1
-1
-2
-3
-4
1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
January
February
March
April
May
June
July
August
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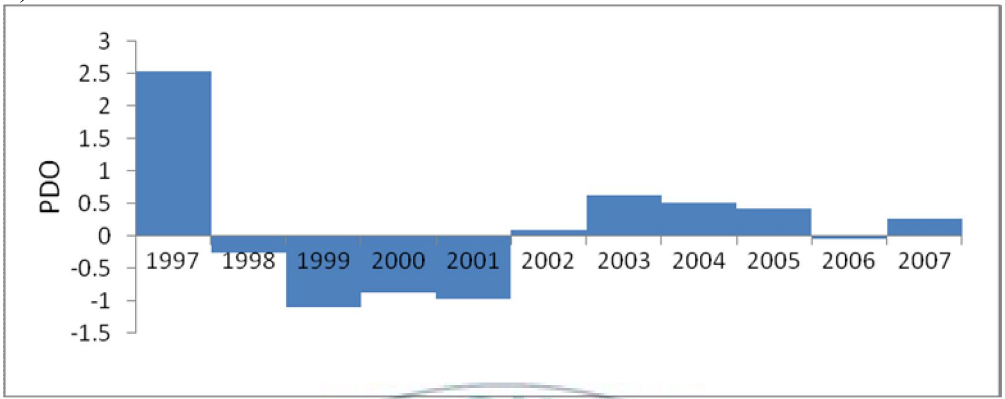
November
September
December

b)



c)

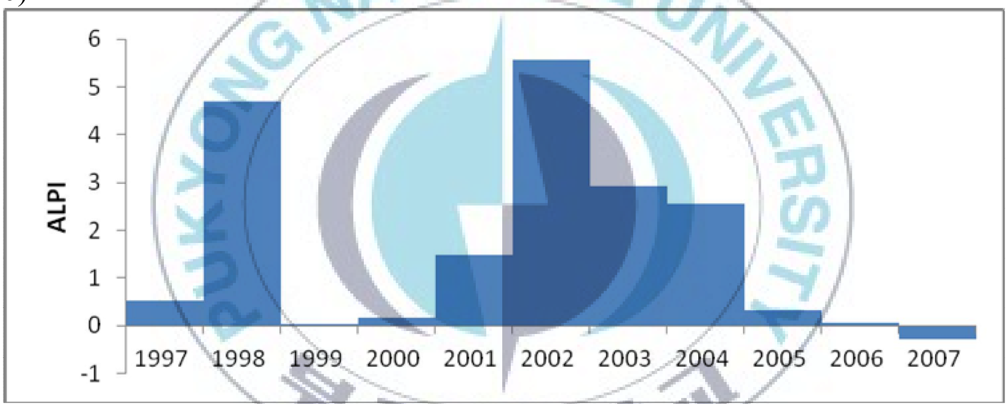


Fig. 3. Change in some environmental and climatic indices during the 1997-2007 period: (a) Southern Oscillation Index (SOI), (b) Pacific Decadal Oscillation (PDO) Index, and (c) Aleutian Low Pressure Index (ALPI).

3.3 The abundance and distribution of skipjack tuna catches

The distribution of the skipjack tuna catches (the average monthly catches) were spread over sea surface temperatures within fished locations during the El Niño period (Fig. 4). The skipjack tuna are shown to be sparsely distributed over a wider area, due to the boundary of warm pool (i.e., convergence zone) expanding toward the east. This particular zone is well documented as a higher biologically productive area whereby cooler water from the east "cold tongue" meets with the warm pool, and convergence zone is not clearly shown. Warm pool seems to extend towards the north.

In La Niña period, there is a very different pattern from that of the previous one shown (Fig. 5); with huge amounts of catches found within a specific area in the warm pool region. The convergence zone can be identified here as showing the exact boundary of the cold tongue and warm pool. This zone is a very biologically productive area.

