Worldwide results of tropical tuna tagging : half a century of recoveries

Comparing results obtained in the Indian ocean and in other areas

By Alain Fonteneau and Jean-Pierre Hallier

Our deep aknowledment are given to SPC and IATTC for the tagging data that they have kindly provided and their full scientific support in the preparation of this work. They are also given at a personal level to Kurt Schaefer and Bill Bayliff from the IATTC, for their valuable advice in the preparation of this conference

A comparison of results obtained by dart tag tagging programs done world wide on tropical tunas

Yellowfin
Thunnus albacares

Skipjack,
Katsuwonus pelamis

Bigeye
Thunnus obesus

Data & goals of this work

- Tagging has been commonly used since the fifties in many studies of tropical tuna stocks, and these results have been commonly used by scientists at various regional scales
- However, global comparisons done at a worldwide scale between the results of these tagging programs have been very seldom conducted
- This work will target:

 A global comparison & synthesis of the world wide tagging and recoveries files of tropical tunas, in the today context of increasing fisheries.

 This work will be limited to a comparison of **basic data & results**, for instance concerning apparent **movements & growth** of tropical tunas, without any attempt to use complex models that have been often used in their analysis (for instance to study migration, growth, natural mortality or exploitation rates)

 The main parameters associated to the various tagging programs done world wide, such as reporting rates, shedding rates, mortality due to tagging, will be simply compared and discussed.

 One of the primary goals being **to compare the activities & results of the recent IOTC tagging program with the results obtained by similar programs**

 Its conclusion will discuss the scientific interest & optimal conditions of future tropical tuna tagging programs.

Dart tags & tuna tagging: introduction & overview

- **Dart tag tagging**: tagging has been traditional method used to tag animals for centuries. Tagging with dart tags has been widely & increasingly used by all tuna RFOs during the last 60 years…
- A method now in tough competition with modern **electronic tagging**
- Electronic tagging, a technological concept born in 1986, actively developed since the early nineties, have been producing a new & fascinating behavioural dimension to tuna tagging results obtained from these tags
- However, **large scale tuna tagging programs using "conventional dart tags"** remain essential today, because of their **multiple potential results that are still unique today and essential for all tuna stock assessments** : for instance concerning growth (by sex), natural mortality as a function of age & sex, population size and exploitation rates at age, etc..
- As most electronic tagging results remain widely scattered and confidential so far, this presentation will be limited to the results of dart tag programs developed worldwide by the various tuna commissions and in relation with results & data that are needed in their stock assessment analysis.

Data made available and used in this work

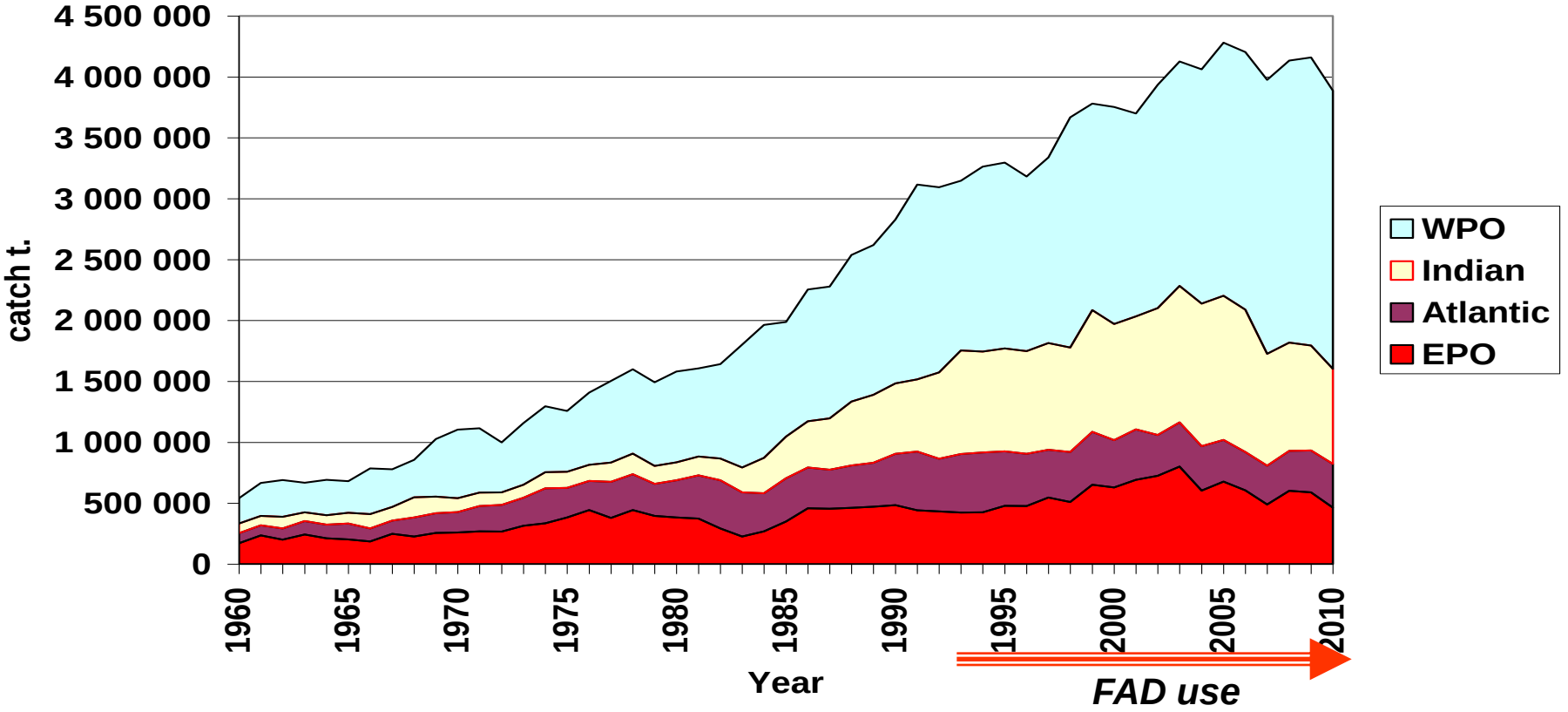
- This presentation will compare the main results obtained by the IOTC tagging programs and by similar tagging done in the other oceans, based on the recoveries of tagged tunas.
- All tagging and recovery data have been provided by the 4 tuna RFOs & bodies: IATTC, ICCAT, IOTC & SPC.
- Yearly tagging data cover the period 1960-2010 for all RFOs
- Recovery data cover the 1960-2011 period in the Atlantic and Indian oceans, and only the 1960-2006 period for the Pacific ocean obtained from SPC and IATTC (as recent tagging results are still analyzed by scientists and kept confidential)
- This data set corresponds to a large majority of tuna tagging & recoveries obtained world wide by scientists, keeping in mind that some tuna tagging done at a national or sub regional levels may be missing from this data base provided by the tuna RFOs (for instance by Japan, Hawaii, Australia and other countries).
- The **recovery data** are the main source of comparative analysis in the work done.
- Basic statistics of catches by 5° squares and catch at size have been also obtained from the various RFO WEB sites and also used

Tagged tunas: recaptured, recovered and reported

- Tagged fish can be recaptured, but the tag won't necessarily be recovered, as it may fall off the fish when the boat is at sea, or doing unloading, and be lost.
- If it is recovered: but it won't necessarily be returned or reported by the fishermen, stevedores or canneries. This is for instance the case for longline catches: most tagged tunas are well identified, but many tags recovered by longliners are not reported to scientists.
- The word "recoveries" in this talk will corresponds to tags that returned and reported.

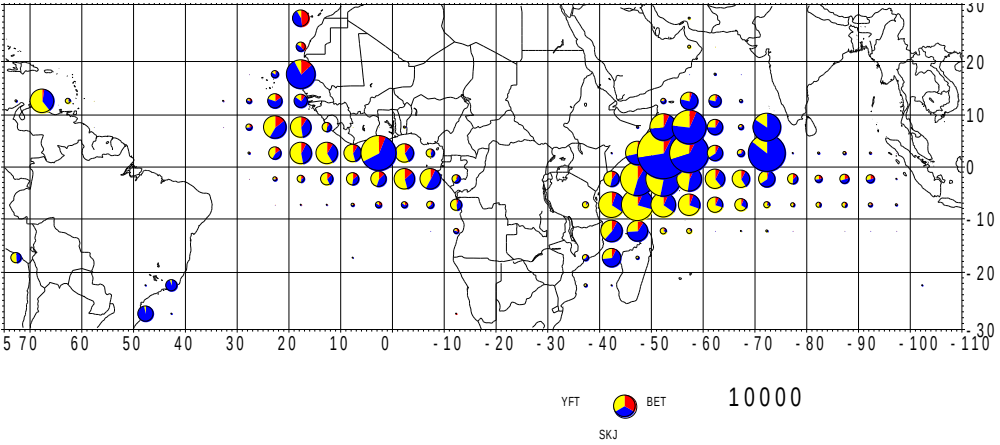
- **Errors in recovery files:** it should be kept in mind that all these recovery data still contain a significant percentage of errors, for instance in the dates of recoveries, in the size and species tagged or recovered, in the fishing location, etc.
- **Species identification** at tagging and at recovery has been often observed in all recovery files & especially for small yellowfin and small bigeye that are quite difficult to identify (for scientists & fishermen alike)
- The amount & types of these errors appear to be variable between files; these potential errors have been sometimes identified and recorded in the basic files (IOTC & SPC).
- The present work will try to identify and to eliminate these errors in the recoveries. This work will be done on a case by case basis, using similar rules in the 4 oceans, always based on a sub sample of the tagging results after a selection of a sub set of results.
- **Shedding rates: an** important parameter that has been estimated in most tagging programs, a question discussed but based on the literature
- **Reporting rates of tags:** a very important parameter, cannot be estimated world wide from the presently available data. This point will be briefly discussed but mainly based on the literature. Reporting rates of tags by longliners and by purse seiners will be examined on a semi quantitative basis, according recoveries and catches of large YFT & BET reported by these 2 fisheries.

Trend in fisheries: Yearly catches of tropical tunas by ocean, 1960-2010

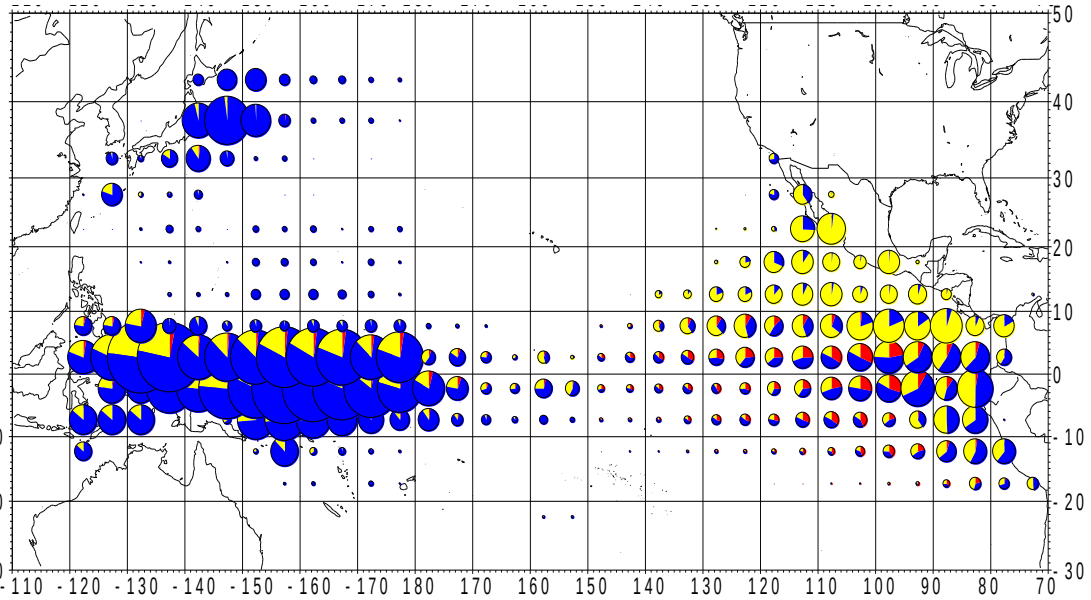


- Tropical Tuna stocks: Increasing catches & Increasing exploitation rates of most stocks.
- Today stock assessments by RFOs indicate that they are close to be overfished or moderately overfished;
- Major use of FADs by PS since 1994: today 35% of tropical tuna catches caught on FADs.
- Declining catches noticed for some stocks since 2005.
- Subsequently increasing & deep need to obtain fully reliable stock assessment analysis, based on realistic tuna models: using realistic stock structure, growth and natural mortality by sex and age, and also realistic population sizes & exploitation rates, at least at some age.

Fishing zone of surface fisheries: average catches by species of surface fisheries during recent years (1996-2006)



- ✓Total catches by area are widely dominated by catches between 20°N & 15°S
- ✓Assymetrical fisheries in the Atlantic (dominated by Gulf of Guinea catches) and in the Indian ocean (dominated by Western IO)
- ✓Continuous fisheries in the equatorial Pacific, but more important in the Western than in the Eastern Pacific, few fisheries in the central areas
- ✓Significant Northern fisheries in the N East Atlantic & off Japan.

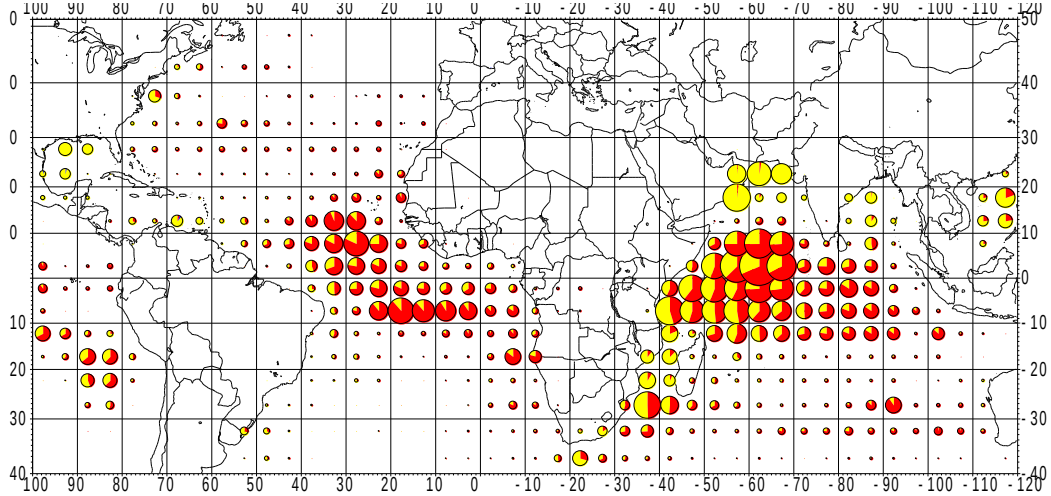


YFT BET

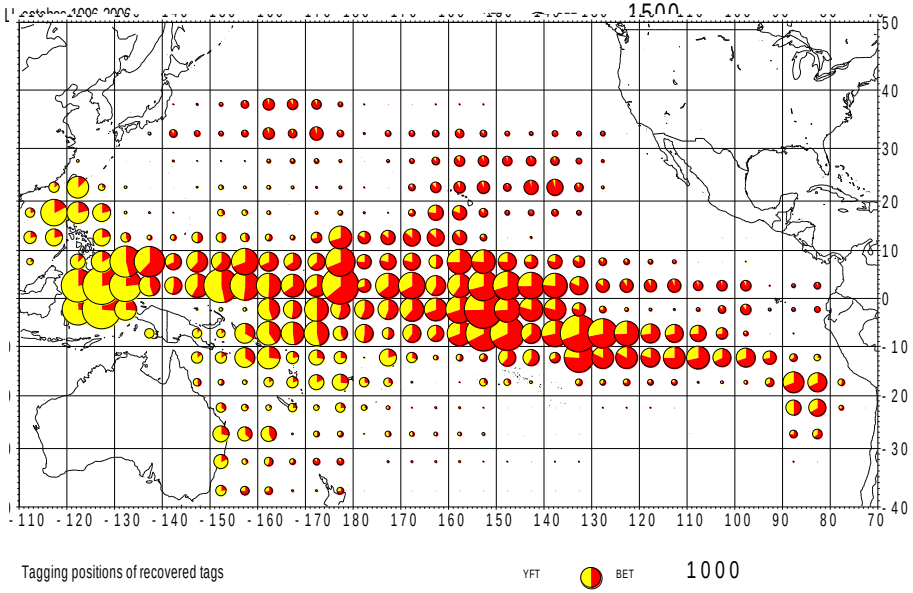
SKJ

10000 t.

Average catches by species of longline fisheries during recent years (1996-2006)



15°N-15°S areas:
Period 1980-2006,
An average of 73% of YFT catches & 80% of BET catches

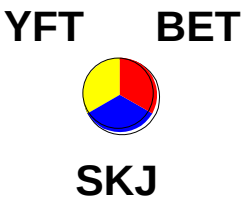


- Catches of tropical tunas targeting adult YFT & BET are taken in much wider latitudinal areas, often reaching 50°N and 40°S
- But total catches of longliners are much higher in the intertropical areas between 15°N & 15°S, due to higher fishing efforts & to higher sustainable CPUEs

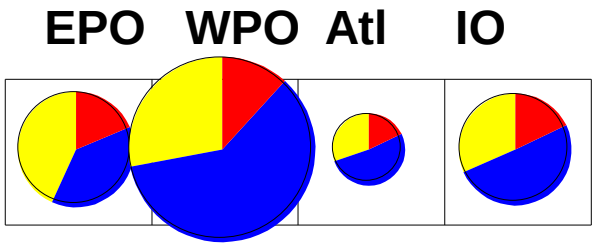
Statistical overview of tropical tuna tagging done world wide 1960-2010
1.4 million tags deployed & over 180.000 tags recovered

	YFT	SKJ	BET	Total Tags
Releases	380 636	914 838	159 670	1 455 144
Recoveries	49 079	94 835	38 113	182 027
% recoveries	13	10	24	13

Tagging

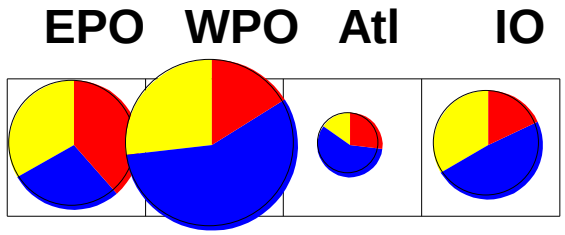


Deployments /ocean	YFT	SKJ	BET	Total Tags
Eastern Pacific	109 487	131 227	39 618	280 332
Western Pacific	170 713	620 148	63 780	854 641
Atlantic	25 299	43 448	14 864	83 611
Indian Ocean	75 137	120 015	41 408	236 560
Total	380 636	914 838	159 670	1 455 144
%	26,2	62,9	11,0	100,0



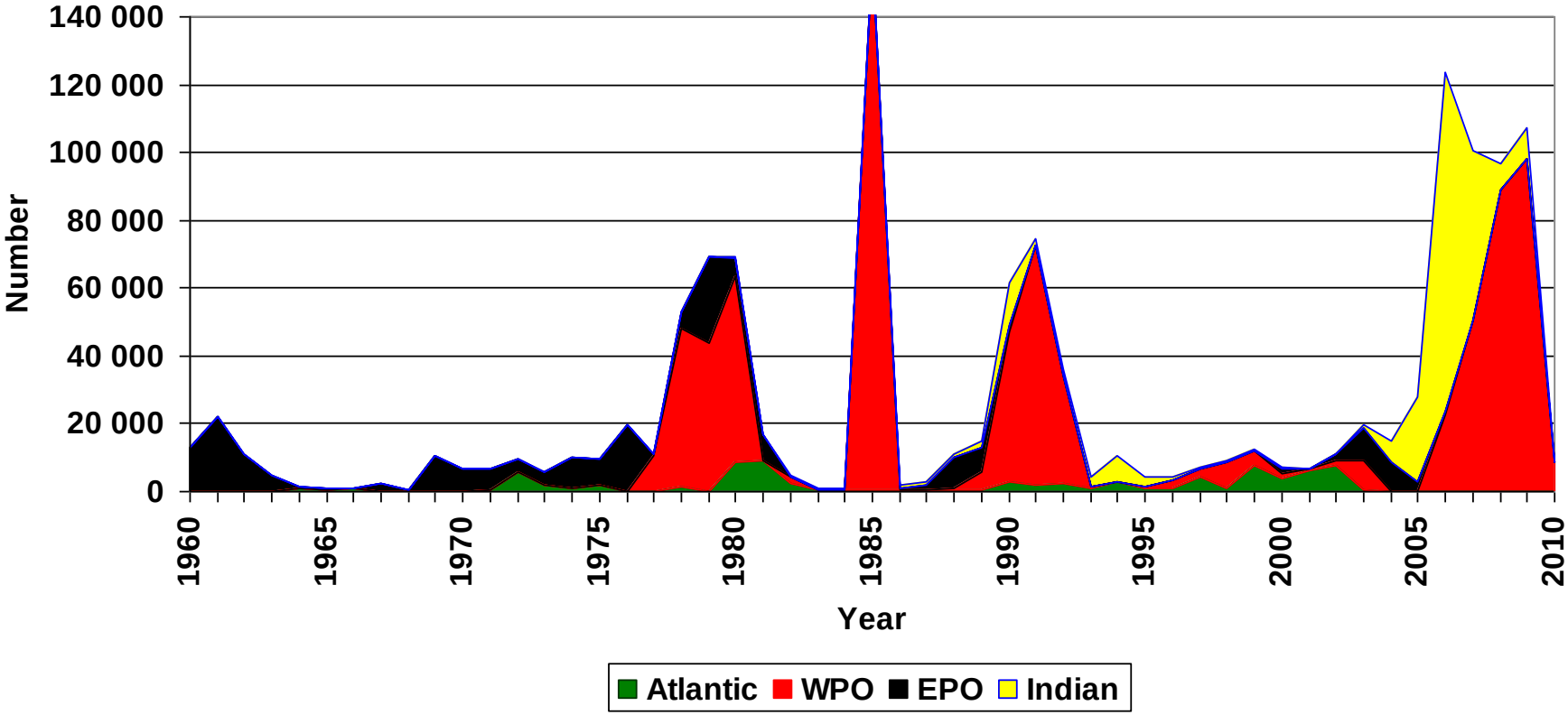
Recoveries

Recoveries /ocean	YFT	SKJ	BET	Total Recov.
Eastern Pacific	15 429	13 294	16 921	45 644
Western Pacific	21 303	57 456	12 487	91 246
Atlantic	1 744	6 607	3 086	11 437
Indian Ocean	10 603	17 478	5 619	33 700
Total	49 079	94 835	38 113	182 027
%	27,0	52,1	20,9	100,0



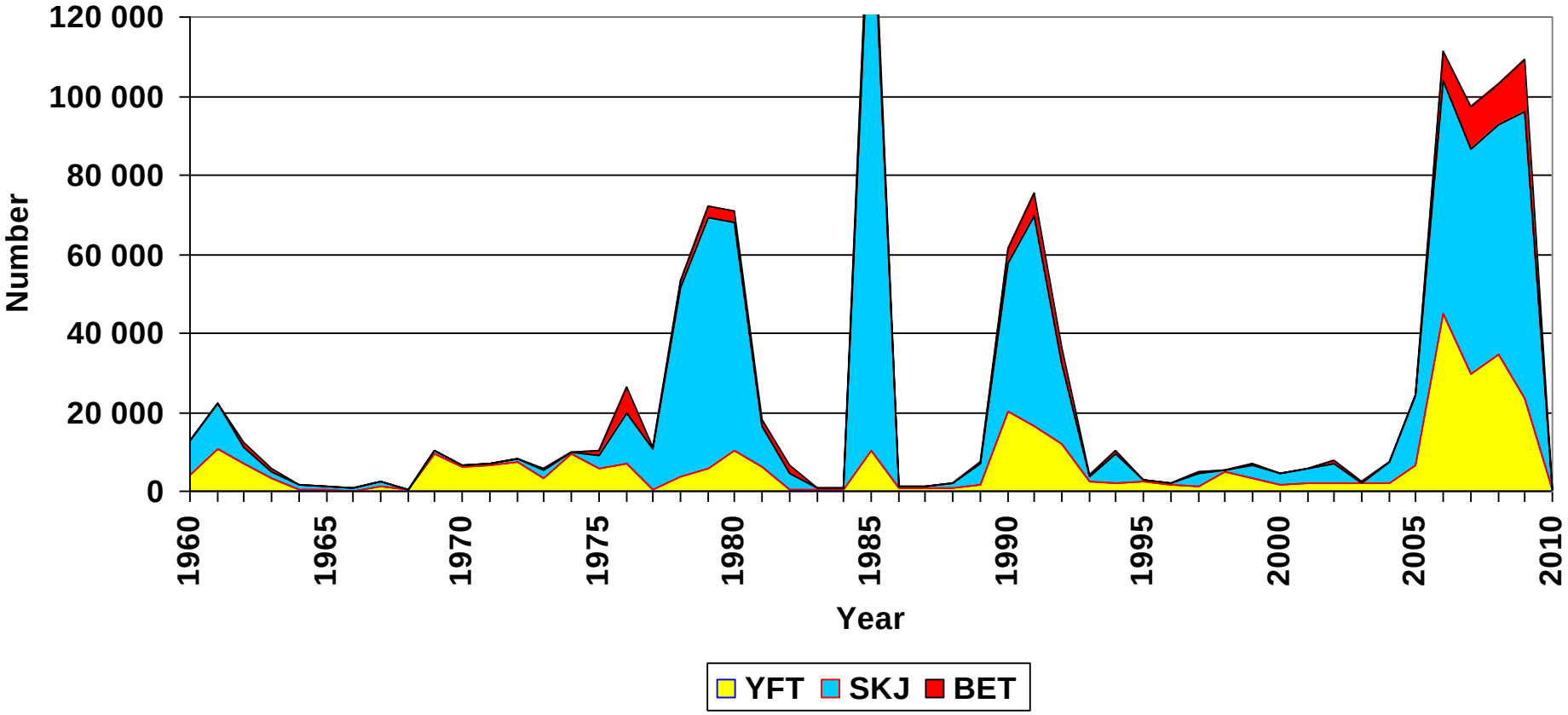
- Western Pacific showing by far the larger numbers of tagged tunas: about 850 000
- EPO and IO showing similar totals, >200 000 tunas tagged,
- Atlantic: quite low numbers of tags released, only 83 000, but much smaller area & stocks

Tropical tuna tagging done world wide: numbers of tunas tagged yearly in each ocean/area



- EPO area mainly showing historical IATTC tagging 1960-1980, very limited afterward
- WPO showing 4 large scale tagging programs since the late seventies (SPC tagging)
- Atlantic showing few & scattered tagging since the early seventies
- Indian Ocean: Maldivian SKJ tagging in the early nineties & major tagging during recent years: period 2005-2008

Numbers of tunas tagged world wide yearly by species



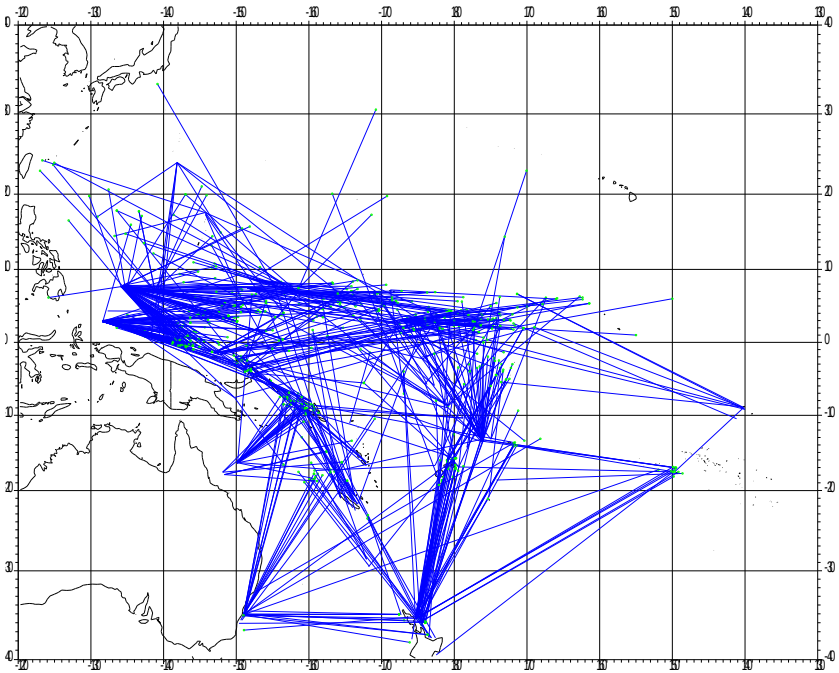
-SKJ has been always the dominant species in tagging programs, being easily fished and tagged in great numbers: 62 % of tropical tuna tagging (This conclusion being valid in the 4 areas).

