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Estimation of catch-per-unit-effort of Indo Pacific sailfish (*Istiophorus platypterus*) caught with gillnet in the north of Indian Ocean

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Abstract

Data concerning catches of Indo Pacific sailfish (*Istiophorus platypterus*) is limited. Only approximate estimations are available in the Indian Ocean Tuna Commission (IOTC). In addition there are not catch-effort data of handline and gillnet boats, which have caught most of the unloaded sailfish. Estimations of catch-per-unit-effort (CPUE) in a conventional way are not feasible. However, the number of gillnet boats have been reported to IOTC by Iran, Oman, Sri Lanka and Pakistan. Those four countries rank among the top five higher sailfish catches. In this paper the number of boats is tentatively used as a proxy of the carrying capacity and of the effort. In order to calculate CPUE assumptions concerning relative efficiencies of boats of Iran and Oman of different sizes were also necessary. Estimations of CPUE calculated here indicate that: a) Catches were probably underestimated in the beginning of the Iran, Sri Hence and maybe Oman time series; and b) Estimations of catch of Oman and Pakistan of the end of time series were remarkably high if compared to the number of boats reported. Some revision may worth the effort. CPUE time trends as calculated for Iran, Pakistan and Sri Lanka were consistent with each other in the sense all of them have indicated that CPUE had decreased since 1995 in a regular pace. Although the results were encouraging, they might be carefully considered due to the assumptions underpinning to calculate CPUE.

1. Introduction

Most of billfish caught in the Indian Ocean are Indo Pacific sailfish (*Istiophorus platypterus*) (SFA) or swordfish (*Xiphias gladius*). While the later is the target of a couple of longline fleets (e.g. Portuguese and Spanish), the SFA is a bycatch of all fleets. Available data concerning bycatch species are usually biased or incomplete. Typically only approximate catches and some life history information are available. Hence data poor approaches (DPA) are an alternative to assess the bycatch species status.

In the DPA framework new attitude is required (MacCall, 2015). Quantities are not precisely knowable, even thought, one need to find out what are the policies to be used based on data available. Often the principles beneath DPA are: a) Grab and explore all available data, even incomplete; b) Explore “what-if” possibilities; c) Borrow information (with caution); d) Adapt conventional models or try out new models. In this paper I went over to look at available information, in an attempt to estimate an alternative catch rate using the limited data. Hopefully the alternative catch rates are useful estimations of relative abundance.

Estimation of relative abundance indices is a cornerstone of the several stock assessment approaches. Often commercial catch and information concerning effort (e.g. number of hooks or of fishing sets) are used to calculate the catch-per-unit-effort (CPUE) of large migratory pelagic fish (e.g. tuna and tuna like species). Usually there is information about the fishing gear characteristics (e.g. number of hooks between floats), and also data concerning when (month, daytime) and where (latitude and longitude) the fishing gear were operated. All the available information is then used to standardize CPUE in order to estimate relative abundance indices. However, there are not such data for SFA.

Most of SFA were caught by gillnet and line (e.g. trolling) fleets, while longline catches were low. More than 80 % of the total SFA were caught by Iran, India, Sri Lanka, Pakistan and Oman fishing fleets as estimated by the Indian Ocean Tuna Commission (IOTC) (ANON, 2014 a). Those countries are in the north margin of Indian Ocean, hence Oman Sea, Arabian Sea, Laccadive Sea and Bay of Bengal arise as fishing spots for SFA.

In the IOTC databases there are approximate estimations of the annual nominal catch of SFA but there are not data about catch-effort relationship of gillnet. However, there is information concerning the historical time series of the number of boats of some countries. What-if the number of boats is useful to estimate fishing effort proxies? That alternative to estimate effort and annual CPUE is explored in this paper. Hopefully the CPUE time series calculated in this work are useful to carry out stock assessment of SFA.

2. Data and Analysis

Data concerning nominal catch of SFA were made available by the IOTC secretariat before the meeting (ANON, 2015 a). Hereafter that data is denominated “catch database”. In this database there are information of catch by year, country, and gear. Follow below more detail about gears linked to high catches of SFA. Gillnet catches of SFA are classified as: a) “Gillnet” (GILL); b) “Gillnet operated attached to a longline” (GL); or c) “Offshore gillnet” (GIOF). “Lines” can be subdivided in: a) “Hand line” (HAND); b) “Coastal longline” (LLCO); and c) “Troll line” (TROL). Longline gear categories are: a) “Longline” (LL); b) “Longline fresh” (FLL); and c) “Longline operated attached to gillnet” (LG).

IOTC databases include information on catch and effort for longline gear category (see Andrade, 2015), and there are very detailed information in the databases of some contracting parts (e.g. Japan and Taiwan), which allow for very comprehensive and useful analysis to be carried out for billfish (e.g. Okamoto and Ijima, 2015). However, there are not detailed catch-effort data for most of the other gears, which imposes difficulties to calculate CPUE. The alternative to calculate effort proxy and CPUE is to use the historic of number of boats as proxies of fleet carrying capacity and also of effort. Historic of the numbers of boats as it appears in the IOTC database was kindly prepared and made available by Ms. Lucia Pierre of IOTC Secretariat. This information is hereafter denominated “boat database”.

In the boat database there is information concerning number and size of crafts (Length Overall –LOA or Gross Register Tonnage – GRT) by year and by gear as reported by the contracting parties. The gear categories in boat database are similar to those of the catch database. In some cases the number of boats of a given gear category (e.g. GIOF) was split into two or more size categories (e.g. 50-100 GRT and more than 100 GRT) in the boat database. Hence a CPUE calculation is not straightforward, cause there are two types of effort units (number of boats in 50-100 GRT category, and number of boats in > 100 GRT category), and only one aggregated catch. If one assumes that the efficiencies of the boats of different size are similar, total effort would be the sum of the numbers of boats, and the calculation of CPUE is a simple task. However, fishing powers of boat of different sizes may be different. Hence it is not sensible to sum the numbers of boats of the two categories of size.

To convert the number of boats of a given category in the equivalent number of boats of another category is an alternative. If this is feasible, the two efforts (number of boats) may be summed up, and a CPUE can be calculated. The efficiencies of the different boat categories can be calculated by solving a linear system $Y = X\beta$, in which Y is the vector (length n) of SFA catches, X is the matrix (dimension $n \times k$) with the number of boats in each k category, and $\beta = \{\beta_1, \ldots, \beta_k\}$ is the vector of parameter that represents the relative efficiency of the three different boat categories. The above model may have unique solution only if $n \geq k$. However, remind that all roots or estimations of β components might be not negative.

If available, the estimation of β can be used to covert the effort of one category to the effort of other category, then the two efforts (e.g. number of boats) are summed up to calculate the total effort and the CPUE. For illustration purposes suppose that in a given situation the total aggregated catch is $C = 180$, and the effort of the category 1 was $f_1 = 10$, while the effort of category 2 was $f_2 = 20$. In addition suppose that we got $\beta_1 = 0.5$ and $\beta_2 = 2$ after solving the above linear system. Then the CPUE calculation in tons per number of boats of type 1 would be $C/\left(f_1 + f_2\,\beta_2/\beta_1\right) = 180/(10+80) = 2$. This calculation resembles the “fishing power” concept in its simplest form. In the following text the total effort calculated after applying the above approach is called “effective” effort. In the example it is the denominator of the equation. Finally, ordinary scatterplots and basic statistical analyses were used to explore catch, effort and CPUE time series. Smooth splines and loess were calculated to make easier to assess the bivariate relationships between the variables.

3. Results

3.1. Catch and Boat Databases

Most of SFA unloaded in Indian Ocean was caught by Iran, India and Sri Lanka and Pakistan, followed by Oman, Tanzania, Indonesia and Madagascar as estimated by IOTC (Figure 1). The top five catches are of countries located in the north margin of the Indian Ocean, which is fishing ground where the catchability and/or the abundance of sailfish is high. Two of the other countries with high catches are located in the southwest margin of Indian Ocean close to (Tanzania) or bathed by Mozambique Channel (Madagascar). In the east margin Indonesian fleet also catches a relatively high quantity of sailfish.

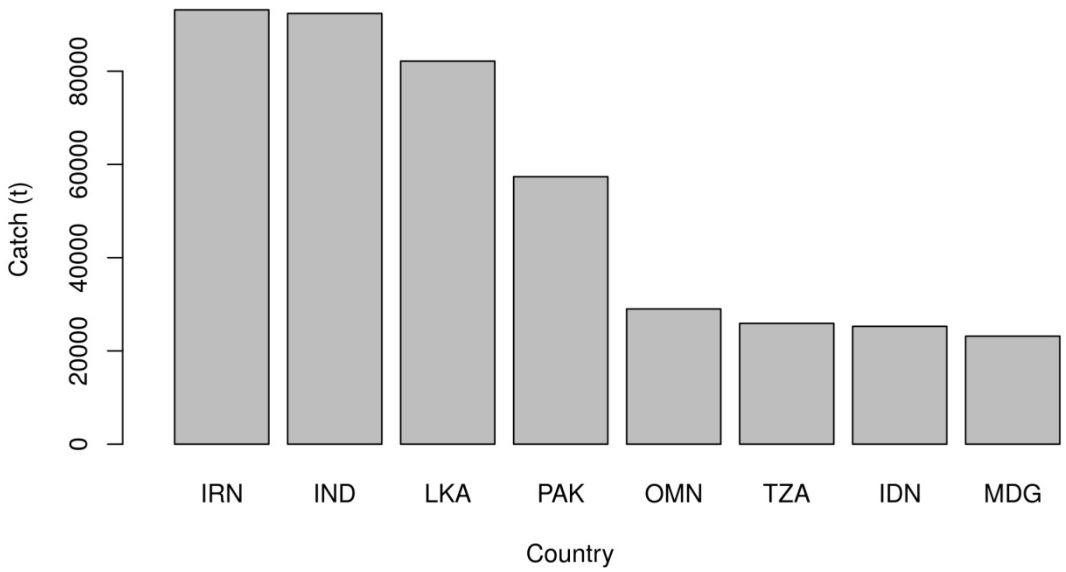

Figure 1 – Aggregated catch of Indo Pacific sailfish (1950-2014) as estimated by IOTC. Contracting parties: Iran (IRN), India (IND), Sri Lanka (LKA), Pakistan (PAK), Oman (OMN), Tanzania (TZA), Indonesia (IDN) and Madagascar (MDG).