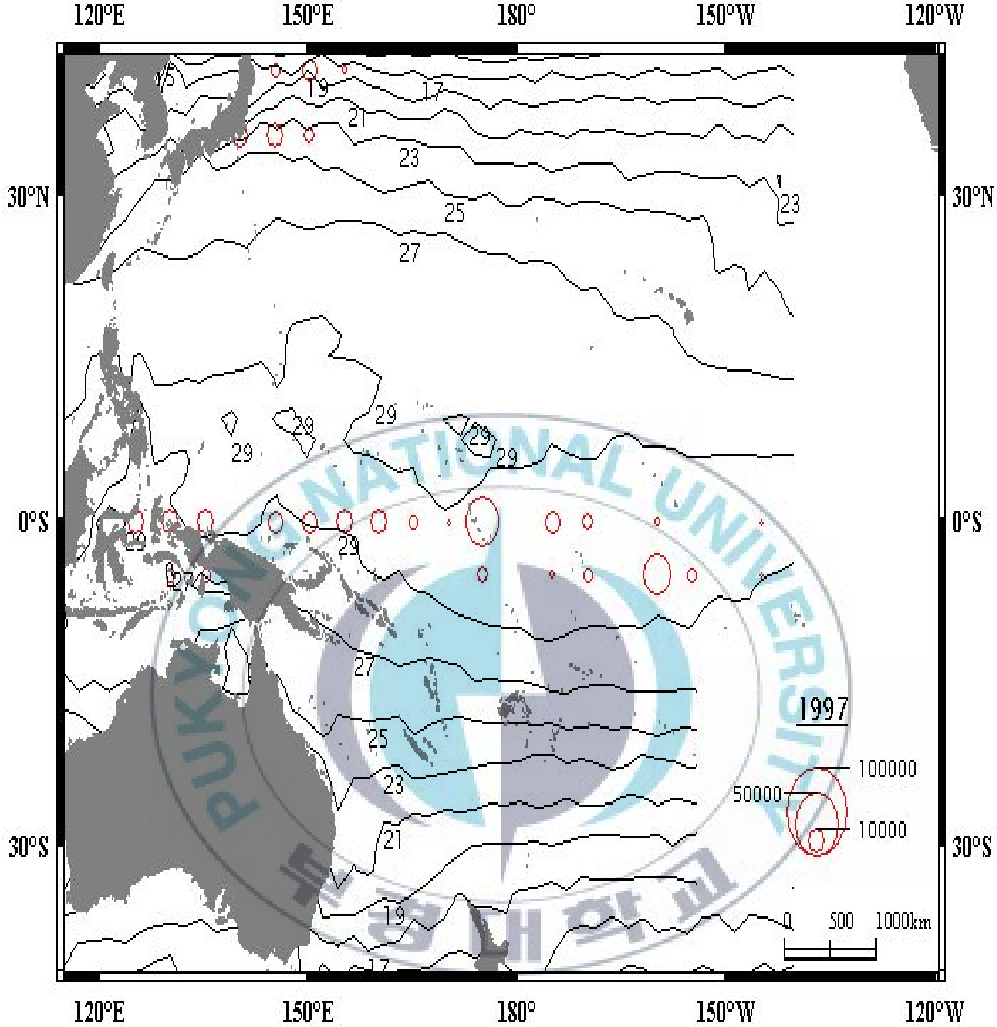


Fig. 4. The distribution and abundance of skipjack tuna in June-December 1997

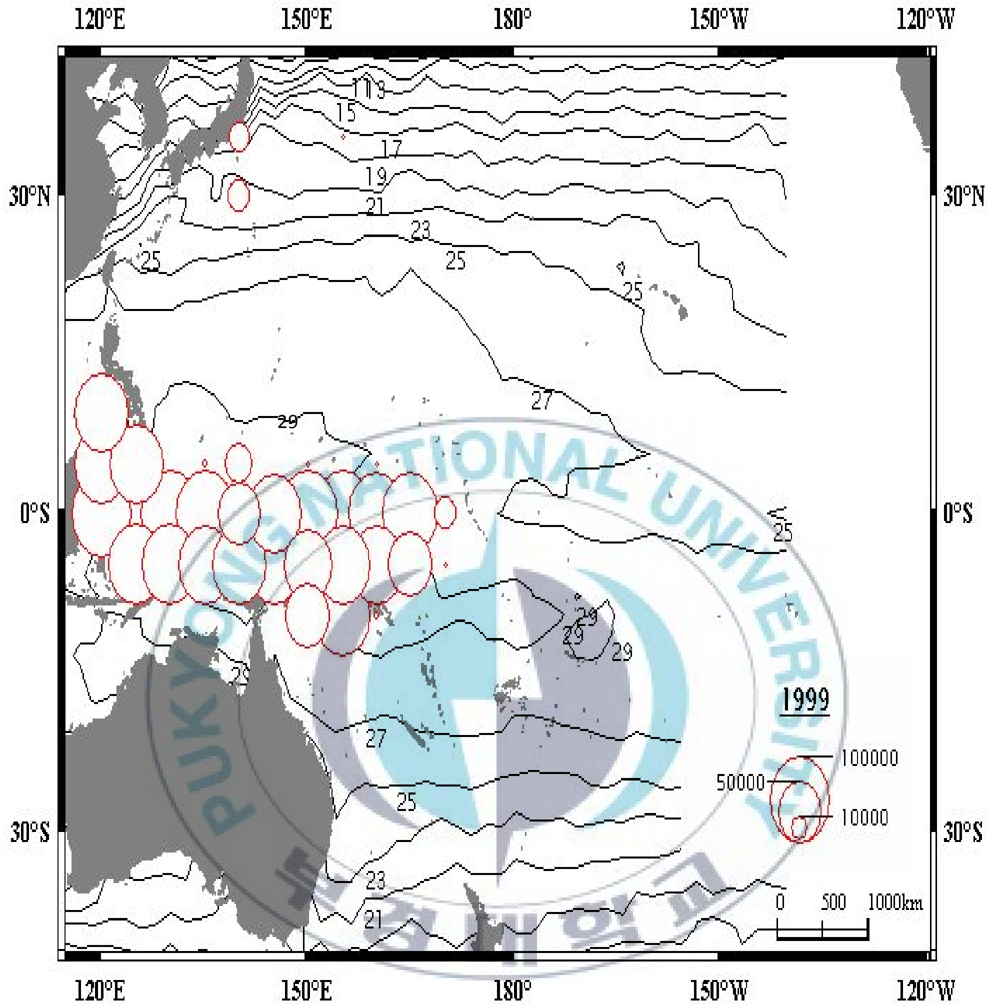


Fig. 5. The distribution and abundance of skipjack tuna in January-June 1999

3.4 The abundance and distribution of yellowfin tuna catches

For yellowfin tuna catch, a similar trend to that of the skipjack tuna was shown. The catches of yellowfin tuna were also scattered according to sea surface temperature to investigate the relationship between its distribution and environmental condition. In El Niño period, there appears to show a sparse amount of the annual averages as well as the distribution of the yellowfin catches over the second half of 1997 (Fig. 6). Although in terms of this particular species the above may not be a true representation of the population as unlike skipjack tuna, yellowfin tuna inhabit a slightly lower temperature range. In addition the convergence zone is not clearly defined; with a horizontal displacement of the 29° isotherm shifting towards the north. Catches are drawn out over a wider area similarly to the temperature ranges. However, the catches of yellowfin tuna in La Niña period are generally greater than the previous graph, indicating a similar trend to that which was observed of the skipjack tuna over the same period (Fig. 7). Therefore, indicating a greater abundance of the catches in an area with a well-defined temperature range.

