Spatial-Temporal Distribution Characteristics of Bigeye and Yellowfin Tunas in Kiribati Waters

Aketa Mature Taanga, Yi-Hui Cai, Hsueh-Jung Lu and I-Hsun Ni*

Department of Environmental Biology & Fisheries Science,
National Taiwan Ocean University, Taiwan, ROC (*niih@mail.ntou.edu.tw)

ABSTRACT Information on the distribution characteristics of tuna resources in Kiribati EEZ waters in three zones (Zone 1: west Gilbert region, Zone 2: central Phoenix region, and Zone 3: east Line region) as well as their relationship with the ocean environment is critical for sustainable managing the migratory tuna resource and fishing practices in this region. Therefore, this study is designed to investigate the spatial and temporal distribution and concentration of bigeye (BET) and yellowfin tuna (YFT) in Kiribati EEZ waters in relation to sea surface temperature (SST) and thermocline depth so as to better understand the tuna resources management basis in Kiribati waters. The geographic and temporal distribution and concentration were first displayed. Paired t-test was utilized to compare the distribution between the two tuna species based on Catch per Unit Effort (CPUE) derived from the Korean longliners during 1996 to 2004, and also among the three zones of Kiribati EEZ waters. Environmental conditions of the three zones were then compared and correlated with the CPUE of YFT and BET. In addition, the effect of ENSO phenomena on the environmental conditions and the distribution of YFT and BET within the three zones were also examined. The BET was relatively higher in the Zone 3 whereas YFT predominate in the Zone 1 and the Zone 2 due to oceanographic differences among the three zones and the ecological habitats of the two tuna species. It was suggested that *El Niño/Southern Oscillation* (ENSO) phenomena altered the oceanographic conditions of the three zones that in turn change the distribution of the two tuna species. During *El Niño,* the warm phase of ENSO, resulted in having more BET in all the three zones and the opposite observed during *La Niña* (cold phase) replacing by having relatively higher catch rate for YFT, particularly in the Zone 2. Although the results of the study are from short periods (1996 to 2004) in considering oceanographic anomality, these environmental variations should be considered into sustainable fisheries management of tuna fisheries in Kiribati EEZ waters.

KEY WORDS: Tuna Distribution, ENSO, Sea Surface Temperature, Thermocline.

INTRODUCTION

Kiribati is located in western central Pacific Ocean (Fig. 1a) with 33 islands and owns approximately 3.5 million km² Exclusive Economic Zone (EEZ) within a geographical location of 167°W-146°E and 8°N-14°S (Fig. 1b) in three zones: Zone 1- the Gilbert region in the west, Zone 2 - the Phoenix region in the centre, and Zone 3 - the Line Islands region in the east. Tuna is the most economically important fish species in Kiribati waters. Commercially fished in Kiribati waters are the four tuna species, skipjack tuna (*Katsuwonus pelamis*), albacores tuna (*Thunnus alalunga*), yellowfin tuna *(T. albacares)* and bigeye tuna *(T. obesus)*. The fishing licensing fees represent the highest incomes for the government and indeed responsible for subsidizing government budget. In 2001, licensing fees composed more than 50% of the major revenues of the Country.

In order to set up local tuna fishery in Kiribati to maximize the benefit from tuna resources, information on the distribution characteristics of tunas in Kiribati waters as well as their relationship with ocean environment is critical for managing migratory tuna resource and fishing practices in these regions. This study is, therefore, designed to investigate the spatial and temporal distribution and concentration of bigeye (BET) and yellowfin (YFT) tunas in Kiribati EEZ waters in relation to sea surface temperature and thermocline depth so as to better understand the tuna resources in Kiribati waters. BET and YFT have been focused in this study since they are the two most economically viable species. Not only that they attained higher prices in comparison with other tuna species in Japan Sashimi market (Hampton et al., 1998) but also they are the two major target species of longliners in Kiribati EEZ waters (Fig. 2).