-YFT tagging corresponds to 26 % of tags, and BET to only 11 %.

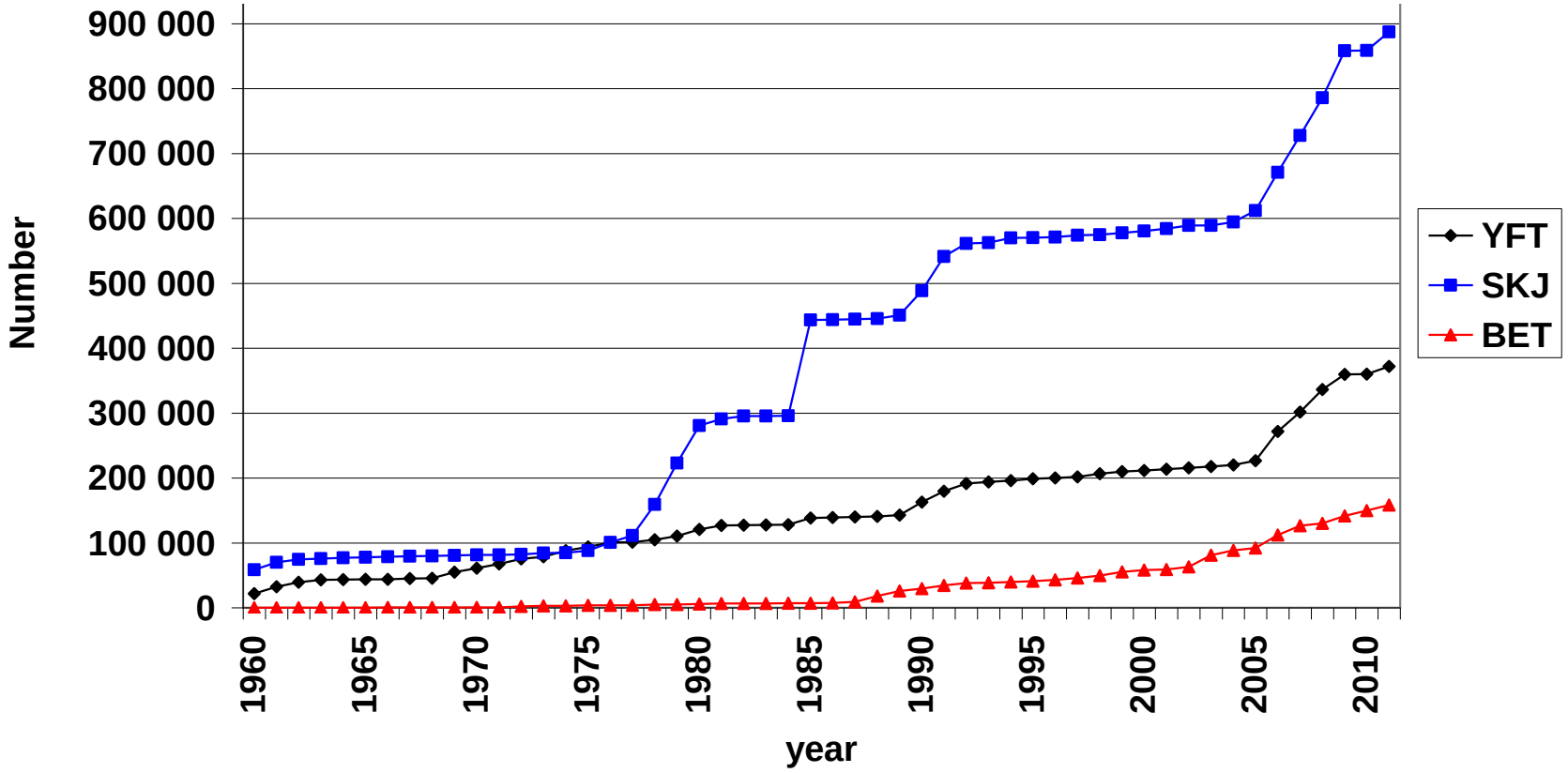
-YFT was the dominant species until the mid seventies (dominated by IATTC tagging)

1977-1980 Skipjack Survey & Assessment Program (SSAP) by SPC : the first large scale intensive & oceanic wide tagging program planned in the Western Pacific

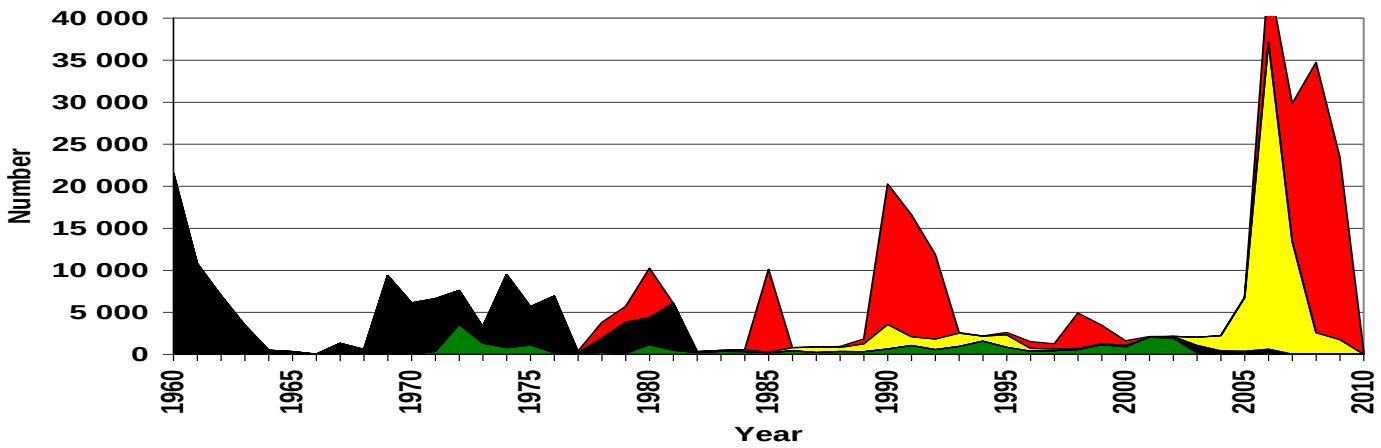
- A very well planned & well ran large scale tagging program
- Mainly targeting SKJ (145.000), but also significant numbers of YFT tagged (10.000), but no BET (only 60!)
- A large tagging programme allowing to show SKJ & YFT movements and to demonstrate the very low exploitation rate of the SKJ stock (a total catch of only 400.000 t. in 1980 , & today SKJ catches over 1.5 million t.)



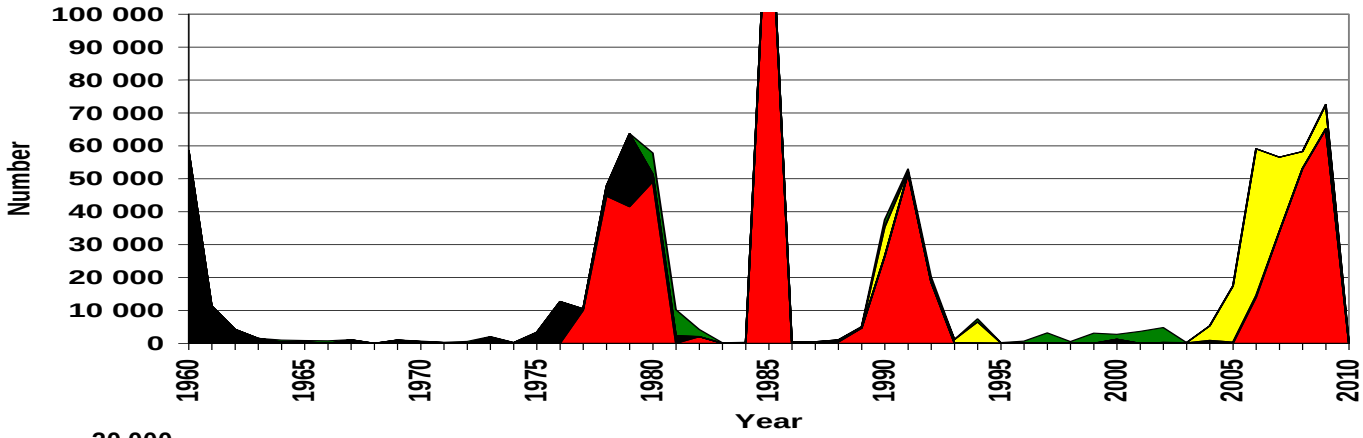
Cumulated numbers of tags released worldwide by species



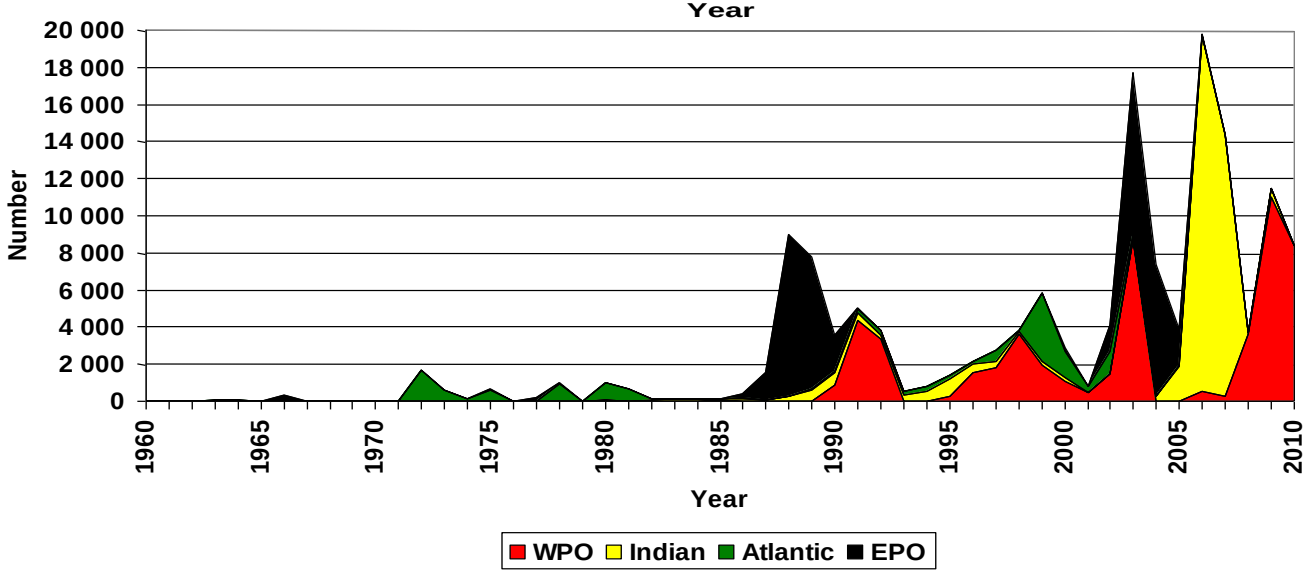
- Quite different historical patterns of numbers of tags released for the 3 species:
- SKJ: a long history of active tagging: IATTC since 1952, SPC 1977 , ICCAT 1981, IO 1990
- YFT: tagged & recovered in significant numbers by the IATTC since the fifties, and later by all the other tuna bodies, but in smaller numbers
- BET significantly tagged & recovered only since the late eighties; BET remains today the « less tagged tuna species » in all oceans & world wide.
- 21th century tagging have been targeting the 3 species



Yellowfin tagging



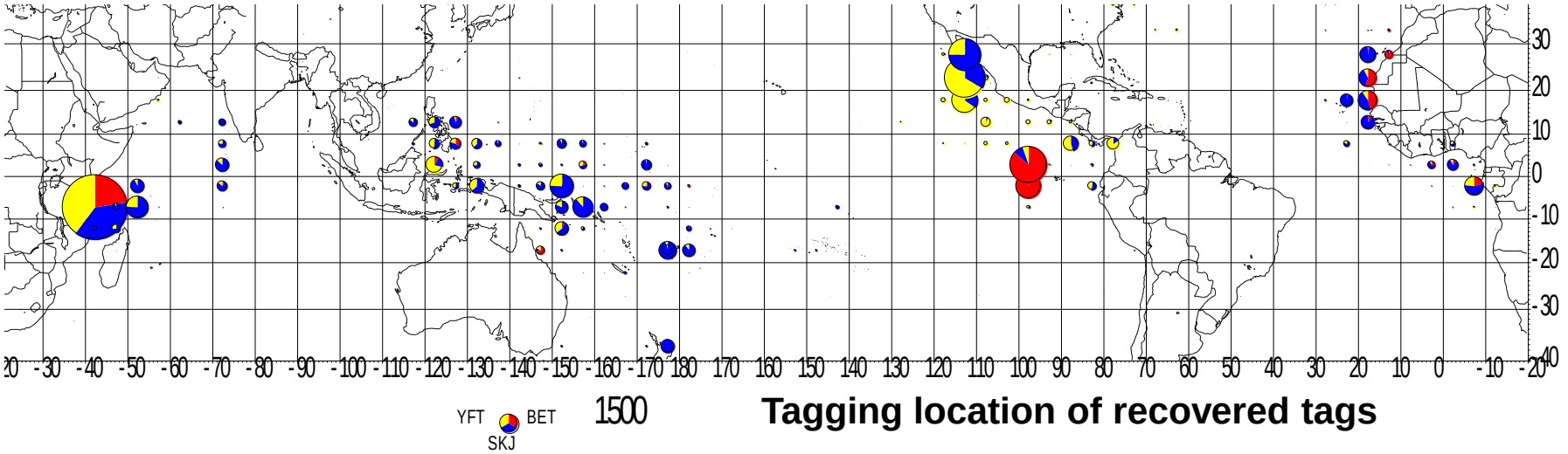
Skipjack tagging



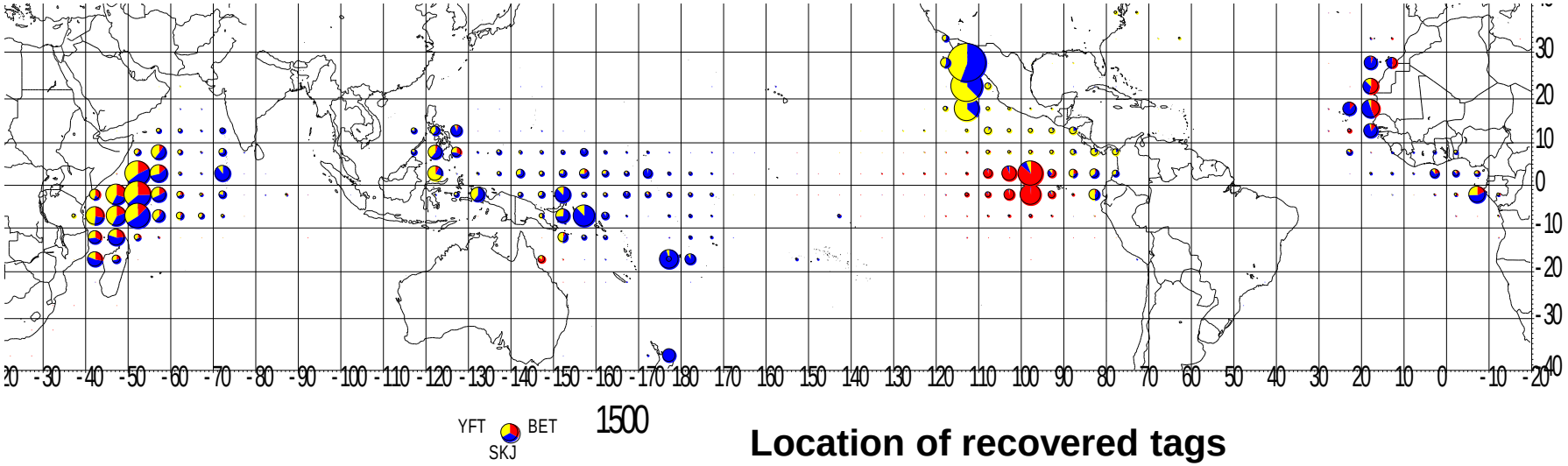
Bigeye tagging
(1st BET tagging done by LeGuen & ORSTOM in the early 70ies!)

Geographical location of tuna tagging & recoveries world wide

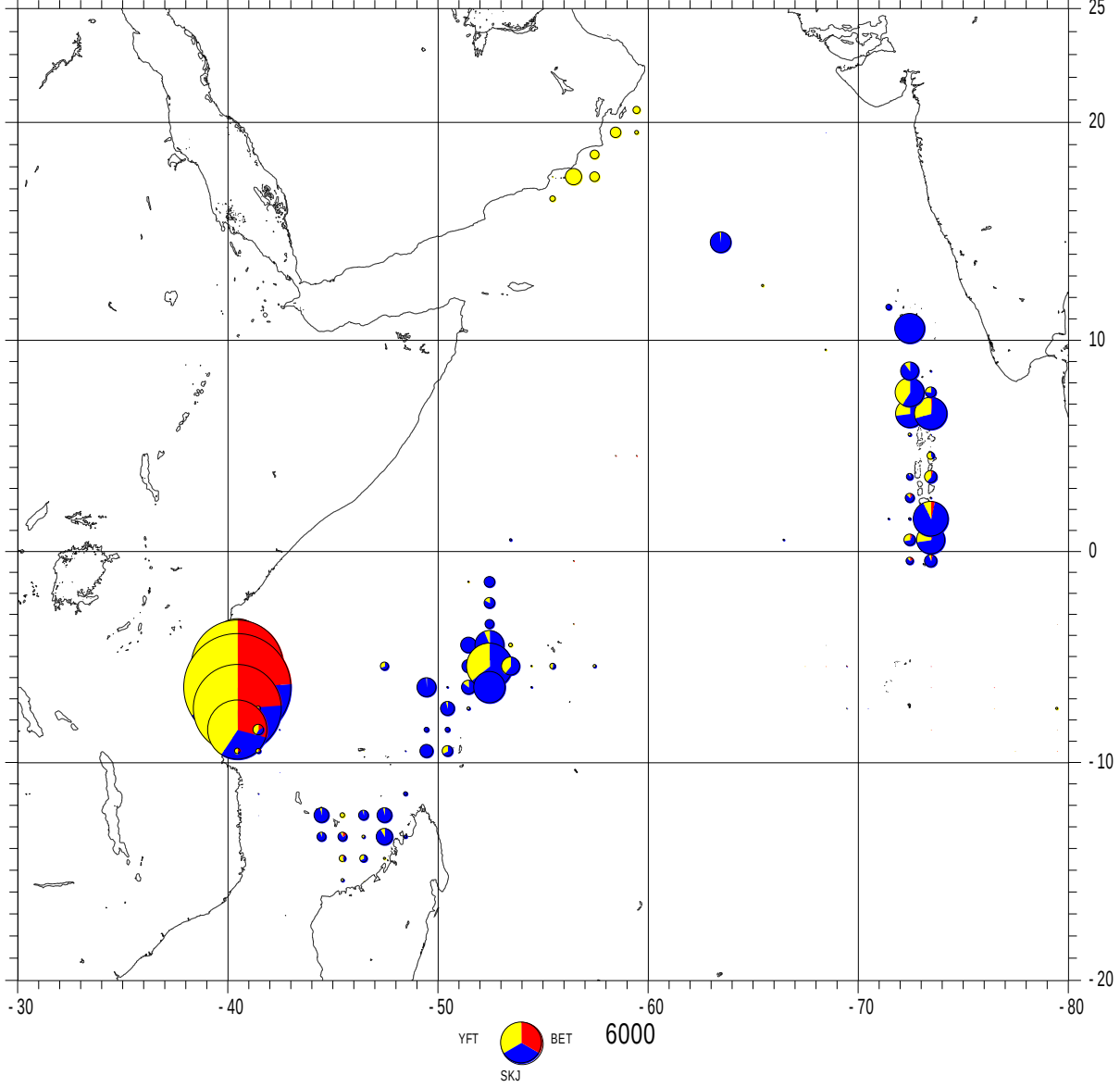
IOTC ***SPC*** ***IATTC*** ***ICCAT***



Tagging location of recovered tags



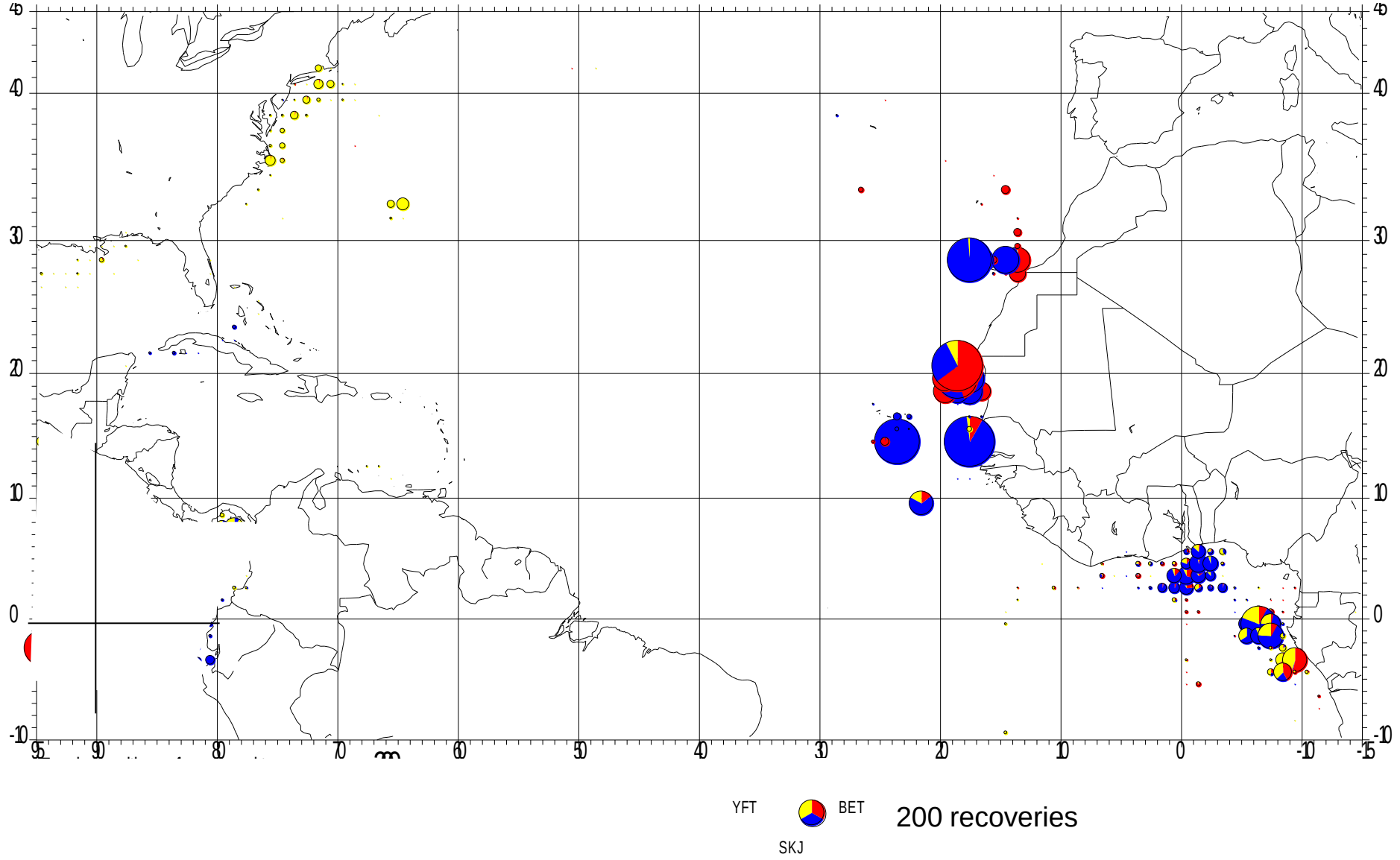
Location of recovered tags



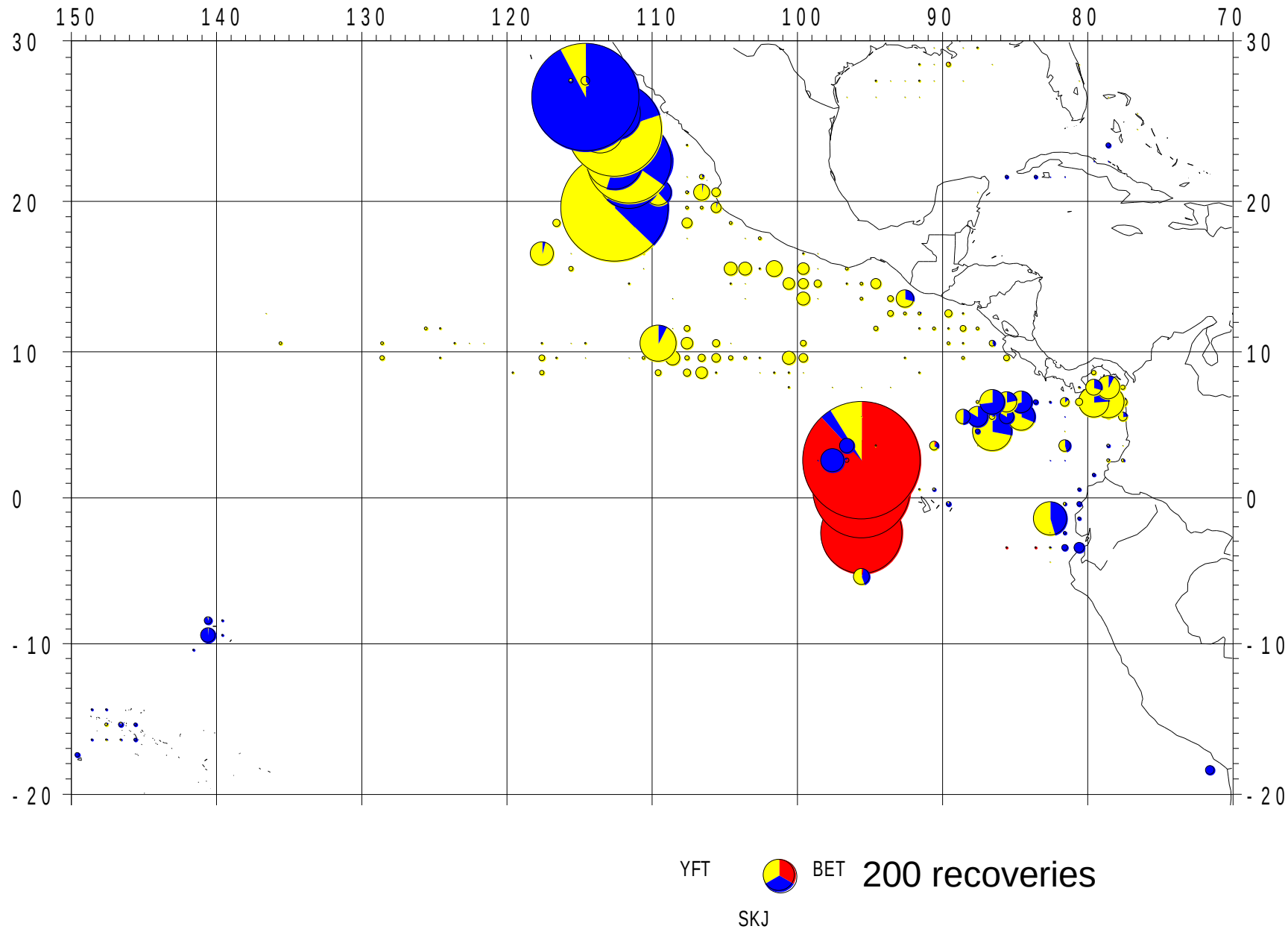
NB: 60% of tags released in the coastal area off Tanzania