Sailfish have been caught by fishermen using several gears, but gillnet, followed by line and longline are the major gear groups (Figure 2). Catches of gillnet can be further split into general gillnet (GILL), offshore gillnet (GIOF) and gillnet operated attached to a longline (GL). Most of SFA caught with “line” are linked to hand line (HAND) and to troll line (TROL) gear subdivisions. Finally, the SFA caught with “longline” can be further split into three subdivisions: general longline (LL), longline fresh (FLL), and longline operated attached to gillnet (LG).

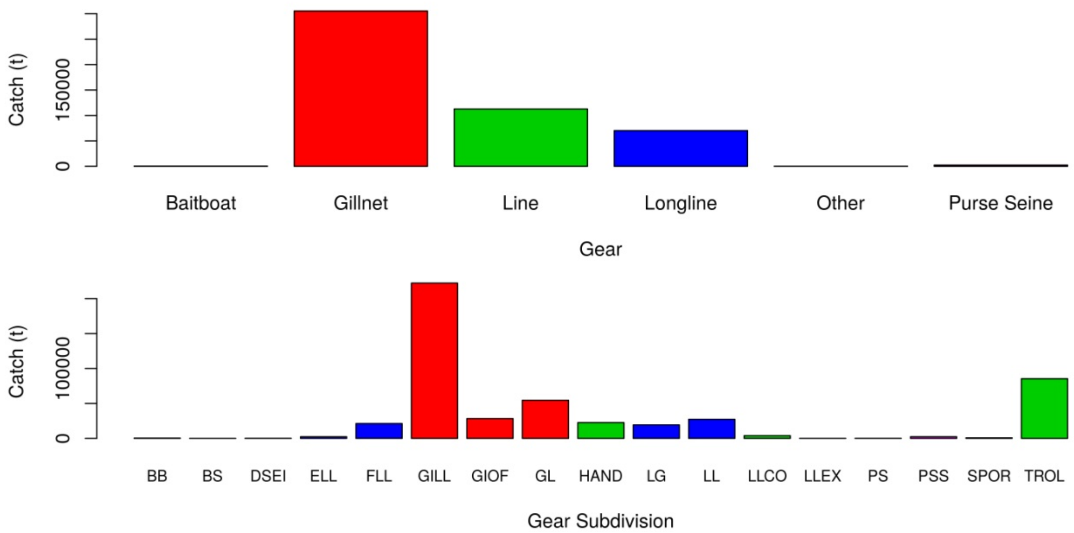

Figure 2 – Catch by major gear groups (upper panel) and by gear subdivisions: baitboat (BB), beach seine (BS), Danish seine (DSE), longline targeting swordfish (ELL), longline fresh (FLL), gillnet (GILL), offshore gillnet (GIOF), gillnet operated attached to a longline (GL), hand line (HAND), longline operated attached to gillnet (LG), longline (LL), coastal longline (LLCO), exploratory longline (LLEX), purse seine (PS), small purse seine (PSS), sport fishing (SPOR), and troll line (TROL).

Above figures stand for aggregated catch (1950-2014) calculations. However, there were important changes across the years. Catches of gillnet were not that high before 1990's, but a very fast increasing trend appears starting in 1991 (Figure 3 A). Most of catches of gillnet major group were classified as generic gillnet (GILL) (Figure 3 B). Catches assigned to GILL category showed two jumps, one in the beginning of 1990's and another in the end of 2000's. Catches of GL subdivision increased steadily from 1990 to 2011 and then decreased fast in the end of the time series. Catches of offshore gillnet (GIOF) were very low before 2002, but they peaked in mid 2000's and in mid 2010's.

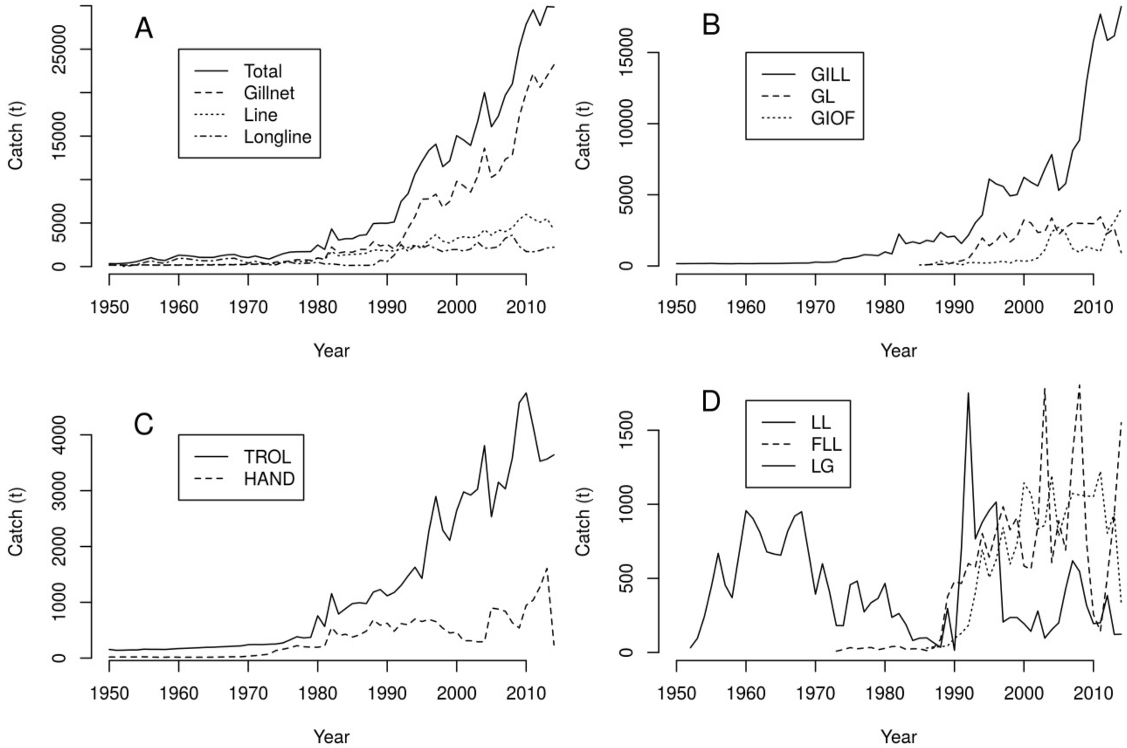

Figure 4 – Catch by year and by gear major group (A) and by gear subdivision (B, C and D). Gear subdivisions are: generic gillnet (GILL), offshore gillnet (GIOF), gillnet operated attached to a longline (GL), hand line (HAND), troll line (TROL), longline fresh (FLL), longline operated attached to gillnet (LG), and generic longline (LL).

Catches of major gear group line increased steadily from 1980 until the end of the time series (Figure 3 A). Most of the line catches were linked to troll line gear subdivision (Figure 3 C). Catch time series of hand line (HAND) were low and the variability was high after 2000. Notice also that hand line catch was close to zero in the very end of the time series. Overall longline cathes were low before 1970, close to zero in 1970's and 1980's, but there was an increase trend in the beginning of 1990's (Figure 3 A). Catches were close to 2,000-3,000 t since them. Catch time series of the three longline subdivisions (LL, FLL and LG) showed a very complex pattern, with peaks and plunges, and erratic variations across the last decades (Figure 3 D). Due to the unstable behavior longline databases were not retained for this analysis.

Gillnet and line catch time series by country and by gear subdivision are showed in Figure 4. Notice that Iran-GILL, Pakistan-GILL, Sri Lanka-GL, India-GILL and Iran-GIOF were the major crossing country-gear categories concerning sailfish caught with gillnet (Figure 4 A). Catches of Iranian gillnet category (GILL-IRN) have increased fast in 1995 but the estimations stand close to 2,100 t from mid 1990’s to 2008. In the end of 2000’s catches peaked to more than 7,500 t, decreased to 5,000 t, and finally increased again to approximately 8,000 t. Estimations of Iranian offshore gillnet fleet (GIOF-Iran) were in general low, but peaked in 2005 and in 2014. Catches of Pakistanian gillnet fleet (GILL-PAK) have increased steadily from 1990 to 2006, but then increased very fast to approximately 6,000 t until 2012. In 2012, 2013 and 2014 estimated catches of Pakistan were very much the same.

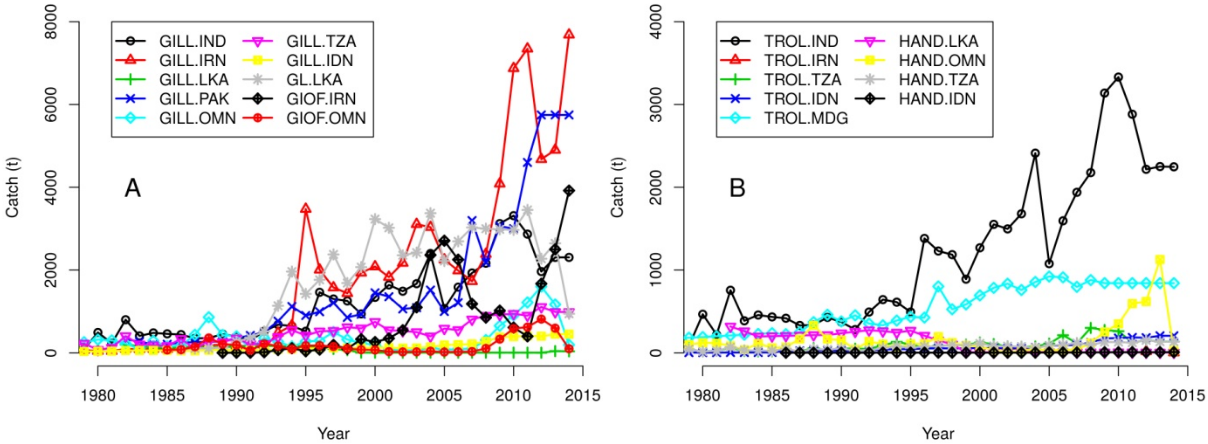

Figure 4 – Gillnet (A) and line (B) catches of Indo Pacific sailfish as estimated by IOTC by country and by gear subdivisions. Countries: Iran (IRN), India (IND), Sri Lanka (LKA), Pakistan (PAK), Oman (OMN), Tanzania (TZA), Indonesia (IDN) and Madagascar (MDG). Gear subdivisions: generic gillnet (GILL), gillnet operated attached to longline (GL), offshore gillnet (GIOF), troll line (TROL), and hand line (HAND).