The study only look at the distribution of BET and YFT in Kiribati EEZ waters in three regions since they are the major fishing ground of the two commercially tuna species. Being located at the Equator, all the marine environments of the three areas are strongly influenced by the major equatorial current system, particularly the westward-flowing South Equatorial Current and the eastward-flowing equatorial countercurrent. In addition, other environmental phenomenon like *El Niño/Southern Oscillation* (ENSO) also influences the environmental condition of these areas. The two phases of ENSO (*El Niño* and *La Niña*) and their strength are typically classified by an index. Indices that are commonly used to classify ENSO events include regional sea surface temperature indices such as Nino 3.4.

No studies have been done that look at the distribution of BET and YFT among the three EEZ. Therefore the main objective of this study was to investigate the characteristics of the spatial-temporal distribution of BET and YFT within Kiribati EEZ waters in relation to environmental factors:(a) To display the distribution and concentration of YFT and BET among the three zones; (b) To expose the sea surface temperature and thermocline depth among the three zones; (c) To investigate the relationship of YFT and BET in relation to environmental factors such as sea surface temperature and thermocline depth; (d) To examine the effect of ENSO on the environmental conditions of the three zones and distribution of the two tuna species (YFT and BET) in Kiribati waters; (e) To compare the effect of the ENSO's warm (*El Niño)* and cold (*La Niña*) phases on the distribution of YFT and BET in each of the three zones.

MATERIALS AND METHODS

Tuna catches and catch per unit effort (CPUE) among the three areas

The catch and effort data (1996-2004) for YFT and BET was provided by Secretariat of Pacific Community (SPC). The dataset was provided by Japanese, Korean, Taiwanese, Canadian, Vanuatu and Kiribati-flag offshore longline fleets (Fig. 2). The data are compiled by month into a 1° × 1° grid with catch in number of fish and effort (number of fish per hundred hooks). A monthly time series of a total production for both YFT and BET was plotted from 1996-2004 for an overview of the total production among the three zones.

This study chose only Korean dataset with the following reasons: (a) to avoid variation of catch rates among different fishing nations; (b) Korean catches composed almost 75% (Fig.3) of all the total tuna longline fisheries; (d) Korea is the only Nation that operates in all of the three Zones during 1996-2004; (e) Korean vessels catch are more uniformly in terms of Gross Registered Tonnage (over 300).

CPUE is often used as an index of fish stock abundance and will be most reliable when sampling units (fishing vessels) are as homogeneous in their characteristics and operating behavior. The CPUE in this study was calculated as $CPUE_{ij} = (N_{ij}/H_{ij}) \times 100$, where $CPUE_{ij}$: is the Index of abundance in month j at i^{th} area; N_{ij}: the number of Fish in month j at i^{th} area; H_{ij}: the number of hooks (effort) in month j at i^{th} area; i: the area with midpoint of 1° × 1° grid; and j: the month of the year. Therefore the CPUE is basically the number of fish caught per 100 hooks.

A paired t-test was used to compare the distribution of the two species (BET and YFT) among the three zones. This was made between the annual averages of CPUE of BET and YFT in every 1°×1° grid (with catch) comprising individual zones. Annual average of CPUE for both species are calculated for each zone and plotted for comparison among Zones.

Environmental Data

The SST in each $grid^{-1}$ $zone^{-1}$ was average for each year and displayed on a map using MapInfo Software. Additionally a monthly average time series of depth of themocline in the three zones was also plotted for comparison. A time-longitudinal (1996-2004, 168°E-146°W) plot along the equator (2°N-2°S) for Depth of 20°C isotherm (proxy for thermocline depth) and SST was uploaded from the Tropical Atmosphere Ocean project (TAO) data. This section plot (168°E-146°W, 2°N-2°S) was selected as it covered part of all the three zones (Kiribati EEZ). The image was used to display dramatic differences in the environmental condition among the three zones. Oceanic Nino Index (ONI) is a de-facto index for identifying *El Niño* (warm) and *La Niña* (cool) events in the Tropical Pacific Ocean. It is a 3 month running-mean of SST anomalies for the based period of 1971-2000 of Nino 3.4 region (5°N-5°S and 170°W-120°W) (Fig.6a). The threshold for ONI to define ENSO periods is displayed as *El Niño* - characterized by a positive ONI greater or equal to 0.5°C for a period of at least three consecutive seasons; *La Niña* - characterized by a negative ONI less or equal to 0.5°C. A monthly ONI from 1996-2004 was downloaded from NOAA National Weather Service Climate Prediction Center via the web site (http://www.cpc.noaa.gov/data/indices).