Map showing the location of tropical tunas tagged by species in the Indian ocean

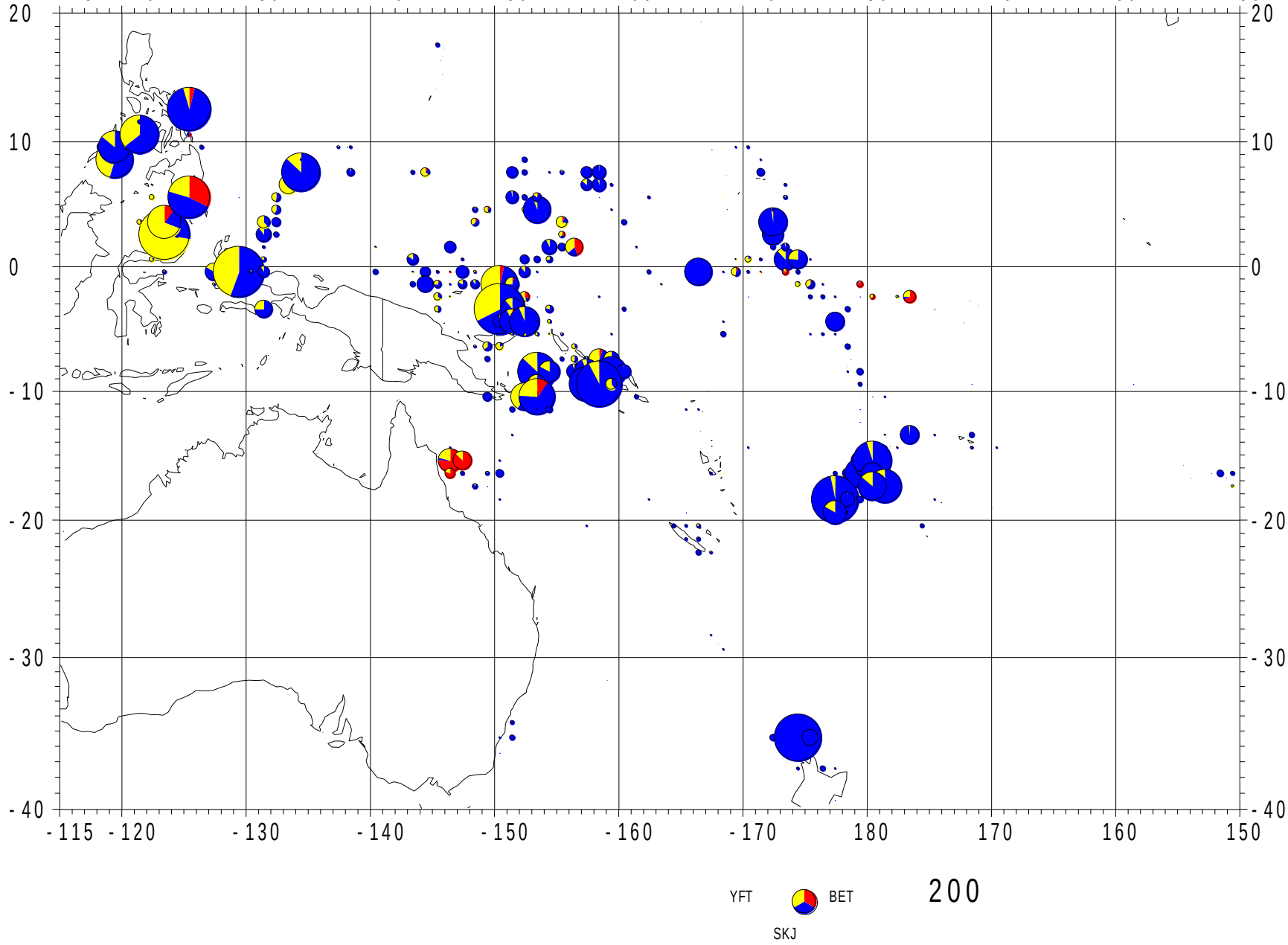
NB: additional tagging have been also done in the Eastern IO, 3138 tunas tagged, but with only 17 tags recovered



Map showing the location of tropical tunas tagged by species in the Atlantic ocean



Map showing the location of tropical tunas tagged by the IATTC, by species, in the Eastern Pacific



Map showing the location of tropical tunas tagged by SPC, by species, in the Western Pacific

Comparative analysis of recoveries

(1) Time at liberty in the recoveries of the 3 species in the 4 tagging areas

Time at liberty is a very important parameter/result in all tagging programs:

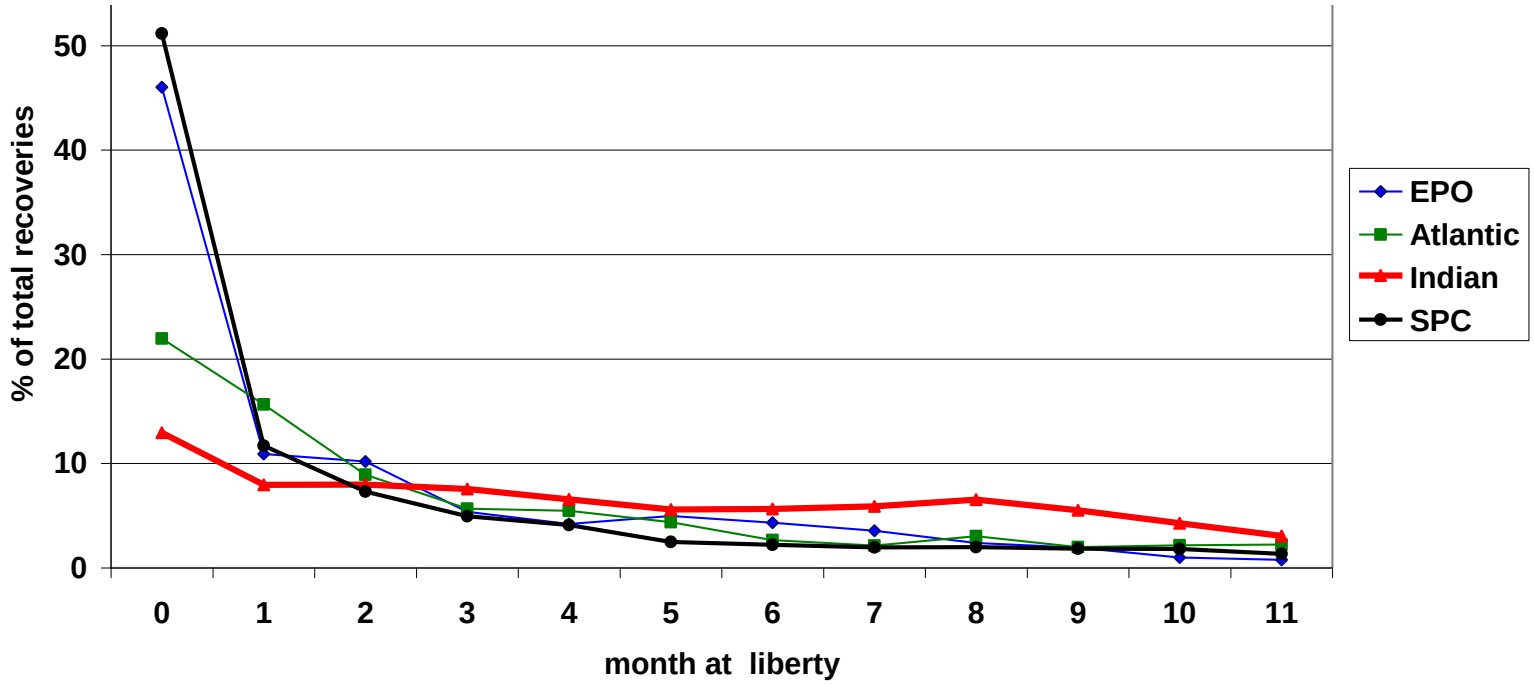
Short term recoveries, for instance 1 or 2 month after tagging, are most often of **little scientific interest**, because tagged tunas do not have enough time to significantly grow or move and to properly **mix** with the untagged population (when they are of some interest only in peculiar studies)

Consequently, the percentage of short term recoveries should be as low as possible for all tagging programmes targeting improved stock assessments.

The frequently observed high percentage of short term recoveries has often been the consequence of **tagging cruises conducted very close to active fishing areas (of PS or BB).**

The average **percentages of these short term recoveries** have been identified and compared in the total numbers of recoveries in the 4 tagging areas.

Time at liberty of tagged tropical tunas caught during the first year at liberty in the various oceans (total of the 3 species recovered)



% of recoveries within 2 months	
Indian Ocean	20,9
Atlantic	37,6
Eastern Pacific	56,9
Western Pacific	62,9

- Lowest rate of short term recoveries observed in the **Indian Ocean: 21%**
- Highest rates in the Eastern & Western Pacific: 57 & 63%
- This typical pattern tend to be very similar for the 3 species tagged and recovered

(2) Comparison between rates of well documented recoveries

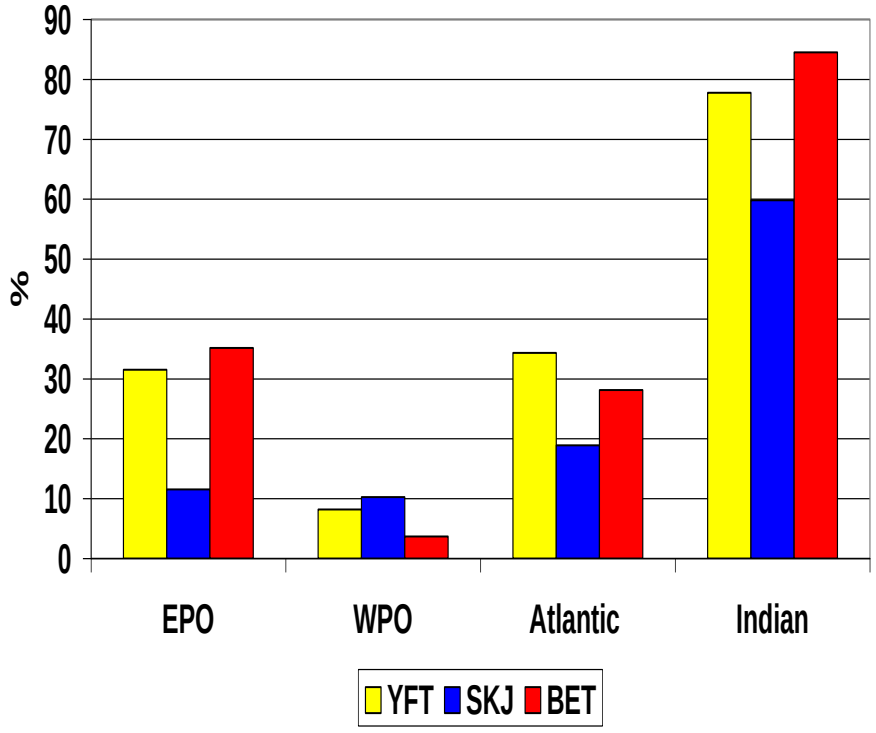
✓An important parameter in the success of tagging programs is to obtain a high percentage of well documented recoveries: recovery dates, positions, species, sizes..

✓ Large numbers of well documented recoveries are for instance essential to evaluate tuna growth & movement at oceanic scales

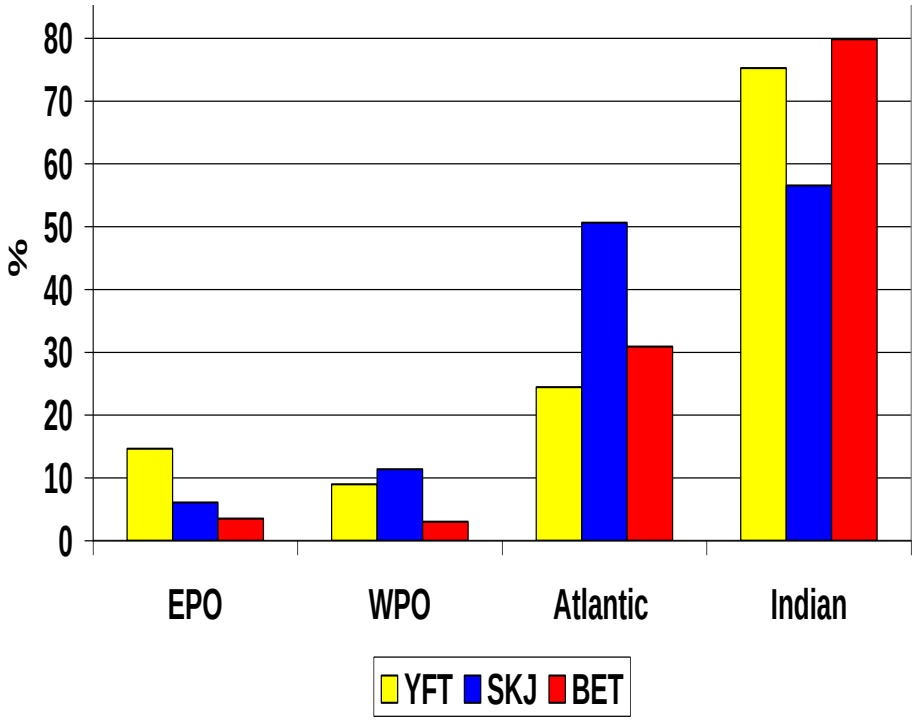
✓ Performances of tagging programs tend to be highly variable between oceans, often with very low % of fully well documented recoveries; the Indian Ocean tagging has obtained very good performances: obtaining high rates of sizes, dates & position for its recoveries, mainly because of the PS fleets and its Seychelles landing that have been permanently well followed by the SFA & IOTC staff and in full cooperation with purse seine crews & boat owners.

Movement Recoveries	Numbers				%			
Total recoveries /ocean	**YFT**	**SKJ**	**BET**	**Total Recov.**	**YFT**	**SKJ**	**BET**	Total
EPO	4 599	1 426	5 950	**11 975**	32	12	35	27
WPO	1 741	5 892	458	**8 091**	8	13	4	10
Atlantic	599	1 249	868	**2 716**	34	19	28	24
Indian	8 246	10 452	4 749	**23 447**	78	60	85	70
Total	**15 185**	**19 019**	**12 025**	**46 229**	32	24	32	28

Growth Recoveries	Numbers				%			
Total recoveries /ocean	**YFT**	**SKJ**	**BET**	**Total Recov.**	**YFT**	**SKJ**	**BET**	Total
EPO	**2 137**	**754**	**597**	**3 488**	15	6	4	8
WPO	**1 909**	**6 527**	376	**8 812**	9	15	3	11
Atlantic	**426**	**3 344**	**953**	**4 723**	24	51	31	41
Indian	**7 975**	**9 882**	**4 485**	**22 342**	75	57	80	66
Total	**12 447**	**20 507**	**6 411**	**39 365**	26	25	17	24



Percentage of recoveries that are well documented for movement studies



Percentage of recoveries that are well documented for growth studies

- Rates of recoveries that are of well documented for growth and movement studies appear to be very good in the Indian Ocean tagging. They are variable (from low to medium) in the other oceans.
- The IO high rates of well documented recoveries are also due to recoveries widely concentrated in time & in a main landing port, Victoria, these recoveries being mainly collected from an homogeneous & fully cooperative EU PS fleet.

(3) Average growth rates between tagging and recovery dates for the 3 species tagged in the 4 areas

- A simple method has been used to estimate the growth rates at size (following by M.B Schaefer 1961, Fonteneau & Gascuel in 2008, and al) :

✓ Simply **calculating the average monthly growth rate between tagging and recovery,** and assigning this growth rate to the mean size of this period.

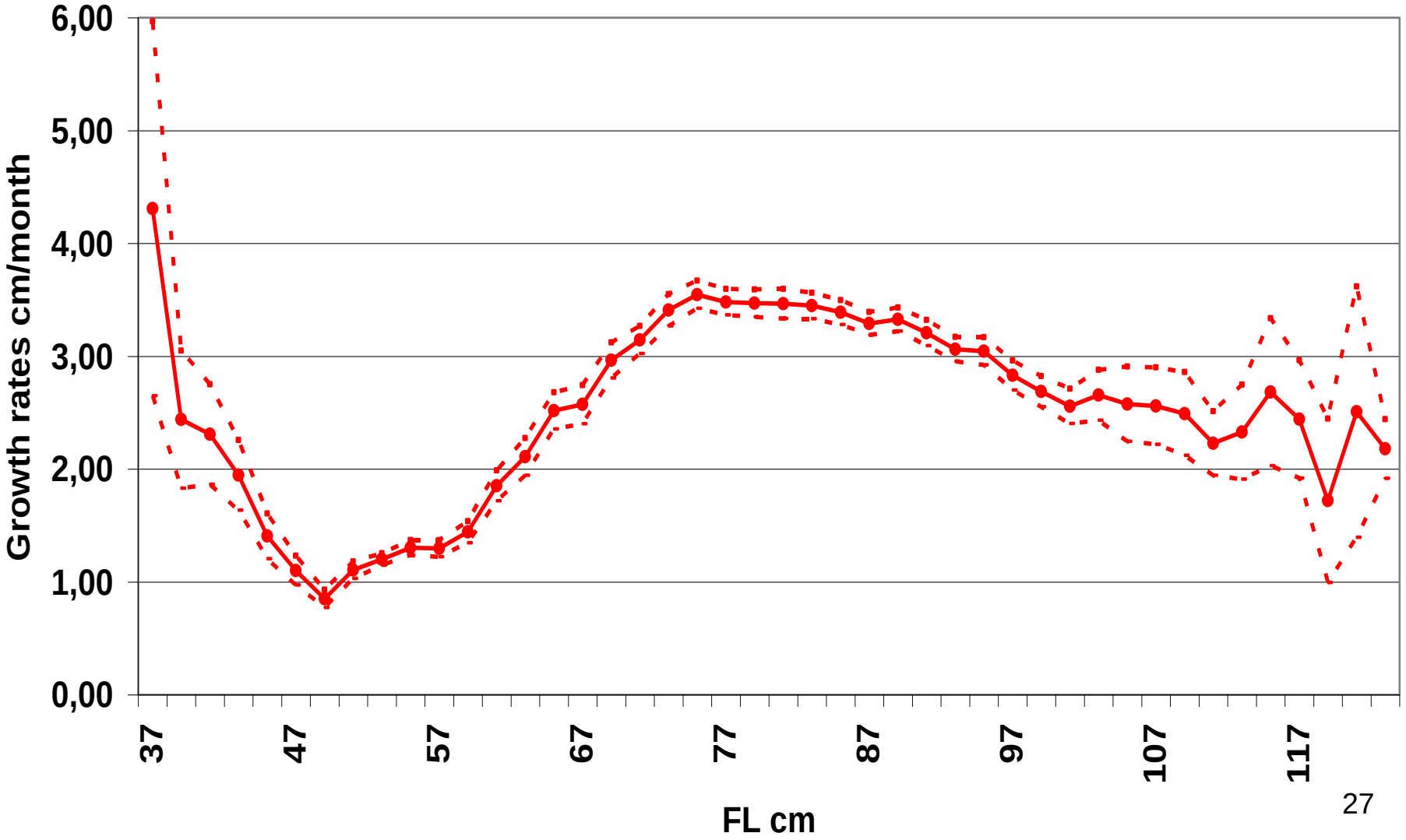
✓ An estimated **uncertainty** of this average growth at size is also calculated assuming a normal distribution of these values

✓ This basic result allows to do a synoptic & quite realistic comparison of the apparent growth rates at size of recovered tunas

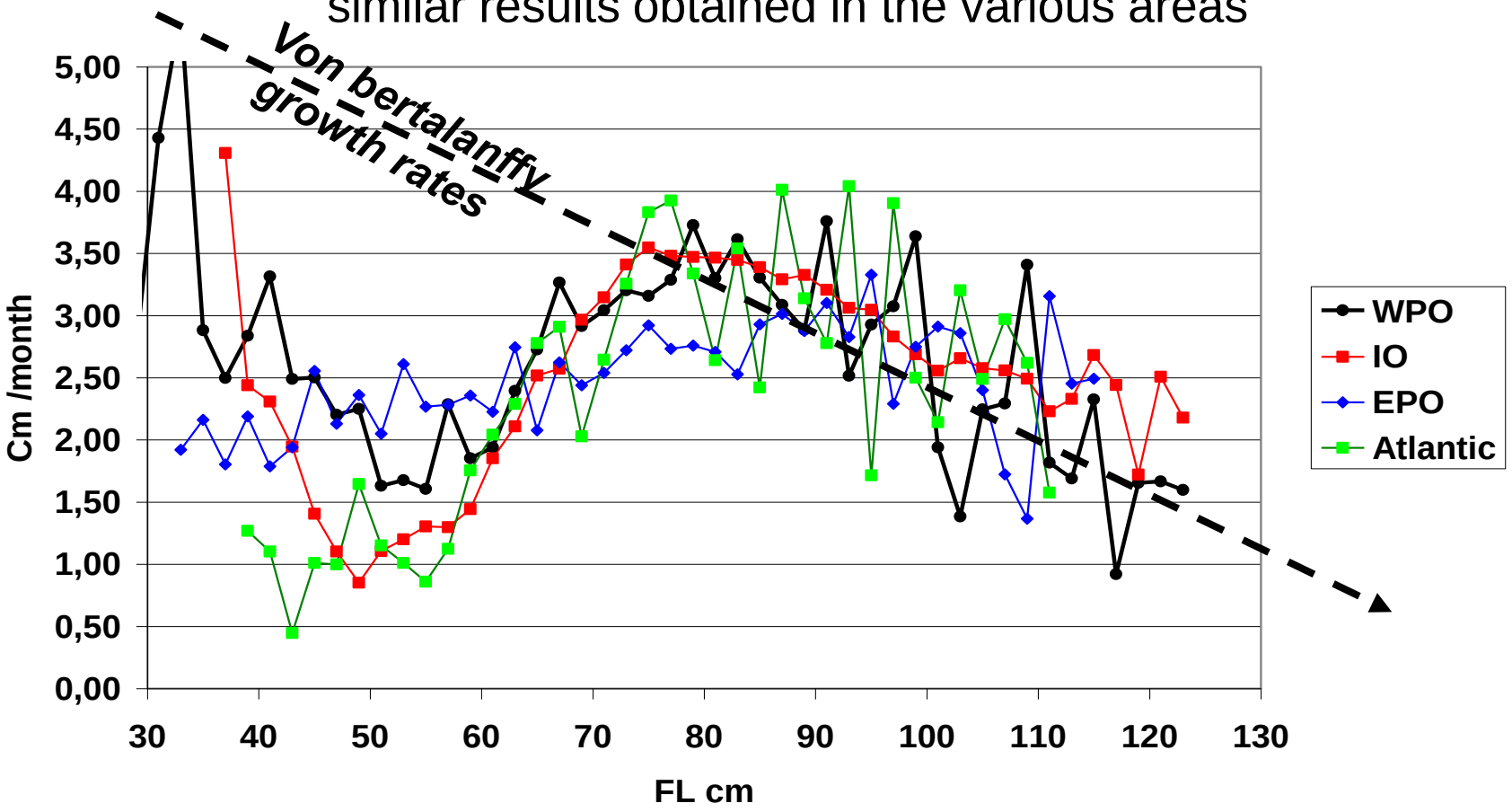
✓ Keeping in mind that this simple parameter may sometimes provide a slightly **biased image of the real growth curve:** simulation studies show that this simple parameter is showing quite well the growth of small tunas (after limited time at liberty), but overestimating the growth of large individuals (after long durations).

✓ Keeping in mind that all the growth studies based on recovery data are most often dealing with frozen **tunas that have shrunk**. This potential bias has been analysed by scientists (Schaefer) but it will not be taken into account in this global comparative study, assuming that this bias is similar for the 3 species and in the 3 oceans.

An exemple of typical result obtained: average monthly growth rates of Indian Ocean yellowfin between tagging & recovery, and 95% confidence interval estimated for this mean



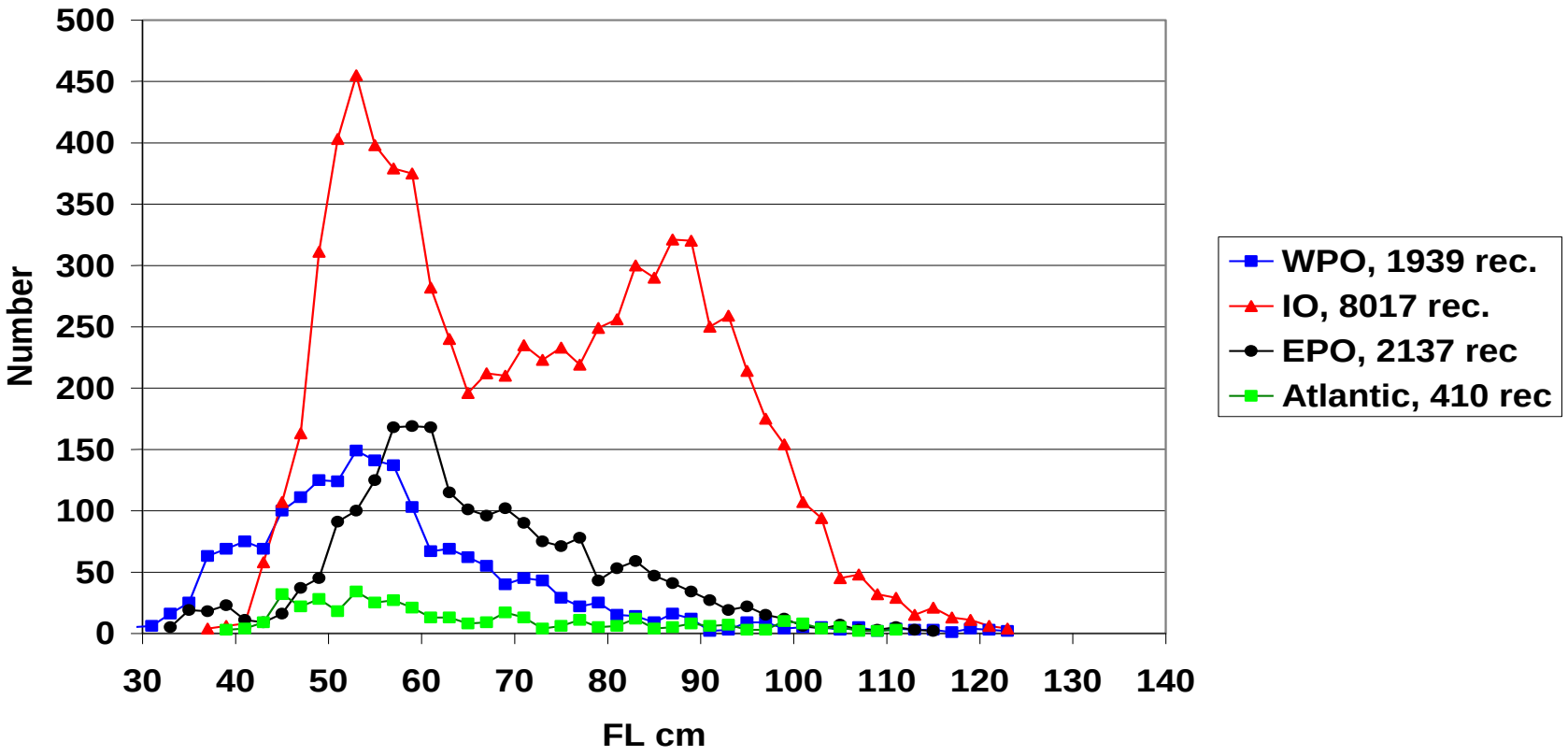
Yellowfin average growth rates at size between tagging & recovery: similar results obtained in the various areas



Growth rates at size typically showing in the 4 oceans similar multistanza growth pattern: a slow growth stanza for YFT <75cm, when in the traditionnal Von Bertalanffy model, the growth rates are maximal in this size range between 30 & 80 cm

