Did ecological anomalies cause 1993 and 2003-2004 high catches of yellowfin tuna (*thunnus albacares*) in the western Indian Ocean?

and

- review of other possible causes (strong recruitments, high catchbilities and excess fishing efforts) -

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Abstract

We primarily investigated ecological anomalies if they caused 1993 and 2003-2004 high catches of yellowfin tuna in the Arabian Sea and the western part of the tropical western Indian Ocean respectively. We also reviewed other possible causes (strong recruitments, high catchbilities and excess fishing efforts). We then integrated results & knowledge and discussed possible causes synthetically. As a result, it was likely that two high YFT catch events were caused by combinations of these factors by different weightings.

CONTENTS

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1. Introduction

In 1993*, there occurred the abnormal high catch of yellowfin tuna (*Thunnus albacares*) (YFT) by the Taiwanese longliners (LL) in the Arabian Sea and made a record high annual catch (88,000t) (Figs. 1 & 2(a)). According to the Taiwanese industry in Kaoshiung, there are three possibilities on the causes of this high catch (based on the personal communications): (a) excess fishing efforts: very few LL vessels had been fishing in that area before 1993 and many Taiwan LL vessels suddenly began to enter that area when some vessels found unusual high catch rate during their experimental fishing, which was considered to be major cause of the high catch, (b) abnormal environmental conditions; in 1993 high surface sea temperature were observed, which might relate to the high catch, and (c) strong cohort: there were favorable environmental conditions for spawners such as strong upwelling in the spawning areas near Oman for a few years before 1993, which might produced consecutive strong cohorts and related to the high catches from 1993-96, especially in the waters off Oman and Pakistan. In 1994, however, their total catch decreased to 34,000t (39% of the 1993 catch). After 1997, YFT catch decreased probably due to the diminish of these consecutive strong cohorts or decrease of the local YFT stocks, then, many Taiwanese LL vessels left there.

However in 10 years later, during 2003-2004*, high catches of YFT were recorded again, for this time, by both purse seine fisheries (PS) and LL in the western tropical waters of the Indian Ocean (Figs. 1 & 2(b)) different location from the 1993 high catch incident. Such high catches (450-500,000 t) easily exceeded more than 1.5 times of the estimated MSY level (around 300,000 t). Hence concerns on YFT fisheries managements have been rapidly growing recently after the second high catches were reported (IOTC, 2004). Thus, it is essential to elucidate the causes of such events in order to provide practical and effective advices in conducting proper managements incorporating such high catch.

In general, we consider that there are four possible causes for such events and they might be integrated and intermingled by different levels, i.e., (a) ecological anomalies, (b) strong recruitments (cohort), (c) increase of catchabilities of fishing vessels & gears and (d) increase of fishing efforts. In this paper, we mainly investigate if (a) ecological anomalies cause high YFT. As a first step we conduct qualitative analyses using thematic maps on various ecological parameters. Qualitative justification by statistical analyses plan to be conducted in the future. We also discuss on (b) strong recruitments (cohorts), (c) increase of catchabilities of fishing vessels and gears and (d) increase of fishing efforts by reviewing papers and information in the past.

Note (*) High YFT catch in 1993 started in the later period of 1992 and for the high catch in 2003-2004, it started from the later period of 2002 and continued to 2005. Thus we also considered these extra years in our study,

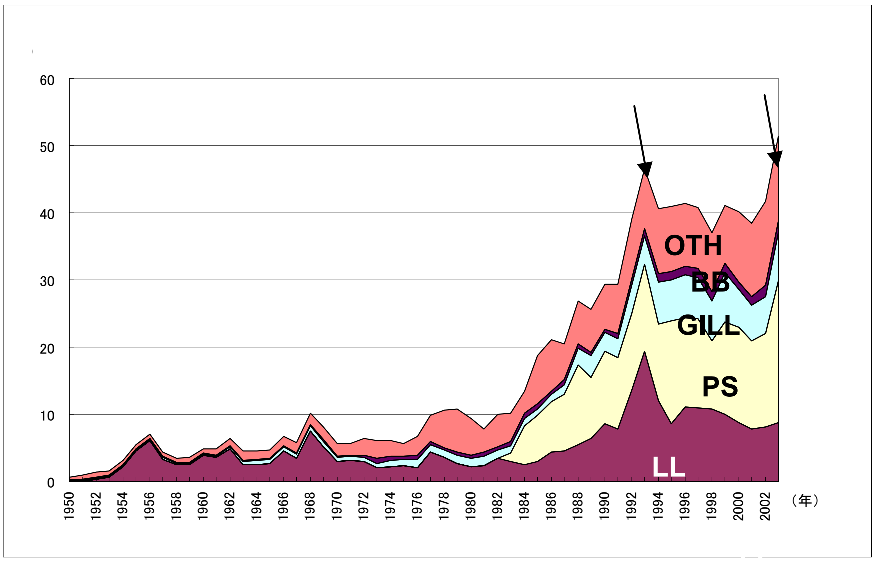
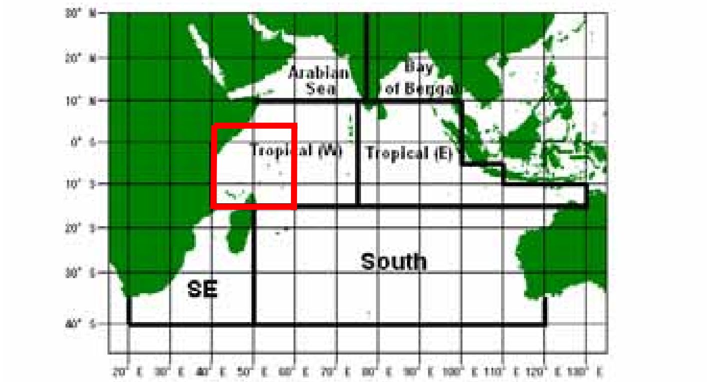
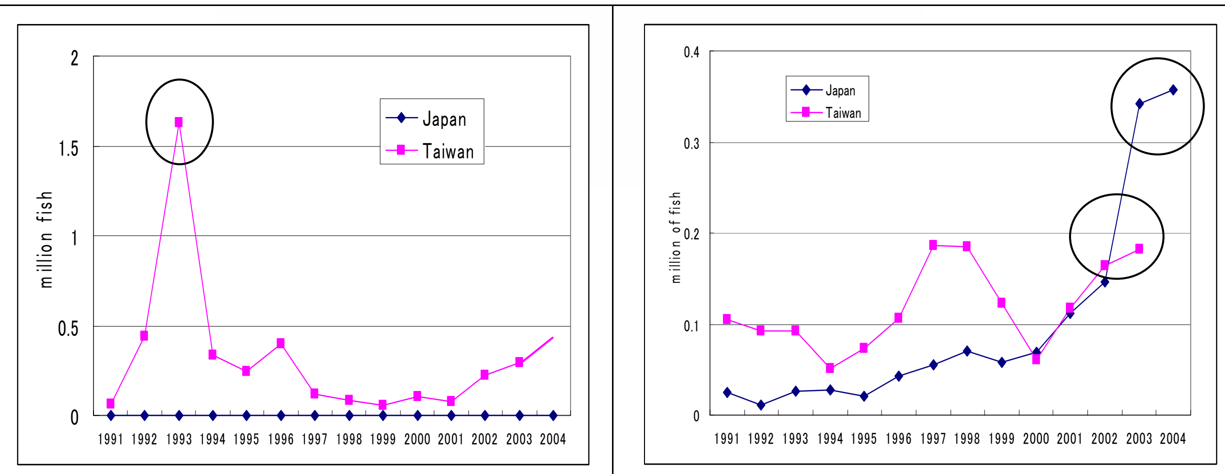


Fig. 1 YFT catch by gear type in the Indian Ocean (10,000 t)

Note : BB: bait & boat (pole & line) fisheries, GILL: gillnet fisheries





(a) Arabian Sea**	(b) western part of the western tropical Indian Ocean (Red squared area: 40°E-60°E x 15°S-5°N)

Fig. 2 Nominal YFT catch (million of fish) for Japan and Taiwan LL*

Note(*) : High catch in 1993 in the Arabian Sea by Taiwan LL and in 2003-2004 in the western part of tropical western Indian Ocean by Japan LL & Taiwan LL are circled. Taiwan LL catch in 2002-2003 were not too high comparing to the catch of Japan.

Note(**): Based on the weekly report from Taiwanese tuna industry, the estimate of 2004 catch in the Arabian Sea was about 0.45 million fish. A preliminary comparison of the first quarter catch between 2004 and 2005 suggested that the catch in 2005 is about 5 times of that in 2004. However, the fishing season of 2004 was late from normal, i.e., the peak catch happened in the second quarter rather than in the first quarter. In spite of this, the 2005 catch is expected to be much higher than in 2004, indicating a new increasing catch trend since 2002 in the region.

2. Data preparation

2.1 Period investigated

We analyze catch and environmental data for 14 years from 1991-2004 because the catch levels in this period are more or less constant in higher level (more than 350,000 t) except high catch years in 1993 and 2003-2004 while before 1990, the catch level is not constant, but it shows the sharp increasing trend from almost 0 to 300,000 t in 1952-90 (Fig. 1). In addition we don't have to worry about the environmental regime-shift as long as we use the data in the shorter period (14 years), which will provide us intrinsic (genuine) ecological anomalies objectively in this period that we attempt to analyze. Therefore it is considered that environmental anomalies on high catches can be effectively examined if we use such period.

2.2 Catch

We use tuna longline fisheries (LL) catches (Japan and Taiwan) (5x5 area/month based data) and purse seine (PS) catches (France and Spain combined) (1x1 area/month based data) for 14 years (1991-2004).

2.3 Marine ecological data

We use 9 different marine ecological data, i.e., (1) sea surface temperature (SST), (2) vertical (average) sea temperature(VST) (60-200m), (3) heat storage (HS), (4) thermocline depth (TD), (5) wind (easterly component & its force), (6) wind (northerly component & its force), (7) precipitation, (8) primarily productions and (9) prey(feed) for YFT. Detail descriptions on these data and procedures for data processing & compilations are provided as follows:

(1) SST, (2) VST, (3) HS and (4) TD (based on the JEDAC data)

We obtained global monthly mean gridded temperature data at 0, 20, 40, 60, 80, 120, 160, 200, 240, 300 and 400m from the Joint Environmental Data Analysis Center (JEDAC; http://jedac.ucsd.edu). The SST was calculated using the JEDAC data at 0m.