Inter-relationship between Oceanographic Data and Catch and Effort Data

The monthly average of CPUE in each zone was correlated with environmental factors such as SST and the depth of 20°C isotherm (proxy for thermocline depth). MapInfo Professional (version 6) software was used to overlay the differences in CPUE for BET and YFT for each of the grid with the change in depth of 20°C isotherm and SST during *El Niño* and *La Niña* periods for visual analysis within zones.

Correlation of SSTA of Nino 3.4 region with CPUE of BET and YFT: The SSTA of the area (168°E-146°W, 8°N-14°S) encompassing all the three zones was correlated with that of anomaly of Nino 3.4 region using a time series cross-correlation methods. This was done to compare the time difference for the onset of ENSO based on the ONI, in the tropical Pacific Ocean with that of Kiribati EEZ. In addition, correlation will indicate the reliability of ONI as an index of ENSO in the Kiribati area. For each zone, a time series cross-correlation between SSTA of Nino 3.4 region (base region of ONI) with the monthly average CPUE of BET and YFT was conducted using Statistica software. Monthly SSTA of Nino 3.4 region was correlated with the average monthly CPUE instead of ONI since ONI a 3 months running mean of SSTA of Nino 3.4 region and have different temporal resolution to the monthly CPUE.

Comparison between El Niño and La Niña within zones: After defining the *El Niño* and *La Niña* periods, CPUE of BET in each individual 1°× 1° grid were averaged for *El Niño* periods and *La Niña* periods. The grids which have CPUE of BET during both *El Niño* and *La Niña* periods are used in a paired t-test to find the difference in the catch rate between *El Niño* and *La Niña* periods within each zone. A similar approach was done for comparison of CPUE of YFT during *El Niño* and *La Niña* periods. Additionally depth of 20°C isotherm and SST are also compared between *El Niño* and *La Niña* (proxy of thermocline depth) using identical approaches done for comparison of catch rate.

RESULT AND DISCUSSION

Distribution of bigeye and yellowfin tunas among zones

The total production in numbers of both YFT and BET were different among the three zones (Figure 4). The total monthly production in Zone 1 ranged from 0-15,000 fishes, from 1,000-24,000 fishes in Zone 2 and the highest was observed in Zone 3 (3,000-40,000). In addition the production in each zone fluctuates during 1996 to 2004 without declining trend. The difference in the total production for YFT and BET among the three zones might signify the dissimilarity in distribution and concentration of the two tuna species among zones. The paired t-test comparison of the average CPUE of BET and YFT from 1996-2004 was significantly difference. It showed that BET is abundant in a colder Zone 3 while YFT was more abundant in warmer Zone 1 and Zone 2. The trends in the annual average CPUE of these tuna species (BET and YFT) among the three zones (Fig. 5) evidently suggested a gradual increase of average CPUE of BET from Zone 1 to Zone 3. In comparison with BET, CPUE of YFT gradually increased in the opposite direction. In summary, the BET was mostly abundant in Zone 3, whereas YFT was more abundant in Zone 1 and 2.

Inter-relationship of Environmental Factors and Tunas Concentration

We observed significant differences of the environmental conditions in the three zones. For example Zone 1 and Zone 2 were relatively warmer compared to Zone 3 (Fig. 5). SST differed among the three zones, with a steadily increasing from east to west. Hence, Zone 3 had much lower SST in comparison with the other two western regions. The minimum SST of Zone 3 could be as low as 25°C whereas 26 °C for Zone 2 and 27°C for Zone 3. However, the warm water covered the surface of all the three zones during 1997-1998.