Most of sailfish unloaded at Sri Lanka harbors were caught by a multigear fleet, which uses gillnet in combination with longline (GL-LKA label). Estimations of GL-LKA catches were low in the beginning of the time series but they increased fast from approximately 500 t in1992 to 2,000 t in 1994. After that year the catches of GL-LKA have increased steadily until 2011, and then they dropped fast in the end of the time series. Catches of gillnet Indonesian fleet were low before 1995, but there was an increasing trend until 2010. However, catches in the recent years were lower than in the end of 2000’s. Catches of the other gillnet-country categories (GILL-LKA, GILL-TZA, GILL-IDN, GILL-OMN and GIOF-OMN) were relatively low.

Overall catches of troll line fleets of Indonesia (TROL-IND) and Madagascar (TROL-MDG) were higher than catches of all the other fleets which use line gears (Figure 4 B). In spite there were some peaks and plunges, in general, the Indonesia time series showed an increasing trend since 1990. Catches of troll line fleet of Madargascar increased steadily from 1985 to 2002. However, catches remained close to 800-900 t since then. As minor notes, notice the peak of catches of hand line boats of Oman in the end of the time series, and the low but stable catches of hand line boats of Sri Lanka from 1982 to 1996.

The nineteen catch time series showed in Figure 4 were extracted from the IOTC “catch database”. All of them are potentially useful to estimate catch rates. However, in the “boat database” there is information concerning only five of the countries appearing in Figure 4, and four subdivisions linked to gillnet and line major gear categories. The balance of information is shown in a mosaic plot (Figure 5). In order to calculate the mosaic plot the numbers of boats reported in year in the 1950-2014 timespan were aggregated. Width and height of the bars appearing in Figure 5 indicate the total number of boats in each crossing level. Notice that most of the reports are of gillnet boats (GILL), and that most of these boats are home based in Oman. There are also reports of generic gillnet boats for Iran and Pakistan. The former country also reported boats which fish with offshore gillnet (GIOF). Only Sri Lanka has reported boats that operate gillnets attached to longlines (GL). India has reported boats that operate with coastal longlines combined with troll lines (LLTR). It is also important to remind (see Data and Analysis Section) that GIOF-IRN combination is further split into two categories according to GRT of the boats, and to remind that GILL-OMN combination is also split in two categories according to the size (LOA) of boats.

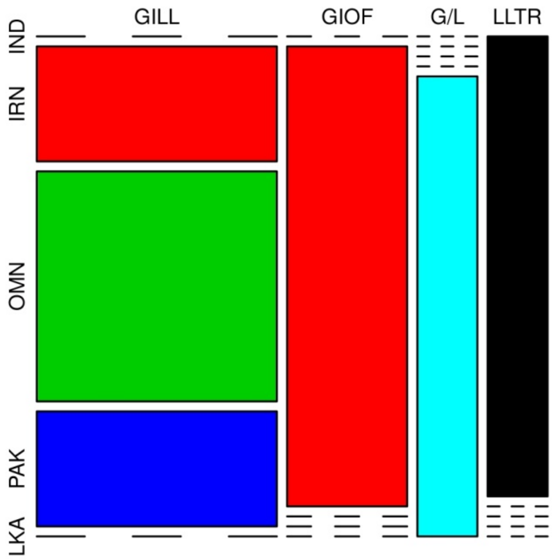

Figure 5 – Balance of the quantity of estimations in crossing levels of gear type (gillnet – GILL, offshore gillnet – GIOF, gillnet operated attached to longline – G/L, coastal longline and troll combination – LLTR) and contracting parties (India – IND – black, Iran – IRN – red, Oman – OMN – green, Pakistan – PAK – blue and Sri Lanka – LKA – light blue).

Notice that only five combinations gear-country (i.e. GILL-IRN, GIOF-IRN, GILL-OMN, GILL-PAK and GL-LKA) showed up in both "catch database" (Figure 4) and "boat database" (Figure 5). It is also important to mention that in the historical reports of LLTR boats of India the number of craft were always the same, namely 225. Hence there is not contrast in the number of boats. After all, the alternatives to estimate CPUE using nominal catch and carrying capacities of the fleets are not so numerous.

3.2. Catch, Effort and Cath-per-Unit-Effort

3.2.1. Iran

3.2.1.1 Preliminaries

Sailfish has been caught by boats which operates ordinary (GILL) or offshore gillnets (GIOF). However, in the boat database there is information concerning three categories: GILL boats 0-50 GRT, GIOF boats 50-100 GRT, and GIOF boats > 100 GRT. Therefore calculation of CPUE seems an easy task for GILL, but not for GIOF category. In this paper the two approaches to cope with GIOF were: a) to simplify by assuming that efficiencies of all boats are similar, no matter the size of the boat, or b) to calculate relative efficiencies of the two size boat categories. Follow below the description of the components of the linear models (see

Data and Analysis section) used to calculate the relative efficiencies of the different boat categories, which were then used to calculate effort, and consequently, the CPUE.

Most of billfish caught by Iranian fleets were unloaded in ports located in four provinces, namely Khozestan, Busher, Hormozgan, and Sistan-Bluchestan (Rajaei, 2012 and 2013) (Figure 6). Dr. Fariborz Rajaei has kindly provided data concerning the catches and the number of boats by size category in each province in 2013 and 2014 (Table 1). Notice that almost all SFA caught by Iranian boats have been unloaded in Hormozgan, and in Sistan-Bluchestan provinces (Rajaei, 2012 and 2013), whose fleets include almost all GIOF boats (Table 1). Those two provinces lie in the south coast of Iran bathed by the Gulf of Oman and by the Arabian Sea (Figure 6). Catches of sailfish are low in the provinces of Khozestan and Busher (Rajaei, 2012 and 2013), which lie in the Persian Gulf (Figure 6). Most of boats home based in Khozestan and Busher located in the Persian Gulf are small and operates ordinary gillnets (GILL).

Figure 6 – South part of Iran with indication of the provinces in which most of the Indo Pacific Sailfish has been unloaded. Map was adapted from www.geographicguide.com/asia/maps/iran.htm.

Table 1 – Catch of Indo Pacific sailfish and number of boats of each Iranian province in 2013 and 2014. Gear categories are gillnet (GILL) and offshore gillnet (GIOF). Sizes of boats are in Gross Register Tonnage (GRT). Source: Dr. Fariborz Rajaei – Senior Expert – Iran Fisheries Organization.

Year	Province	Number of Boats			Catch
		GILL (0-50 GRT)	GIOF (50-100 GRT)	GIOF (>100 GRT)	Catch (t)
2013	Khozestan	139	3	0	0
	Busher	1,498	55	0	3
	Hormozgan	2,932	175	55	1,444
	Sistan and Bluchestan	502	301	283	5,954
	Total	5,071	534	338	7,401
2014	Khozestan	103	2	0	0
	Busher	1,415	65	0	1
	Hormozgan	2,711	168	55	2,231
	Sistan and Bluchestan	633	250	220	9,375
	Total	4,862	485	275	11,607

In order to calculate the relative efficiencies of the two GIOF boats categories (50-100 GRT and > 100 GRT) using a linear model I have tried out several alternatives concerning the response vector (Y) and the matrix of explanatory variables (X): A.1) Y = all catches of all provinces in all years and X = numbers of boats of all categories; A.2) similar to A.1 but Khozestan data was dropped off; A.3) Similar to A.2 but Busher data were dropped off; A.4) Similar to A.3 but GILL data were dropped off; and A.5) similar to A.4 but data of 2013 and of 2014 were analyzed separated.

Only approaches A.4 and A.5 for the year 2013 resulted in positive and useful estimations of boat efficiencies, namely $\beta_{GIOF\ 50-100\ GRT} \cong 3.94$ and $\beta_{GIOF>100\ GRT} \cong 24.70$ (solution A.4), and namely $\beta_{GIOF\ 50-100\ GRT} \cong 2.46$ and $\beta_{GIOF>100\ GRT} \cong 18.42$ (solution A.5 year 2013). Note that both estimations render similar relative efficiency ($\beta_{GIOF>100\ GRT}/\beta\_{GIOF\ 50-100\ GRT}$) calculations, 6.27 (solution A.4) and 7.49 (solution A.5 year 2013). Therefore results indicate that boats GIOF > 100 GRT are seven times more efficient than the smaller boats GIOF 50-100 GRT. Those relative efficiencies estimations were used to convert the number of boats GIOF > 100 GRT in number of boats GIOF 50-100 GRT, and finally to estimate CPUE in each year of the 1950-2014 timespan.

Another interesting issue arises if the data in Table 1 are compared with IOTC catch and boat databases. Data of 2013 are used to illustrate the question. In the IOTC catch database there is an estimation of total catch of GILL boats (4,901 t) in 2013. In the boat database there were reported 5,071 GILL boats in 2013 just like in Table 1. However, certainly the 4,901 t of SFA were not caught by such fleet of 5,071 boats! Data in Table 1 and also Rajaei (2012 and 2013) clearly indicate that almost all SFA were caught only by 2,932 + 502 = 3,434 GILL boats home based in the Hormozgan and Sistan-Bluchestan provinces. Therefore the GILL catches can not be straightforward assigned to the number of GILL boats in the IOTC databases. Data in Table 1 sheds light on 2013 and 2014, but there is not helpful information to disentangle data concerning the other years. Clearly new information will be necessary to shed light on the issue in the future. However, by now, some tentative calculations are feasible.

I have considered the following alternatives to cope with the uncertain concerning the link between catch and boat databases: B.1) To calculate a GILL CPUE by assuming that the number of small GILL boats reported in the IOTC database is a good proxy of the number (and the effort) of GILL boats home based in Hormozgan and Sistan-Bluchestan, where almost all SFA have been unloaded; B.2) To assume that reports of GIOF boats are a good proxy of effort and that efficiencies of GIOF boats were similar, not matter the size. The CPUE was calculated by dividing the GIOF catch as reported in the IOTC database, by the sum of numbers of GIOF boats of the two size categories (50-100 GRT and > 100 GRT); B.3) Similar to B.2 but reports of GIOF boats were assumed to be good proxy of effort of all Iranian gillnet fleet (ordinary plus offshore gillnet boats) hence the CPUE was calculated by dividing total (GILL + GIOF) catch by the sum of numbers of GIOF boats of the two size categories (50-100 GRT and > 100 GRT); B.4) Similar to B.2 but the number of 50-100 GRT boats were converted in number of boats > 100 GRT before the calculation of CPUE (see Data and Analysis section); B.5) Similar to B.4 but reports of GIOF boats were assumed to be good proxy of effort of all Iranian gillnet fleet (ordinary plus offshore gillnet boats) hence the CPUE was calculated by dividing total (GILL + GIOF) catch by effective numbers of GIOF boats.