These data are integrated vertically between 60 and 200m at each position by interpolating data vertically with the third order polynomial functions of depth by Akima's spline method at first. Depths between 60-200m are used as they are the YFT swimming (habitat) depths. We then calculated the vertically integrated sea temperature (VST) by evaluating the finite integral of these polynomial functions analytically and substituting the depth range to the resultant fourth order polynomial functions. Here, we chose the Akima's spline method because this method is known to suppress artificial wiggles more than other types of spline interpolations. To obtain realistic vertical sea temperature profiles near the upper and the lower boundaries of our computational range, we used data both at depths shallower than 60m and deeper than 200m. We computed vertically averaged temperature between 60 and 200m by simply dividing these vertically integrated temperature by the distance between the upper and the lower boundaries, 140m. The heat storage between 60 and 200m is computed by multiplying these vertically integrated temperature data by constant density and specific heat (Auad et. al., 1998).

The grid spacing of original data is 5-degree in longitude and 2.5-degree in latitude. We calculated horizontal average of 5-degree longitudinal and 5-degree latitudinal blocks. We took a consideration that the metric distance between two points separated by a fixed longitudinal distance reduces with the increase of latitude by giving a weight proportional to a cosine of latitude. This procedure is roughly equivalent that we approximated our 5x5-degree block as a trapezoid and calculated vertical averaged temperature at its center of gravity.

We also obtained the monthly mean thermocline depth (TD) from JEDAC, i.e., the depth at 20^{o}C (Wyrtki, 1971; Peter and Mizuno, 2000) in each 5x5-degree blocks in the same manner as above except that we skipped the vertical integration.

(5)-(6) Wind (easterly & northerly component & forces) (based on NCEP/NCAR)

http://www.cdc.noaa.gov/cdc/data.ncep.reanalysis.derived.html

The wind data were National Centers for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) reanalysis data obtained from Climate Diagnostics Center, National Oceanic and Atmospheric Administration (NOAA/CDC) U.S.A. Those that we used are monthly mean surface data covering entire globe with 2.5-degree spatial interval both in latitude and in longitude. We calculated mean wind speed of 5x5-degree blocks in the same manner as described before.

(7) Precipitation (NOAA/CDC) *http://www.ncdc.noaa.gov/oa/climate/research/ghcn/ghcngrid_prcp.html*

Precipitation data are used to investigate how the large rainfalls around the Indus River limit the YFT distribution off the waters in the Indus River (the north-eastern Arabian Sea). This is because such large rainfalls lower the salinity and oxygen levels which further limit (block) YFT distribution as often observed in the Bay of Bengal (Ishizuka, 1990; Mohri & Nishida, 1999).

The blended monthly mean global precipitation data, consisting of satellite observations and NCEP /NCAR reanalysis, are obtained from NOAA/CDC. This data set is gridded with spatial interval of

2.5 degrees both in latitude and in longitude with no missing data. We applied the same method described above to obtain horizontal average of 5x5 degree blocks.

(8) Primarily production

The monthly mean primarily production data were provided by the courtesy of Dr. Kameda (National Research Institute of Far Seas Fisheries), who estimated primarily production from the satellite observed ocean color (Kameda and Ishizaka, 2005). These data are global coverage with 4,096 points in longitude and 2,048 points in latitude. We calculated horizontal mean primarily production of 5x5-degree blocks in the same manner as described before.

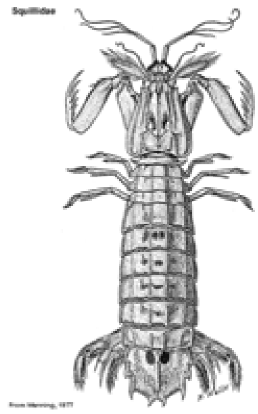
(9) Prey

There are no specific numerical data on the prey (feed) information for YFT as there are no long-term, continuous and systematic samplings (data) and analyses for the YFT stomach contents except the on-going one such as THETIS project by IRD, France. In general YFT usually feed small pelagic, crustaceans and cephalopods. For this study, we have only partial information based on the personal communications and Fonteneau *et al* (2004) as follows.

According to Mr. Warashina, a veteran tuna scientist (Yaizu tuna fishing port branch, National Research Institute of Far Seas Fisheries), LL fishers observed abnormal amount of *Portunus trituberculatus* (Miers) or swimming crab (common English name) (Plate 1) in YFT stomachs in the tropical western Indian Ocean around 40-50E and 10S-5N during the high YFT catch period in 2003-2004 and its high catch has been continued to 2005. Similar event was also observed in the waters off Western Australia (off Fremantle) for southern bluefin tuna which caused its high catch in the past.

In these cases, extra ordinary amount of swimming crabs were spawn above the sea mounts probably due to the favorable ecological conditions such as highly bloomed zoo & photo planktons due to high primary products probably caused by the unexpected local upwelling. The unexpected local upwelling may be caused by the abnormal winds. In these events, LL fishers said that thousands of swimming crabs were observed (and attached to) even in the side & bottoms of the LL boat itself and gears (lines, buoys etc). Vertical distribution of the swimming crab ranges from the surface sea to 100m depth depending on the environmental conditions, which is a part of the vertical distribution of YFT.

Another similar event in the same area and the same period was reported by Fonteneau *et al* (2004). In this case it was *Natosquilla* (Plate 2), which was also confirmed by Ms Nancy Gitonga, Director, Fisheries Department, Kenya).

	
Plate 1 *Portunus trituberculatus (*Miers*)* (swimming crab) *http://tortuga-web.com/reeflections/gallery/photopages/mauireef/hawaiianswimcrab.html*	Plate 2 *Natosquilla* *http://www.crustacea.net/crustace/stomatopoda/www/squilli.htm*

2.4 Socio ecological data

Socio ecological data in our study means noises caused by movements (traffic) of battleships and sorties from these ships during the Gulf (1992), Afghanistan (2002) and Iraq (2003) Wars. Japanese LL fishers claimed that such noises likely shifted medium size YFT schools in the Arabian Sea to the southern waters (tropical western Indian Ocean, high YFT catch area) during the Iraq war (2003). This is because they could not observed YFT schools in the southern part of the Arabian Sea, their YFT fishing grounds before and after the Iraq War and more YFT schools could be exploited in tropical western Indian Ocean and they considered that the cause of this incident was by the traffic noises by many battleships move back & forth in the entire Arabian Sea.

There have been several reports that noises affect tuna movements and distributions, e.g., Ikeda (1986), Yamada (1994), Nishida & Tanio (2001) and others, in addition to personal communications with Mr. Warashina (tuna scientist, NRIFSF, Shizuoka, Japan), Mr. Kato (acoustic engineer, Oki Electric Industry Co., Ltd., Shizuoka, Japan) and Mr. Fukuchi (acoustic marine ranch expert, System Engineering Inc., Kanagawa, Japan).

Under such circumstances, we collected both qualitative and quantitative information relating to such noises in the Persian Gulf and the Arabian Sea from 1990 to 2004 to examine if they affect YFT distribution and further affect high YFT catch. There have been four big events attract attention as a cause influencing the calmness of the Arabian Sea from 1990 to 2004. First, around August in 1990 with the invasion of Iran to Kuwait, US and other coalition's warships, submarines and other supporting ships had been deployed and the total number of ships was more than 180. After that, with the start of the Gulf war on January 17 in 1991, there was a second peak of the number of the ships.

Some sporadic strikes were seen in 1993 and 1996. The latter peak was after the attack of September 11 in 2001, the U.S.A had started the anti-terrorist operation. The United States deployed Navy and Marine Corps to the Arabian Sea. Then it leads to the strikes against Afghanistan on October 7 in 2001. After that the attention had gradually moved towards Iran. At last on March 20 in 2003, the military campaign had started and it was the last peak of the number of vessels in the Gulf.

We checked the number of aircraft carriers, destroyers, frigates, submarines, support ships, other vessels, the number of cruise missiles and the number of sorties in these incidents. Then we tried to show the noise numerically. However, the biggest problem was all the numbers were top secret and not open to the public. Therefore we had to take a plenty of time for collecting and picking up articles from the Newspapers and data through internet from abroad. Especially, unlike the situation from 1990 to 1991, after 2001, we found most of the detailed information was written ‘not specified’, ‘confidential’ or ‘not written’ at all. Therefore the data gathering needed more arduous effort. Therefore, there are some differences of number. Although the data were not fully collected, we think that it is appropriate to use this data as minimum levels to understand the rough situation. Table 1 shows the summary.

Table 1 Summary of noises caused by battleships during the Gulf, Afghanistan and Iraq Wars (1990-2004) in terms of number of battleships deployed and sorties.

	type of noise	traffic noises	noises from battleships		
Year	waters affected by noises=>	Persian Gulf and the whole Arabian Sea	Persian Gulf and inshore waters in the northern Arabian Sea		
	possibilities to affect YFT distributions	traffic noises likely affect YFT distributions in the Arabia Sea	such noises unlikely affect to YFT distribution due to the inshore waters where there are less YFT schools		
	Event	Number of battleships deployed	Number of Sortie (bombers)	number of cruise missile fired from battleships	Precision Guided Munitions fired by battleships
1990	invasion to Kuwait by Iraq (build-up for the Gulf war)	181	0	0	0
1991	Gulf war	130	116,000	282	5,750
1992		?	0	0	0
1993	air strike (Iraq)	10	?	30	80
1994		0	0	0	0
1995		0	0	0	0
1996	air strike (Iraq)	?	?	44	?
1997		?	0	0	0
1998		?	0	0	0
1999		0	0	0	0
2000		0	0	0	0
2001		50	4,177	88	?
2002	air strike (Afghanistan)	?	0	0	0
2003	Iraq war	105	37,000	750	23,000
2004		30	0	0	0

Note (1): These figure are considered to be the minimum level (see the text for the reason).
Note (2): Battleships imply aircraft carriers, destroyers, frigates, submarines, support ships, mother boats or any relevant vessels relating to these Wars.
Note (3): From 1990 to 1991 and from 2001 to 2004, a great number of vessels had been deployed around the Arabian Sea using ‘Diego Garcia’ as a military base.
Note (4): Source - Asahi daily shinbun (newspaper), National Defense Academy of Japan and internets (http://www.IISS,org and http://www.Global Security.org)

2.5 Summary

Table 2 summarizes the information used in this study and Table 3 shows available periods.