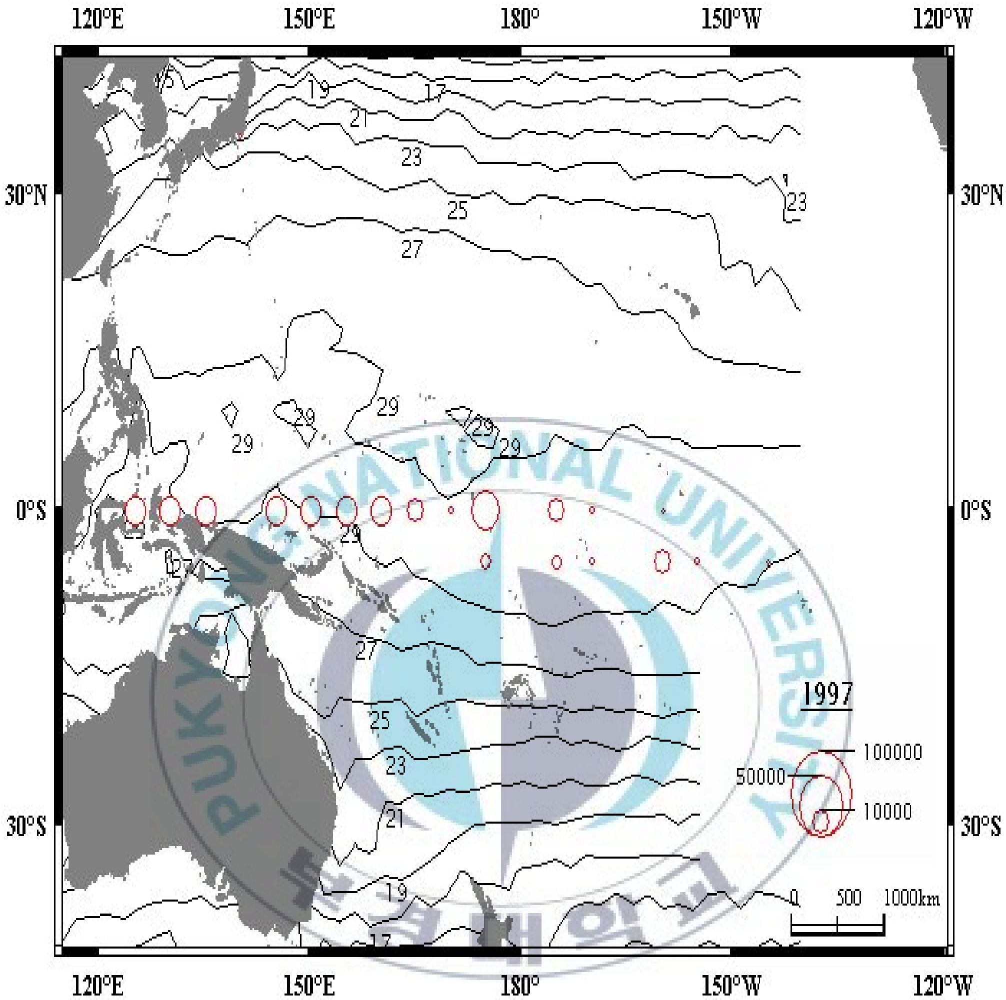


Fig. 6. The distribution and abundance of Yellowfin tuna in June-December 1997

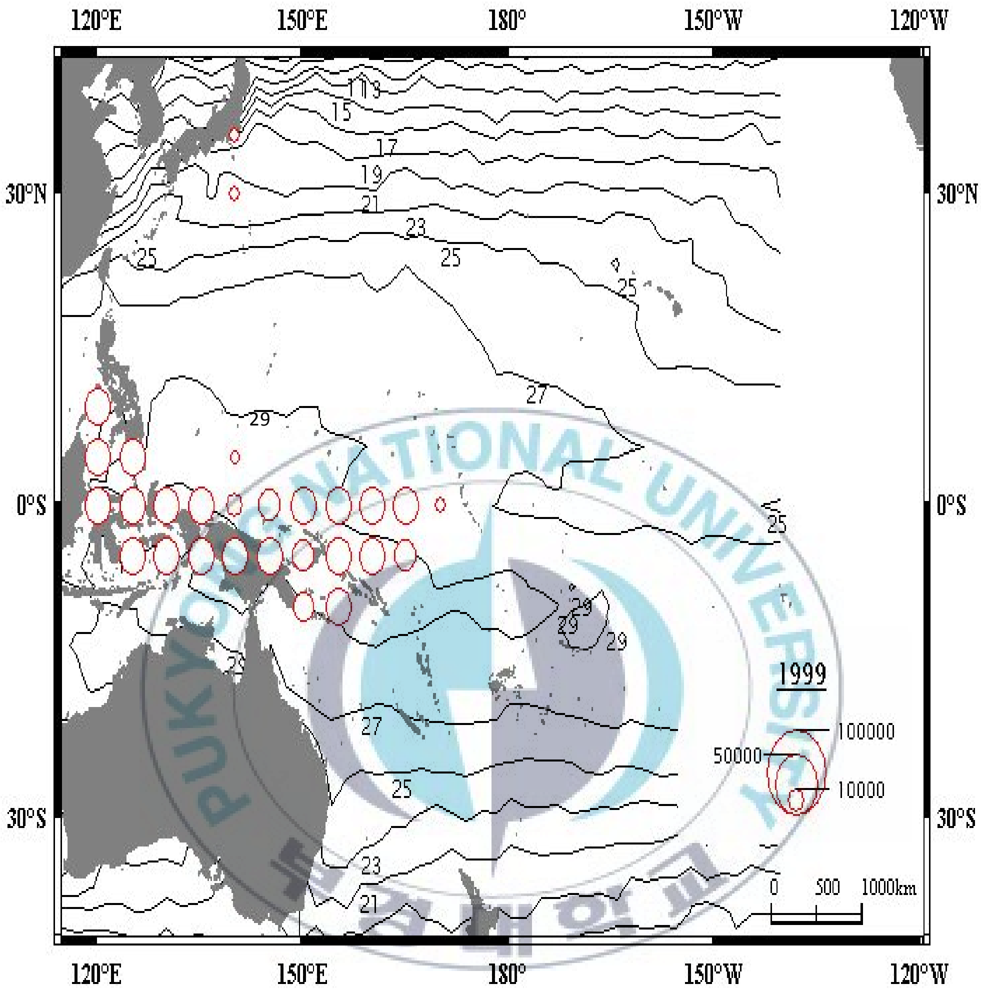


Fig. 7. The distribution and abundance of Yellowfin tuna in January-June 1999

3.5 Relationship between the climatic indices

Correlations of annual averages of catch and three given climatic indices were shown (Table1). The only significant relationship shown is that of the Southern Oscillation Index (SOI) and the Pacific Decadal Oscillation (PDO) as they both are directly related; hence there are no significant relationships at $p < 0.01$ shown between the yellowfin or skipjack tuna to all indices.

Table 1. Correlation coefficients between tuna catch and some climatic indices.

		Skipjack	Yellowfin	ALPI	PDO	SOI
Skipjack	Pearsons Correlation	1	.469	-113	-111	.052
	Sig (2-tailed)	0	1.46	.740	.744	.879
	N	11	11	11	11	11
Yellowfin	Pearsons Correlation	1	1	-3.59	.294 .	.456
	Sig (2-tailed)	0	0	.278	381	. 159
	N	11	11	11	11	11
ALPI	Pearsons Correlation	-.113	-3.59	1	.018	-.894 **
	Sig (2-tailed)	.740	.278	0	.957	0
	N	11	11	11	11	11
PDO	Pearsons Correlation	-.111	.294	.018	1	.431
	Sig (2-tailed)	.744	.381	.957	0	.185
	N	11	11	11	11	11
SOI	Pearsons Correlation	.052	.456	-.894 **	.431	1
	Sig (2-tailed)	.879	.159	0	.185	0
	N	11	11	11	11	11

*** Correlation is significant at the 0.01 level (2-tailed)*

4. DISCUSSSION

4.1 Tuna abundance and distribution

As was shown within the results there is a significant difference in the yearly averages of catches also within the two species. The factors affecting distribution and abundance are known to depend heavily on the natural environment, Tuna distribution and abundance mainly depends on two environmental factors: water temperature and food availability (Lehodey *et al*., 1997). As was shown from the results the greatest variability's observed were during years which had the greatest fluctuations.