3.2.1.2. Approach B.1

Catch, effort (number of boats) and CPUE as calculated under the alternative B.1 are shown in Figure 7. Notice that discontinuities ("jumps") appear in the series. For example, the number of boats experienced a three times increase from 1991 to 1992, but the catch did remained very low. The number of boats did not change much from 1994 to 1995, but the catch in 1995 was three times higher. The number of boats had decreased fast in the beginning of 2000's, but did not. Catches peaked in 2010-2011 but the numbers of boats in these two years were not particularly high, instead they were rather lower than in if compared to the previous years. The relationships between the number of boats and catch, and between the number of boats and catch rate were similar. Low catches (and catch rates) occurred along with low or high effort, while high catches only occurred when the effort was in an intermediate level. Notice also that catch rates in the very beginning of the time series were very low, which was not expected. Catch rates were expected to be relatively high in the 1970's because previous catches and fishing mortality were probably low, hence the biomass was expected to be relatively high. The low catch rates in 1970's and 1980's are probably an indication that overall catches were underestimated in the beginning of the time series.

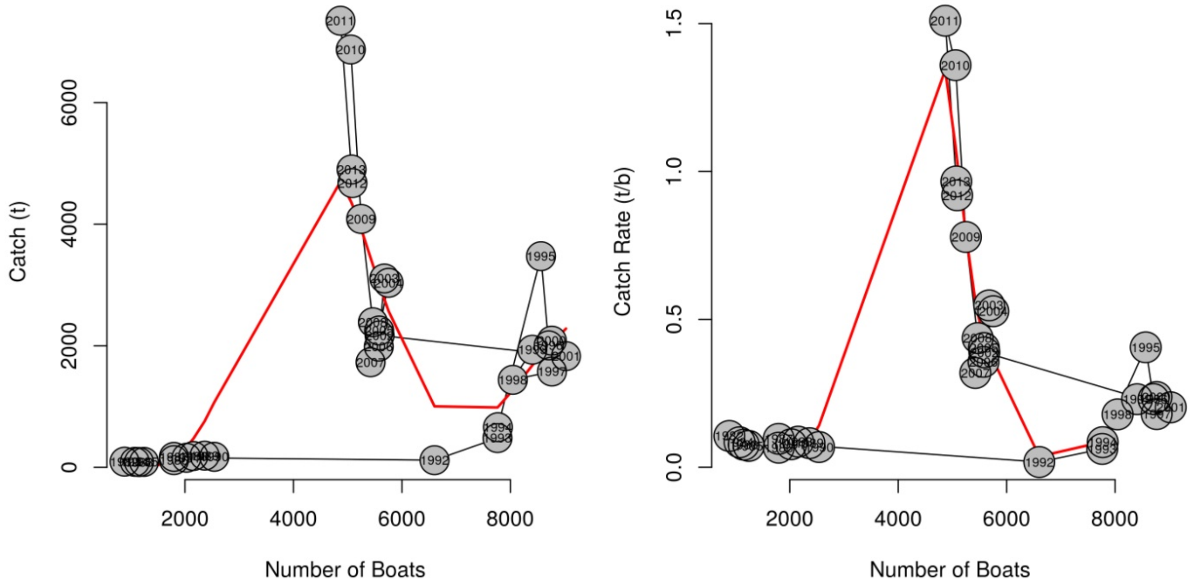

Figure 7 – Catch, number of boats and catch rate as calculated for Iranian boats which operates with ordinary gillnets. Years are indicated by the numbers inside filled gray circles. Red lines stand for a spline fitting, while black lines line link consecutive years.

3.2.1.3. Approach B.2

In the approach B. 2 the efficiencies of the boats were assumed to be equal, no matter the size of boat. Results of the calculations under approach B.2 are in Figure 8. Catch, effort (number of boats) and catch rates time series are continuous in the sense there are not jumps. The estimations had increased (or decreased) smoothly as year went by. Overall effort, catch and catch rate had increased until mid 2000's, decreased from 2005 to 2011, and increased again until 2013. Notice also that the catch rates are very low in the beginning of the time series. Once again this is an indicative that the catches were probably underestimated.

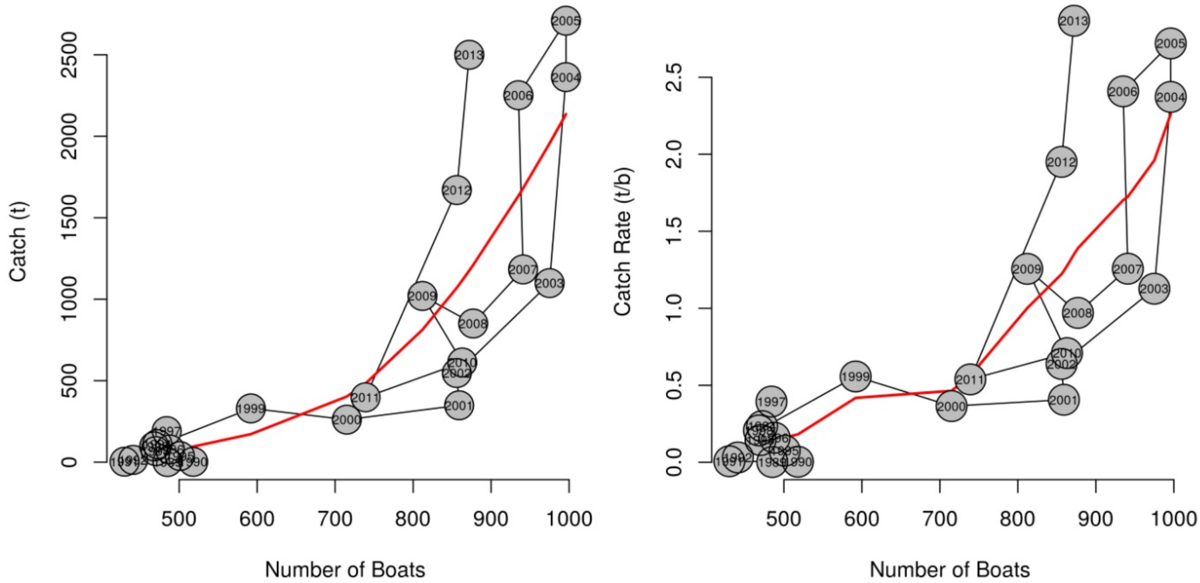

Figure 8 – Catch, number of boats and catch rate as calculated for Iranian boats which operates with offshore gillnets. Years are indicated by the numbers inside filled gray circles. Red lines stand for a spline fitting, while black lines line link consecutive years.

3.2.1.4. Approach B.3

If one assumes that only GIOF boat reports are valid as proxy of effort for all the Iranian fleet, the CPUE is calculated by dividing total catch (GILL + GIOF catches) by total number of boats (GIOF 50-100 GRT boats + GIOF > 100 GRT boats). Calculations are shown in Figure 9. Notice that two phases showed up separated by the year 2000. Before 2000 catches and effort were low, while catches and effort were relatively high after 2000. Catch rates were very low before 1994, but they were in general similar from the mid 1990’s until to 2008, while number of boats had experienced a twofold increase. In opposition, the number of boats did not change much after 2008, but catch rate had experienced a twofold increase. In general the slope of relationship between the number of boats and catches were positive before 2000, but slightly negative after 2000. Similar pattern appears in the scatterplot showing the relationship between the number of boats and the catch, though the slope was strongly negative after 2000.

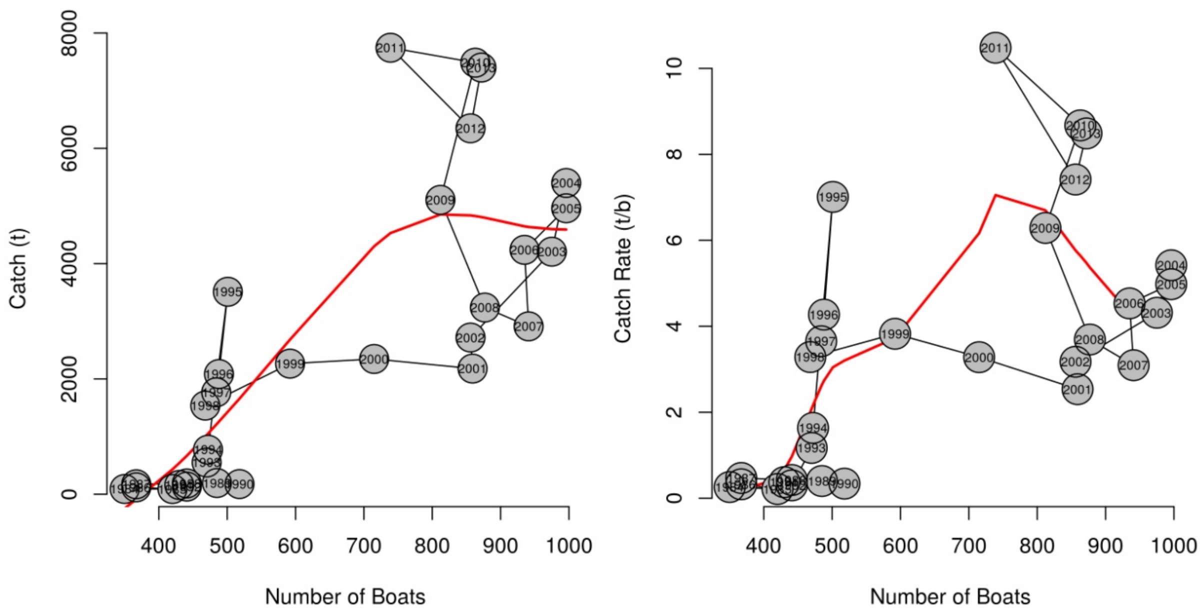

Figure 9 – Total catch of Iran, and number of boats and catch rate as calculated for boats which operate with offshore gillnets. Total catch Years are indicated by the numbers inside filled gray circles. Red lines stand for a spline fitting, while black lines line link consecutive years.

3.2.1.5. Approach B.4

Relative efficiencies of large GIOF boats (> 100 GRT) were higher than those of the intermediate size (50-100 GRT) in 2013 and 2014 as calculated using data of Table 1. Hence the assumption that the relative efficiencies of the boats were or equal is probably flaw, at least for the years in the end of the time series. One alternative is to assume that the relative efficiencies calculated based on 2013 and 2014 data holds for the entire time series. The efficiencies are then used to convert efforts and before they are summed to calculate the total "effective" effort (see Data and Analysis section). Here the proxy of effort is the number of boats. Original and effective numbers of boats are shown in Figure 10. Notice than if we assume that the efficiencies of the boats (50-100 GRT and > 100 GRT) are different, the estimations of effort after 2004 are much higher (red and blue lines) than those calculated assuming the efficiencies of the boats are very much similar (black lines) (Figure 10). Notice also that changes took place in recent years as intermediate size boats (50-100 GRT) have been replaced by large boats (> 100 GRT) since 2005.