Table 2 Summary of the data used in this study.

Type	Category	Specification	Unit	Sources
YFT catch data	Japan LL	5^ox5^o area based data	number	Database (National Research Institute of Far Seas Fisheries, Japan)
	Taiwan LL	5^ox5^o area based data	number	Database (Fisheries Agency, Council of Agriculture, Taipei, Taiwan)
	PS (Spain & France)	1^ox1^o area based	ton	IOTC database
Marine ecological data	sea temperature	SST	^{o}C	JEDAC *(http:// jedac.ucsd.edu)*
		VST (Vertical average sea temperature) (60-200m) (2^ox5^o area based)		
	MDL (mixed layer depth)		m	
	HS (heat storage)	60-400m	Joule	
	surface wind	easterly wind & force component (5^ox5^o area based)	m/s	NCEP (*http://www.cdc.noaa.gov/cdc/data.ncep.reanalysis.derived.html)*
		northerly wind & force component (5^ox5^o area based)	m/s	
	PP (primary product)	2048x4096 pixels for the glove	mgC/(day*m^2) C: carbon	Dr Kameda (NRIFSF) based on ocean color data (satellites)
	precipitations	Around the Indus River (2.5x2.5 area based)	mm/day	NCEP *(http://www.ncdc.noaa.gov/oa/climate/research/ghcn/ghcngrid_prcp.html)*
	prey (feed)	*(Qualitative information)*		Personal communications and Fonteneau *et al* (2004)
Socio ecological data	noises	number of battleships and sorties during the Gulf, the Afghan and the Iraq wars	number	News media, internets and National Defense Academy of Japan

Table 3 Available period of the data (marked zones)

Class	Type	91	92	93	94	95	96	97	98	99	01	02	03	04
Fisheries (catch) data	LL(Japan)	■	■	■	■	■	■	■	■	■	■	■	■	■
	LL(Taiwan)	■	■	■	■	■	■	■	■	■	■	■	■	
	PS	■	■	■	■	■	■	■	■	■	■	■	■	
Natural environmental data	SST	■	■	■	■	■	■	■	■	■	■	■	■	
	VST	■	■	■	■	■	■	■	■	■	■	■	■	
	MDL: mixzed	■	■	■	■	■	■	■	■	■	■	■	■	
	HS: heat storage	■	■	■	■	■	■	■	■	■	■	■	■	
	Surface wind	■	■	■	■	■	■	■	■	■	■	■	■	■
	PP						■	■	■	■	■	■		
	Precipitations	■	■	■	■	■	■	■	■	■	■	■	■	■
Socio ecological data	Noises	■	■	■	■	■	■	■	■	■	■	■	■	■

3. Methods and results

In this study we attempt qualitative analyses as a first step by creating thematic maps by Marine Explorer version 4.2 (*http://www.esl.co.jp/index.htm*) (Marine GIS software). Two types of thematic maps are made, i.e., (a) high catch and (b) ecological anomalies. Then, all the thematic maps are displayed on one sheet in order to search spatial correlations between high catch and ecological anomalies. All thematic maps are created by standardized GIS base maps for effective and consistent comparisons and searches. When we search such correlations, we also pay attention on the time lag effects. For the future we plan to conduct the statistical analyses based on the results for this time.

3.1 Thematic mapping for high catch [thematic maps (1)-(3) in Map 1]

Top 5% and 5-10% of the annual YFT catch in all 5x5(or 1x1) grid areas where at least one YFT was exploited in 14 years (1991-2004) are depicted by red and pink respectively. Then for the rest of non-0 YFT catch they are depicted in grey color. This drawing process is applied for each LL (Japan, Taiwan) and PS (Spain & France combined) catch data. In this way, we can easily identify the locations of the high YFT catch areas in 14 years.

3.2 Thematic mapping for ecological anomalies

(1) Marine ecological data [thematic maps (4)-(11) in Map 1]

For the parameters of the ecological anomalies except prey (feed) information, we compute annual anomalies in each 5x5(or 2.5x2.5) area in 14 years (1991-2004). Anomalies are defined by the differences between the grand mean value for 14 years and the annual mean value for each parameter in each 5x5(or 2.5x2.5) area Then, top 25% and next 25-50% are defined as high and low positive anomalies which are colored by read & pink respectively. Similarly, bottom 25% and next 25-50% are defined as high and low negative anomalies then colored by dark & light blue respectively. For the prey information, we depict the high concentrated areas by hand according to the information of Fonteneau *et al* (1994) and also personal communications with Warashina (NRIFSF) and Ms Gitonga (Kenya),

(2) Socio ecological information [thematic map (12) in Map 1]

In similar way as for the prey information we map two types of noise levels by hand according to the information we collected, i.e., red represent the high noise waters due to the deployments of the many battleships and many sorties by missiles and bombers, while pink for the waters with less noises caused by the frequent traffics of the battleships and mother ships.

3.3 Integrated analyses

In order to search spatial correlations between high catch areas and waters with ecological abnormalities we display all the thematic maps for high catch & ecological anomalies by time series in two panels (Map 1a&b). In Map 1 we focus on maps during 1992*-93 (high YFT catch in Arabian Sea by Taiwan LL) and also for 2002*-2004 (high YFT catch in the tropical western Indian Ocean by LL (Japan and Taiwan) and PS. In these maps, we made circles for the high catch zones and also for the corresponding waters with high anomalies consistently appeared in each period. We did not make circles for anomalies that don't show consistency.

We also check similar anomalies appeared in the same areas in different years why high catch were not observed even there exist similar anomalies. This practice will assist for us to understand the real mechanism creating high catch events, i.e., combinations of several particular anomalies (unique patterns) may be found as the real cause high YFT catches.

4. Discussion

4.1 Ecological anomalies

(1) 1993 high catch

Based on Map 1, it is observed that during 1992-93 there were high anomalies of rainfalls around the Indus River which likely lowered salinity and oxygen levels in the waters the eastern Arabian Sea. According to Romena and Nishida (2000), the favorable salinity for YFT is 35.1-35.3 and dissolved oxygen 2.4-3.0 ml/l. For this case, it was considered that the waters were less than these lower limits. In addition there were high anomalies of the SST, vertical mean sea temperature, deeper thermocline depths and heat storages. These phenomena imply that the deep warm water pool favorable for YFT aggregations was formed, concentrated and kept for a certain period in 1992-93 in the central Arabian Sea.

Consequently YFT concentrations were likely sustained in 1993. As a result, once Taiwanese LL found this aggregation in this virgin fishing ground in 1992, many Taiwanese LL continuously shifted to this area, made concentrated operations and recorded historical high catch in 1993.

Note (*) High YFT catch in 1993 started in the later period of 1992 and for the high catch in 2003-2004, it started from the later period of 2002 and continued to 2005. Thus we also considered these extra years in our study, It was suggested that such highest fisheries success may probably have any relations to development of an ENSO events. From Climate and Marine Department Japan Meteorological Agency (2002), the year 1993 was the presence of El Nino event in the Pacific Ocean, but no remarked oceanic event was seen in the Indian Ocean.

The reason why such warm water pool being kept for a certain period is likely that as explained waters consisting extremely low salinity and oxygen levels in the eastern Arabian Sea played as a wall against this warm water pool and currents (winds) may play also important roles to keep and sustain this warm water pool (hence YFT schools) in the central area. However it is difficult to interpret how did winds play such roles based on their anomaly maps in Map 1. This is because the winds (monsoons) vary by season and average annual maps can not inform details concretely (Sudo, 1994). Hence we need to further investigations creating seasonal anomaly maps in the future.

Another potential cause may be the traffic noises produced by battleships and sorties during the Gulf war and air strikes to Iraq in northern Arabian Sea during 1991-93. Such noises might keep the YFT away to southern waters although it is again difficult to prove this potential affects scientifically as we don't have quantitative noise data. But similar events have been reported by Ikeda (1986), Yamada (1994), Nishida & Tanio (2001) and many others, in addition to personal communications with Mr. Warashina and Mr. Kato and Mr. Fukuchi as previously cited. .

(2) 2003-2004 high catch

Based on Map 1, it is clearly observed that high positive anomalies of primary products were developed in 2002 in the tropical western Indian Ocean (waters off north Madagascar), which likely continued to 2003-2005. This event most probably enhanced food chain reactions in the waters off north Madagascar, i.e., high primary products produced high concentrations nutrients such as chlorophyll, phosphate, silicate, nitrate and etc., which enhanced to produce zoo & photo planktons. Then, it is likely that enriched zoo & photo plankton attracted many small pelagic, crustaceans and cephalopod. As a result, swimming crabs and *Natosquilla*, prey for YFT were highly produced, consequently YFT were highly aggregated in that area.

In addition, in 2002-2003 there were negative anomalies of SST and also vertical mean sea temperature (60-200m) in the same area, i.e., waters where YFT inhabits became cooler than in the normal situation. This probably related with development of the high negative anomaly of the thermocline depths in the same areas, i.e., the thermocline depths became much shallower. The cause of the cooler waters might be originated by strong anomalies of the south-westerly wind (currents) observed in the same area. But the concrete mechanism can not be explained from the available information.

Map 1 (a) see the separate file (A3 size)

Map 1 (b) see the separate file (A3 size)

Now we discuss why YFT caught by PS fed more *Natosquilla,* while YFT by LL fed more swinnig crab even in the same area. Adult YFT usually staying 50-200m above the thermocline, but during 2003-2004 YFT are likely shifted to much shallower waters as the thermocline depth became shallower. As *Natosquilla* inhabit in shallower waters (surface to 70m?) more close to PS fishing depth, while for swimming crab, a little deeper (surface to 100m) more close to for LL fishing depth. Thus YFT caught by PS had chances to feed more *Natosquilla*, while YFT caught by LL fed more swimming crab. Especialy these two species of preys were highly bloomed in the same period and same waters, these phenomena were very much escarated.