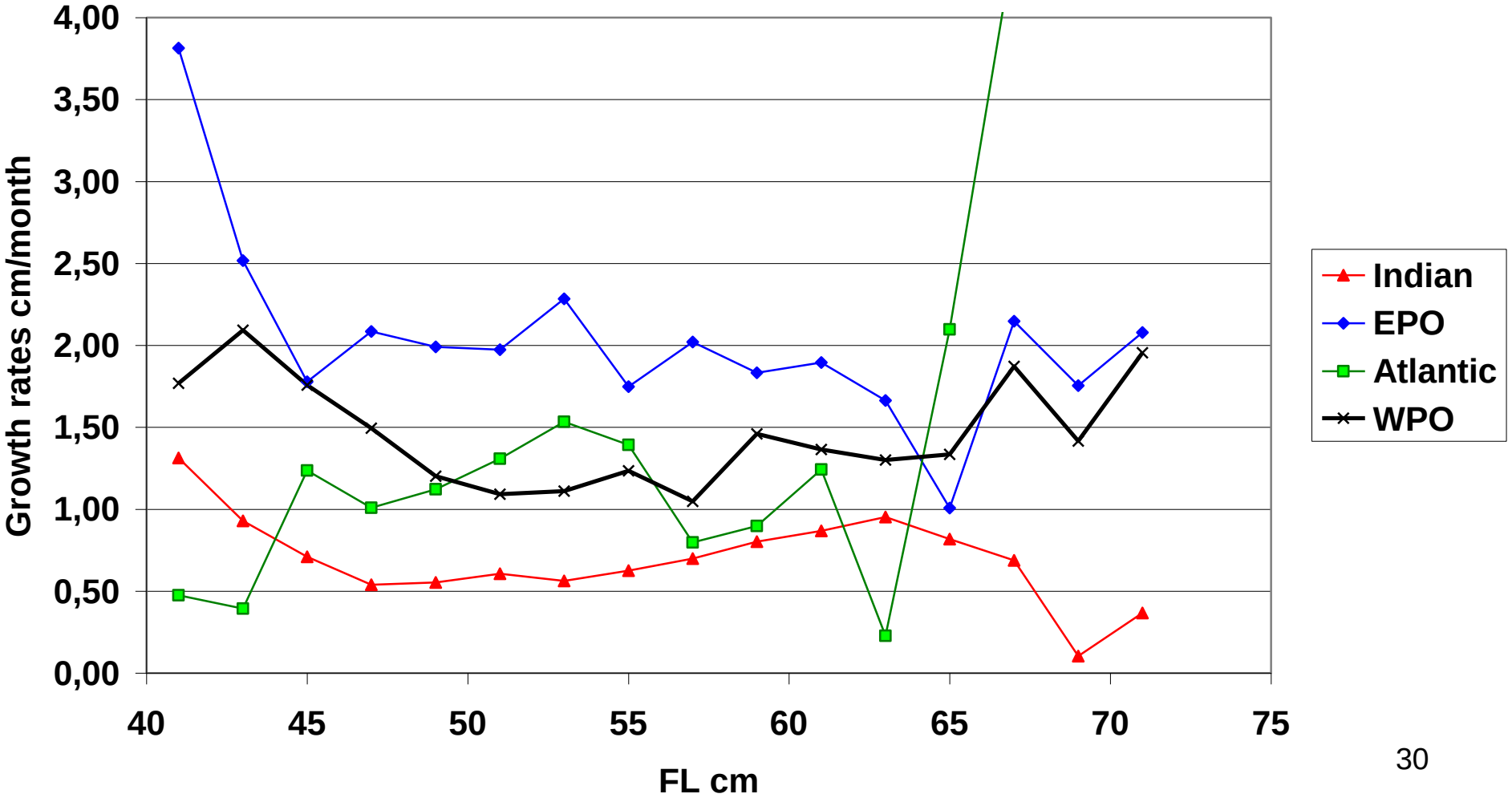
And a logical very fast growth between birth and recruitment sizes at 40 cm observed in the WPO & IO (WPO being the only area with sufficient numbers of small YFT recoveries)

✓A result probably indicative that yellowfin does not follow a Von Bertalanffy growth curve, as in this model, growth rates at size should be linearly decreasing.
✓Keeping in mind that this basic result is based on widely heterogeneous sample sizes by ocean: in term of numbers of recoveries & of sizes of YFT recovered in each ocean (& much larger in the IO)

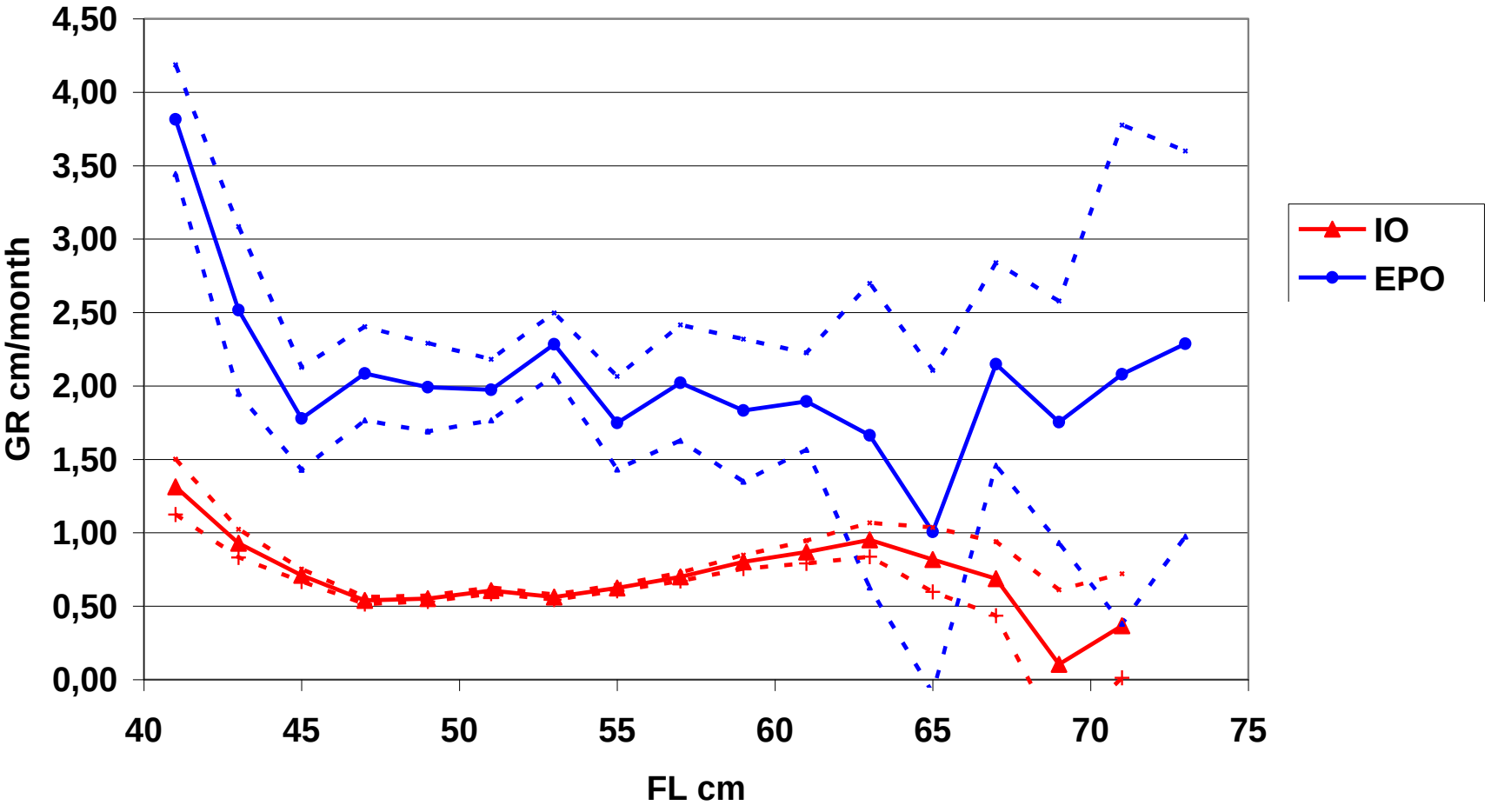


Numbers and sizes of recovered yellowfin available in each of the growth study

SKJ average growth rates at size between tagging & recovery: widely different growth rates estimated in the various areas



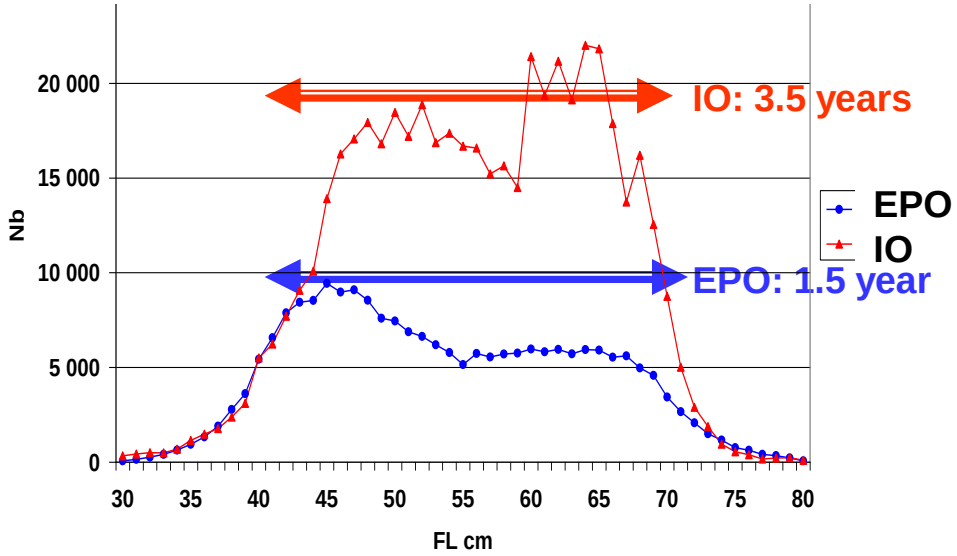
For instance wide difference of SKJ growth rates are observed at all sizes between the EPO & the IO



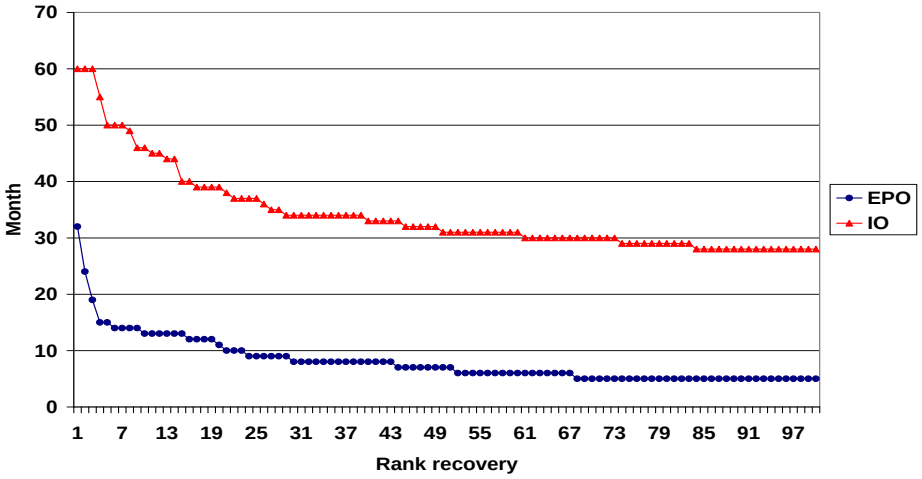
A visible confirmation of the known differences in the k & L_∞ parameters estimated by IATTC & IOTC scientists

SKJ fished in the EPO & the IO:biological differences & mysteries?

(based on similar numbers of SKJ tagged in the EPO & IO, 80.000 & 120.000, producing 12000 & 17000 recoveries)



Average catch at size of skipjack observed in the Indian and eastern Pacific oceans: similar average SKJ sizes caught in IO & EPO



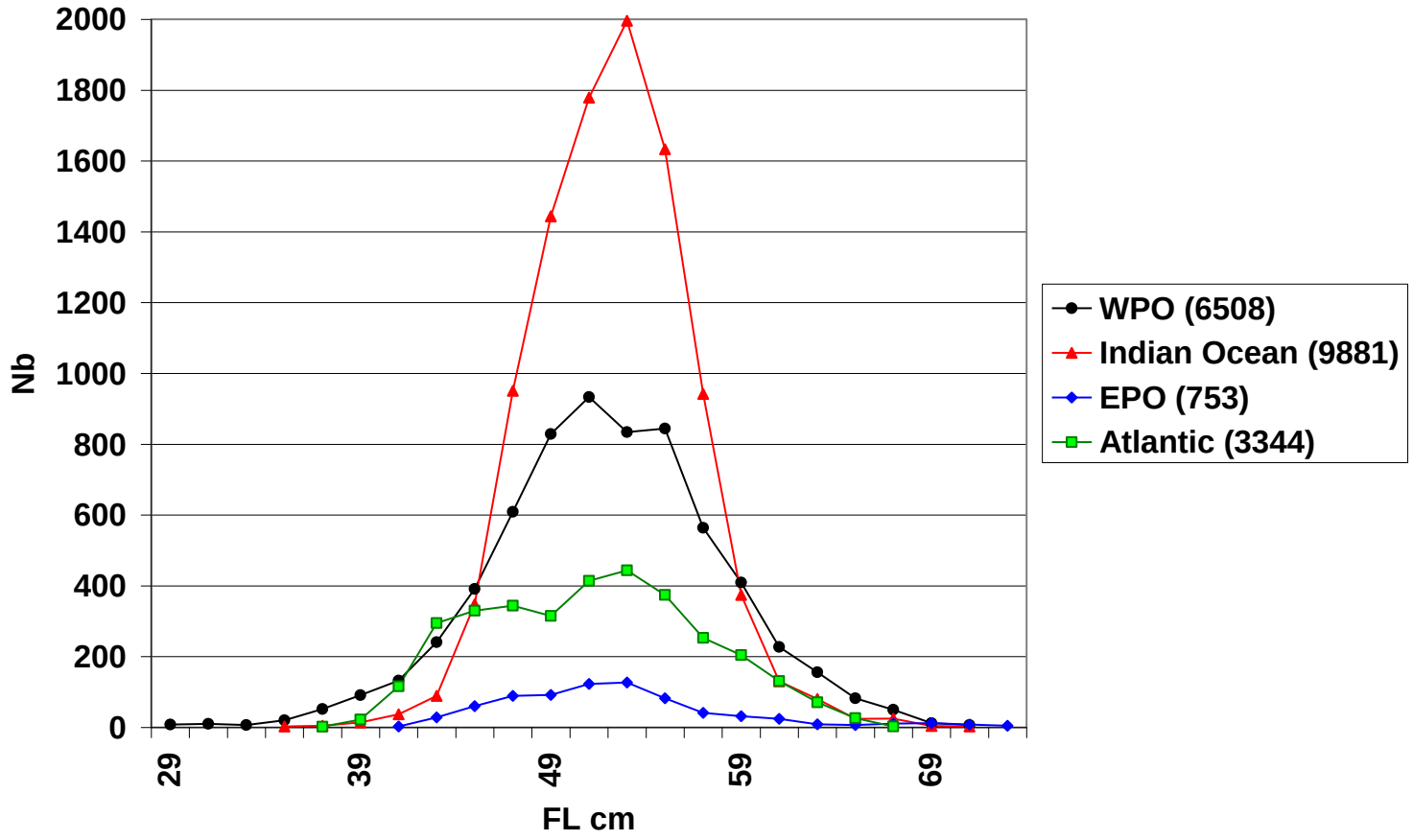
Month at liberty observed for the 100 skipjack recoveries showing the longest period at liberty in the Indian and Eastern Pacific oceans (sorted by decreasing durations)

- ✓ **SKJ catch at size (and probably their L infinity?) are very similar in the IO & EPO**
- ✓ **But growth rates that are well estimated from recoveries are totally & significantly different: SKJ growing nearly 3 times faster in the EPO**
- ✓ **Much larger duration at liberty observed for tagged SKJ in the IO Then a totally different duration between 40 & 70 cm in the 2 oceans: 1.5 year in the EPO & 3.5 years in the IO**

Such SKJ results are very strong and unquestionable,

but such biological heterogeneity between oceans remains quite mysterious and difficult to explain

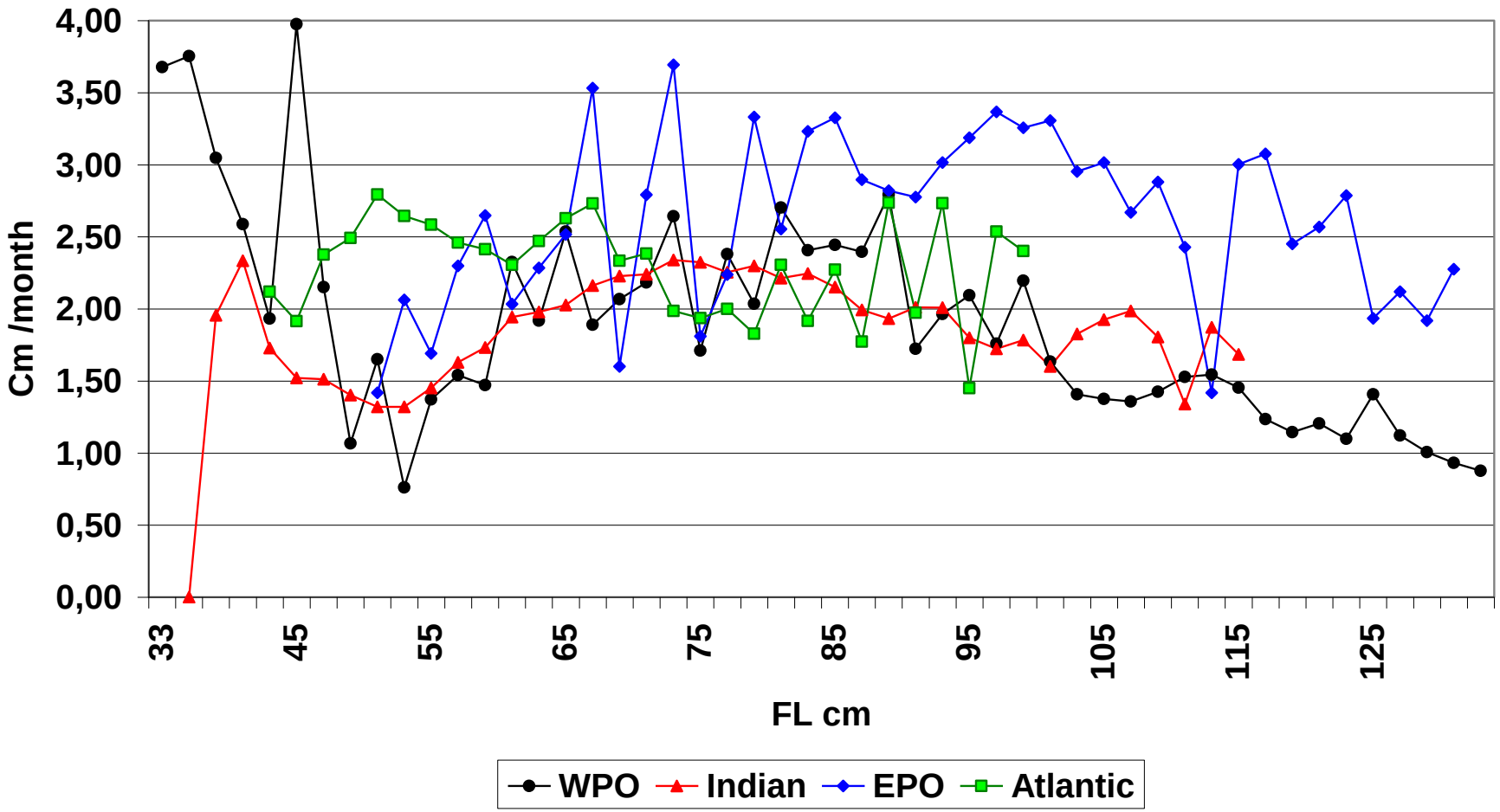
Keeping in mind that the sizes of recovered SKJ used in this study are very similar in all oceans, even if the numbers of usable recoveries are widely different (& much larger in the IO)



Numbers and sizes of recovered skipjack that are available in each of the growth study

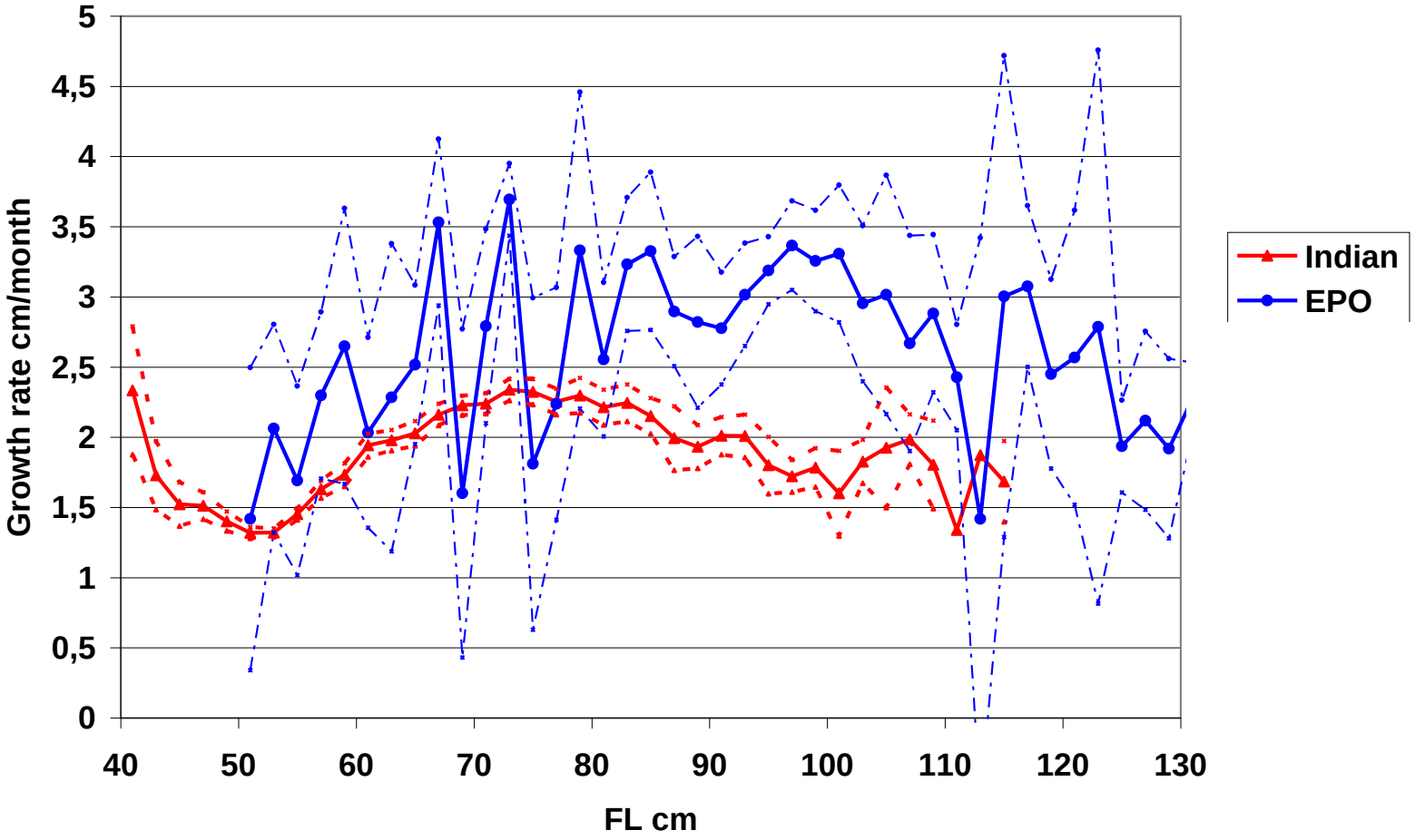
Bigeye average growth rates between tagging & recovery:

similar growth rates at size estimated in the various areas

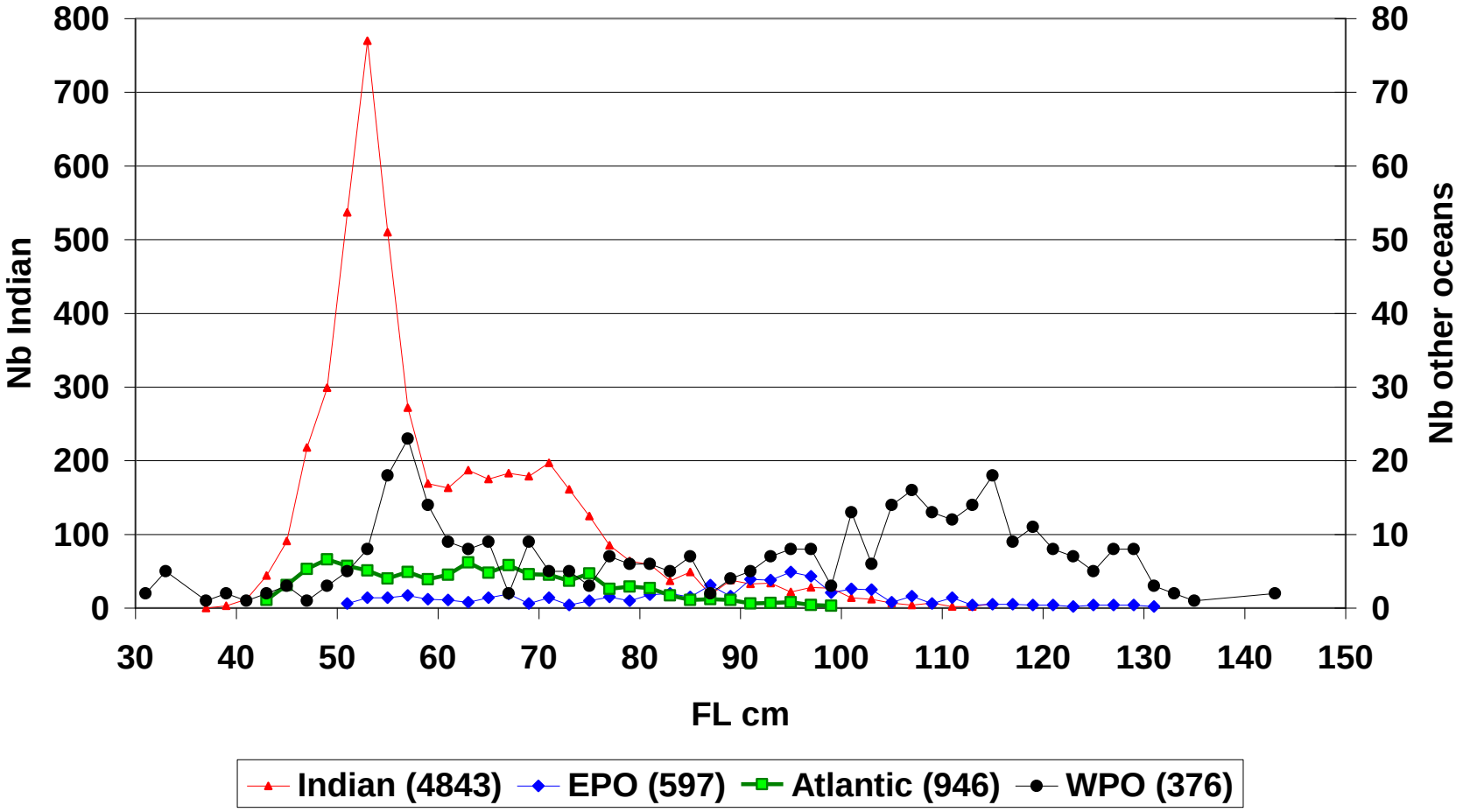


These growth rate at size of BET are also potentially showing, as for YFT, the existence of a slower growth stanza of pre adult BET (between 45 and 65 cm). BET growth rates in the EPO are significantly higher than in the IO (as for SKJ)

BET average growth rates at size (cm/month) in the EPO & the IO (and the uncertainty in the average)



✓Again, keeping in mind that this basic result is based on widely heterogeneous sample sizes by ocean: in term of numbers of recoveries & of sizes of BET recovered in each ocean
✓& much larger in the IO