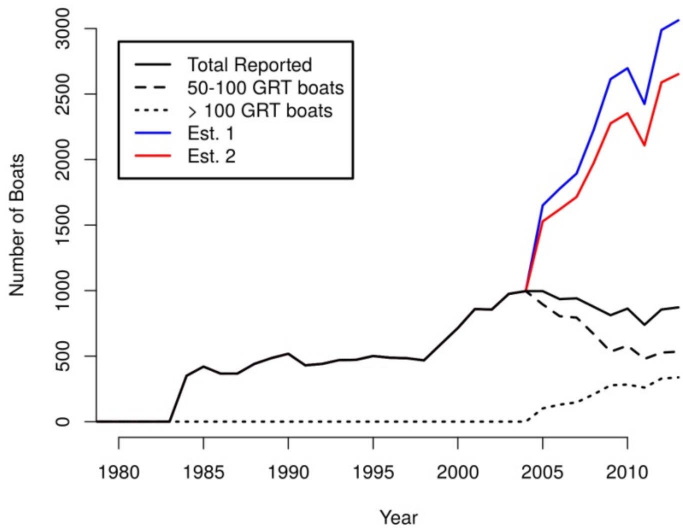

Figure 10 – Number of boats as reported in the IOTC databases (black lines), and effective number of boats as calculated relying in the estimations of 7.49 (blue line) and 6.27 (red line) relative efficiencies.

Relationships between catch, effective number of boats and catch rates are in Figure 11. Effort had increased continuously all across the years. Catches had increased until 2005, decreased in the end of 2000's, and increased very fast in the end of the time series. Sequential up and down time trends appear in the relationship between effective number of boats and catch. Similar pattern arise in the dispersion diagram showing the relationship between number of boats and catch rates. However, catch rate had increase faster than the catches in the very end of the time series.

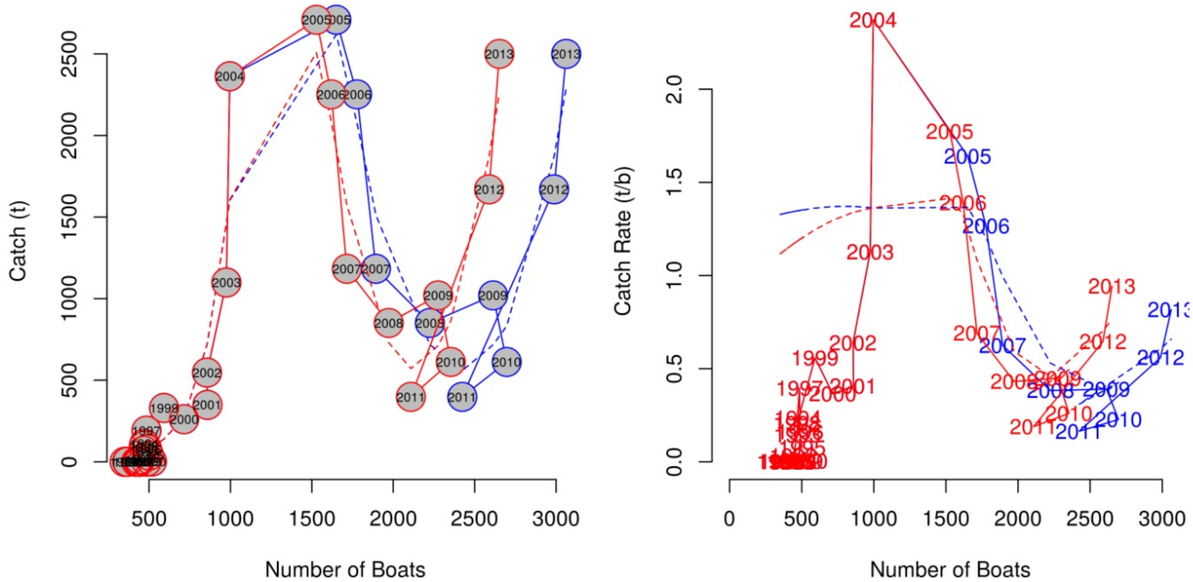

Figure 11 – Catch, effective number of boats and catch rate as calculated for Iranian boats which operates with offshore gillnets. Years are indicated by the numbers inside panels. Dashed lines stand for local regressions (spline – left panel; loess right panel). Calculations carried out using estimations of 7.49 and 6.27 relative efficiencies are shown in blue and red colors respectively.

Notice that catch rates in the beginning of the time series were very low or even zero (Figure 11) hence the hypothesis that catches and consequently catch rates were underestimated before mid 1990's arises. To reduce bias in the catch time trend would be of major importance. One simple alternative to be discussed in the future is to fit some local regression smooth line (e.g. loess) and to use the model to predict the catches for biased year timespan. The example is illustrated in Figures 11 and Figure 12. In the right panel of Figure 11 dashed lines stand for the loess model fitted to 2001 onwards. In the Figure 12 loess model predictions we used to calculate the "rebuilt" catch time series, by assuming the model is useful to predict the catches of year of the beginning of the time series.

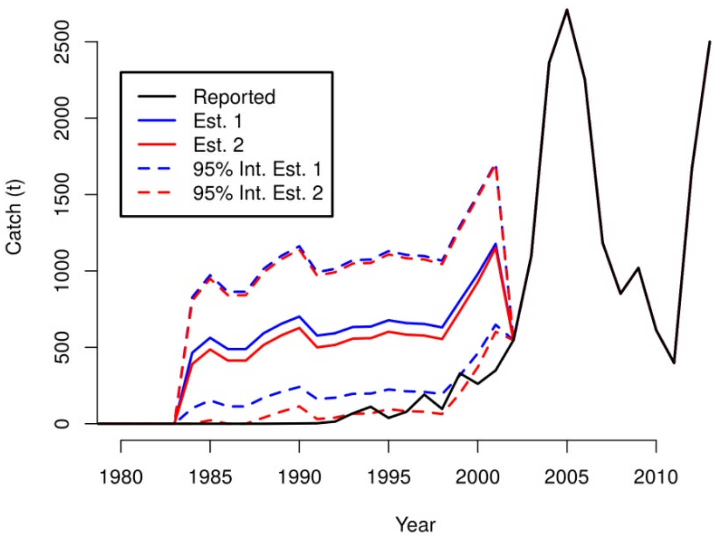

Figure 12 – Catches of Iranian boats which operated with offshore gillnets as reported in the IOTC dataset.

3.2.1.6. Approach B.5

In general the catches and the effective numbers of boats had increased continuously across the years (Figure 13). However the catch rates had decreased after 1995 hence negative relationship appears in the scatterplot showing catches and effect number of boats. Catch rates in the very beginning of the time series were low. As mentioned before the very low catch rates seem to be an indicative that the catches (and catch rates) were underestimated in the beginning of the time series. Results of the approach B.4 and B.5 were grossly similar after 2000, as both showed that catch rates had decreased in the last years. The main difference between the estimations calculated under approaches B.4 and B.5 is that the catch rate decreasing trend starts earlier (mid 1990's) when using approach B.5.

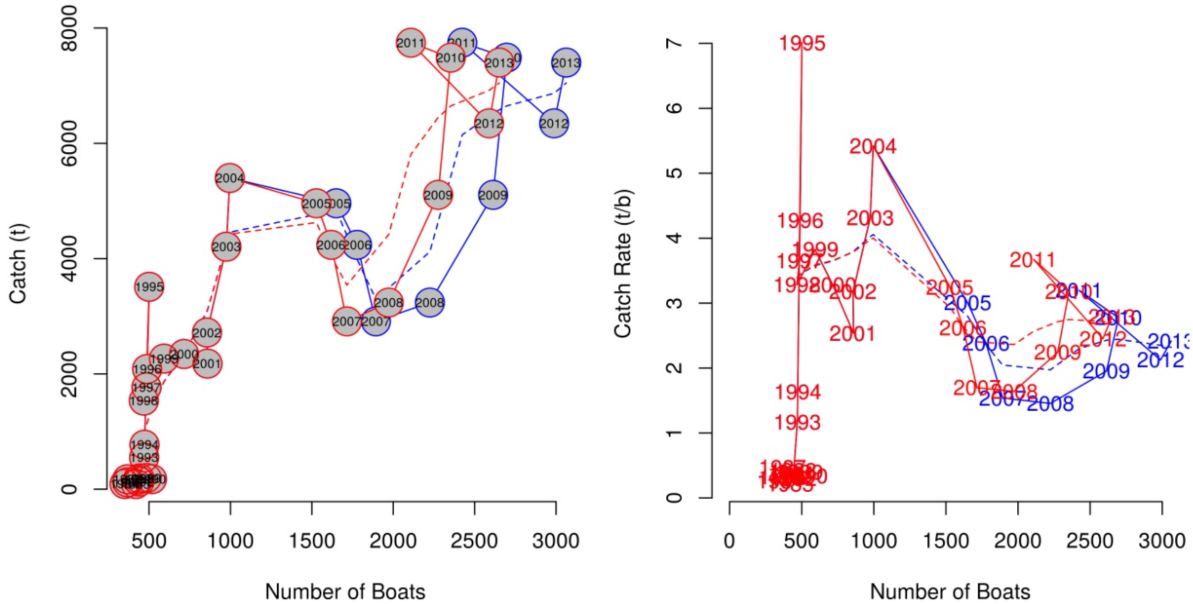

Figure 13 – Total catch (ordinary plus offshore gillnet), and effective number of boats and catch rate as calculated for Iranian boats which operates with offshore gillnets. Years are indicated by the numbers inside the panels. Dashed lines stand for local spline regressions. Only 1993 onwards data were used to fit the spline line showed in the left panel. Calculations carried out using estimations of 7.49 and 6.27 relative efficiencies are shown in blue and red colors respectively.

3.2.1.7. Catch rate time series

In order to make comparisons easier all the estimations for Iran are showed together in Figure 14. In this figure straightforward calculations based on the data as they appear in the IOTC database are in gray (approaches B.1, B.2 and B.3). Colored lines stand for calculations with “corrections”, as the relative efficiencies of the boats were took into account (approaches B.4 and B.5) and the years linked to very suspicious underestimations of catch were dropped off. In the example showed in Figure 14, years before 2002 were discarded when using approach B.4, and years before 1995 were discarded when using approach B.5. Overall the main difference between corrected and not correct approaches is that the formers showed decreasing time trends, while the later approaches resulted in increasing time trends or eventually in peaks and plunges in the end of the time series.