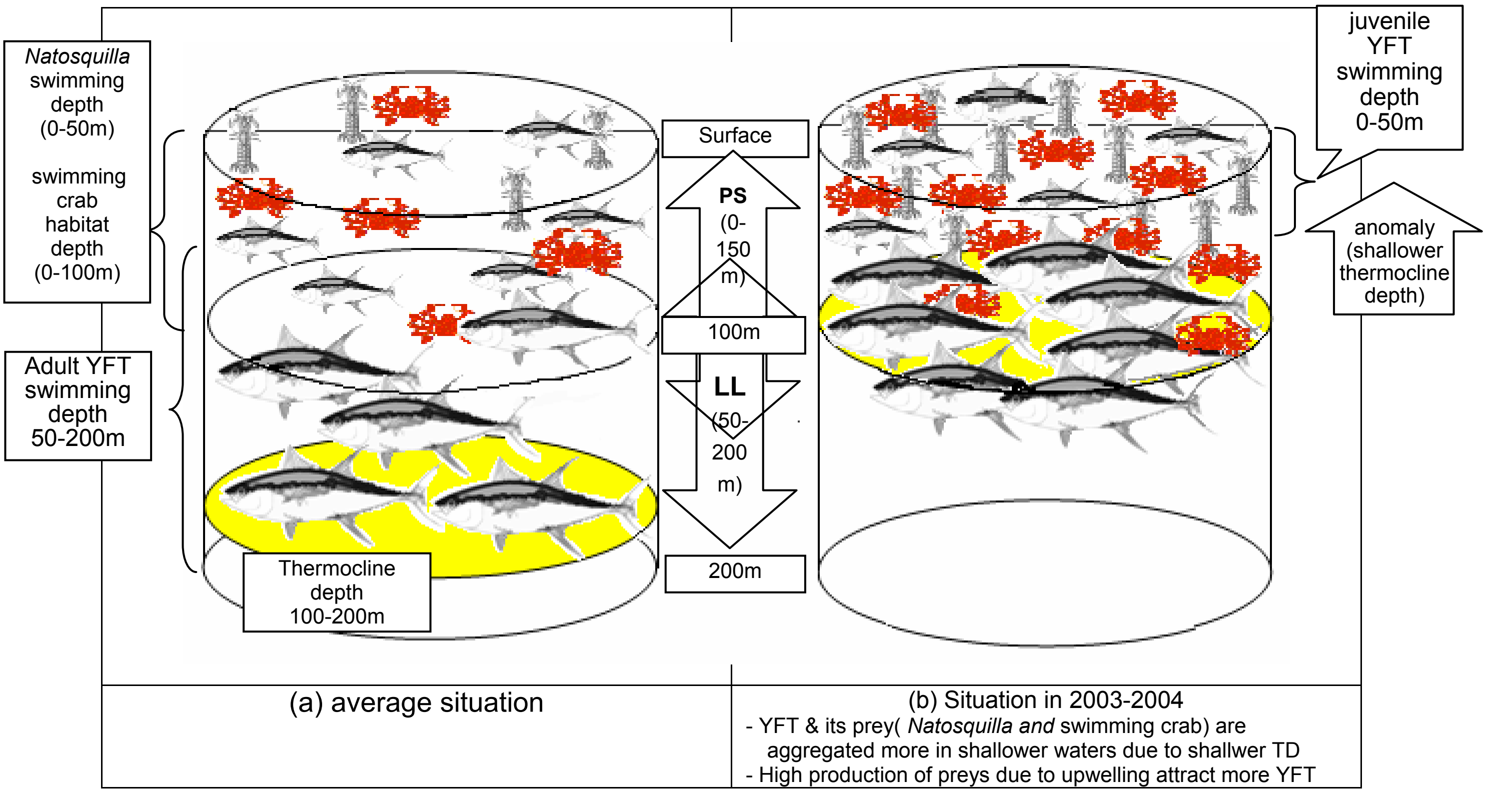


Fig 3 Assumed relashions of depths among thermocline, YFT habitats and its prey (*Natosquilla and* swimming crabs*)* during 2003-2004 high YFT catch event.

We now discuss why the medium size YFT which are not usually seen in this tropical area but in the Arabian Sea, were heavily exploited by both LL and PS for this time. The reason may be very crude but it might be caused by trafic noises made by battleships around the Arabian Sea during the Afghan and Iraq Wars in 2002-2003 (see Map 1).

This is because so many battleships (aircraft carriers, destroyers, frigates, submarines, support ships, mother boats or any relevant vessels relating to these Wars) heavily moved back and forth in the Arabian Sea areas the in this period. That is why the Japanese LL fishers claimed that medium size YFT normally exploited in the southern Arabian Sea seemed to disappear and they likely moved to south, tropical western Indian Ocean. However as Taiwanese LL could exploit YFT catch in the western Arabian Sea consistently in these years (Map 1), it seems that some YFT school seriously affected by noises moved to south. As a conclusion, it is not possible to judge if such phenomena actually happened based on the available rather qualitative information collected in this study although we can not deny such events completely.

(3) General discussion on ecological anomalies

In this study, we conducted crude annual basis analyses as a first step. Hence we could get only crude findings. We certainly need to do more specific (fine-scale) analyses by focusing affected areas (such as for Arabian Sea and western tropical waters) and also considering the seasonal factors because both fisheries and ecological factors in this area are largely affected by monsoons (seasons) (Sudo,1994). In the season centering on the summers of Northern Hemisphere, the southwestern monsoon exert an great influence on the above sea zones, in where the winter seasons are brought a strong impact by northeastern monsoon. In addition to the spatial-temporal factors, we need the statistical justifications for various hypotheses (qualitative findings) in this study. We plan to do such more specific studies in the future.

In the high YFT catch during 2003-2004, we need to investigate if Korean LL and artisanal fisheries in the same area got high YFT catch in order to confirm consistency with our results. Taiwan showed a partially high YFT catch (Fig. 2b, page 3) but we have not checked Korean LL and artisanal fisheries yet. If there were no consistencies, we need a clear scientific reason in order to support our preliminary findings obtained by Japan & Taiwan LL and also PS (Spain & France combined). In addition, similarly, we need to also check if there were no high catch on other tuna species such as albacore, bigeye and swordfish in the same area and in the same period. Without clearing such issues, our findings in this study can not be supported sufficiently.

4.2 Other factors (recruitments, catchability and excess effort)

We will review other possible factors causing large YFT catch, i.e., large recruitments (strong cohort), catchability (gear & vessel) and excess efforts.

(1) Recruitments (strong cohort)

Stecquert *et al* (1993) reported that yellowfin tuna in Western Indian Ocean are able to reproduce all year long. Kaymaram (1998) noted that fishing grounds and fishing periods in the Oman Sea are well-known to be of aspects of upwelling and high productivity. It was speculated that yellowfin tuna in the Oman Sea are highly migratory for feeding within this area and one year after they move into further southern waters for spawning behaviors. John (1998) provided a review of biological studies referring to yellowfin tuna in the Indian Ocean during 1985-95, in which John reported that the spawning season is considered to be extending from November to April.

Based on the annual trends of adult YFT abundance indices of Japan and Taiwan LL (Shono *et al,* 2005 and Wang *et al,* 2005), there are occasional jumps every 5-7 years since 1968 (Fig. 4), which are likely the signs of the strong cohort. Another reference, results of the ASPM analyses (Nishida *et al* 2002) also show that the annual trend of the YFT recruitment (age 0) indicate the strong cohort periodically (also about every 6-7 years) (Fig. 5). These imply possible strong recruitments (cohorts). But they indicate that such clear and strong cohorts exist before 1990, but there are no significant ones afterwards.

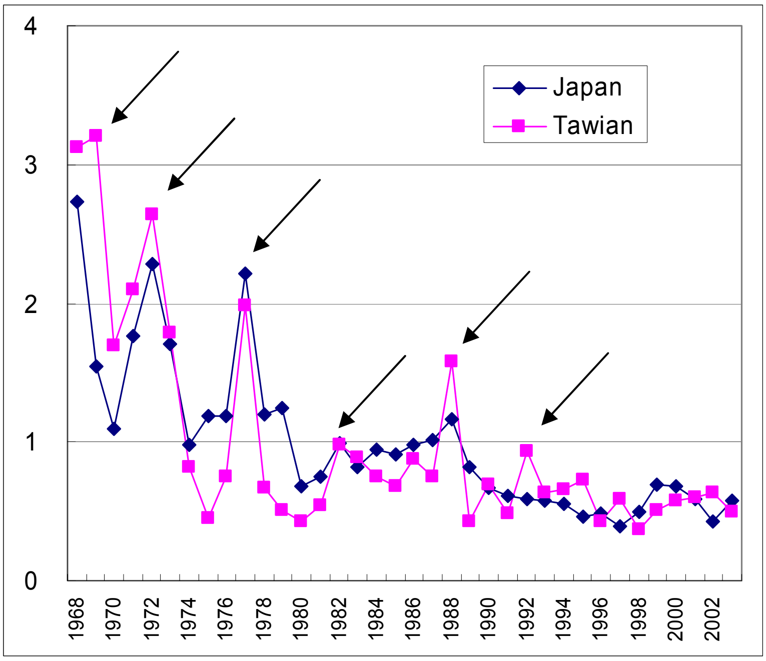


Fig. 4 Trends of annual abundance indices of Japan and Taiwan LL (Shono *et al*, 2005 and Wang *et al*, 2005).

Note :Jumps by high YFT catch in 1993 (Taiwan) and 2003-2004 (Japan) do not appear in this graph because this graphs show the figures for the whole YFT fishing grounds in Indian Ocean which mask such jumps unlike Fig. 3 specifically showing CPUE in these two areas.