Inter-relationship of BET and YFT with Depth of 20°C Isotherm: The average depth of thermocline in Zone 3 ranged from 95-155m that was always shallower in comparison with Zone 1 and Zone 2. In contrast, the average thermocline depths in Zone 1 and Zone 2 were much deeper, ranging from 140-185m. Alternatively, the depth of the thermocline among the three zones could also explain the dissimilarity in the distributions of YFT and BET among the three zones. The thermocline depth was observed to be shallower in Zone 3 compared to Zone 1 and Zone 2. The depth of thermocline was negatively correlated to the catch rate of BET. Hence when the thermocline became shallow, the catch rate of BET increased in Zone 1 and Zone 2. High abundant of YFT in warmer regions were in Zone 1 and Zone 2 whereas BET dominated in a colder Zone 3 (Fig. 5). In summary, the result of monthly correlation between CPUE of BET with the depth of the thermocline was significant in all three zones but they were negatively correlated.

Correlation of SSTA of Nino 3.4 region with CPUE (BET and YFT): The use of ONI, defined two major El Niño and La Niña periods existed within the study periods i.e. 1996-2004. The SST anomalies of the study area were significantly and highly correlated with that of the Nino 3.4 region. Correlation coefficient indicated that the SSTA of the two regions were positively correlated. The significant correlation between CPUE of both BET and YFT tunas with SSTA of Nino 3.4 region in all of the three zones indicated that the catch rate of BET and YFT were both highly affected by ENSO period but displayed different responding time. Catch-rate of BET seemed to response more quickly to the effect of ENSO compared to YFT.

Comparison of CPUE and Environmental condition between El Niño and La Niña within Zones: There were two El Niño and three La Niña events fall within the study periods. Only the two major El Niño and La Niña periods were used for the comparison. An obvious significantly increase in CPUE of BET occurred during *El Niño* compared to that of *La Niña* periods, within each of the three zones. There were no significantly difference in CPUE of YFT between *El Niño* and *La Niña* periods in Zone 1 and Zone 3.

SST of the three zones increased during *El Niño* but decreased during *La Niña* periods. The difference was significant in all of the three zones. Moreover the BET CPUE seemed to be high when SST increased in all the three zones and low when SST decreased.

As for the depth of 20°C Isotherm, the difference was significant in Zone 1 and 3. In Zone 1, thermocline depth was observed to rise (shallower) in most grids during *El Niño* compared to that of *La Niña* periods. In Zone 2, the result of the paired t-test indicated an insignificant difference in the depth of the thermocline among the grids composing this zone between *El Niño* and *La Niña* periods. Conversely the thermocline depth in the grids in Zone 3 was significantly different between *El Niño* and *La Niña* periods. It was observed that the depth of the thermocline became shallower in Zone 3 during *La Niña* while it deeper during *El Niño*.

CONCLUSION

1. Yellowfin and bigeye tunas were the two major target species of distant longliner fleets operating in Kiribati EEZ waters that had been divided with three zones: Zone 1 - west Gilbert region, Zone 2 - central Phoenix region, and Zone 3 - east Line region.

2. Korea was the major foreign Country to harvest tuna from all three zones in Kiribati waters with longliners. Korean's catch composed nearly 75% of all the total tuna catches in Kiribati waters.
3. The geographical and temporal distributions of bigeye and yellowfin tunas as well as environmental conditions were different among the three zones during 1996-2004.
4. Zone 3 was relatively colder in comparison with Zone 1 and Zone 2. Thermocline depth, based on the Depth of the 20°C Isotherm, was relatively shallower in Zone 3 compared to Zone 2 and Zone 1.
5. Bigeye tuna was abundant in the eastern Line region, as speculated that prefered colder water and deeper waters, and therefore, they were more abundant in east region having relatively shallower 20°C isotherm in comparison with central and west regions.
6. Yellowfin tuna was relatively abundant in Zone 1 and Zone 2 as suggested this fish species preferred relatively warmer and shallower waters.
7. The catch rate of BET tuna increased directly with the increase in SSTA of Nino 3.4 region in Zone 3, two month time lagged in Zone 2 and three month later in Zone 1.
8. The catch rate for yellowfin tuna took longer time responding to the increase in SSTA of Nino 3.4 region in all three zones.
9. During *El Niño* periods, warm phase of ENSO resulted in having more abundant bigeye tuna in all the three zones of Kiribati EEZ waters and the opposite observed for *La Niña* (cold phase). Alternately *La Niña* periods would increase the abundant of yellowfin tuna, especially in Zone 2.