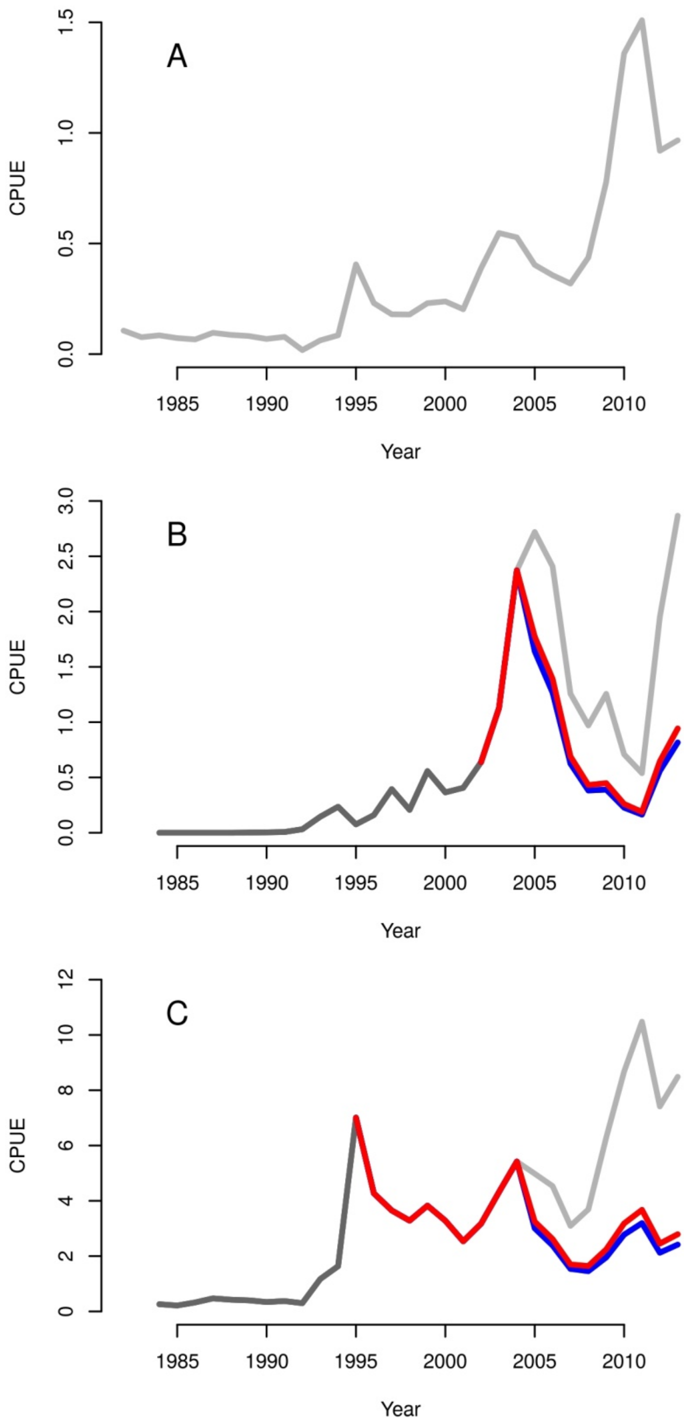

Figure 14 – Alternative estimations of catch per unit effort (CPUE) of Iran as calculated based on gillnet databases. A – approach B.1; B – gray line stands for approach B.2, while colored lines stand for the approach B.4 as calculated using two different estimations of relative efficiencies of boats (6.27 – blue, and 7.49 red); C – gray line stands for the approach B.3, while colored lines stand for the approach B.5 using the two estimations of relative efficiencies of the boats.

3.2.2. Oman

3.2.2.1. Preliminaries

In the IOTC database catches of SFA were reported for ordinary (GILL) and for offshore gillnet (GIOF) boats. However, there are not GIOF reports in the IOTC boat database. In addition, ordinary gillnet boats have been split into two categories according to their sizes (1-10 m LOA or 10-24 m LOA). For simplifying purposes those two categories of boats are just as “small boats” and “large boats” to simplify. In opposition to the Iran case, there is not information that sheds light on the relative efficiencies of the two boat categories of the Oman database. Even thought there are many alternatives to calculate CPUE because there are two catch time series and two time series of number of boats. Here I have considered three approaches: C.1) To assume that summation of all numbers of boats (1-10 LOA + 10-24 LOA) is a good overall proxy of effort. Hence CPUE was calculated by dividing the total catch (GILL + GIOF) by the total number of boats (1-10 LOA + 10-24 LOA); C.2) To assume that the number of small boats (1-10 m LOA) is a valid effort proxy of the part of the fleet whose catches were classified as GILL in the IOTC database; C.3) To assume that the number of large boats (10-24 m LOA) is a valid effort proxy of the part of the fleet whose catches were classified as GILL in the IOTC database.

3.2.2.2. Approach C.1

Catches had decreased from 1985 to 2000, while the number of boats had decreased in the same timespan (Figure15 – left panel). In 2000’s there catches, catch rates and effort were very much similar in six years (2001-2004, 2006 and 2007). Those similar years appear like a bunch of circles in the bottom of the scatterplots. Number of boats had remained lower than 15000 until 2009, but in 2010 close to 4800 boats were added up to the fleet, which continued to increase to reach more than 22,000 boats in 2013. In general catches were lower than 700 t until to 2008, but they had experienced a more than twofold increase. In the recent years catches were higher than 1,700 t. Time trend of catch rates was similar to the time trend of catches, though the catch rates did not increase as fast as catches after 2008. Overall there are distinct phases: 1985-2000 timespan in which catch, catch rates had decreased and effort had increased; 2001-2008 timespan in which there are several very much similar estimations; and 2009 onwards when the catches and effort had increased very fast. Some spline smooth lines fitted to different timespans appear in the left panel of Figure 15 to illustrate the conflicting time trends observed in the beginning and in the end of the time series.

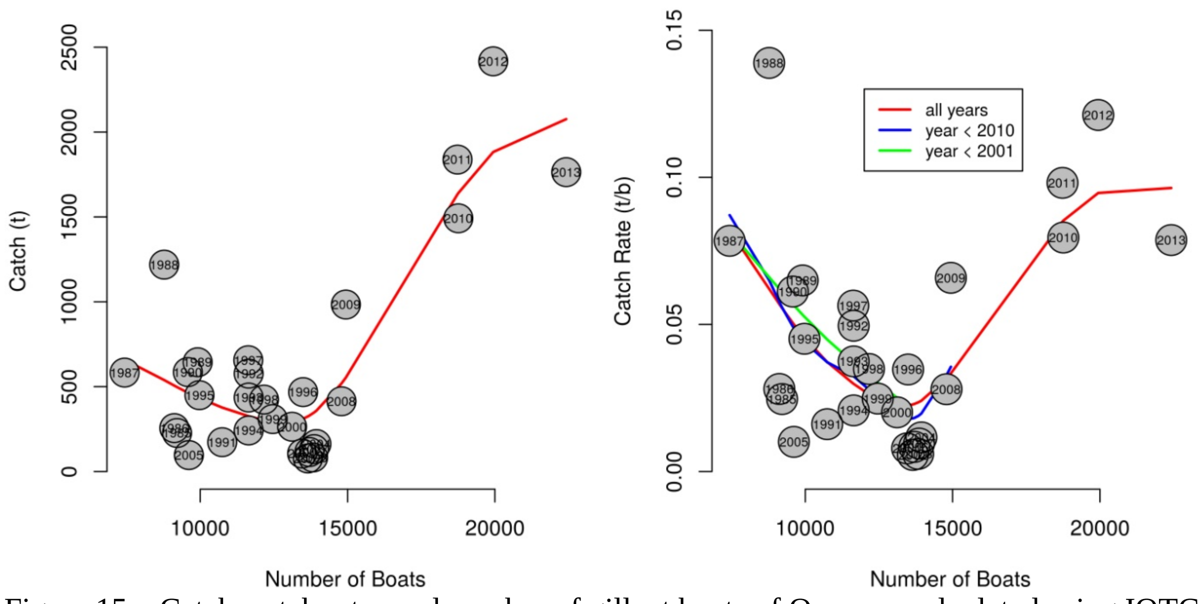

Figure 15 – Catch, catch rates and number of gillnet boats of Oman as calculated using IOTC database. Years are indicated by the numbers inside filled gray circles. Red lines stand for

spline smooth lines fitted to the complete time series, while blue and green lines stand for the spline fitted to years before 2011 and before 2001 respectively.

3.2.2.3. Approach C.2

In the approach only GILL catches and the number of small boats (1-10 m LOA) were used in the calculations. Results gathered using approach C. 2 were very similar to those of approach C.1 (Figure 15) hence they were not showed not clutter. The similarity arises because most of the catches were classified as GILL and because the numbers of small boats were more then 20 times higher than the numbers of large boats. Hence to look at GILL catches and small boats separated (approach C.2), and to look at all data aggregated (approach C.1) results in very similar calculations of catch, effort and catch rate time trends.

3.2.2.4. Approach C.3

Only catches classified as GIOF and only large gillnet crafts (10-24 m LOA) were analyzed. There are some discontinuities in effort, catch and catch rate time trends. The time series starts in 1985 with close to 550 boats, low catches (70 t) and low catch rates (close to 0.1 t/b). However, the catches had had a twofold increase in 1987, while the number of boats had decreased to approximately 440. Number of boats had increased fast from 1987 to mid 1990’s. However, after a twofold increase to 400 t in 1988, the catches had decreased and were close to 180 t until 1996, when more than 700 boats were reported. In the following year the number of crafts decreased very fast to approximately 400 boats. In general the number of boats and the catches were low from 1998 to 2008. However, both catches and numbers of boats had increased very fast in 2009 and 2010. Similarly the relationships between the number of boats and the catches, and the number of boats and the catch rates showed positive slopes. However, the correlations were weak due to the high variances, and the discontinuities in the time trend are of concern.