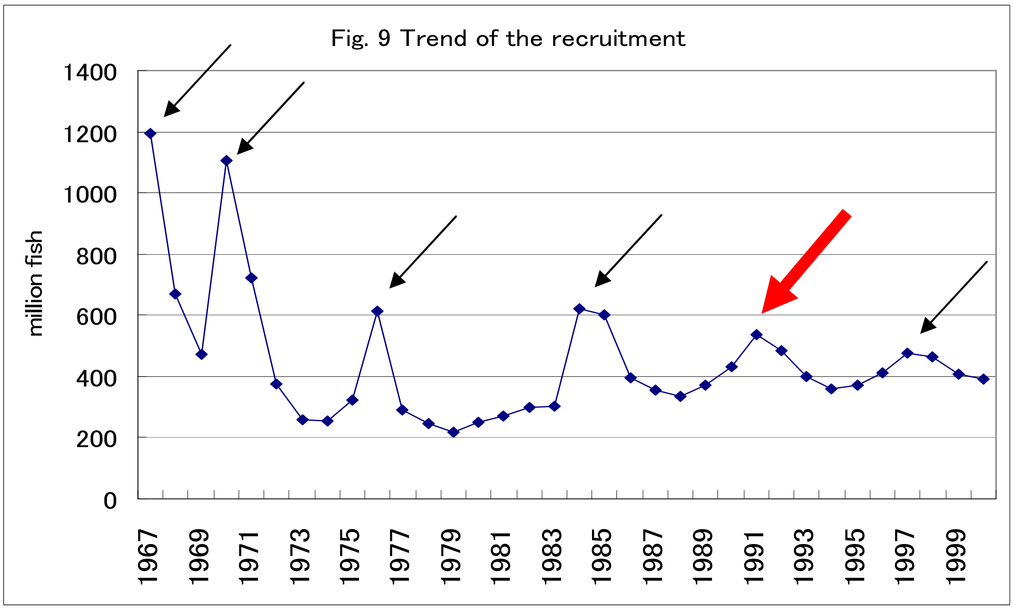


Fig. 5 Trends of annual recruitment (age 0) based on the results of the ASPM analyses (Nishida *et al.*, 2002)

Therefore for the 1993 high YFT catch, the 1991 high recruitment (red arrow in Fig. 5) possibly one of the causes. This is because there are favorable environmental conditions for spawners such as strong upwelling in the spawning areas near Oman in 1990-1992, which might produced large conservative recruitment consequently produced large population in 1992-95 in the Arabian Sea (80% of the catch are age 3-4 YFT), especially in the waters off Oman and Pakistan. After 1997, YFT catch decreased probably due to the diminish of these consecutive strong cohorts or decrease of the local YFT stocks, then, many Taiwanese LL vessels left there. (Stequert *et al*, 1993, John, 1998 and Gomyo *et al*, 2003).

(2) Catchability (q)

- 1993 high YFT catch

Regarding q, it may be not the important factor for the 1993 high YFT catch because Taiwanese LL did not add special gears & devices nor improve them during 1992-93 according to the Tawainses LL indutries.

- 2003-2004 high YFT catch

For the 2003-2004 high catch, the situation of q on the LL is likely same, while for PS, newly equipped ominiscan sonar might increased q (Fonteneau, *et al,* 2004). However, even PS introduced high perfomance sonar, it wiil take 10-20 years for skippers to get used to it efficiently in terms of species group identification, estimation of the school weight and tracking abilities of the fish school (Nishida *et al* 1986). In Japan only experienced sonar specialists more than 10-15 years can handle such ominiscan sonar effectively. Nishida *et al* (1996) showed that accuracy of identification of species groups of the school and also accuracy of estimated fish school are proportional to years of their experiences based on investigation of 20 sonar epecialists with 7-20 years of experiences. Thus it is unlikely that sudden introduction of the omniscan sonars to PS immediately and quickly increase q.

Based on these facts, it is unlikely that high YFT catch in 1993 and in 2003-2004 were significantly caused by increase of q (deplyments of effective gears and devices).

(3) Fishing effort

- 1993 high YFT catch

According to Taiwanese LL industry, very few LL vessels had been fishing in that area before 1993 and many Taiwan LL vessels suddenly began to enter that area as the virgin fishing ground once good fishing conditions were found. Thus, in addition to the good fishing conditions, fishing efforts by many LL are also one of the causes of the high YFT catch in 1993 (Fig. 6).

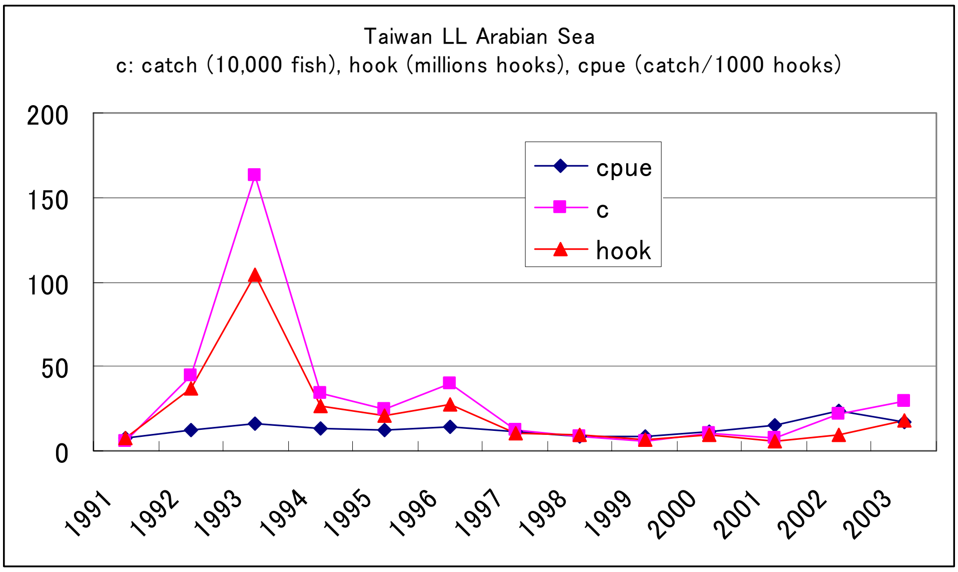


Fig. 6 Trend of the annual catch, effort and CPUE of Taiwanese LL in the Arabian Sea (1991-2003)

- 2003-2004 high YFT catch

For this case, similar situation was happened for Japanese LL, i.e., once good fishing were found, many LL started to concentrated into same fishing grounds in the same periods (Fig. 7). Thus, excess fishing effort is also one of causes besides the good fishing conditions.

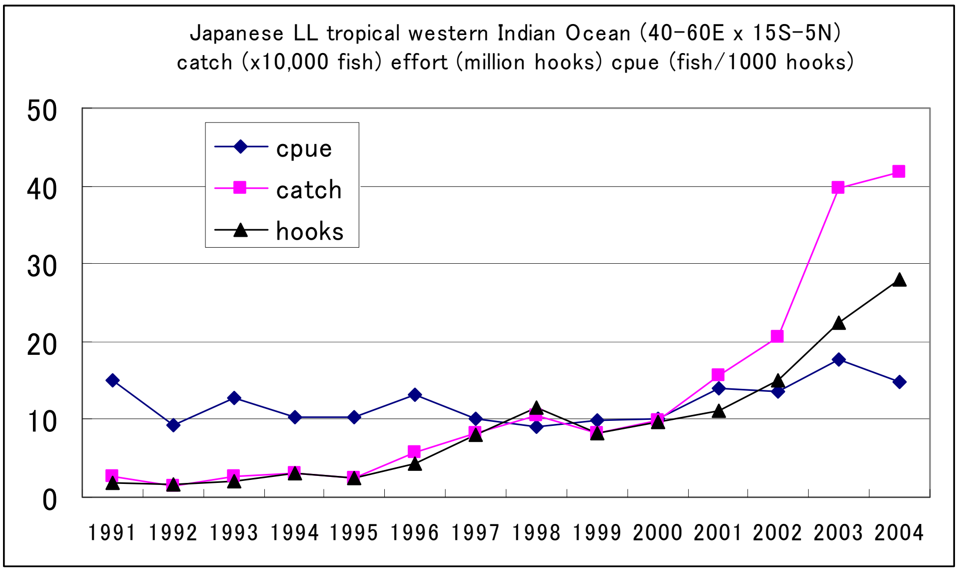


Fig. 7 Trend of the annual catch, effort and CPUE of Japanese LL in the tropical western Indian Ocean (40-60 N x 15S-5N) (1991-2004).

For PS, it is considered that the same situation likely happened although we have not fully investigated in this study. For the AF, it is not known as we did not analyze their data.

7. Summary

Based on the knowledge and information obtained in this study, we make two types of summaries, i.e., cartoons (Figs. 8 and 9) showing the mecahnizim and one summary table (Table 4) for 1993 and 2003-2004 high YFT catch events.

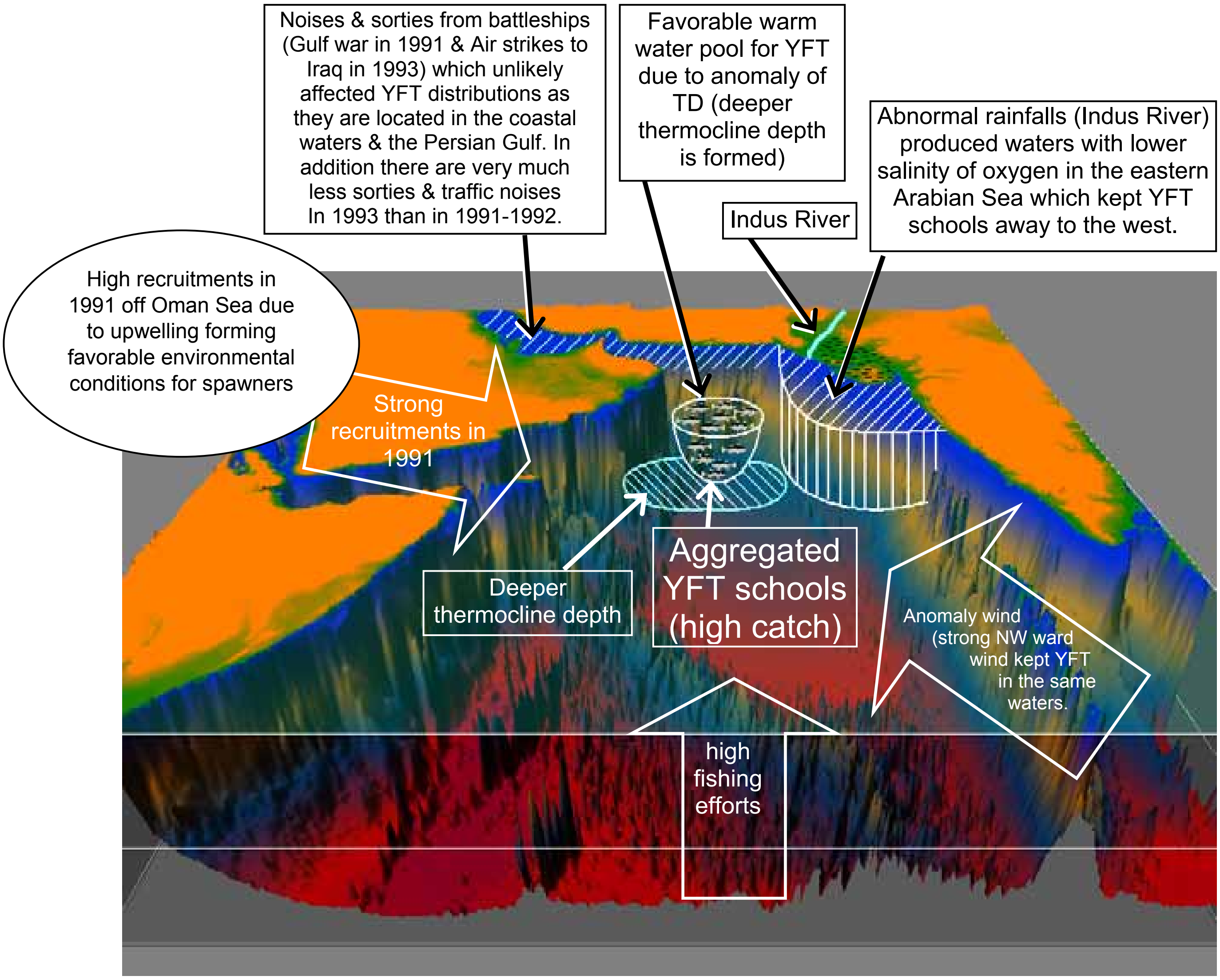


Fig. 8 Assumed mechanism of the 1993 YFT high catch based on the knowledge and information obtained in this study.