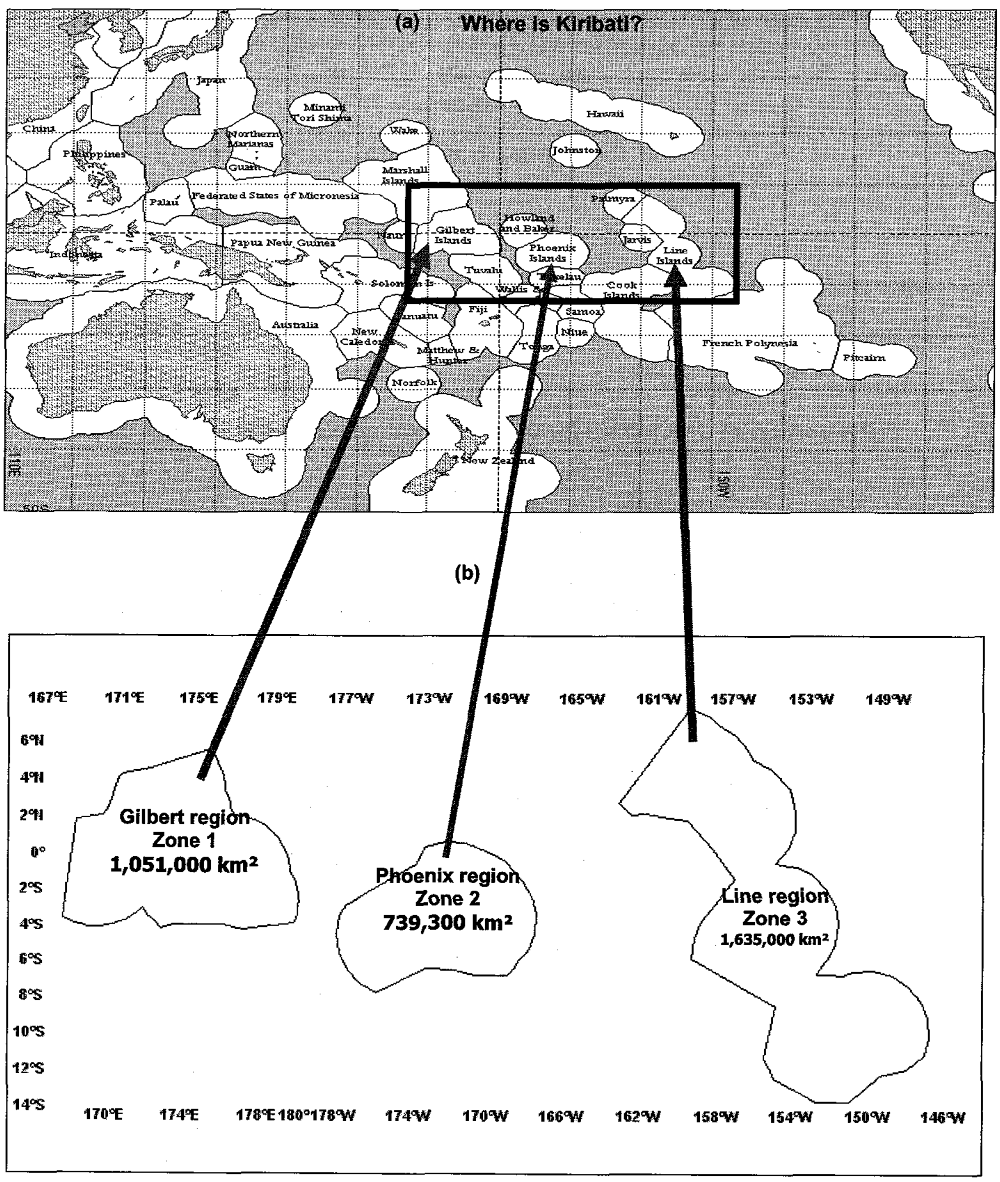

Figure 1. (a) Kiribati EEZ with other Pacific Countries in the Western Central Pacific Ocean; (b) Kiribati EEZ is divided into west Gilbert, central Phoenix and east Line regions.