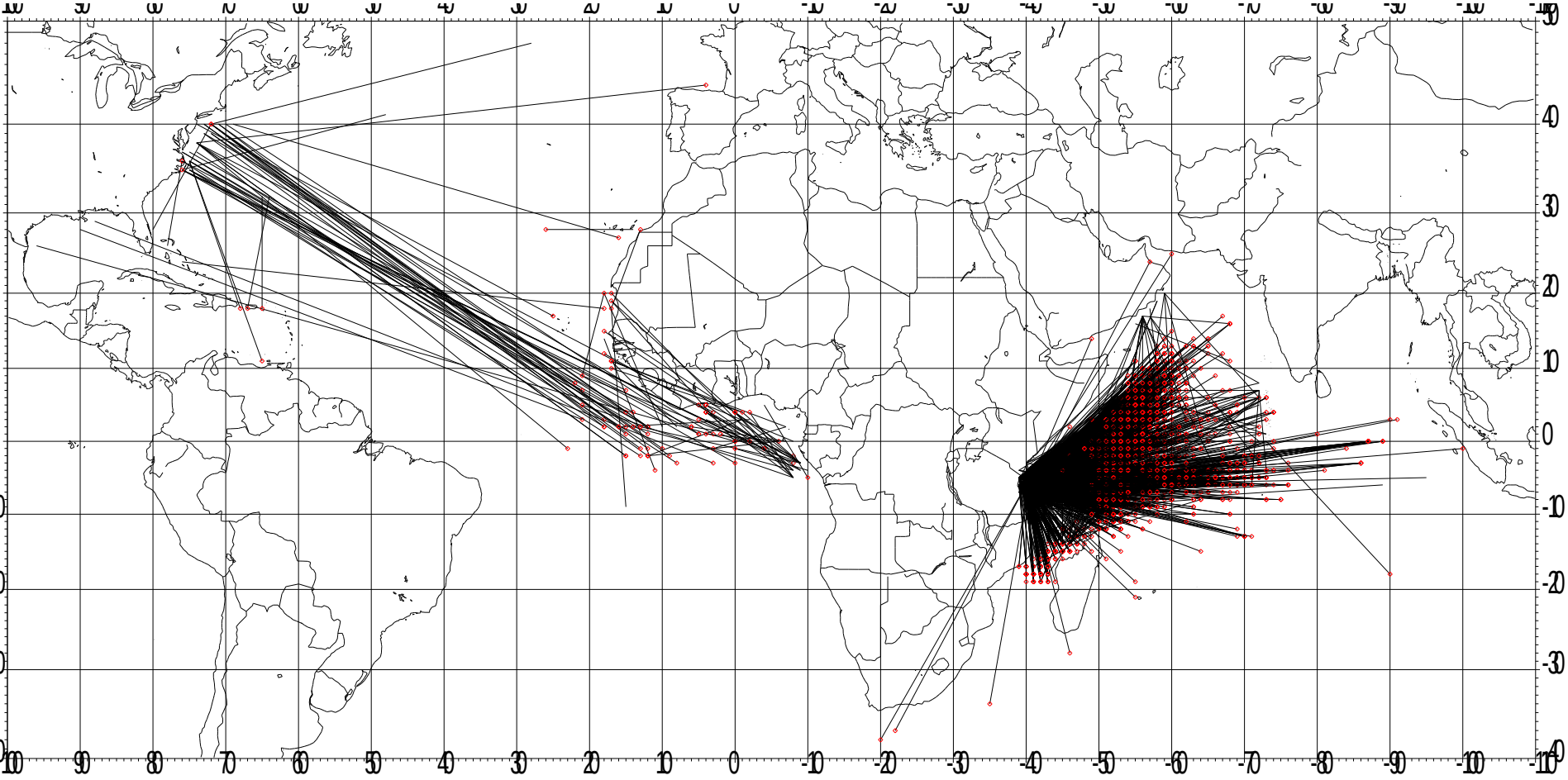


Numbers and sizes of recovered bigeye that are available in each of the growth study

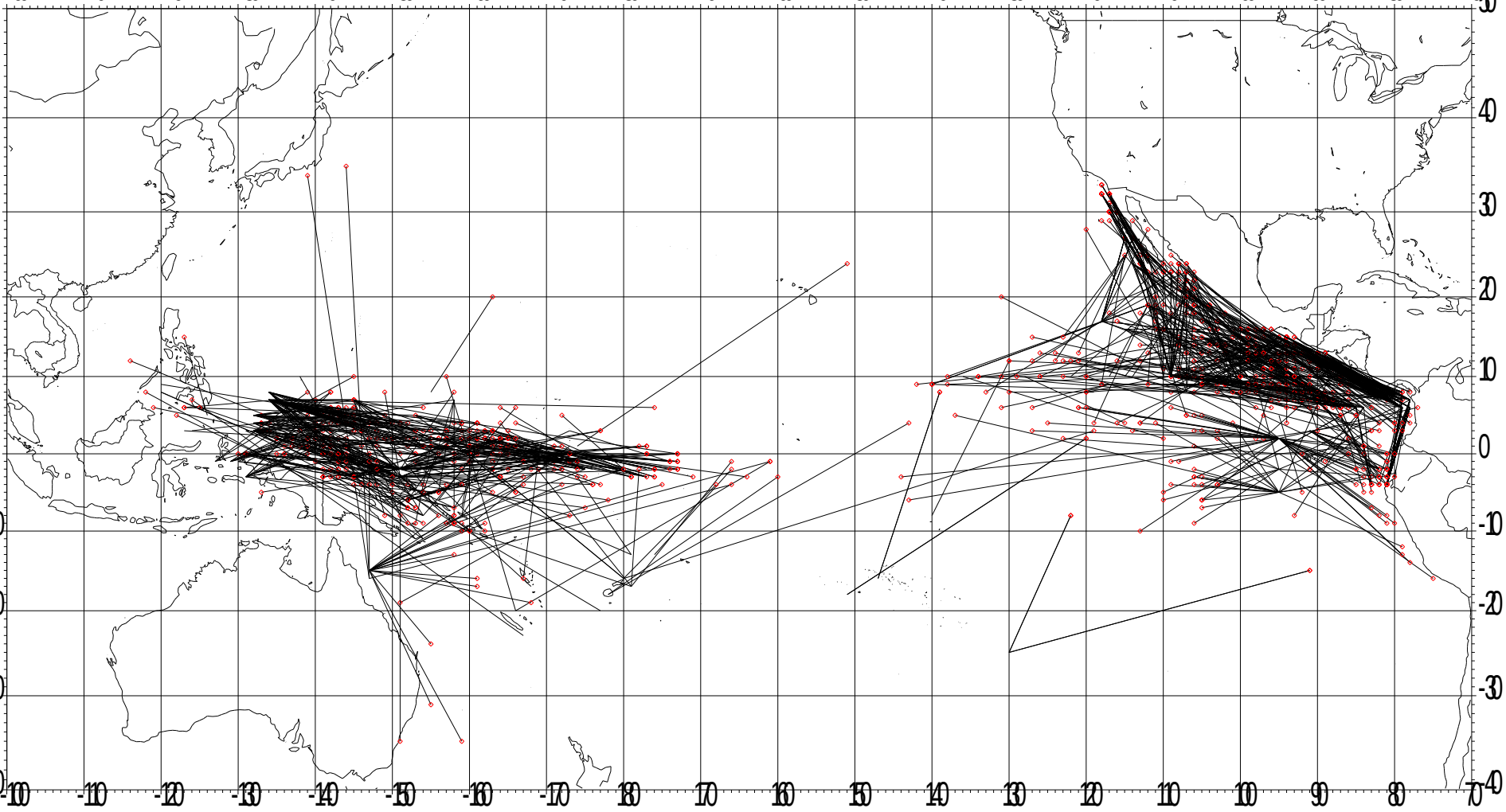
4- Tag recoveries & tuna movements

- Tunas have been classified by lawyers in the article 64 of the Law of the Sea as being **« highly migratory species »** that cannot be managed at the scale of EEZ, but only by oceanic RFO such as IATTC, ICCAT, IOTC and WCPFC.
- But on the other side, there has been some recognition that some fractions of tuna stocks/populations are often « **viscous ones** » (Mac Call) and **showing only limited movements** (Hilborn & Sibert 1986)
- Dart tags recoveries allow to estimate the apparent movements and viscosity of tuna resources,
- The following comparative work will simply analyze and discuss the apparent movements of recoveries that are apparent world wide from recoveries.
- *Always keeping in mind that these apparent movement are totally conditionned by fishing zones & widely dependent of the reporting rates by gear.*

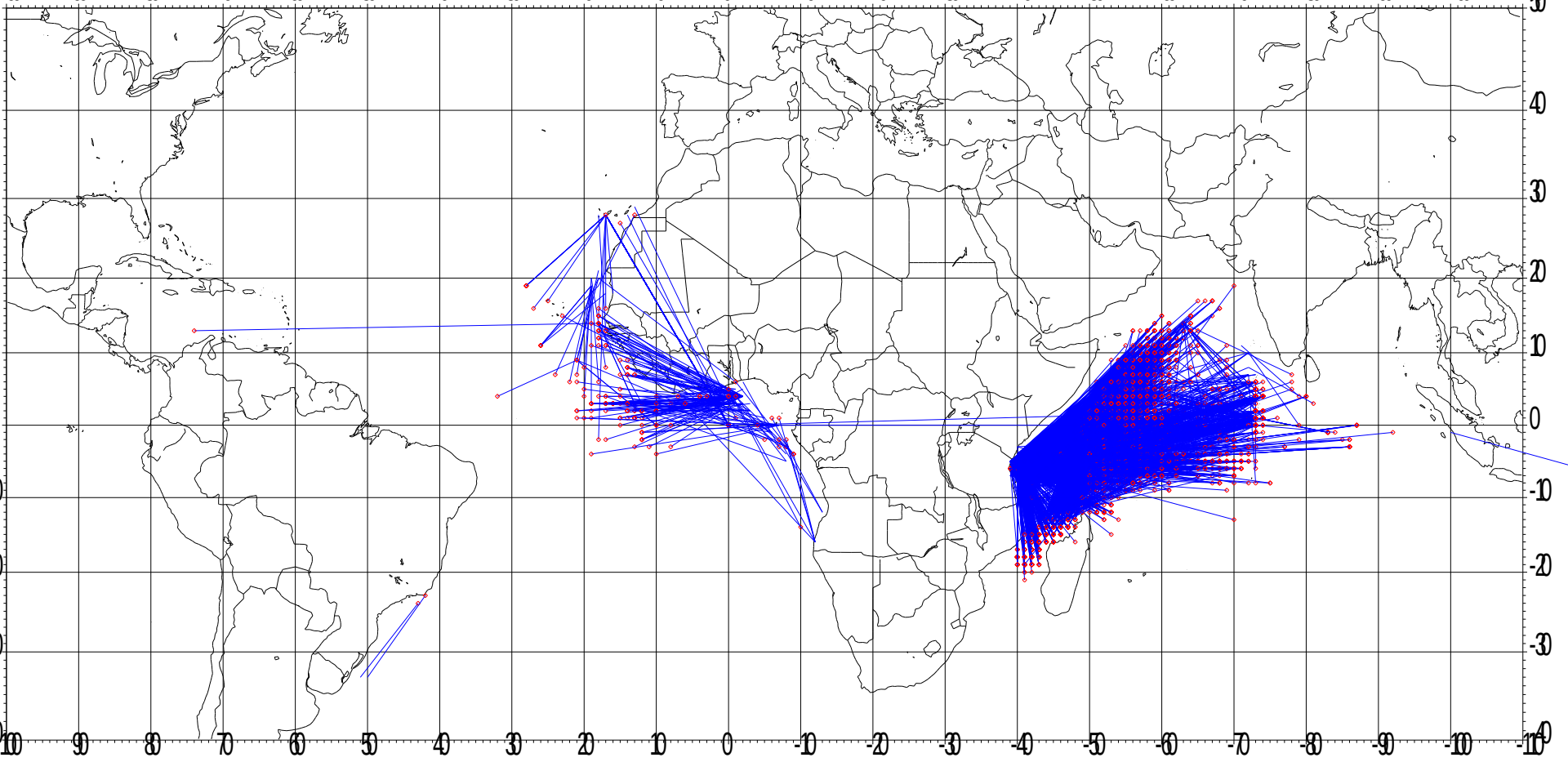
4-1- Basic maps of trajectories of tuna recoveries observed worldwide



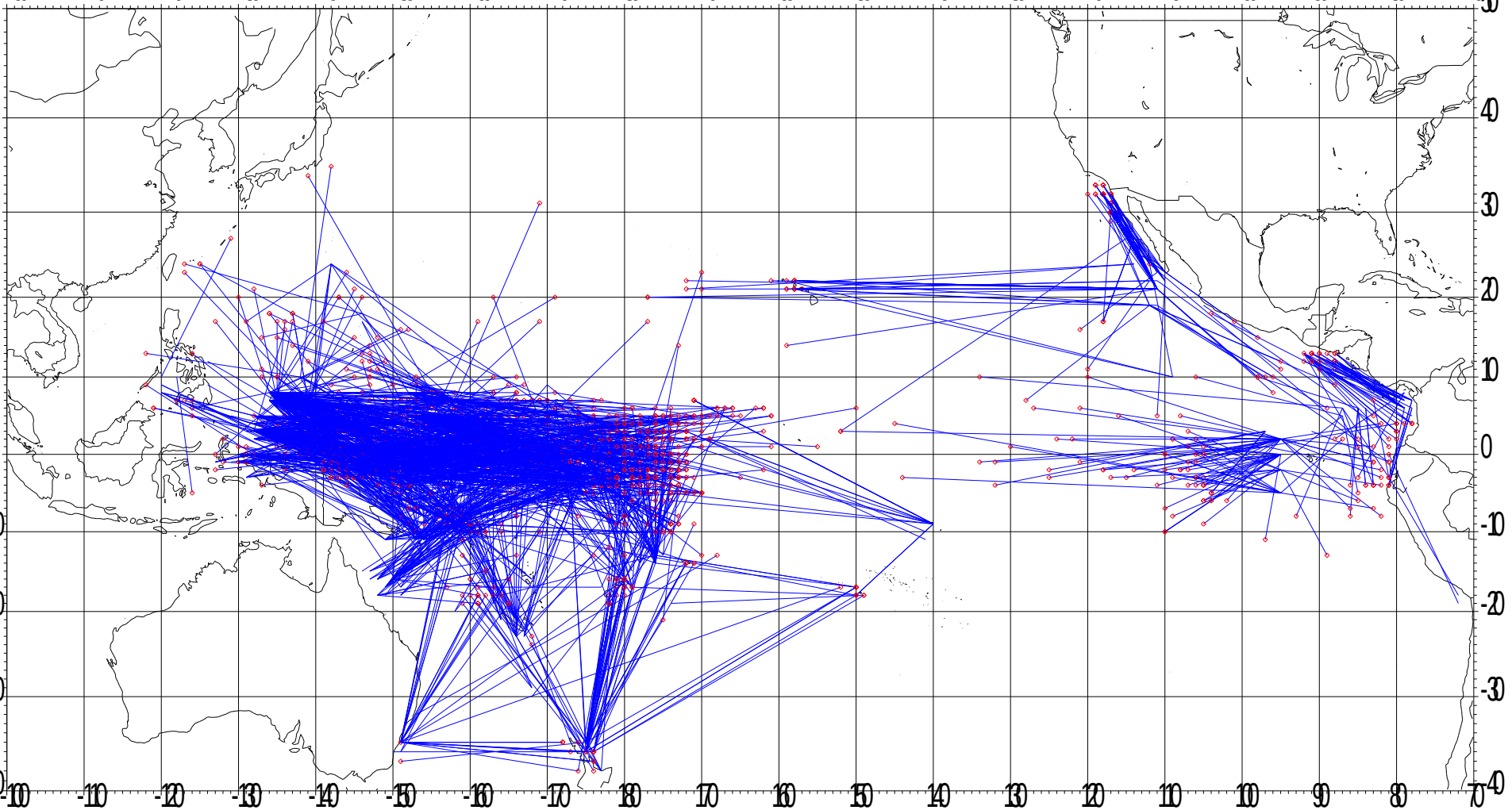
All YFT recoveries distances > 600 miles



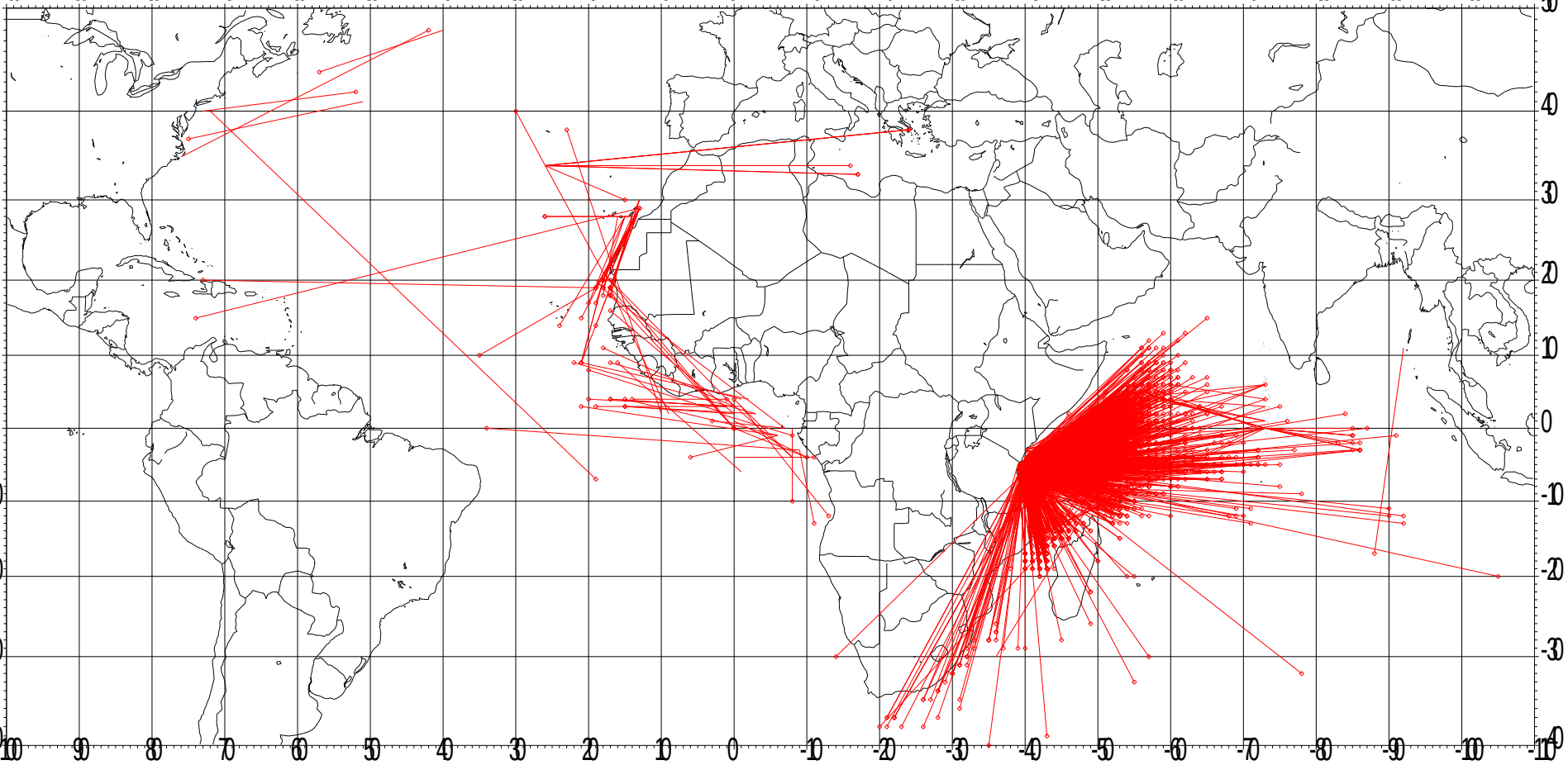
All YFT recoveries distances > 600 miles



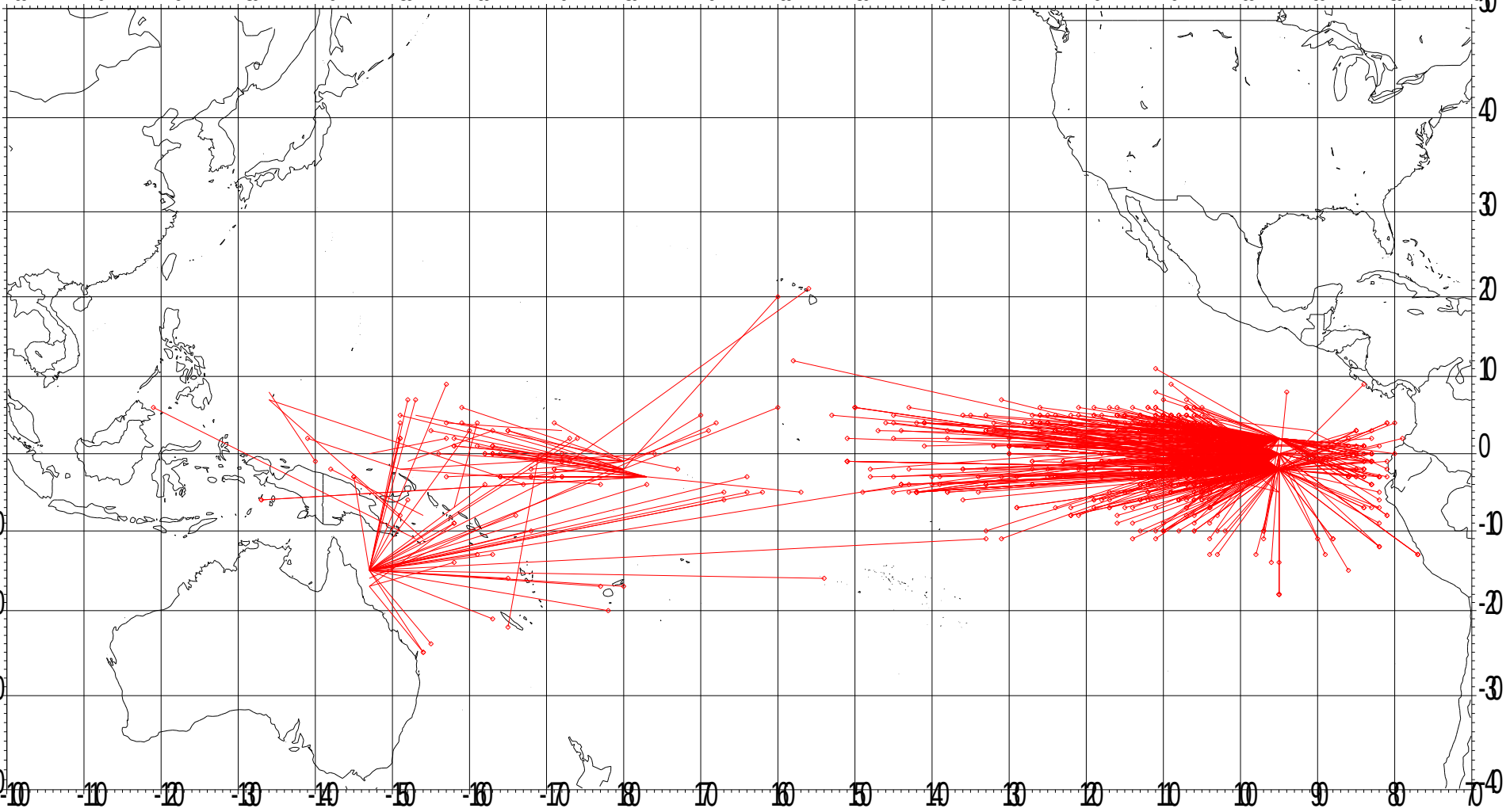
All SKJ recoveries distances > 600 miles



All SKJ recoveries distances > 600 miles

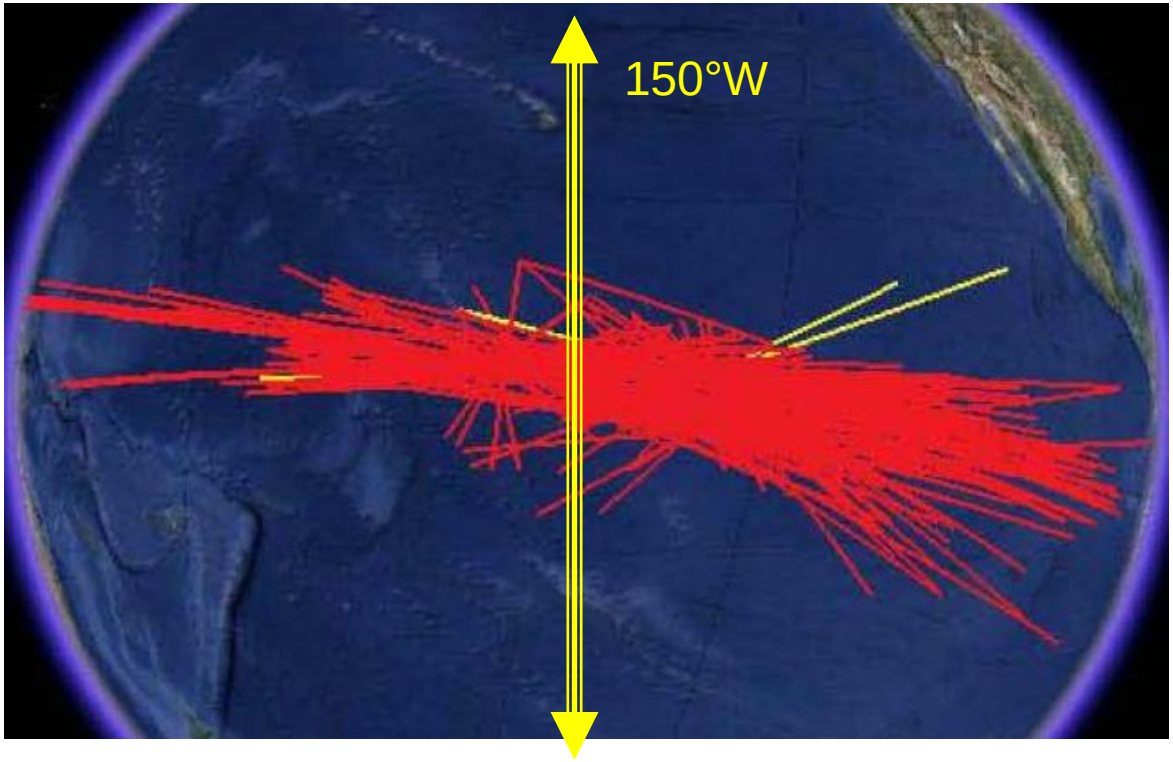


All BET recoveries distances > 600 miles



All BET recoveries caught at distances > 600 miles from tagging locations: **showing very low mixing between E & W stocks**

But these historical recoveries were widely conditionned by the great distances between the tagging locations of these tagging in the Eastern & Western Pacific oceans



- Keeping in mind that recent tagging/recovery data of bigeye done by SPC & IATTC in the central Pacific, not included in the data set available, are now showing considerable movement of bigeye tuna between the Western & Eastern Pacific Ocean across the 150°W stock assessment and stock management boundary
- Given this new information, it has been recommended by the 2012 WCPFC peer review of the BET stock that a new Pacific-wide assessment should be conducted for the BET stock

4-2- An overview of distances and trajectories between tagging & recoveries and a detailed look of movements of tunas tagged in selected strata

- Average distances travelled between tagging and recoveries positions can be estimated at least in 2 ways:

1) **Global average**: dividing the total distances travelled by the numbers of recoveries

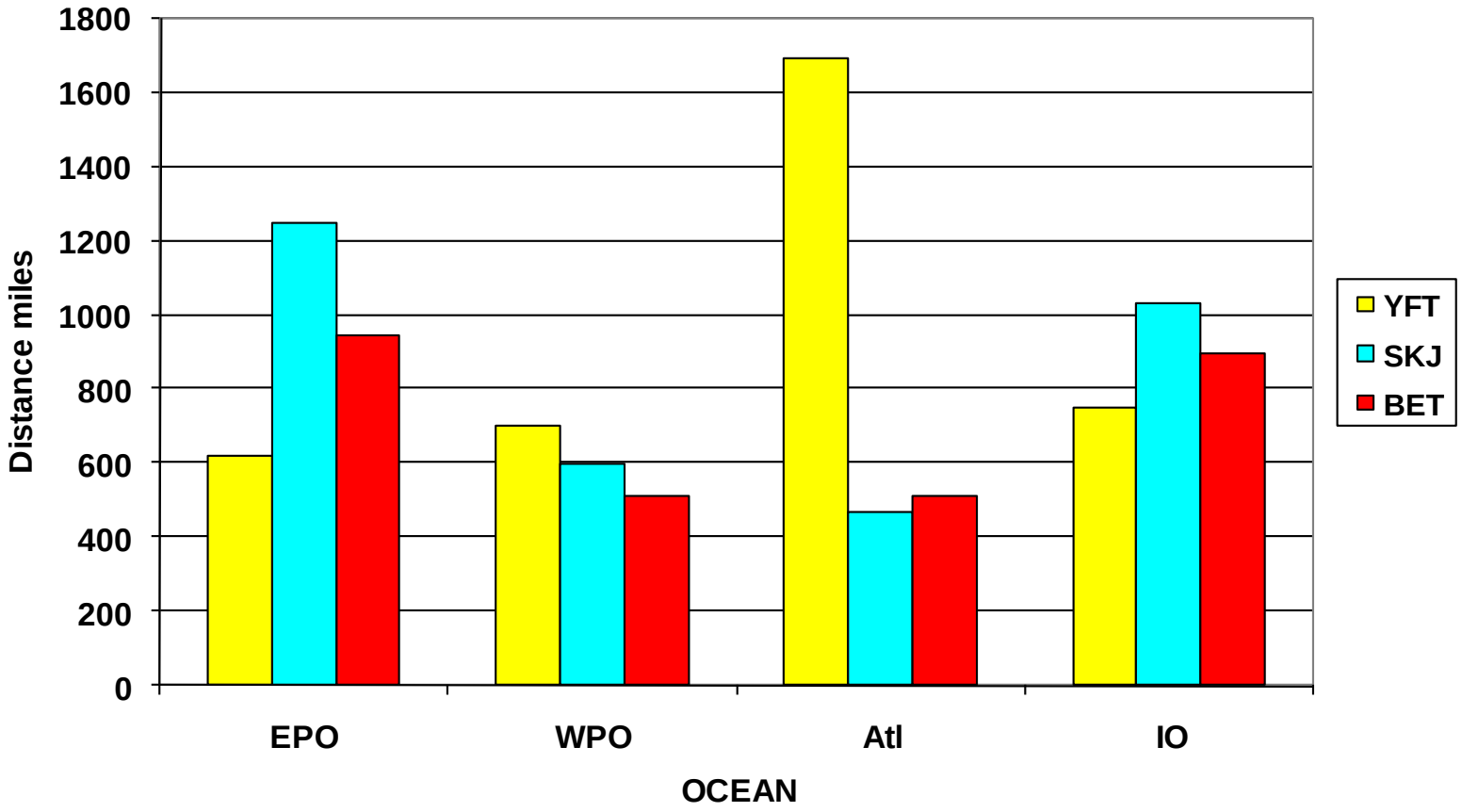
2) **Monthly average distance:** doing this calculation for each period of 1 month at sea (monthly distance) and calculating the average monthly distances observed during the period of recoveries. This method has been selected as being the more representative of tuna movements during their life, as it does not give an excessive weight to the initial period of short term recoveries.