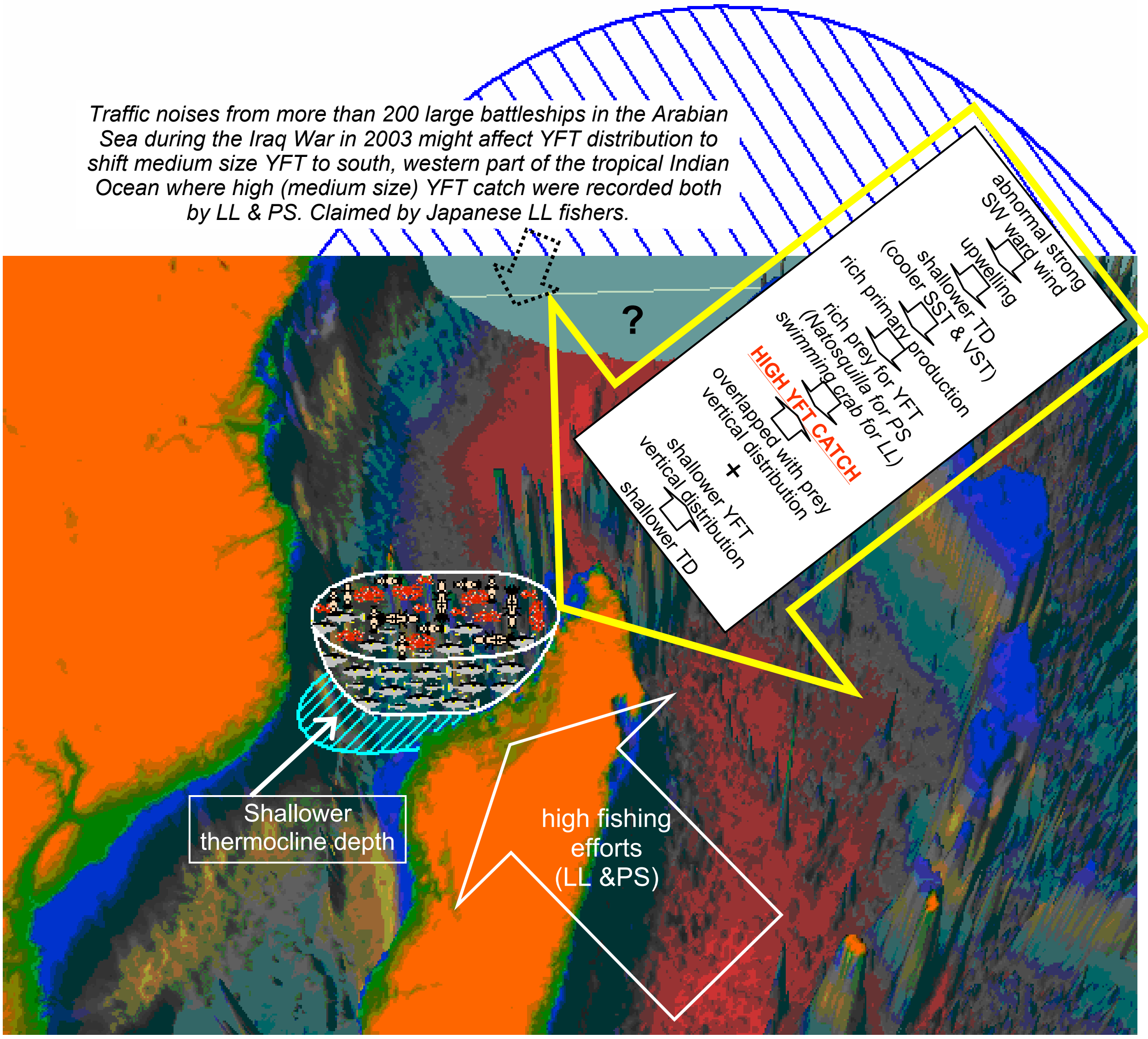


Fig. 9 Assumed mechanism of the 2003-2004 YFT high catch based on the knowledge and information obtained in this study.

Table 4 Summary table for the 1993 & 2002-2004 high YFT events
(factors affecting the high YFT catch are colored by yellow and grey for the grey area)

Factors		1993 high YFT catch (Arabian Sea)	2003-2004 high YFT catch (western part of the western tropical Indian Ocean)
High YFT catch			
high YFT catch occurred?	LL Japan	(no fisheries)	Yes
	LL Taiwan	Yes	Yes but relatively small scale
	LL Korea & others	? (not investigated)	? (not investigated)
	PS (Spain & France)	(no fisheries)	Yes
	PS (others)	? (not investigated)	? (not investigated)
	AF : Artisanal fisheries	? (not investigated)	? (not investigated)
Any high catches for other tuna species?	LL, PS, AF	unlikely ? (not fully investigated)	
Causes of high YFT catch			
Natural ecological anomalies	SST (sea surface temperature) VST: vertical mean sea temperature (60-200m) HS: Heat storage TD: thermocline depth Wind	Higher SST, HS & VST ⇓ warm water pool formed (favorable for YFT schools) in the central Arabian Sea ⇓ *HIGH YFT CATCH* ⇑ abnormal strong NW ward winds likely keep the warm water pool for a loner period	abnormal strong SW ward wind ⇓ upwelling ⇓ shallower TD (cooler SST & VST) ⇓ rich PP ⇓ rich prey for YFT *(Natosquilla for PS swimming crab for LL)* ⇓ *HIGH YFT CATCH* ⇑ overlapped with prey vertical distribution + shallower YFT vertical distribution ⇑ shallower TD
	PP: primary products	No data	
	Prey (feed) for YFT	? (no information)	
	Precipitations (Indus River)	High anomaly likely affect (limit) YFT distribution more to the central Arabian Sea	not applicable
Socio ecological anomalies (noises caused during Gulf, Afghanistan and Iraq Wars)	Traffic noises of battleships	heavy traffic noises causes by more than 200 large battleships (aircraft carriers, destroyers, frigates, submarines, support ships, mother boats etc) likely affected medium size YFT distribution in some extent from the Arabian Sea to south, western tropical Indian Ocean where high YFT catch waters.	
	Noises by sorties	No (sorties were from battleships in the coastal waters where YFT rarely inhabit)	
Recruitments		Large recruitment in 1991	Unlikely
q catchability	Introduction of innovated and effective devices for gears & fishing vessels	no	unlikely
Excess fishing effort		LL (Taiwan)	LL (Japan & Taiwan) and PS (France & Spain). Unknown for other PS & AF

6. Conclusion

According to Mr. Warashina (NRIFSF), several high YFT catch events (or even extremely low YFT catch events) have been often observed not only in the Indian Ocean, but also in the Pacific and the Atlantic Ocean in the past decades. Furthermore, high catch for other tuna species were also observed in the past. Causes of such events are considered to be different by each case. For our case from the view points of YFT fisheries and resources managements in this Indian Ocean, we need to put further efforts to elucidate mechanisms of such events to achieve our common goal, sustainable & optimum utilization of YFT resources.

Following conclusions are based on the qualitative analyses made in this study without statistical justifications. Thus these conclusions need to be observed with cautions.

- It is considered that the large YFT catch in 1993 were likely caused by three factors, i.e., (a) strong recruitments, (b) excess fishing efforts and (c) ecological anomalies (formation of the warm water pool in the central Arabian Sea, large rainfalls in the Indus River limiting the YFT distribution to the central Arabian Sea).

- For the 2003-2004 case, it was considered that high YFT catch in the western part of the tropical western Indian Ocean (40°E-60°E x 10°S-5°N) were likely caused mainly by large ecological anomalies, i.e., formation of favorable environmental conditions made by upwelling through abnormal strong SW ward winds, which enhanced strong food web reactions from primary products, planktons, preys for YFT to aggregation of YFT schools and especially the shallower thermocline push YFT schools shallower waters where there are many preys for YFT such as *Natosquilla* and swimming crabs inhabit shallower waters less than 100m.

- It was further considered that 2003-2004 case that large fishing efforts also contributed the high YFT catch but there seems to be no significant contributions by strong recruitments. This is because before 1990 there were clear strong and periodical cohorts, but after 1990 they seem to be diminishing as YFT stock status is declining.

- It was also considered that there are unlikely significant effects by q (catchability) due to deployments of new gears and/or devices to fishing vessels for both 1993 & 2003-2004 events.

- It is considered that noises by sorties from the battleships during the Gulf, Afghan and Iraq Wars during 1991-2004 unlikely affect to the YFT distributions because sorties were conducted from battleships located in the inshore waters where YFT rarely inhabits

- However, heavy traffic noises causes by more than 200 large & strong battleships (*aircraft carriers, destroyers, frigates, submarines, support ships, mother boats or any relevant vessels relating to these Wars.*) likely affected YFT distributions & movements in some extent in the Arabian Sea. This is because these battleships very frequently moved back & force in the Arabian Sea (many were from Diego Garcia Island, UK territory, Chagos Chagos, Central Indian Ocecan) during the Afghanistan and Iraq wars (2001-2004). But there are no scientific evidences to prove this hypothesis statistically.

- In addition, there are some reservation if such noises shifted medium size YFT from the Arabian Sea to south, the western tropical Indian Ocean as claimed by the Japanese LL fishers. Nothings were concluded at this stage based on the information we collected.