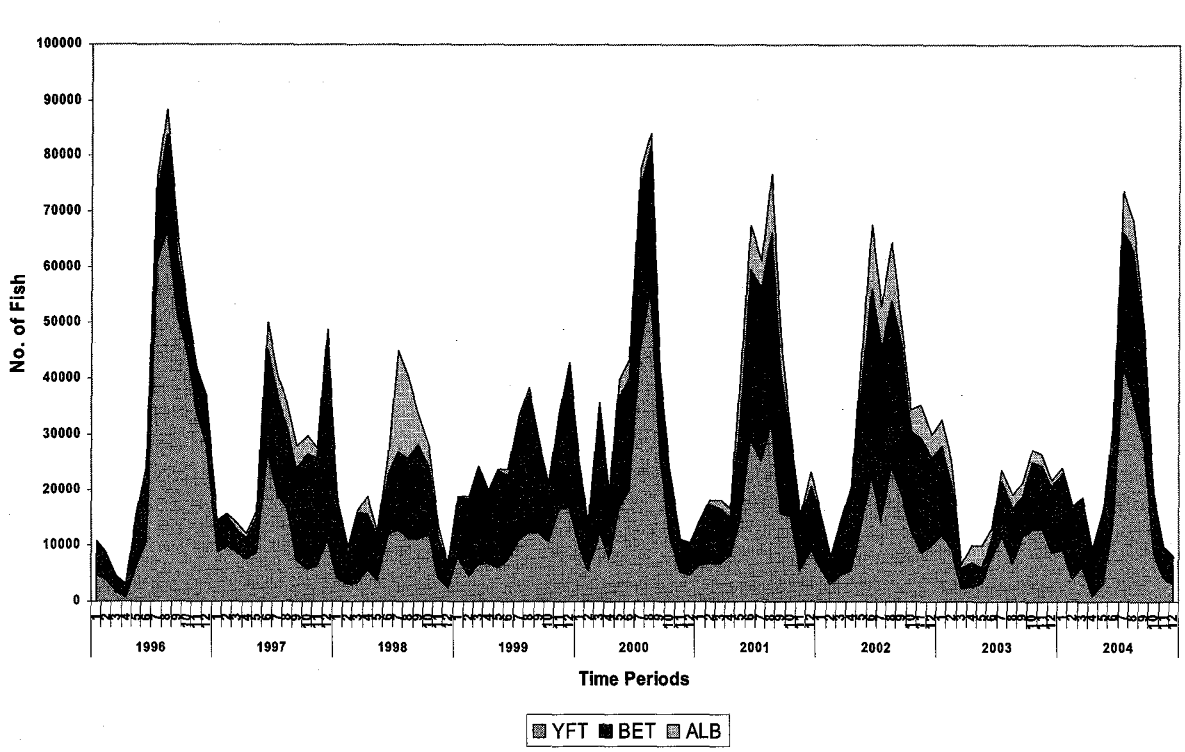

Fig. 2 Time-series of the total catch (No. of fish) of the tuna longliner in Kiribati waters during 1996-2004. Both yellowfin (YFT) and bigeye (BET) tunas dominated the longlining catches, including albacore (ALB).