Tuna are highly migratory species as such are known to swim greater distances foraging for available food source; which are totally dependent on suitable environmental and climatic factors. ENSO or El Niño- Southern Oscillation phenomenon is generally related to the major changes within the wind driven air pressures; which in turn influences the direction of the currents, the periods which show prolonged negative values are generally associated with

El Niño. Therefore it is vice-versa for positive values showing an extreme of the normal environmental conditions known as the La Niña period. SOI air pressure anomalies (Fig. 3) was used to show a clear indication of the extreme environmental conditions, thus the negative values were clearly associated with the El Niño phase but was shown to be opposite for positive value indicating a La Niña period.

The most drastic effects of environmental variability are observed within the El Niño and La Niña periods such that within an El Niño year; it is generally characterized by warmer surface water temperatures in the equatorial pacific, due to lack of strength in trade winds thus a significant decrease of upwelling, which leads to a decrease in the overall productivity. An El Niño event may significantly weaken ocean productivity off the west coast by limiting weather patterns that cause upwelling, or nutrient circulation in the ocean. These nutrients are the foundation of a vibrant marine food web and could negatively impact food sources for several types of birds, fish and marine mammals (Leo, 2009)

Hence, notably within the El Niño & La Niña events which were recorded as 1997 and 2007 respectfully; it shows that during El Niño events there is a drastic decrease for the skipjack tuna catches however there is an increase in the catches of yellowfin tuna. This can also be observed in the La Niña event of 2007 whereby there is an opposite effect with an increase in Skipjack tuna however a decrease in the yellowfin stocks caught. Moreover as was seen within the results pertaining the two respective events of 1997 and 1998 there is in fact a generally trend linking both to the abundance and distribution of skipjack and yellowfin tuna species.