See the following exemple, **SKJ tagged in the Eastern Pacific:**

A **global average distance** of only **330 miles**, a low level mainly driven by the large number of recoveries during the first 2 month at liberty (>50%)

When the **average monthly distances** calculated during the entire period of recoveries & giving the same weight to each month, are estimated at **1200 miles**

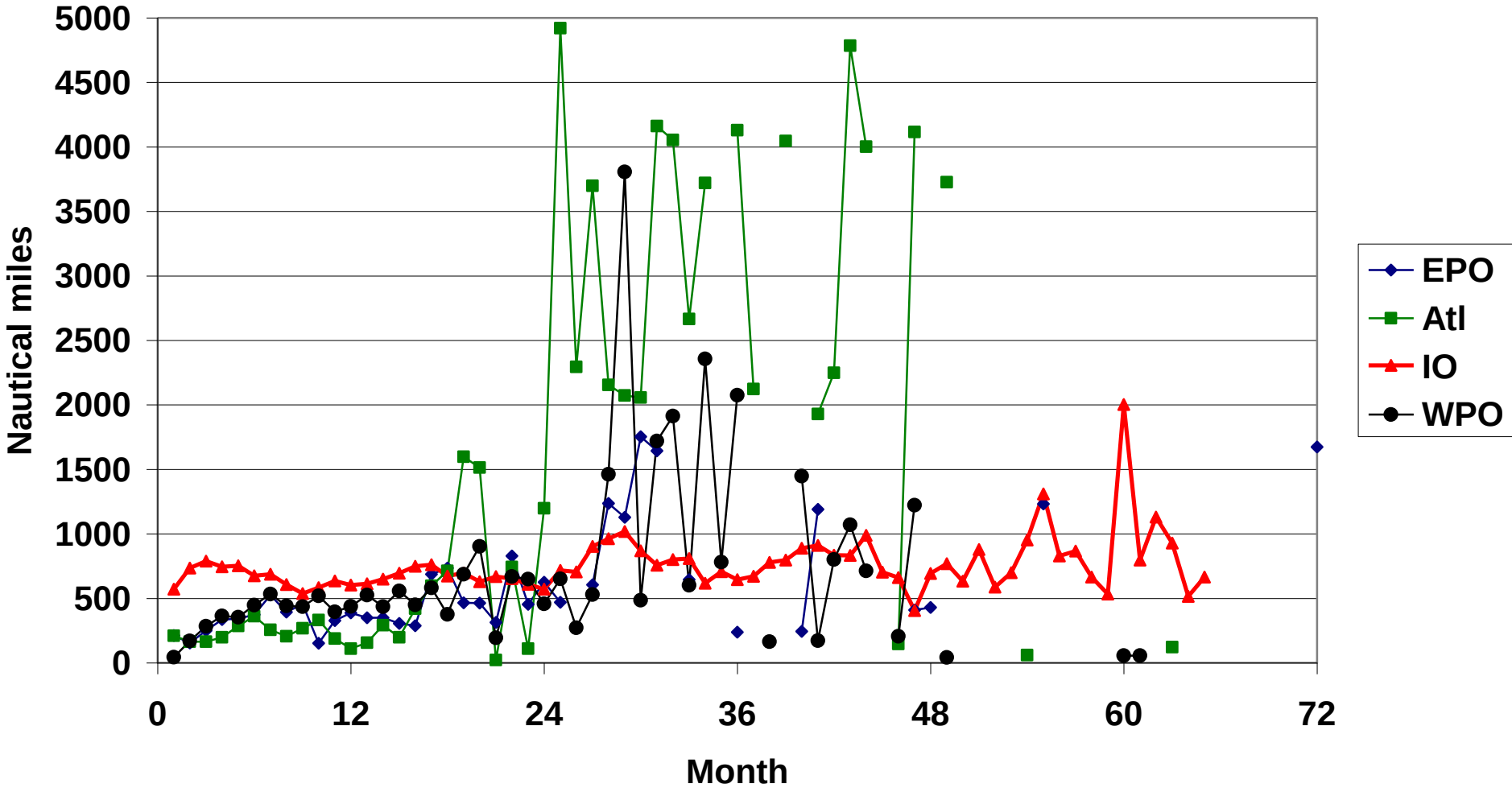
Average monthly distances between tagging & recov position, by ocean



Average of the monthly distances covered by tagged tunas at the recovery (calculated in each area for all the months with more than 1 recovery of the species)

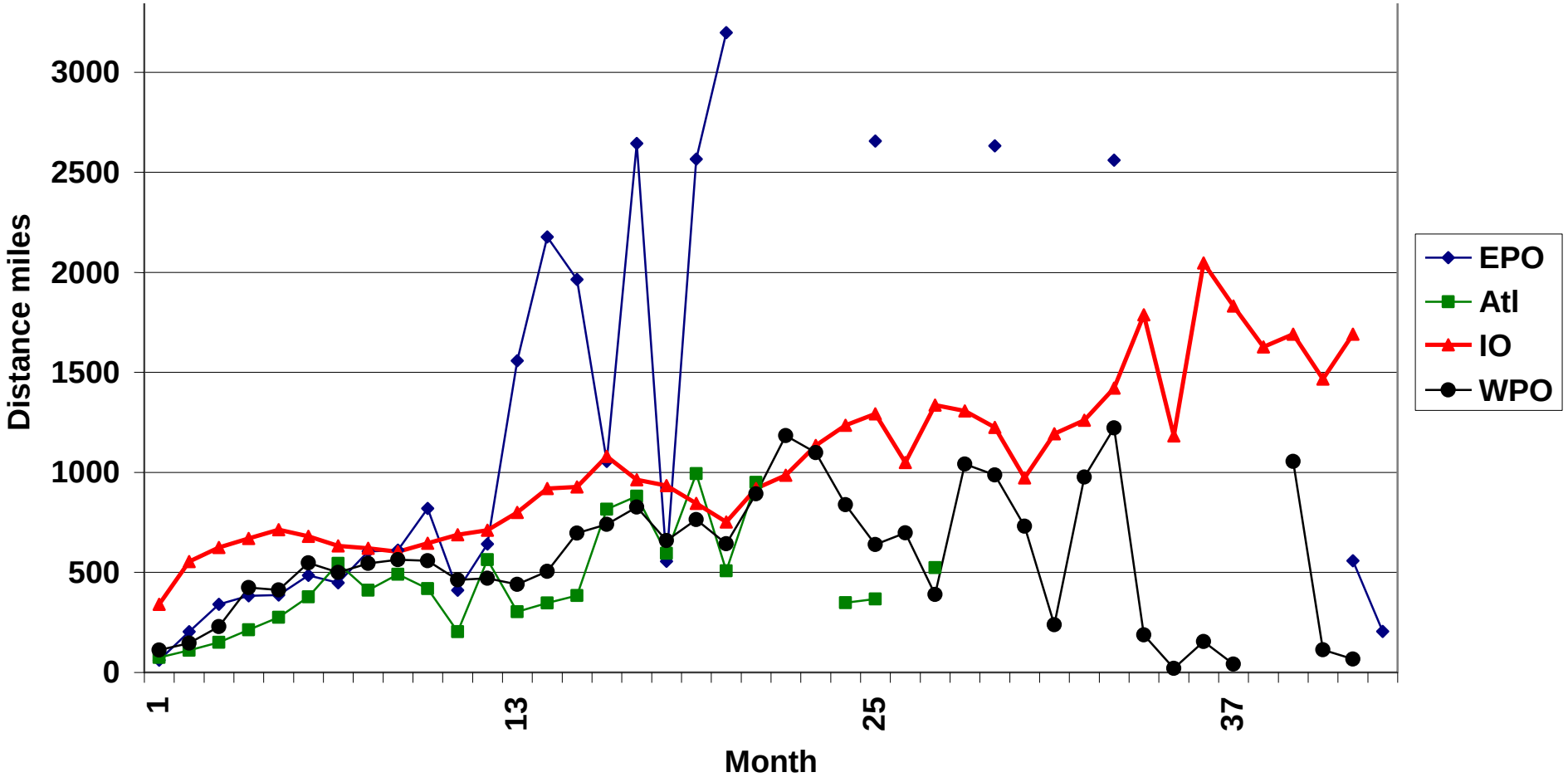
Average distances are variable between species & ocean, but showing similar orders of magnitude

YELLOWFIN monthly distances between tagging & recovery in each ocean



- During the 1st year: maximal distances in the Indian Ocean, minimal ones in the Atlantic
- After 2 years, larger average distances often observed in the Atlantic and Western Pacific

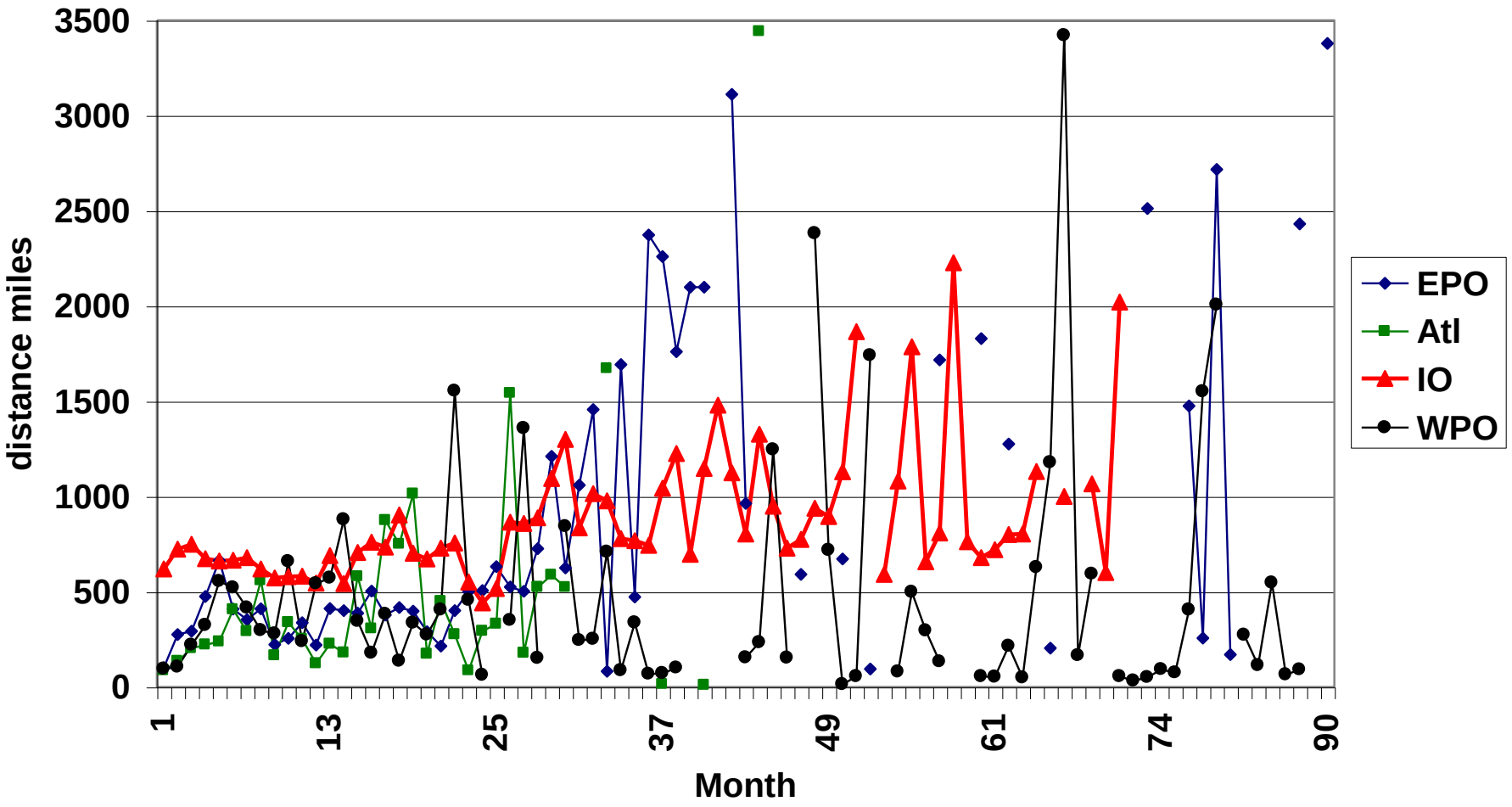
Skipjack monthly distances between tagging & recovery in each ocean



✓During the 1st year: maximal distances in the Indian Ocean, minimal ones in the Atlantic, similar distances in the EPO & WCPO

✓After 1 year, larger average distances often observed in the Eastern Pacific; decreasing distances in the WCPO and steadily increasing distances in the Indian Ocean

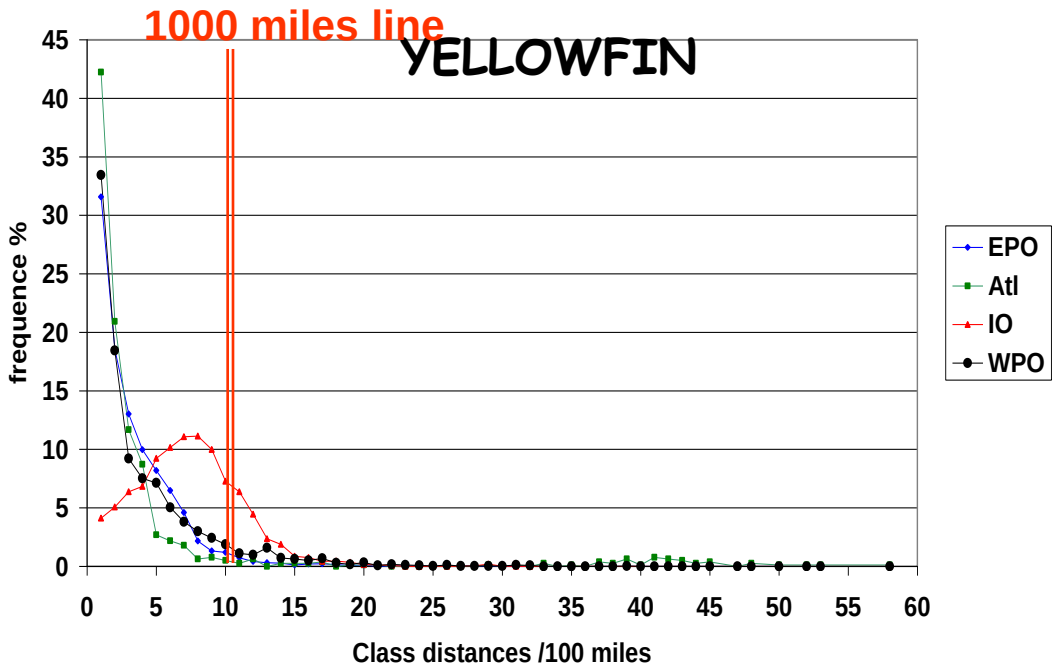
Bigeye monthly distances between tagging & recovery in each ocean



✓2 first years: stable distances observed worldwide but at different levels, larger distances in the Indian ocean

✓Subsequent years: slow increase of distances in the Indian ocean at large levels, the Western Pacific recoveries showing and alternate very small (homing?) & large distances.

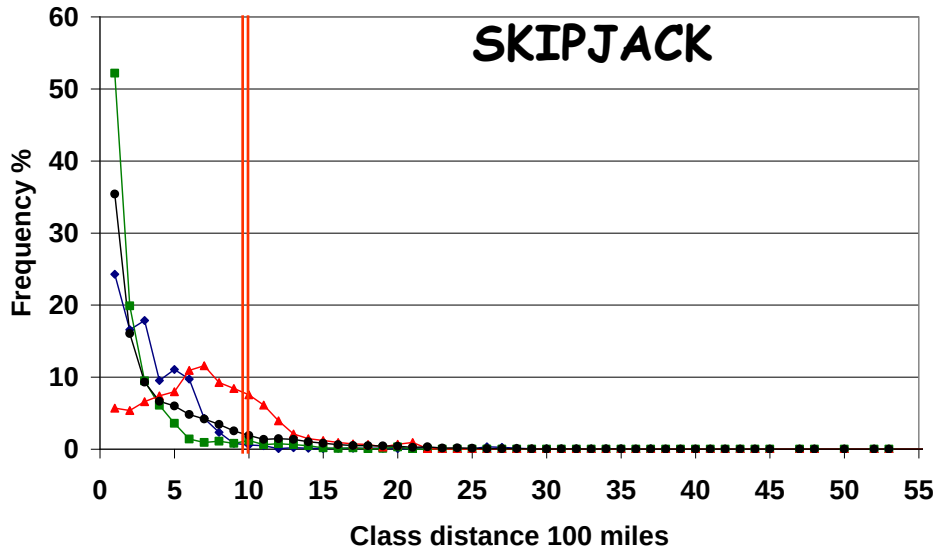
An overview of apparent linear displacements by each species in each area between tagging and recovery

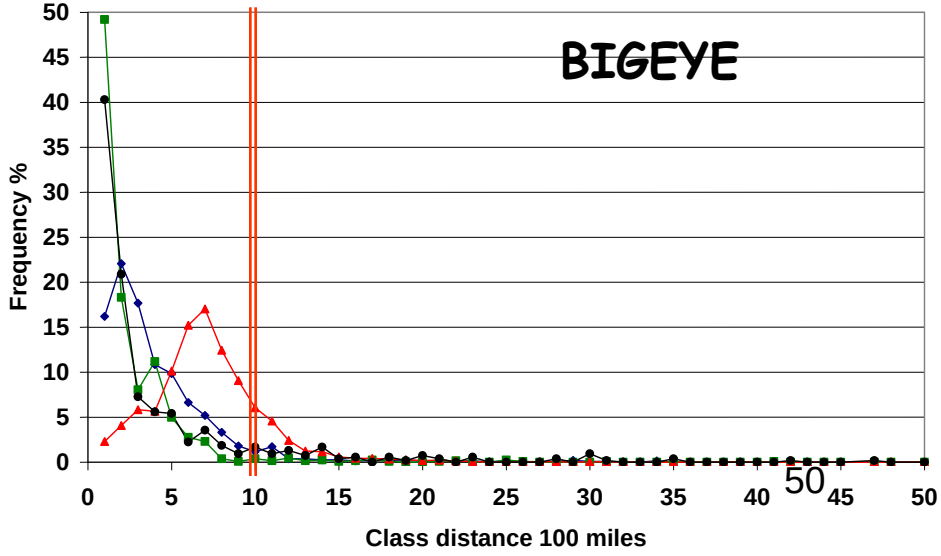


A very peculiar pattern observed in the Indian Ocean for the 3 species:

-Short distances <500 miles have been seldom observed in the IO, when they are widely dominant for all species in other tagging results

-Modal distances in the IO at 700 miles, when in other oceans frequency of recoveries are permanently declining at increasing distances

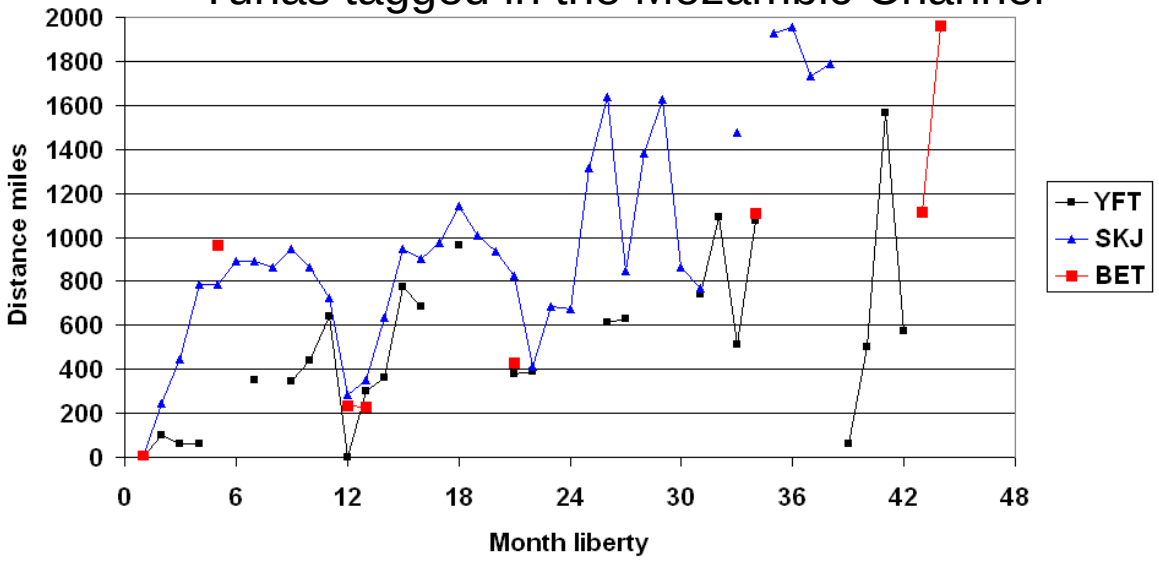


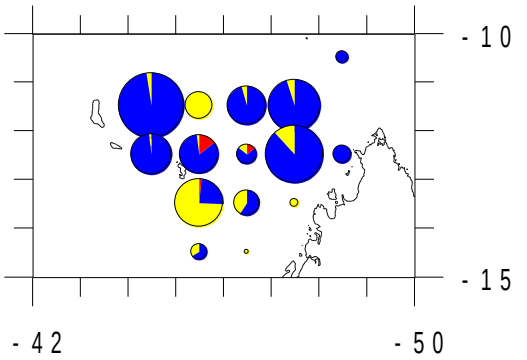


4-3- A case by case look at some peculiar tagging strata

Average distances between tagging & recovery by ocean are an interesting basic parameter to consider, but these results are most often an average of highly variable results, mixing:
(1) fractions of stocks that are showing slow and limited apparent movements
and
(2) highly mobile fractions of stocks showing fast and large scale movements

An Indian Ocean example
Tunas tagged in the Mozambic Channel

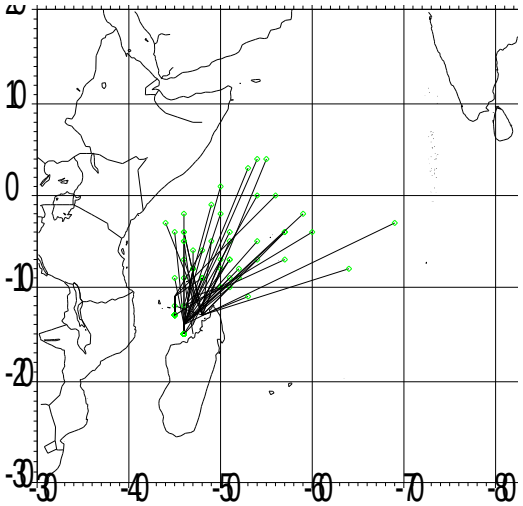


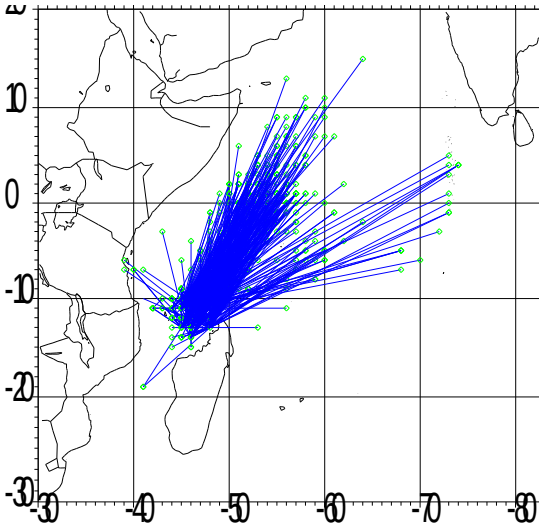


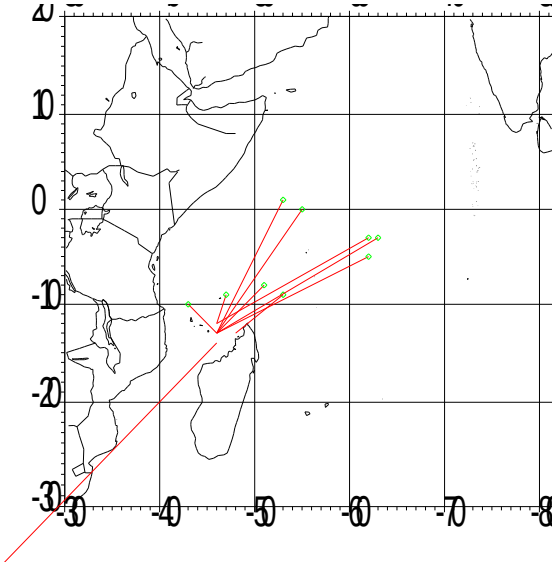
Tagging areas in the Mozambic channel

	Number	Distance
YFT	**52**	**539**
SKJ	**449**	**983**
BET	**11**	**850**

-Clear pattern of seasonal return of tagged tunas
-Larger and increasing distances covered by SKJ

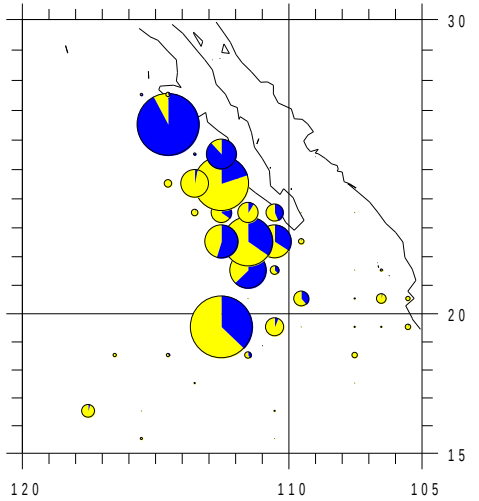


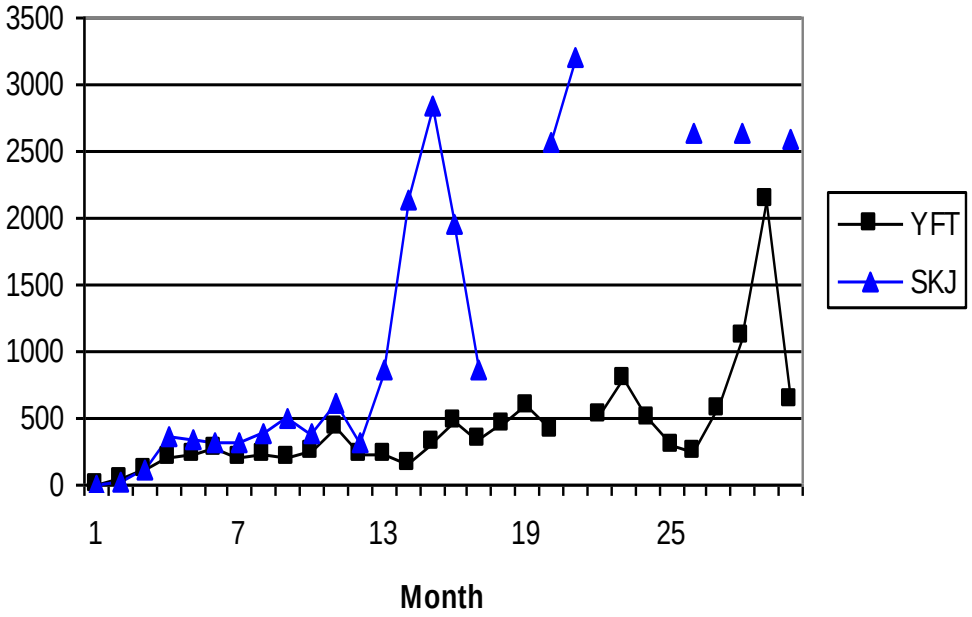




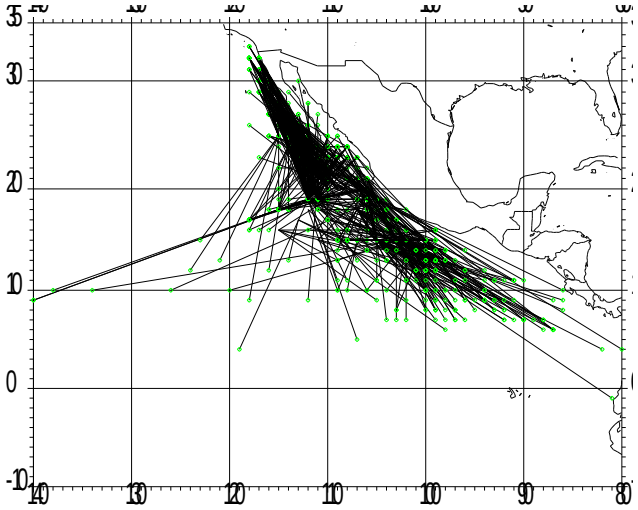
- A seasonal fishing zone and later showing a yearly return of tagged tunas in the tagging area during this short fishing season (March to May)
- This yearly return cannot be a random movement & it typically correspond to a **fidelity of tagged tunas targetting a feeding strata:** tagged tunas remember their tagging-feeding strata, where they come back later each year
- This conclusion is valid for the 3 species: YFT, SKJ and BET
- This fidelity of tunas to a given spawning or feeding placee has been also very well demonstrated by various **archival tag** studies: there is no doubt that long term archival tags detailed trajectories have been providing stronger results than dart tags in this domain (dart tags recoveries being totally dependent of fisheries and of fishermen)