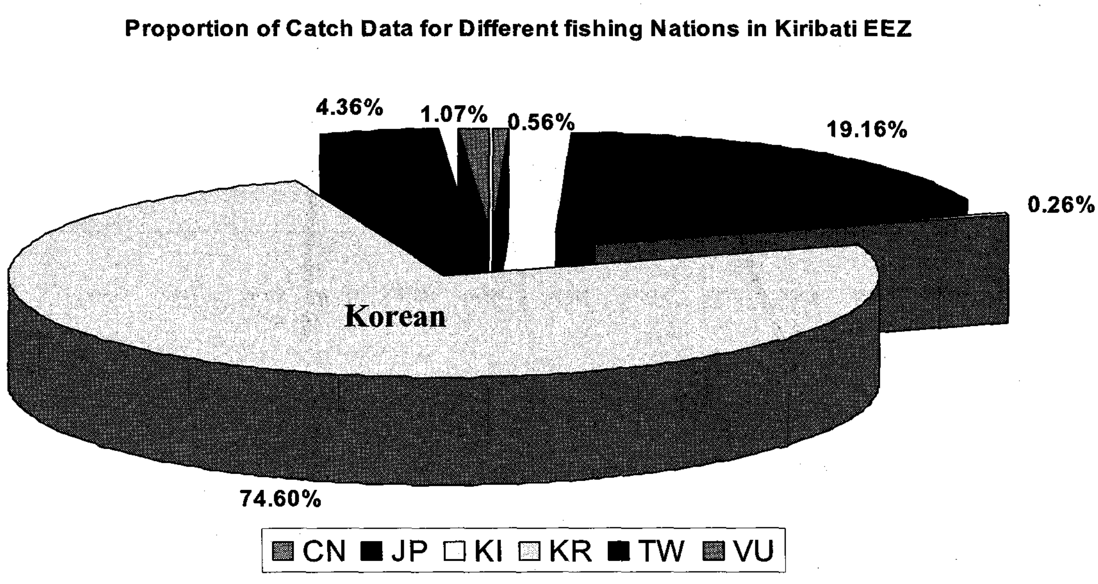

Fig. 3 The proportion of catches for different nations that fish in Kiribati EEZ waters, Korea composed 74% of all the data set. Additionally, Korean has the most complete dataset in terms of spatial coverage among three regions (CN: China, JP: Japanese, KR: Korean, TW: Taiwanese, VU: Vanuatu, and KI: Kiribati).