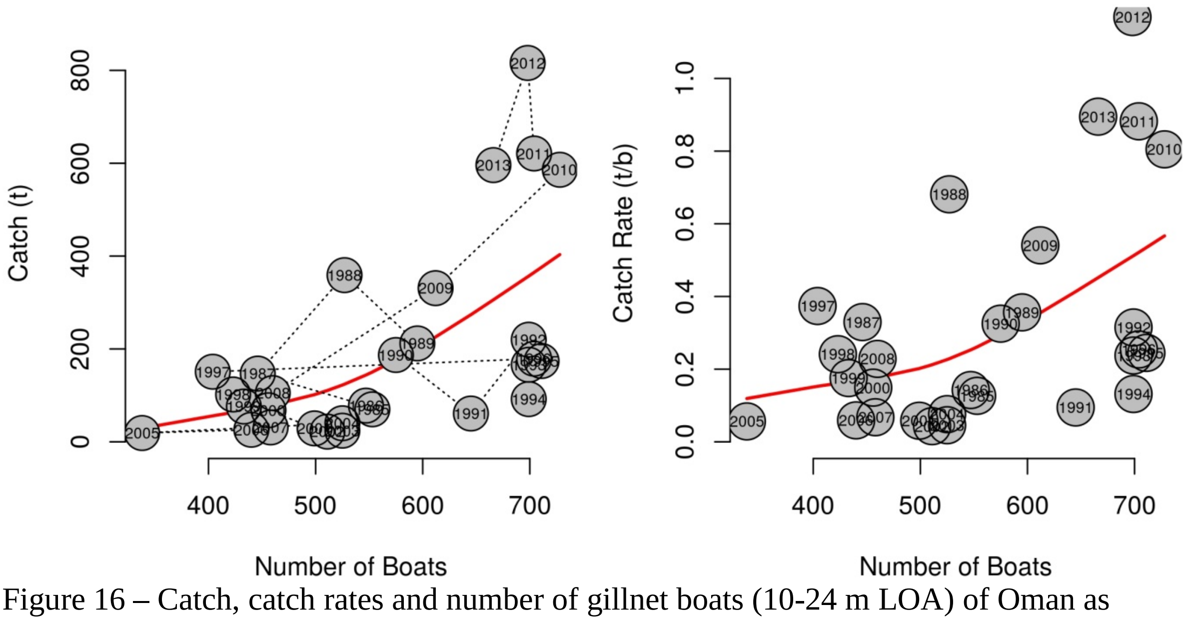

Figure 16 – Catch, catch rates and number of gillnet boats (10-24 m LOA) of Oman as calculated using IOTC database. Years are indicated by the numbers inside filled gray circles. Solid red lines stand for spline smooth, while dotted line in the left panel links consecutive years.

3.2.2.5. Catch rate time series

Estimations of catch rate time series of Oman are showed in Figure 17. Estimations were low in 1985 and 1986, but CPUE had increase fast peaking in 1988. After that CPUE had decreased fast until 1991. Oscillatory variations took place in 1990's. In the 2000's CPUE values as well as the variance were vey low, at least until 2007. After this year CPUE had increased fast. Different tones are used to indicate the three different phases concerning relationships between catch, effort and catch rates across the years (see also Figure 15 and Approach C.1 section above).

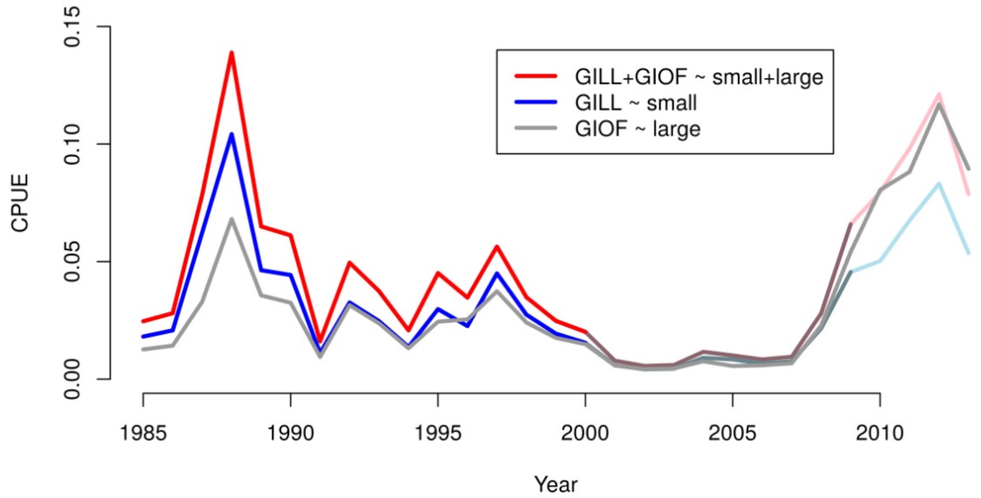

Figure 17 – Catch per unit effort (CPUE) as calculated based on Oman database. Red and reddish lines stand for calculations with total catch (ordinary gillnet GILL + offshore gillnet GIOF catches), and total number of boats (1-10 m LOA small + 10-24 m LOA large). Blue and bluish lines stand for calculations based only in GILL catches and small boats, while gray lines stand for calculations based only in GIOF catches and large boats.

3.2.3. Pakistan

There are just one gillnet catch time series (GILL) and only one gillnet boats category (35-50 t GRT) in the IOTC databases. Therefore main alternative to calculate catch rates is simple divide the GILL catches by the number of boats as they appear in the databases. Results are showed in Figure 18. In general the number of boats had increased in a regular pace all across the years. The same is true for the catch from 1982 to mid 2000's. However, catches had experienced a fivefold increase in the end of the time series. Catch rates were regularly close to 0.6 before 2008, though 1982 was an exception. Likewise the catches, also the catch rates had increased very fast in the end of the time series.

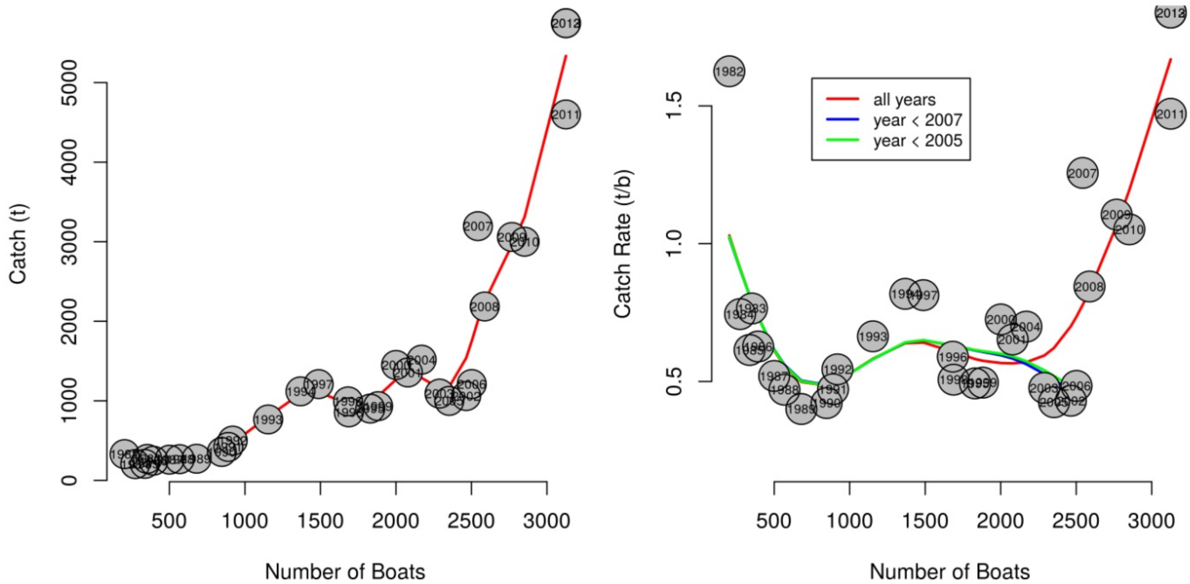

Figure 18 – Catch, catch rates and number of gillnet boats of Pakistan as calculated using IOTC database. Years are indicated by the numbers inside filled gray circles. Red lines stand for spline smooth lines fitted to the complete time series, while blue and green lines stand for the spline fitted to years before 2007 and before 2005 respectively.

Catch rate time series estimated is showed in Figure 19. The estimation of 1982 was remarkable high if compared to the other estimations of 1980's. However the CPUE had decreased continuously in a regular pace from 1983 to 2006. After this year the CPUE had increased very fast. Black and gray tones lines stand for different phases concerning relationships between catch, effort and catch rates across the years (see Figure 18 and comments in the beginning of the section).

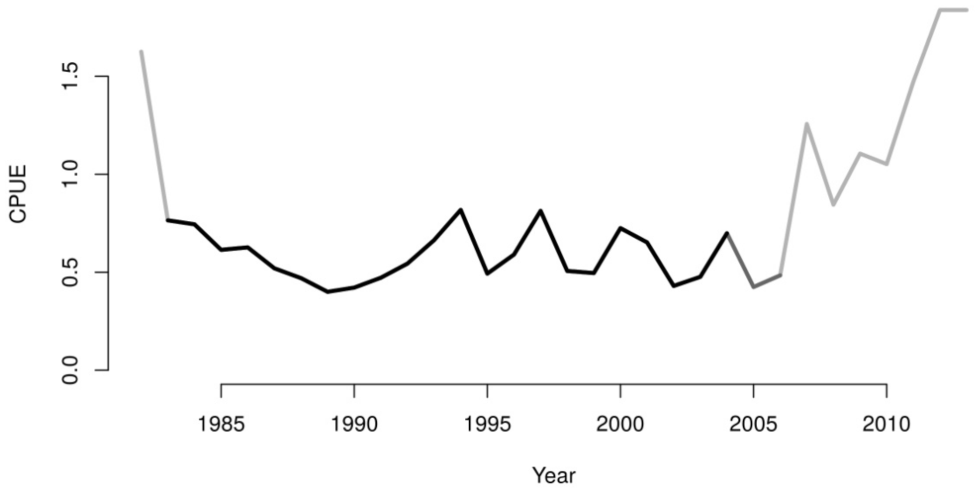

Figure 19 – Catch per unit effort (CPUE) as calculated based on Pakistan database. Black and gray lines indicate the different phases.