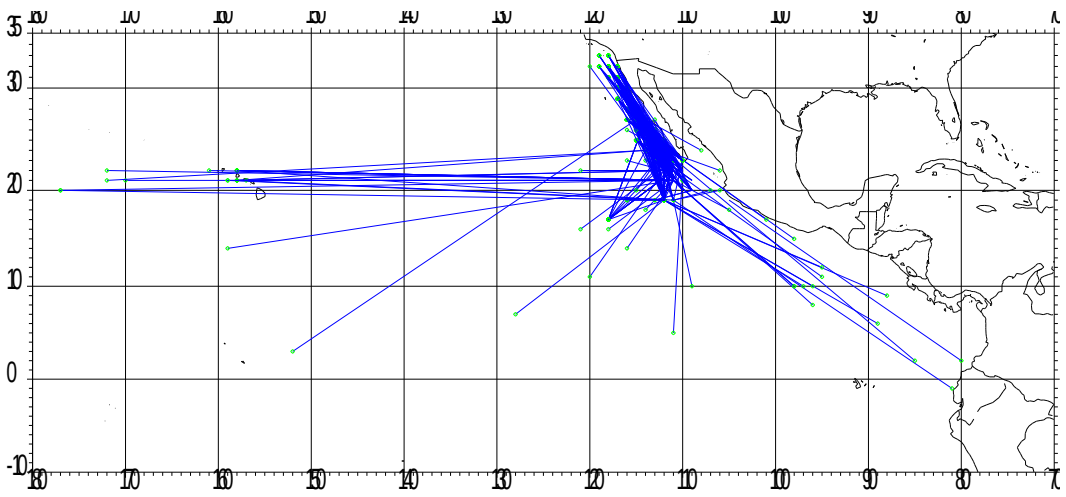
An Eastern Pacific example:
Tunas tagged off Baja California, Mexico



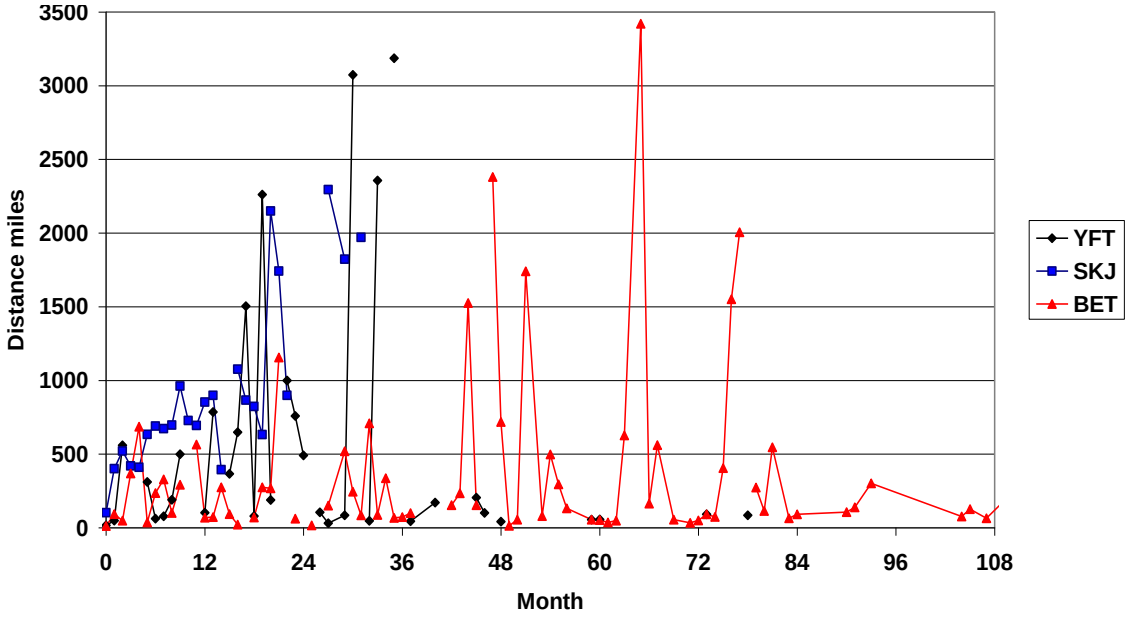


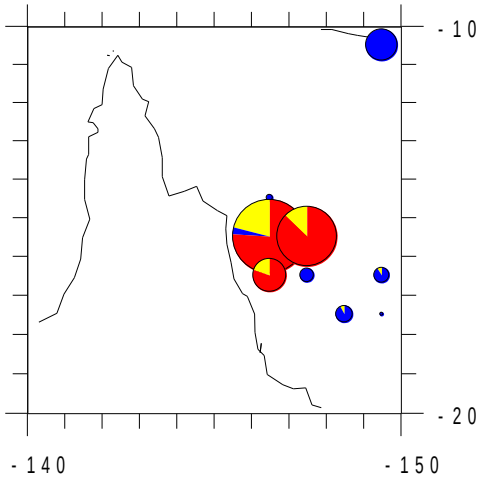
	Number	Distance
YFT	2188	432
SKJ	780	1298



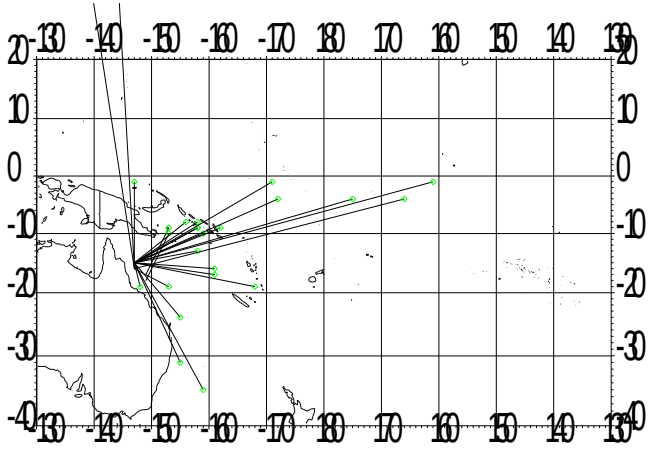


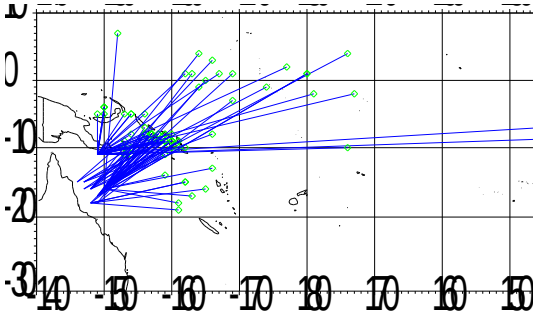
A western Pacific example
Tunas tagged in the Coral Sea

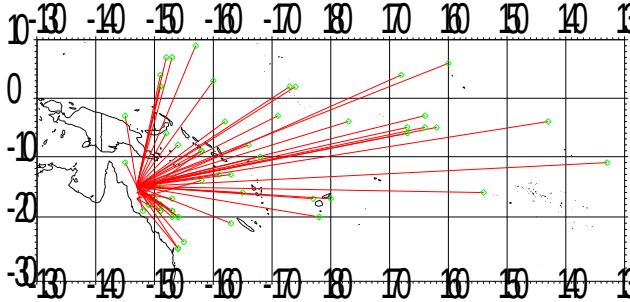




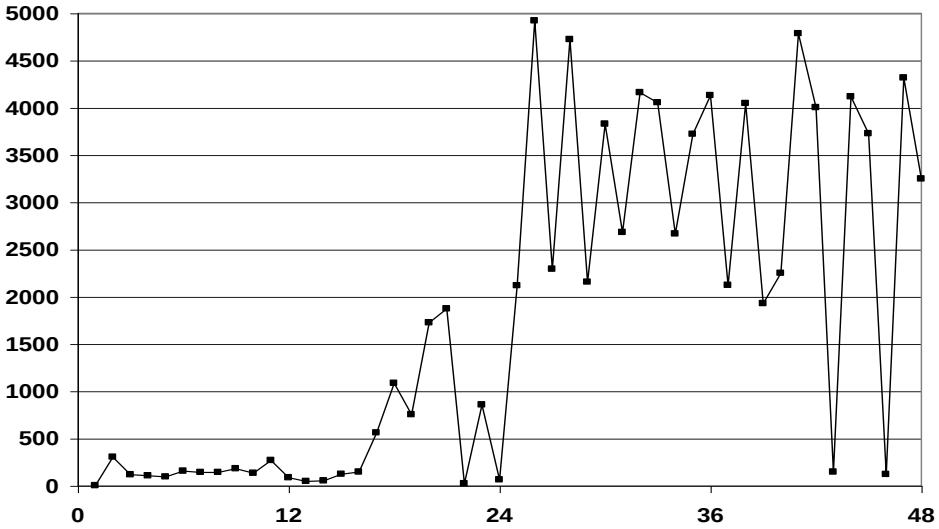
	Number recoveries	Distance
YFT	61	593
SKJ	70	1054
BET	261	432

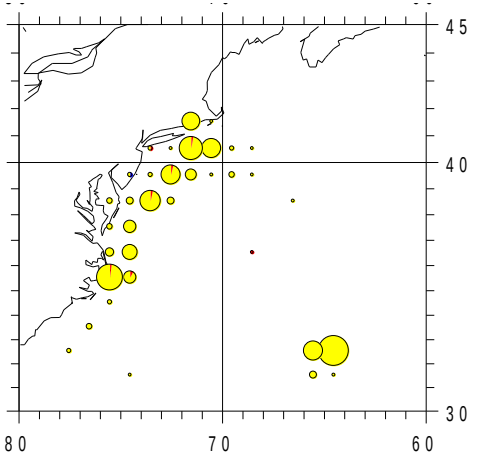




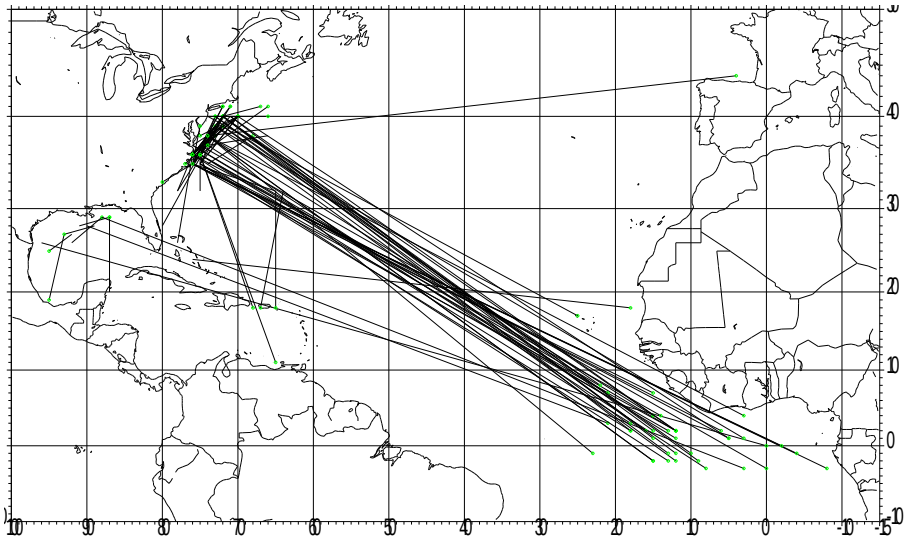


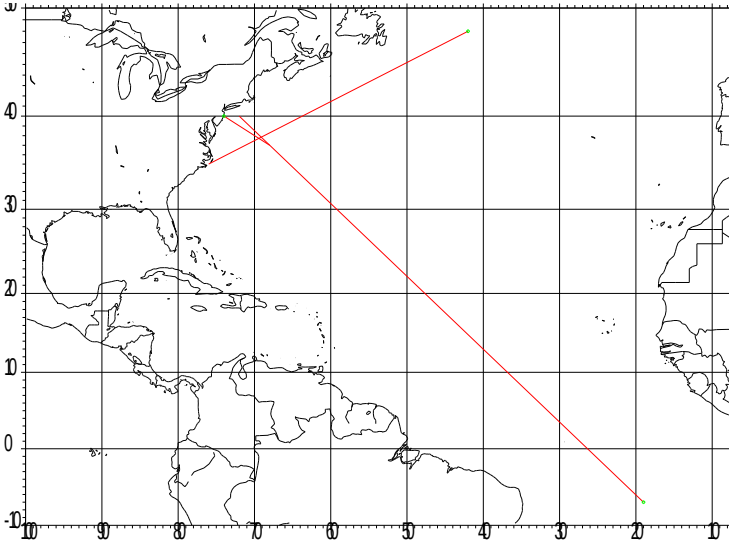
An Atlantic exemple:
Tunas tagged in the USA East Coast by sport fishermen





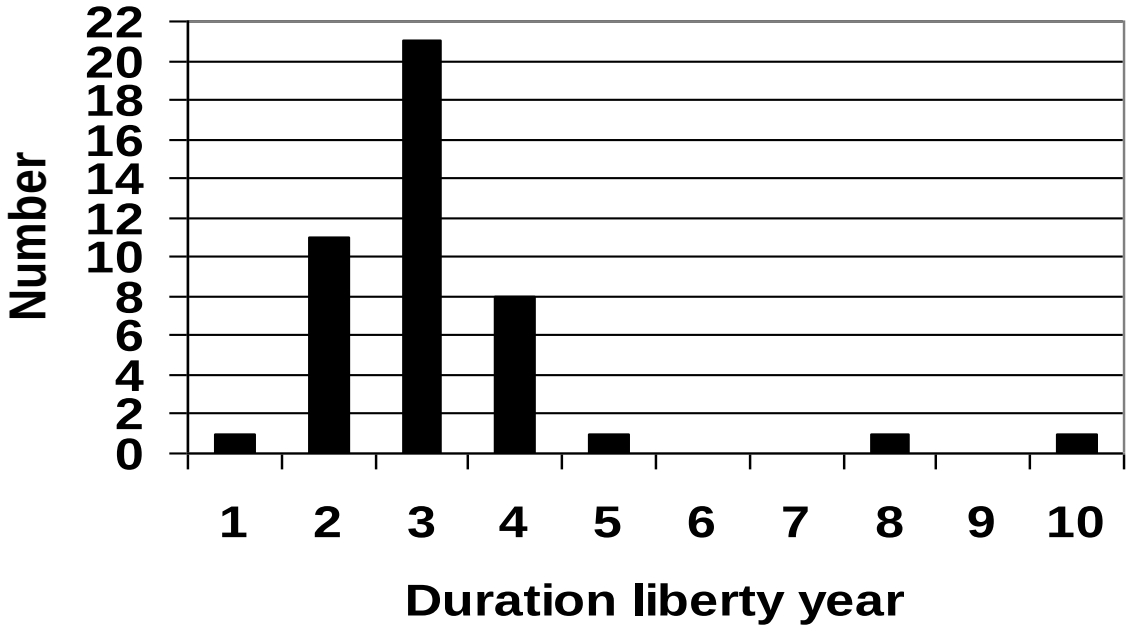
ıst	Number recoveries	Distance
YFT	291	1731
SKJ	9	50
BET	9	962





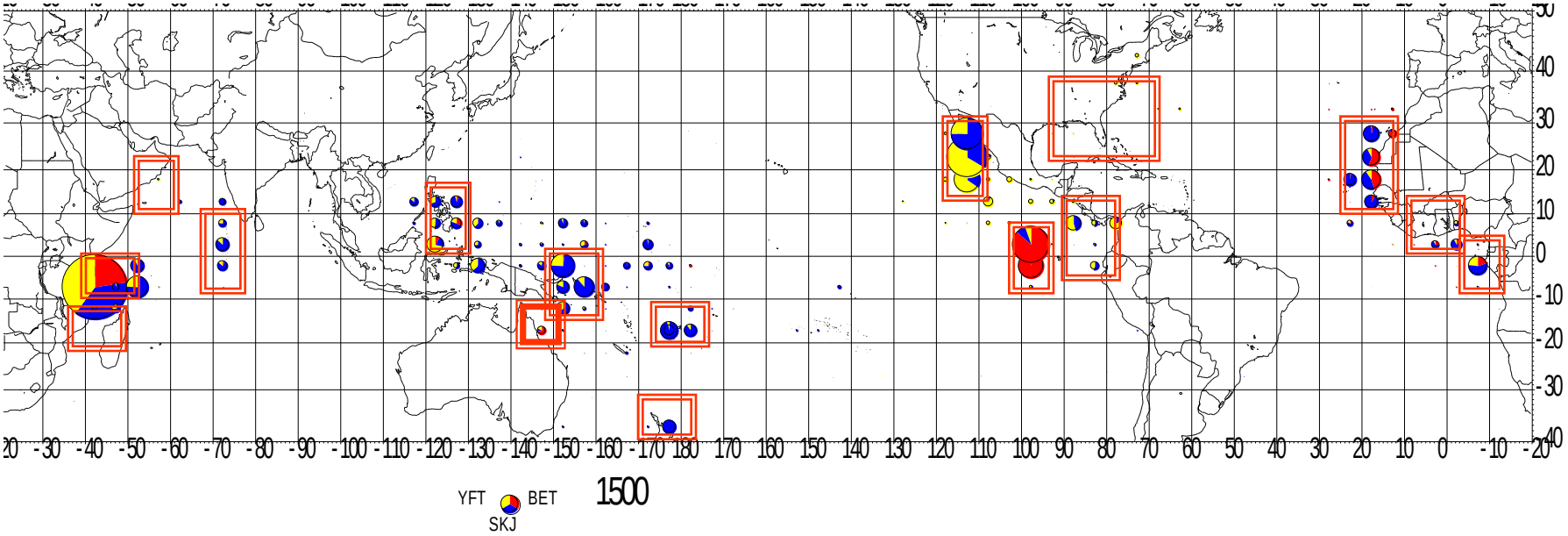
Yellowfin transatlantic recoveries
an interesting & significant migratory « anomaly »

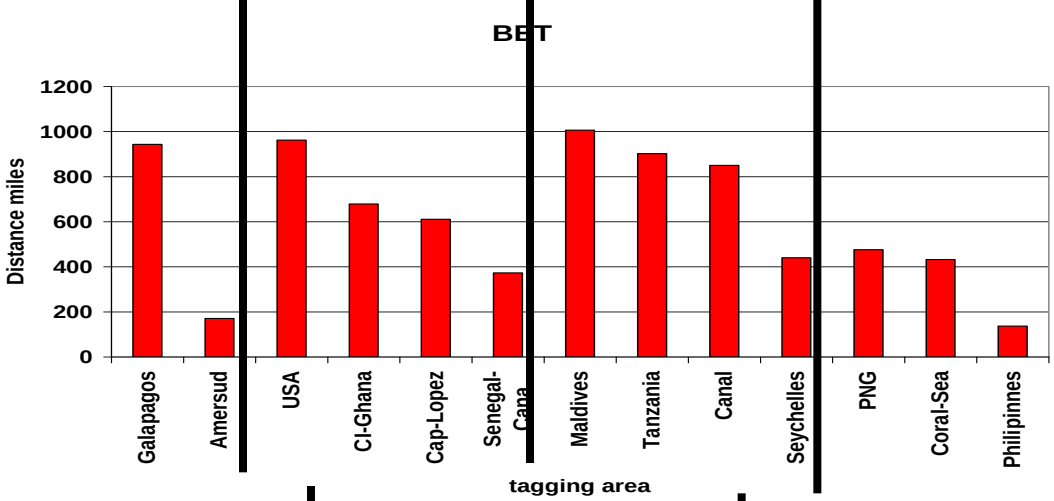
- Real large scale trans oceanic migrations have been seldom observed for tropical tunas
- One exception: the frequent transatlantic movements observed in the Atlantic: **45 YFT** tagged along the USA coast since 1986 have been recovered at adult sizes off Africa
- YFT have been tagged by US sport fishermen in a wide range of sizes: 40 to 135 cm
- Most duration at liberty are **over 1.5 year**, reaching a maximum of nearly **10 years**.
- Large distances covered between tagging and recovery positions: average of 4100 miles
- The basic hypothesis being that this movement corresponds to a **real homing migration**, back towards the major YFT spawning zone in the Guinea Gulf, probably the area where these YFT are born..



➢This structural heterogeneity of the apparent mobility of tuna stocks can be examined on a case by case basis, comparing the recoveries of tunas tagged in selected tagging time and area strata & in the various oceans.

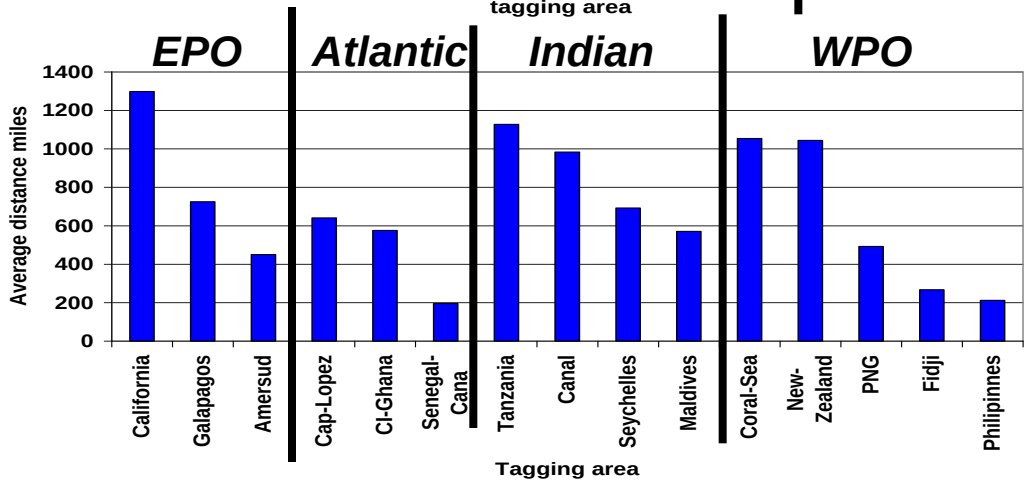
➢This tentative analysis & comparison has been done on the following tagging strata:



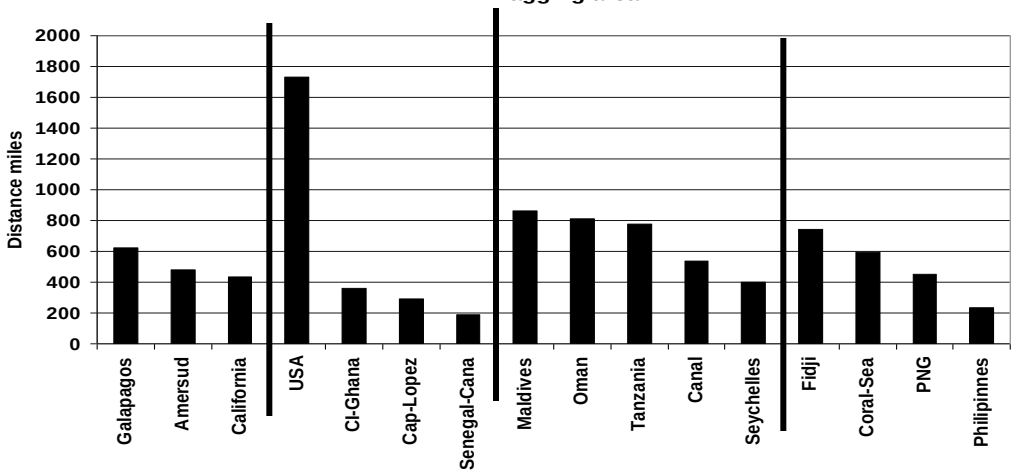


Bigeye

Average distances between tag&Rec positions for tunas tagged in the selected tagging areas,
sorted by ocean & by decreasing distances
A great diversity of distances travelled



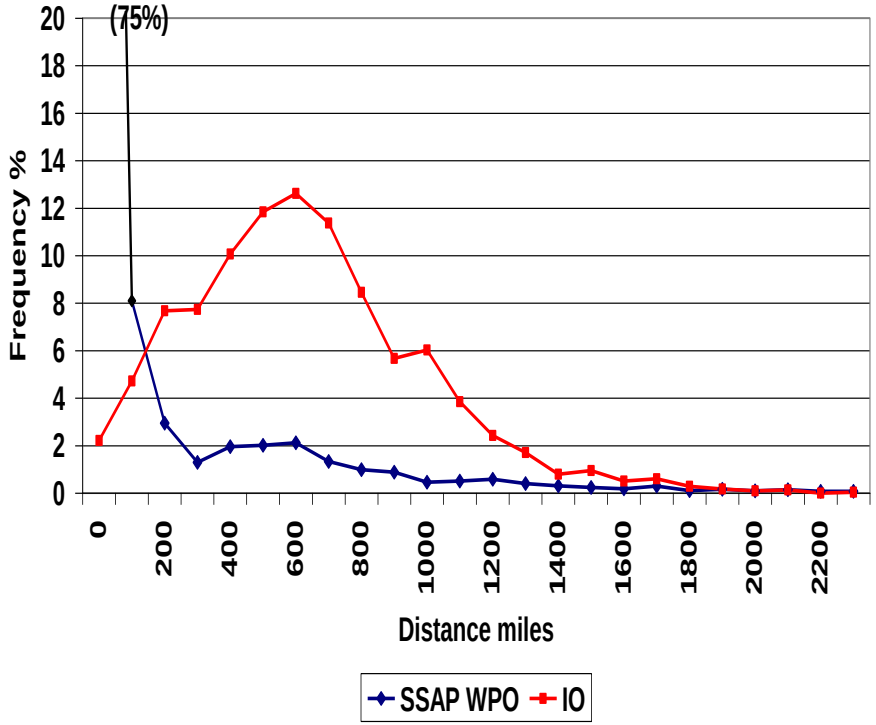
Skipjack

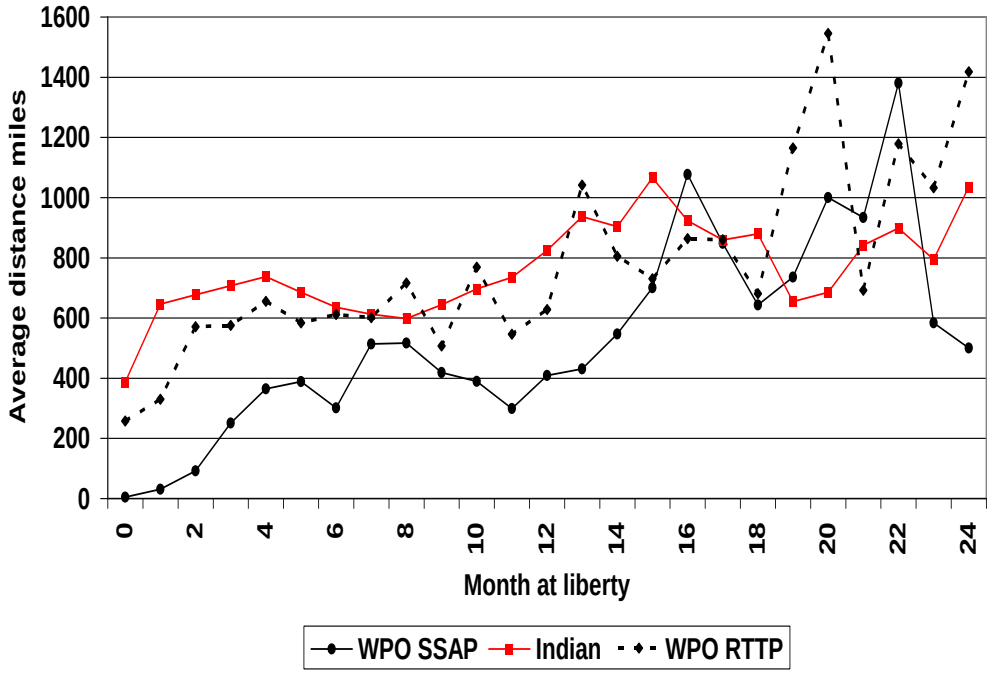


Yellowfin

4-4 Skipjack movements in the Western Pacific & in the Indian Ocean?