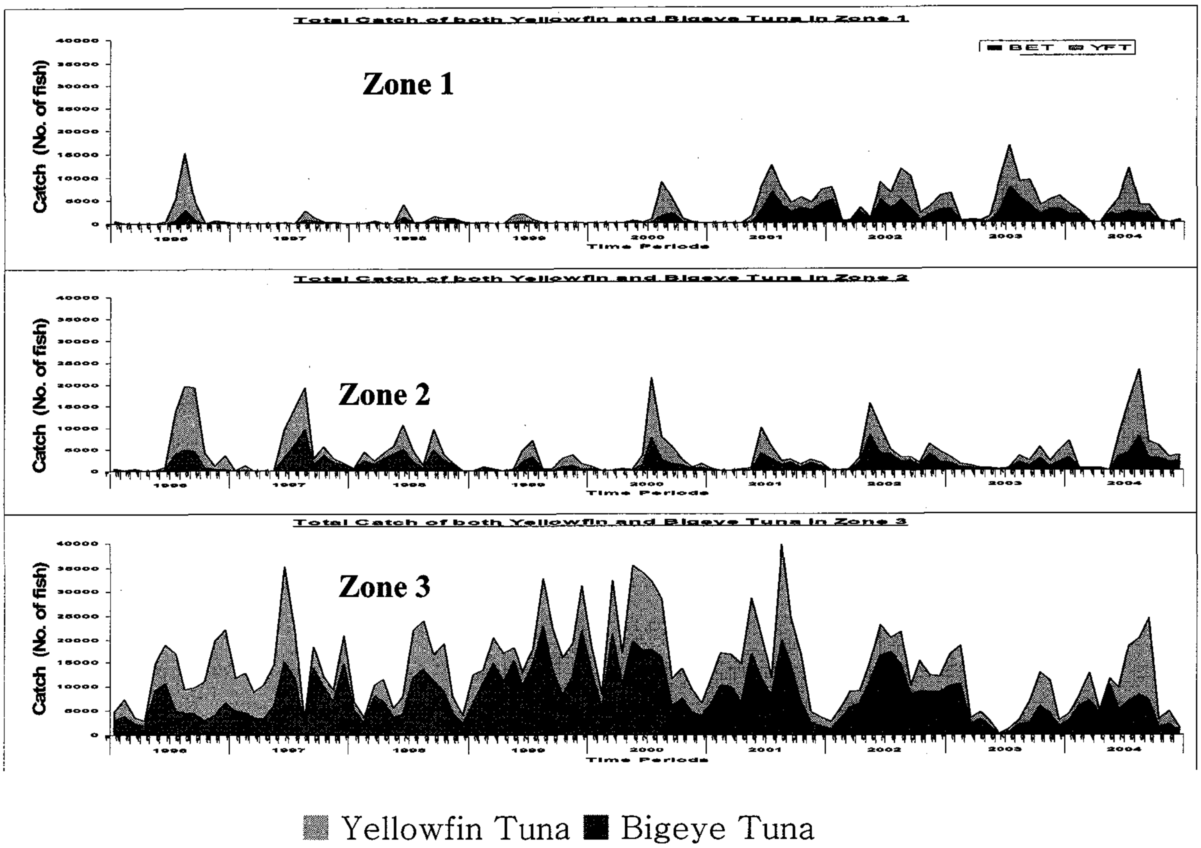

Fig. 4 The time-series of bigeye and yellowfin tuna catches (no. of fish) by Korean longliners in Zone 1, Zone 2, and Zone 3.

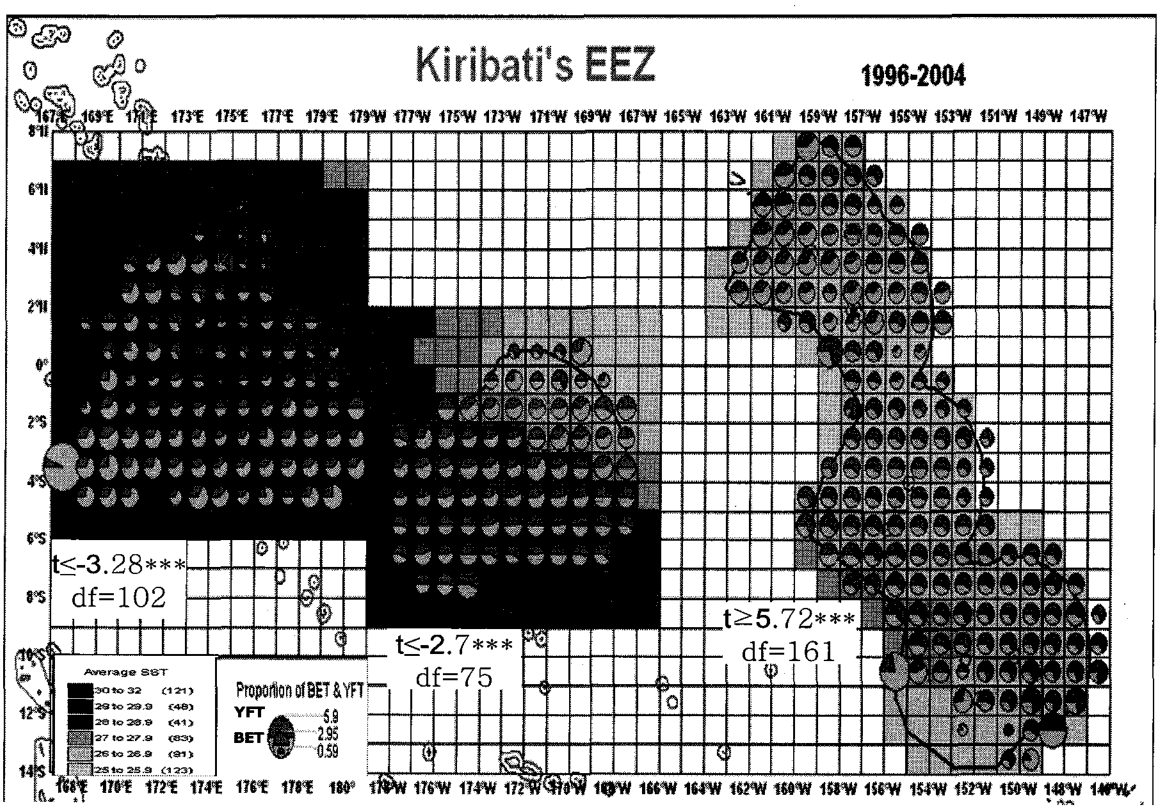

Fig. 5 The average sea surface temperature and CPUE of Yellowfin and Bigeye Tunas of the 3 zones from 1996-2004.