3.2.4. Sri Lanka

Sri Lanka fleet is a particular case as it only operates gillnets attached to longlines (GL). In the IOTC databases there are reports of GL catches only and of GL boats only. Catch rates, catch and effort time series are showed in Figure 20. Overall the catches were low (< 550 t) from 1982 to 1991. However, the catches had increased fast after 1992. In general the catches were close to or higher 2,200 t after 1999. The numbers of boats were between 1000 and 1500 in the very beginning of the time series. After 1993 there were a slight increasing trend, but and approximately 1500 have been operating from 1994 to 2005. Number of boats has increased since then, in a fast pace from 2005 to 2006, in a moderate pace from 2007 to 2010, but again in a fast pace from 2010 to 2011. In the very end of the time series the number of boats (approximately 4,000) did not change much. Catch rate was lower than 0.5 t/boat from 1982 to 1992, but it had experienced a threefold increase in the following years. In the 1993-2005 time span the catch rate was approximately 1.5 on average, but it had decreased fast in the following years to reach close to 0.5 t/boat in the end of the time series. Two phases appear in the scatterplots showing the relationships between the number of boats and catch, and between the number of boats and catch rates. The threshold between the phases seems to be the in the early or in the mid 1990’s. Catches and catches rates were low in the first phase. In the beginning of the second phase catches and catch rates were high, an in the following years catches have remained high while catch rates have decreased. To illustrate the phases the differences between the two phases smooth spline regressions fitted to different timespans are showed in left panel of Figure 20.

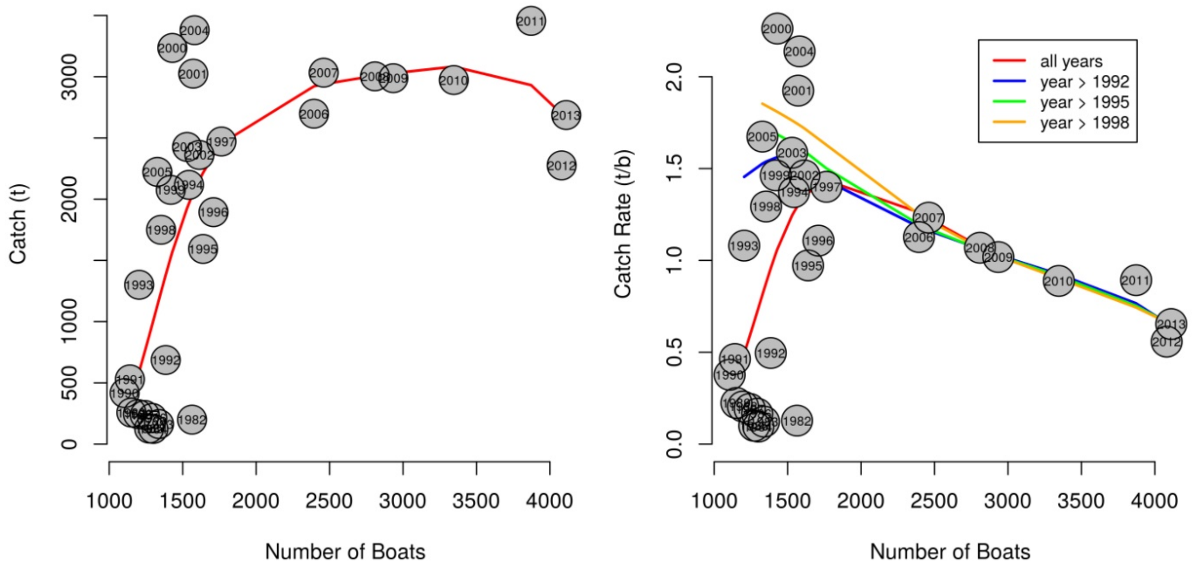

Figure 20 – Catch, catch rates and number of boats of Sri Lanka which operated gillnets attached to longlines as calculated using IOTC database. Years are indicated by the numbers inside filled gray circles. Red lines stand for spline smooth lines fitted to the complete time series, while blue, green and orange lines stand for the spline fitted to years after 1992, 1995 and 1998 respectively.

Catch rate time series is showed in Figure 21. Overall catch rates were low before 1990, but they had increased fast until 1994. After this year the estimations of CPUE did not change much until 1999. However, the estimation of 2000 was much higher than in 1999, and then the CPUE had decreased in a fast pace until the end of the time series. Once again black and gray tones lines stand for different phases concerning relationships between catch, effort and catch rates across the years (see Figure 20 and comments in the beginning of the section).

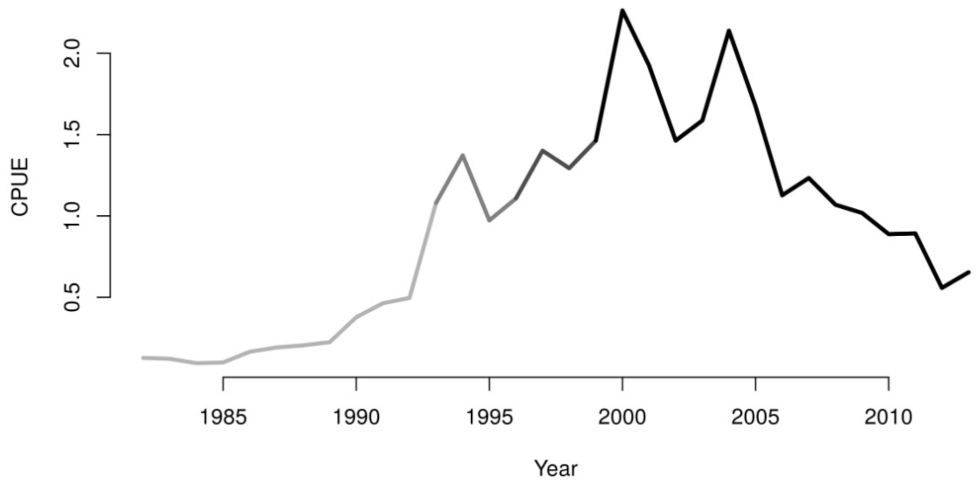

Figure 20 – Catch per unit effort (CPUE) as calculated based on Sri Lanka database. Black and gray lines indicate the different phases.

4. Discussion

The available dataset concerning SFA proved indeed to be very limited by now. Most of SFA have been caught by fishermen which operates ordinary and offshore gillnets, or even mixed gear combinations of gillnet and longline. Catches of boats which operate handlines, specially troll lines, were also high in last decades. However the only available data concerning gillnets and handline fleets are approximate estimations of catches, and historical reports of the number of boats. In addition there are some complications because the gear categories appearing the catch and in the boat databases does not match in all years for some contracting parties. For example, part of the SFA caught by Oman was assigned to offshore gillnet boats, but such there are not reports of the number of boats of this type in the IOTC database. The problem mentioned above is just an example among several other that arose when carrying out the analyses showed in this paper. Hence several assumptions were necessary in order to advance. In this sense all the calculations showed here might be considered as tentative results. However, it is important to highlight that some of the assumptions probably holds, like that catches were underreported in the very beginning of the time series, or that huge increase (or decrease) in the number of boats from one year to another indicate is not reliable. Therefore, calculations underpinned by such assumptions may be useful to amplify the knowledge about SFA stock(s).

The additional “s” between brackets in the end of the previous paragraph was to call the attention to the crucial issue concerning stock structure. The very first attempts to carry out a stock assessment analyzes for SFA took place recently (Anon, 2014 b; Anon, 2015 b; Andrade, 2015). Hence discussions on issues concerning stock structure and stock assessment are only in initial phase. Catch rate might be calculated and interpreted in the light of what we know about stock structure, however, this is an open question despite single stock hypothesis was assumed in the initial analyses.

In this paper were estimated catch rates for Iran, Pakistan, Oman and Sri Lanka fleets. Iran, Pakistan and Oman are nearby each other, and all of them probably fishes mainly in Gulf of Oman and Arabian Sea, which are crossed by the 24ºN latitude. Hence catch rates as estimated based on those three countries databases very likely concern the same SFA stock.

Sri Lanka is not that close of Arabian Sea. Sri Lanka lies close to equator (~ 7°N). It is bathed by Laccadive Sea and it is in south of Bay of Bengal. In spite Sri Lanka is relatively far from the other three countries, the hypothesis that all the four catch rate estimations concern the very same stock is reasonable given: a) highly migratory behavior of billfishes in general; b) the Indian Ocean oceanographic current system; and c) data of different sailfish tagging programs which indicate it carries out long migratory movements (e.g. Hoolihan, 2004; Prince et al., 2006).

The catch rates calculated for Pakistan and Sri Lanka, one of the time series calculated for Iran, and one series calculated for Oman are showed together in Figure 21. The four time series were divided by their means in order to make comparisons easier. In spite of conflicting signals had showed up in some years, three of the time series (Iran, Sri Lanka and Pakistan) similarly showed an overall decreasing time trends across the years in the 1995-2013 timespan. Before 1994 there are only estimations for Oman and Pakistan, and those two time series are very conflictive. All the results showed here might be carefully considered given this was the very first attempt to estimate catch rate for SFA. The usefulness of the number of boats as proxy of effort and the assumptions underpinning the calculations deserve attention and should be further investigated in the future. However, the similarity of 1995-2013 time trends of catch rates as calculated for three different countries is encouraging. Maybe all the three estimations are pointing for the wrong solutions, but at first glance they seem reasonable taking into account that catches were estimated to be high in the last years (ANON, 2014 a).

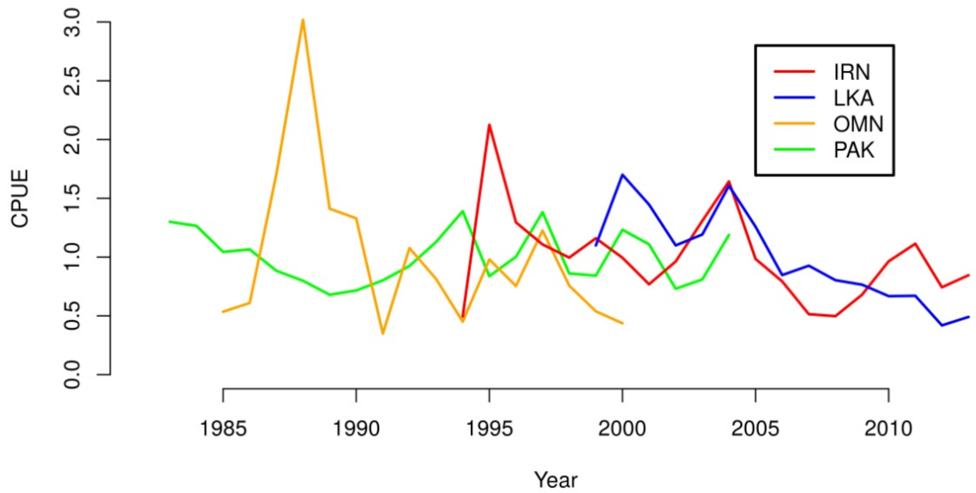

Figure 21 – Scaled catch per unit effort as calculated based on IOTC databases: Iran – IRN, Sri Lanka – LKA, Oman – OMN, and Pakistan – PAK.

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