The oceanographic characteristic which defines the correlation of tuna in terms of environmental variability is the "cold tongue" or the convergence zone whereby tuna; mostly skipjack tuna are found in great abundance; most probably due to an increased level of primary productivity. The largest proportion of the tuna catch (mainly skipjack) in the Pacific Ocean is taken within the warm pool area. Surface tuna fisheries, particularly purse-seine fisheries targeting skipjack, appear to respond to the seasonality of the warm pool (Brained, 2007).

Although it was shown from the results that there were no significant relationships between each of the tuna species and that of three separate climatic indices, this can be explained by the wider area in which temperature data was covered. However, this was not so for the catch data which was generally concentrated within the regions of 0° north and 160 °east. Hence, rising sea surface temperatures will always affect the atmospheric pressure with climatic indices such as the Aleutian Low Pressure Index (ALPI) and Southern Oscillation Index (SOI) shown to be correlated (Table 1); the location and intensity of ALPI is an indicator of climatic systems in the north Pacific (Overland *et al*., 1998). Furthermore, Pacific Decadal Oscillation (PDO) is known as the warming/cooling of surface waters 20°N in the Pacific Ocean and is influenced greatly by ENSO events that are primarily associated with predicting the onsets of changing conditions like the El Niño and La Niña events.

Nevertheless, clear indications on variations or relationships within each index can only be established over a wider location and a longer period of time.

Thus, the movement patterns of tuna may generally be linked to the sea surface temperature whereby the warmer waters are conducive for the spawning and growth however the nutrient rich waters are equally important; therefore both are needed to provide the most conducive environment for both skipjack and yellowfin tuna species populations.

4.2 Ocean Acidification

The impacts of ocean acidification on tuna populations especially those of the tropical areas such as the Western and Central Pacific have not been fully ascertained although according to (Kleiber *et al*., 1987) both physical and chemical conditions within the oceans determine the abundance of prey; hence the distances of "tuna foraging". It is generally the spatial and temporal variances within ocean waters leaning towards a slightly more alkaline state, and is defined as the change in ocean chemistry driven by the oceanic uptake of chemical inputs to the atmosphere, including carbon, nitrogen, and sulfur compounds (Guinotte and Fabry, 2008).

As such there are few known factors which contribute to the increased uptake or release of CO_2 within the surface waters which include atmospheric CO_2 concentrations, sea surface temperatures, and biological (primary) production. In terms of tuna production; the changes in the oceanic chemistry are such that it will inevitably have an influence on primary production and the developmental stages within the life cycle.

However the impacts of ocean acidification on calcified material such as the otolith (known to have a vital role in the development and growth of fish in terms of the hearing and balance within the water column) have not been fully investigated. Moreover studies carried out by (Chekley *et al*., 2009) showed that under elevated CO_2 habitats sea bass larvae were able to grow significantly larger otoliths. Thus indicating there may be a positive role of the rising CO_2 levels within the ocean.

Generally there has been little to no thorough attention paid to this particular area; although it has been widely recognized that rapid changes within the environment may lead to potential threats both to the terrestrial and marine habitats. This also affects the organisms, species biodiversity, food chains and inevitably many of the economically important fisheries which we are so dependent on. As has been increasingly recognized, climatic variations in particular rising sea surface temperature, may inevitably lead to those that are normally experienced during the extreme phenomenon for instance the El Niño period; the future uptake of atmospheric CO_2 will greatly reduce oceanic surface water pH by approximately 0.3-0.4 units by the year 2100 (Caldeira and Wickett, 2003).

Lastly this study revealed that the abundance and distribution of tuna are subject to the various changes within the environment. As was observed over a ten year period from 1997-2007 there were not so many drastic changes which occurred apart from the extreme circumstances as was shown by the El Niño event of 1997 and the La Niña of 1999. Arguably it maybe beyond some degree of control for fisheries scientist and managers however the relationship of climatic factors and ocean acidification are important to better manage and sustainably exploit these resources.

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