- As an overall conclusion we need to concern the 2003-2004 high YFT catch more seriously as a standpoint of YFT resources managements because these high catches most likely occurred by the aggregation of YFT schools due to combinations of favorable ecological anomalies and excess efforts, although there were no significant contributions of strong cohorts unlike in the case of the 1993 event.

- Based on this study we need to study further on the mechanism by more on finer scaled space & temporal analyses. In addition we need to check if and how other fisheries and other tuna species were affected. Then we need to conduct the integrated statistical evaluations using all relevant information to learn weights of the factors affected high YFT catch.

- In the standpoint of YFT managements, we need to establish the urgent management system to restrict excess fishing efforts when such high YFT catch appears by ecological anomalies and not by strong cohorts nor high q (catchbilities) due to sudden deployments of innovated and efficient devices for gears and fishing vessels. .

Acknowledgements

We express our sincere appreciations to the following scientists and experts helping different subjects in our study: Takashi Murakami (Hokkaido University) on heat storage, Ikuo Warashina (NRIFSF), Alain Fonteneau (IRD, France) and Nancy Gitonga (Fisheries Department, Kenya) on prey(feed) situation for YFT, Takahiko Kameda on primary products (NRIFSF), Ikuo Warashina om high YFT catch information in the world, Rikako Watai (Nihon University, previously National Defense Academy of Japan) and Sohtatsu Imuro (Japan Maritime Self-Defense Force, previously National Defense Academy of Japan) on the information of the Gulf, Afghanistan and Iraq Wars.

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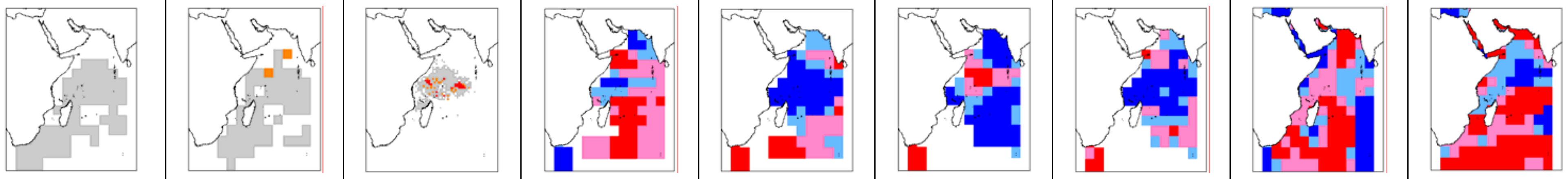
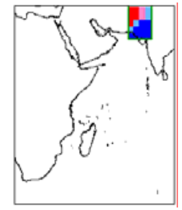
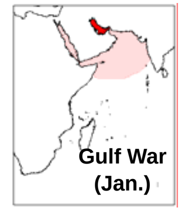
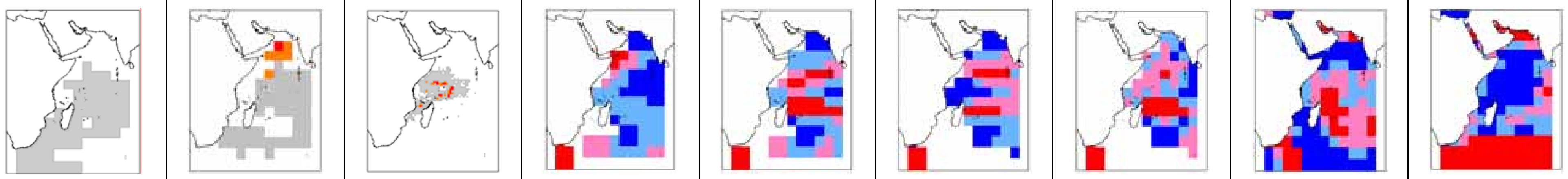
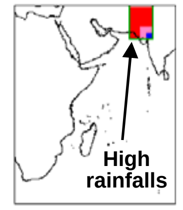
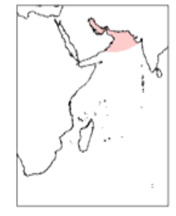
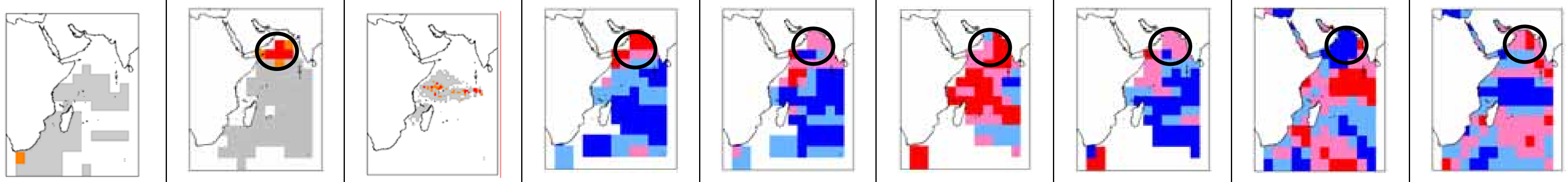
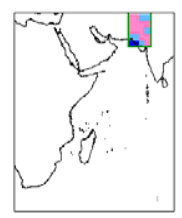
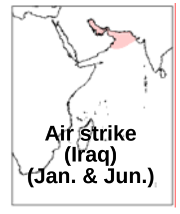
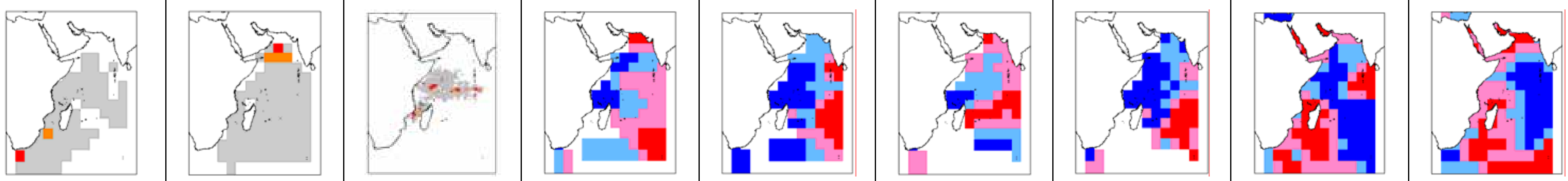
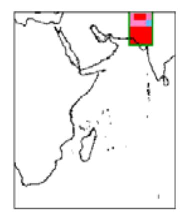
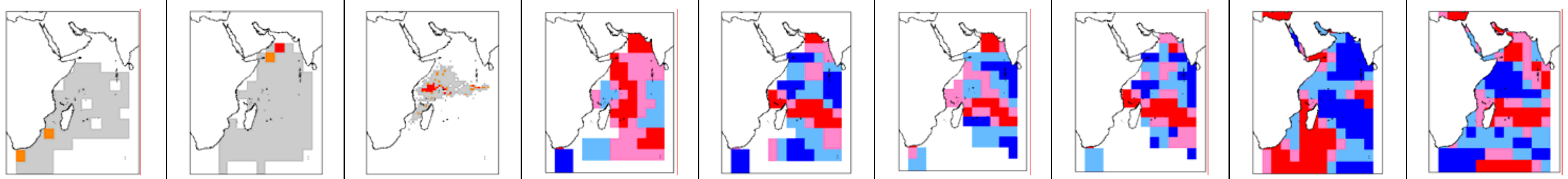
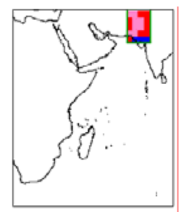
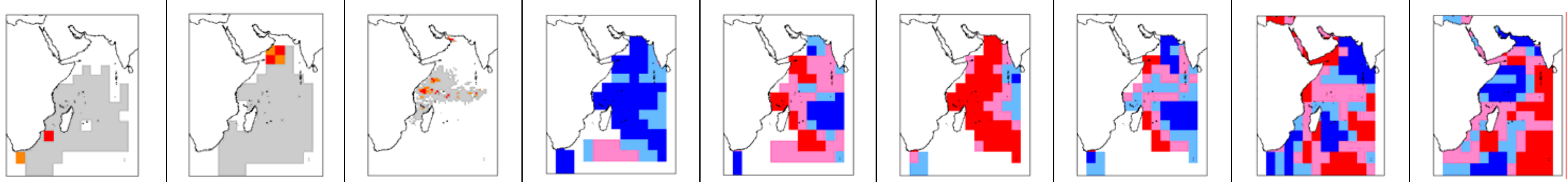
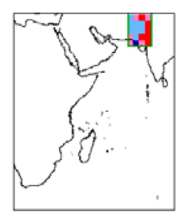
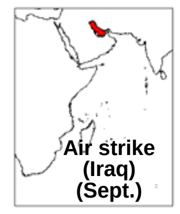
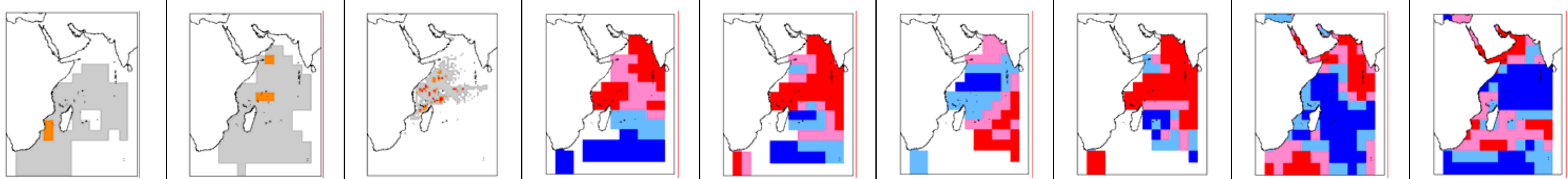
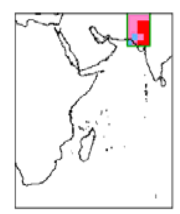
- *Fonteneau et. al.(1994)*
- *Fonteneau et. al.(2004)*
- *Gomyo et. al.(2003)*
- *Ikeda(1986)*
- *IOTC.(2004)*
- *Nishida et. al.(1986)*
- *Nishida et. al.(1996)*
- *Nishida and Tanio(2001)*
- *Nishida et. al.(2002)*
- *Peter and Mizuno*
- *Shono et.al.(2005)*
- *Wang et. al.(2005)*
- *Warashina*
- *Yamada(1994)*

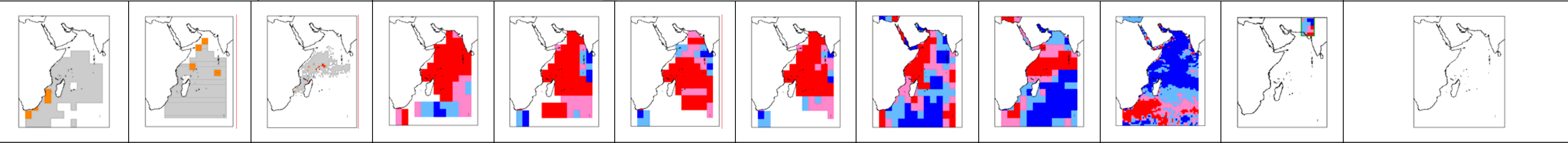
Map 1a High YFT catch in 1992-93 (Arabian Sea) and 2002[a/]-04 (tropical western Indian Ocean) vs. Ecological anomalies (differences from the mean values for 14 years, 1991-2004) (presented by circles)

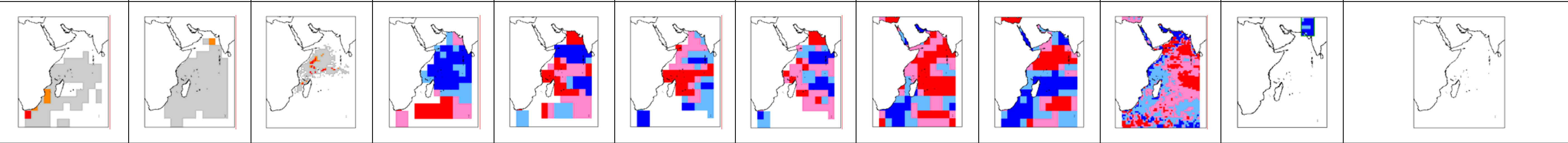
Para-meters =>	(1) Japan LL catch	(2) Taiwan LL catch	(3) PS (France & Spain) catch	(4) SST (sea surface temperature)	(5) Average vertical temperature (40-200m)	(6) Thermocline Depth (m)	(7) Heat storage (joule) (0-400m)	(8) Wind (+ : east ward dir. ⇒ and wind force)	(9) Wind (+: north ward dir. ⇑ and wind force)	(10) Primary product & distribution of *Natosquilla* [b/]	(11) Rainfalls around the Indus River (boxed area) [c/]	(12) Socio environmental noises caused by battleships and sorties (Gulf, Afghan. & Iraq Wars) [d/]
Legend	● Red: highest catch (top 5% in each 5x5/1x1 area during 1991-2003/4) ● Orange: next highest catch (top 5-10%) ● Grey: fishing grounds (non- 0 YFT catch areas) ● Blank: no data, no YFT catch, no operations or land			● Red: high positive anomaly (top 25% in each 5x5(or 1x1) area during 1991-2003/4) ● Pink: weak positive anomaly (25-50%) ● Light blue: weak negative anomaly (bottom 25-50%) ● Dark blue: high negative anomaly (bottom 25%) ● Blank: no data or land								Red: noisiest area Light pink: less noise (traffic noises) Blank: no battleships, nor sorties (or land)
1991										NA		
1992										NA		
1993										NA		
1994										NA		
1995										NA		
1996										NA		
1997										NA		

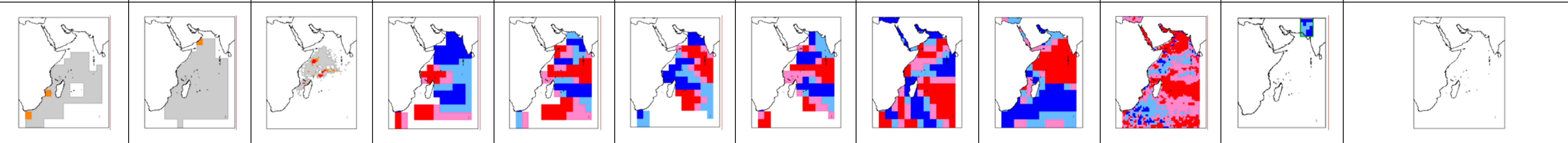
a/ High YFT catch appeared from late 2002; b/ rough concentrated areas are available only for 2002-04 based on Fonteneau et al (2004) and the personal communication with Ms Gitonga (Ministry of Fisheries, Kenya); c/ High positive anomalies (large rainfalls around the Indus River) lower salinity& oxygen levels of the sea waters off the Indus River which likely kept YFT distribution to the middle of the Arabian Sea ; d/ Japanese LL fishers claimed that these noises keep YFT to south from the Arabian Sea (personal communications with Mr Warashina, tuna scientist, Yaizu tuna fishing port branch, NRIFSF).

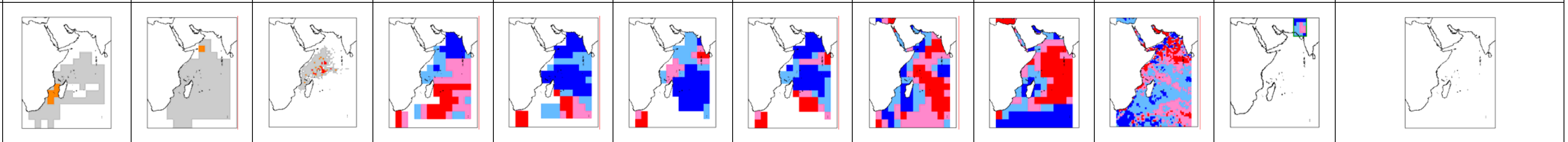
Map 1b High YFT catch in 1992-93 (Arabian Sea) and 2002[a/]-04 (tropical western Indian Ocean) vs. Ecological anomalies (differences from the mean values for 14 years, 1991-2004) (presented by circles)

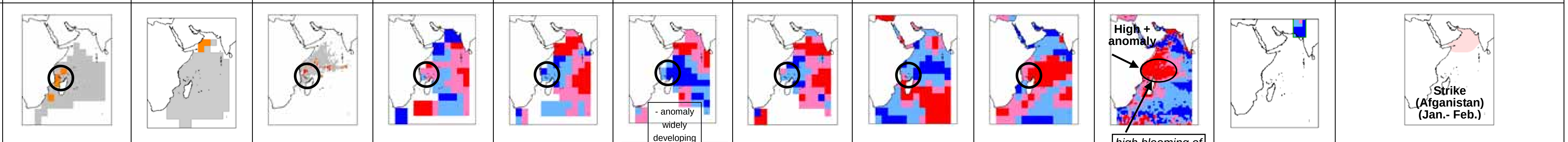
Para-meters =>	(1) Japan LL catch	(2) Taiwan LL catch	(3) PS (France & Spain) catch	(4) SST (sea surface temperature)	(5) Average vertical temperature (40-200m)	(6) Thermocline Depth (m)	(7) Heat storage (joule) (0-400m)	(8) Wind (+ : east ward dir. ⇒ and wind force)	(9) Wind (+: north ward dir. ⇑ and wind force)	(10) Primary product & distribution of *Natosquilla* [b/]	(11) Rainfalls around the Indus River (boxed area) [c/]	(12) Socio environmental noises caused by battleships, destroyers, sorties (missiles, bombers) (Gulf, Afghan. & Iraq wars) [d/]
Legend	● Red: highest catch (top 5% in each 5x5/1x1 area during 1991-2003/4) ● Orange: next highest catch (top 5-10%) ● Grey: fishing grounds (non- 0 YFT catch areas) ● Blank: no data, no YFT catch, no operations or land			● Red: high positive anomaly (top 25% in each 5x5(or 1x1) area during 1991-2003/4) ● Pink: weak positive anomaly (25-50%) ● Light blue: weak negative anomaly (bottom 25-50%) ● Dark blue: high negative anomaly (bottom 25%) ● Blank: no data or land								Red: noisiest (deployed) area Light pink: less noise (traffic noises) Blank: no battleships, destroyers nor sorties (or land)

1998


1999


2000


2001


2002


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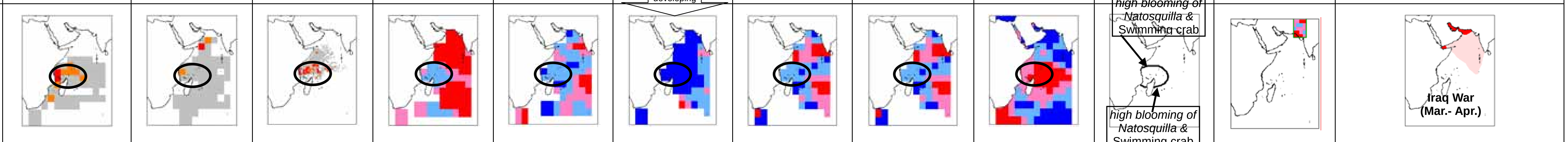
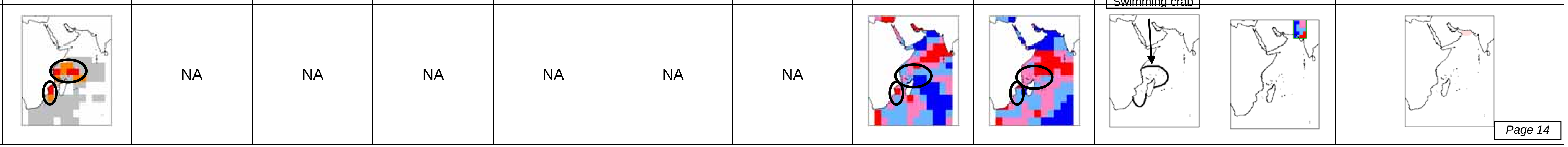


2004


a/ High YFT catch appeared from late 2002; b/ rough concentrated areas are available only for 2002-04 based on Fonteneau et al (2004) and the personal communication with Ms Gitonga (Ministry of Fisheries, Kenya); c/ High positive anomalies (large rainfalls around the Indus River) lower salinity& oxygen levels of the sea waters off the Indus River which likely block the YFT distribution to the middle of the Arabian Sea ; d/ Japanese LL fishers claimed that these noises keep YFT to south from the Arabian Sea (personal communications with Mr Warashina, tuna scientist, Yaizu tuna fishing port branch, NRIFSF).