Hilborn & Sibert 1986 analyzed the short distances covered by SKJ in this area, following left figure, and based on this figure they concluded that «**for countries with large economic zones, stocks of YFT and SKJ may be considered resident** ». On the opposite, it can be noted that the proportion of large distances observed for tagged SKJ in the IO is totally different, showing a high % of long distances, potentially leading to opposite large scale oceanic management.



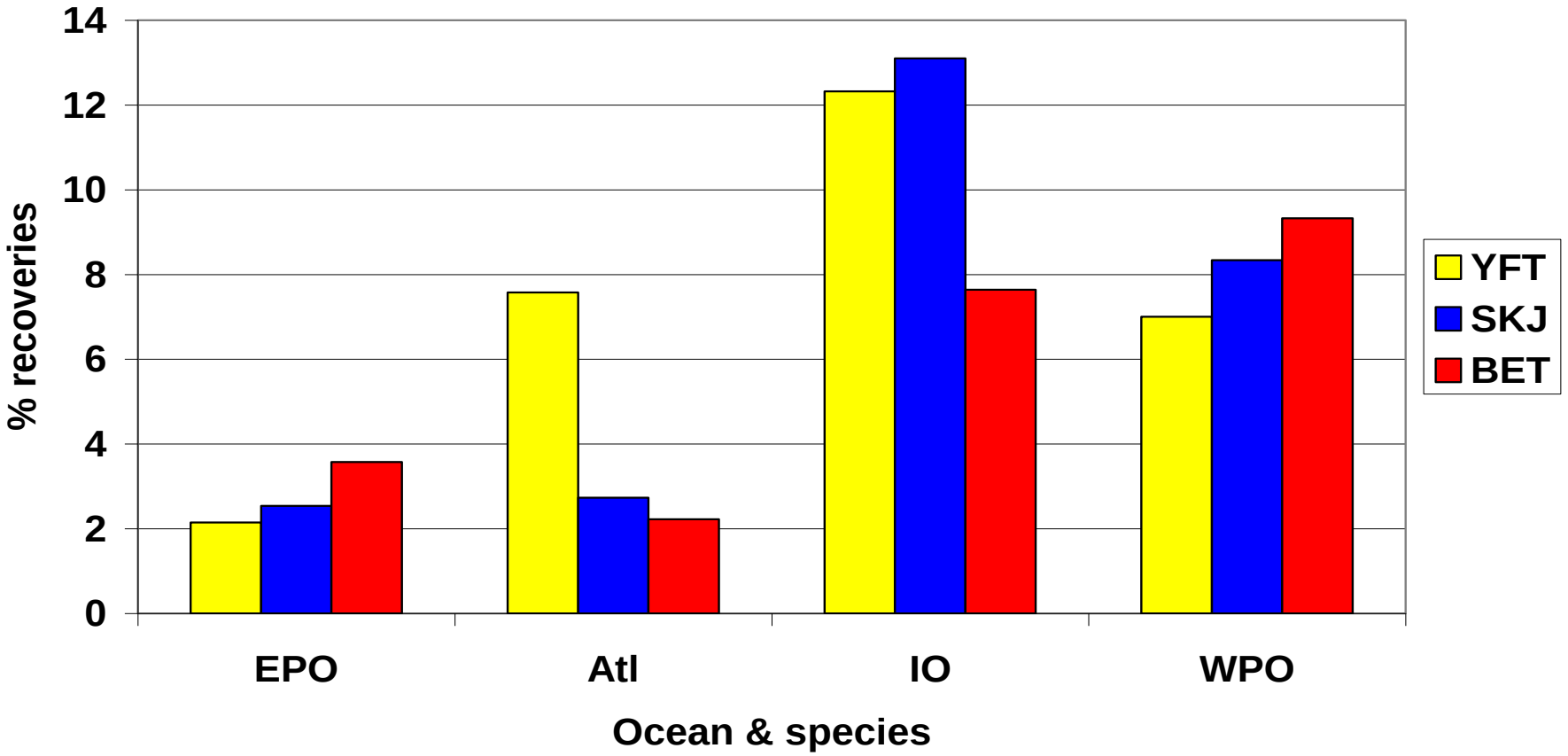


However, these striking differences between IO and WPO SKJ distances observed in the left figure are somewhat artificial & driven by short term recoveries.

On the opposite, the average distances covered by SKJ as a function of their monthly period at liberty (right) shows a quite minor difference between an average distance of 520 miles in the WPO and 790 miles in the IO(and even less for SKJ tagging done in the 90ies: average distance 7 ı).

4-5- Observed frequencies of long distance recoveries

An overview of long distances recoveries >1200 miles, travelled by each species in each area (eliminating all short term recoveries observed during the first month of liberty)



✓ Gold medals to Indian ocean YFT & SKJ, but the IO % are very close to WPO rates (an area winning the gold medal for BET, Coral sea tagging)

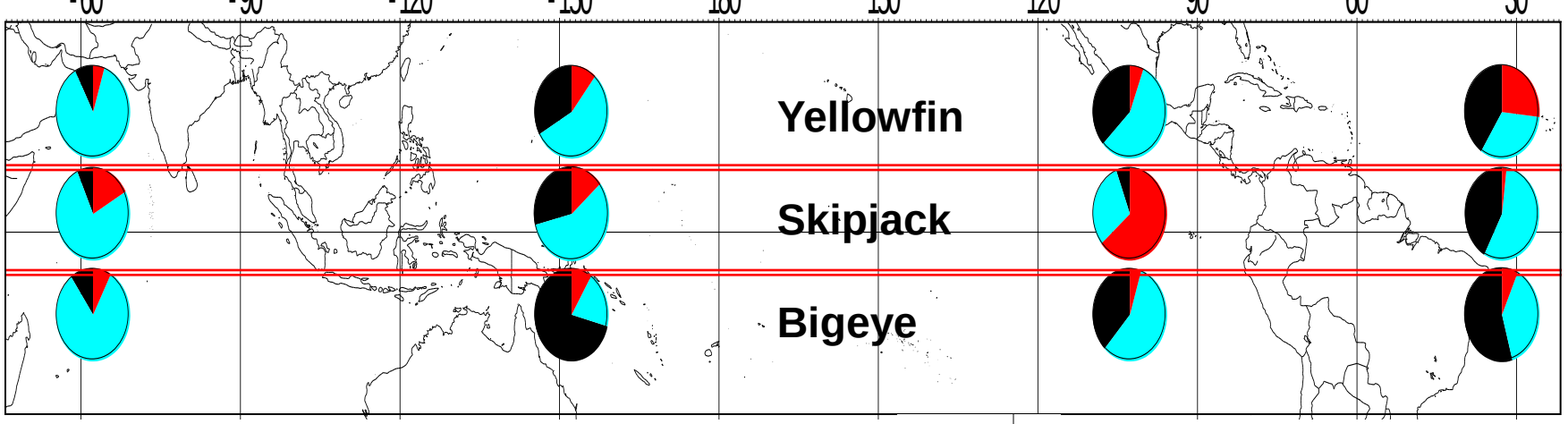
✓ Quite high frequency on long distance for Atlantic YFT (transatlantic migrations)

✓ Rare long distances are observed in all the other cases: ocean & species

4-6- Apparent rate of fidelity of tagged tuna to their tagging areas

- The frequencies of recoveries by species as a function of the distance betwen tagging & recovery locations has been calculated & classified in 3 categories:

1) **Tagged tunas that have been recovered within their 200 miles tagging zones,**
2) **Recoveries at intermediate distances from the tagging zones, between 200 & 1500 miles**
3) **Recoveries very far from the tagging zones : more than 1500 miles,**



Size of a 200 miles circle area

% 200 m recov

% recov >1500 miles

% recov 200-1500 miles

Percentage of tagged tuna recoveries after more than 1 year at liberty:


in their 200 miles tagging zones (black areas),


very far from them (>1500 miles, red areas)


or at intermediate distances (blue areas)

by species: YFT upper, SKJ middle, and BET lower lines

A figure showing high average rates of long term fidelity of tagged tunas (average : **31%**), but also a great variability between species & oceans:

1) Atlantic & WPO showing high rates of fidelity for the 3 species (**46 & 44%),** with exception of **Atlantic YFT (27%** of long distance recov.)
2) IO showing similar rates for the 3 species, and the lowest apparent fidelity (**av. 8** %), a result probably due to the peculiar & limited tagging locations
3) EPO SKJ showing a very low fidelity & high mobility: **64%** >1500 miles.

It should also be kept in mind that the low rates of fidelity, for instance observed in the IO, may be artificially low, & being simply due to the rarity of fishing activities by purse seiners around this tagging area

These high rates of « apparent fidelity » to the tagging areas may correspond:

(1) either to **viscous or sedentary resources** that are spending long periods or all their life in a given region, or

(2) tunas showing one kind **of trophic or reproductive homing behavior towards their tagging areas**. Such behavior has been quite often shown by archical tagging results (for instance Schaefer 2011)

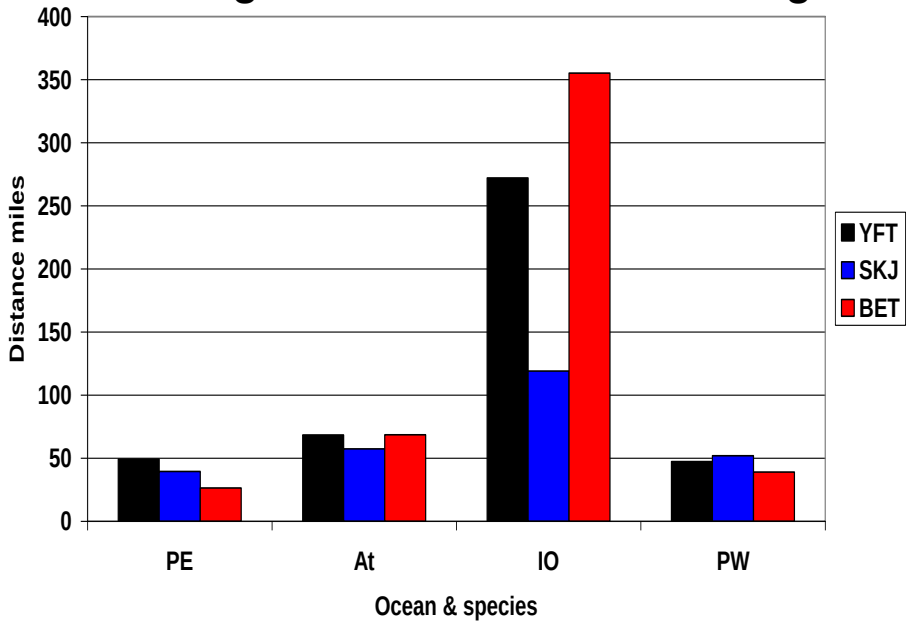
But independently of its causes and mechanisms, **this fidelity is really striking & universal,** taking note that a small area in a circle with a 200 miles radius correspond to a very small proportion of the oceanic biological habitat available to tropical tunas such as YFT and BET: about 0.36% of their habitat in the Pacific ocean, 1.8% of the Indian ocean habitat and 2.6% in the Atlantic.

It would necessarily mean that large fractions of the 3 tuna species would not be the typical tunas that are randomly searching food in their wide potential habitats, but instead showing firm given geographical preferences.

4-7- Short term apparent movements: distance between tag & recov positions during the 1st month at liberty

- ✓ This parameter has been seldom analyzed, because tagged tunas have been most often caught in this short term close to their tagging area
- ✓ This was not the case in the Indian Ocean tagging, where many tagged tunas have been recovered **far from the tagging zone within the 1st month**: an average distance of **249 miles, 5 times larger** than in the rest of the world.
- ✓ The following figures compare these short term distances of recovered tunas that have been observed in the various oceans

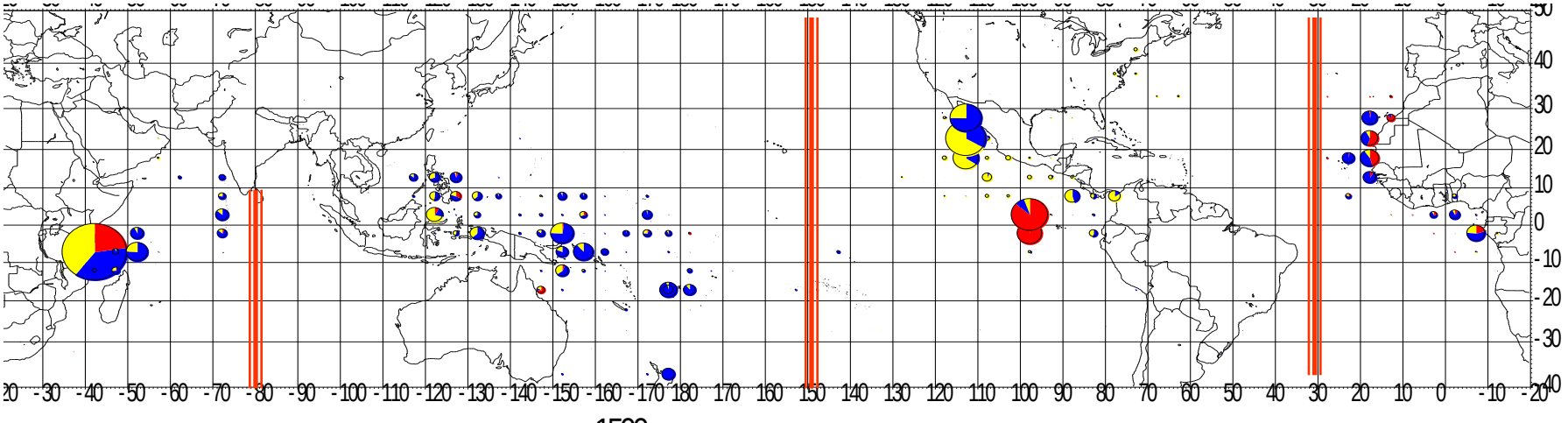
Average distances covered during the 1st month at liberty for the 3 species & by ocean



Ocean	YFT	SKJ	BET	Average
Indian Ocean	272	119	355	249
Eastern Pacific	49	40	26	38
Atlantic	68	57	68	65
Western Pacific	47	52	39	46
Average	109	67	122	99
Average non IO	55	50	45	50

4-8- Conclusion on tuna movements

- All tuna species have been widely confirming the diagnosis by lawyers and their article **64 in the law of the sea**: tunas are highly migratory species, they dont know human EEZ, and their stocks can only be managed by international tuna RFO.
- But wide variabilities are easily observed from tagging data in tuna migrations, between oceans & localized areas & islands, and also between species.
- Today tagging programs may be insufficient to estimate potential mixing rates between potential Western & Eastern tuna stocks located in the Pacific, Indian and Atlantic oceans.
- This structural limitation is mainly due to the present **geographical positions of most tagging** that have been done most often very far from these potential mid-oceanic frontiers.



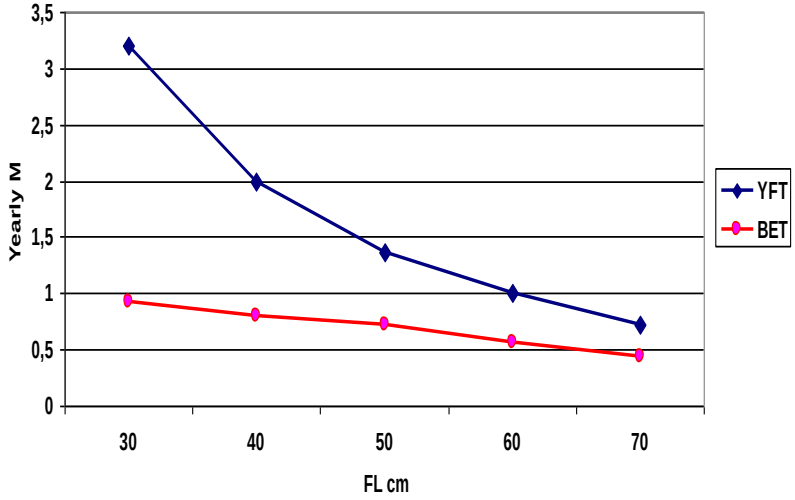
(5) Tag recoveries & natural mortality at age of tropical tunas

- A key stone parameter in all tuna stock assessments, & probably the most cryptic one
- Natural mortality at age can be estimated by statistical analysis of recoveries, but this analysis has been seldom done as it requires **large number of simulaneous tags** and good knowledge of many fishery parameters (reporting rates, selectivities & others).
- And also mature fisheries covering large fishing areas in order to avoid local effects and full mixing of the tagged tuna in the population.
- Relative **Natural mortality of male & female** can also be estimated when sexes of recovered tunas has been identified on a significant number of recoveries.
- As a consequence of these difficulties **Natural mortality has been seldom estimated** for tropical tunas: only by J Hampton WCPO & T Polacheck IOTC.
- Some historical estimates of natural mortality have been done for SKJ & YFT by the IATTC (Fink 1965, Joseph and Calkins 1969, Bayliff 1971) , but their results were less than satisfactory due to various cascading factors.
- Hampton 1992 estimated that natural mortality of WPO skipjack was high & at 1.9-2.3 (yearly) and small yellowfin a lower rate of natural mortality: 0.96-1.2.

An ideal target in the estimation of natural mortality would be to at least to provide a realistic statistical answer to the hypothesis often raised by J Gulland in historical ICCAT meetings:

« small YFT and BET that are living at the same size, in the same schools and in same ecosystem should have similar natural mortality ».

The Indian ocean tagging program is probably the first & only one that could provide some answer to this question because of its large numbers of YFT and BET tagged and recovered simultaneously and with the same uncertainties.



Yearly rates of natural mortality as a function of tuna size presently assumed for small BET & YFT in the Pacific

Major divergences in Mi of juvenile BET & YFT are estimated today in the Pacific& very high M estimated for small YFT

These values of juvenile Natural mortality are very important in most stock assessments. But are they realistic? Tagging/recovery data should allow to answer to this question.

(6) Largest duration at liberty observed world wide for each species

- Maximum duration at liberty is a strong indication of the duration of the exploited life of each tuna tuna species: « **apparent longevity** »
- This result is indicative of the ideal duration that should be used to model the status of the various tuna stocks
- It is also of great interest to compare the « apparent longevity » estimated from tagging results in the various oceans & for each species, because longevity is probably dependent of the species, more than of the ocean.
- The following table show the maximum time at liberty and the average time at liberty of the 5 longest time at sea durations (in years) observed for each species in each ocean

Maximum duration

Species	Indian	Western Pac	Eastern Pac	Atlantic
YFT	6,0	6,5	7,5	9,1
SKJ	4,2	4,6	2,7	2,0
BET	6,8	13,8	7,5	9,4

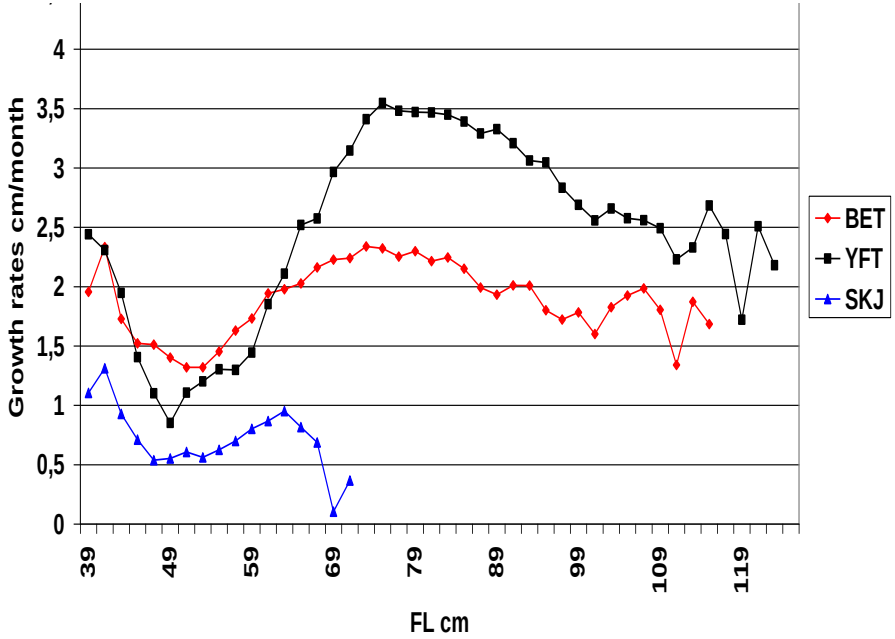
Average maximum duration 5 fishes

Species	Indian	Western Pac	Eastern Pac	Atlantic
YFT	5,8	5,5	4,7	6,2
SKJ	3,4	3,6	1,8	1,7
BET	6,2	10,4	4,7	3,9

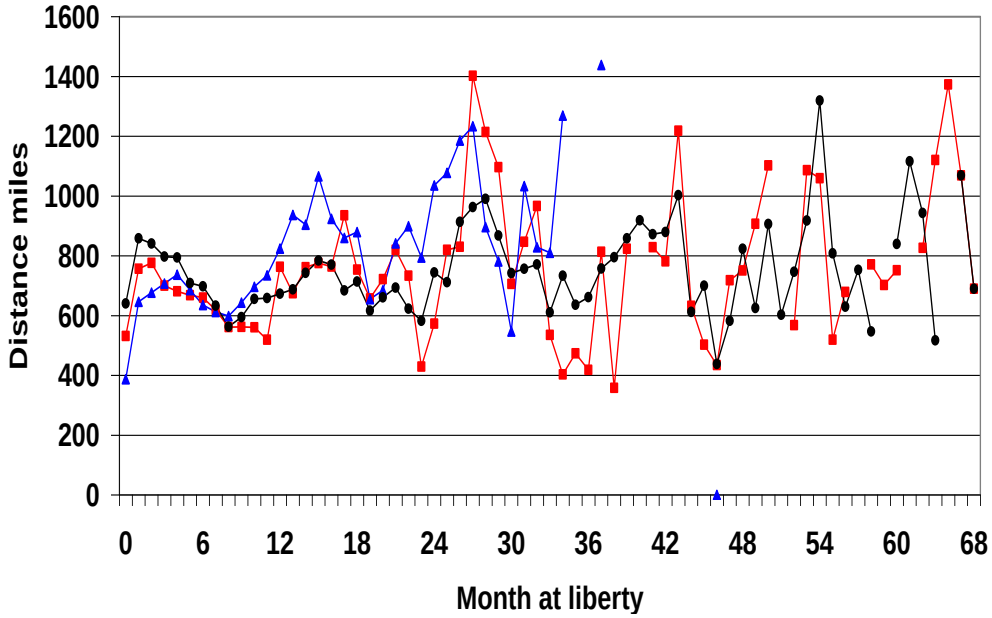
These maximum durations at sea are of course lower than the biological longevity, as these tunas have been tagged most often at ages between 1 and 3 years

(7) An overview of multispecies rates of tagging

- Keeping in mind that the 3 species of tropical tunas are strongly associated in the pelagic ecosystem and in the fisheries,
- That the **ideal fishery management should be multispecific,** It is always very interesting to simultaneously tag the 3 species of tropical tunas, YFT-SKJ and BET, as the subsequent **simultaneous recoveries of the 3 species over times offer very interesting comparative biological results**: longevity, growth, movements, natural mortality at age, exploitation rates of the 3 species, as they are assessed, fished & managed in common.



Comparative growth rates of the 3 species Estimated in the IO

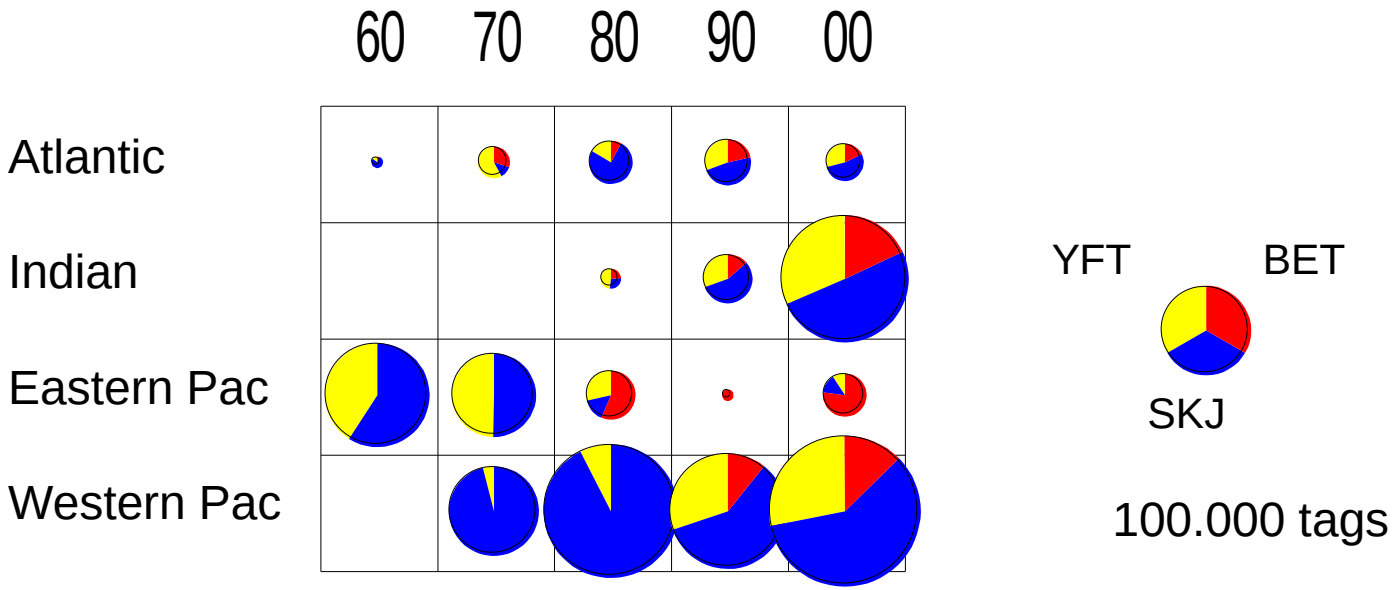


Distances covered between tagging & recovery in the IO by the 3 species

Numbers of tunas tagged by ocean & by 10 years periods:

The best tagging programme can easily be identified based on their **large numbers of tags** deployed and with **the 3 species tagged simultaneously**:
> in the Western Pacific since the nineties (when previous tagging were only on SKJ),
➢in the Indian Oceans during the years 2000

➢ On the opposite, tagging programs have been weak in the Atlantic and Eastern Pacific in term of numbers, due to lack of funding
➢ This lack of recent tagging results may be very serious during recent years of high fishing pressure and active FAD fishing by PS
➢ Several historical tagging programs are also weak in their species composition: for instance not enough bigeye tagged.



(8) An overview of tuna tag shedding estimated world wide

- Tag shedding has been classified in 2 categories: type-1 shedding which occurs immediately & type-2 shedding occuring during the life of the tagged fish
- This tag shedding is of course widely dependent of the taggers expertise: experienced taggers showing much lower shedding rates.
- First estimates of tag shedding obtained by IATTC (Bayliff & Mobrand 1972): type-1 shedding aestimated at about 10 % & type-2 shedding assumed to be constant at an instantaneous yearly rate of about 0.278
- IOTC: Gaertner & Hallier 1998 estimated wuch much lower shedding rates: **type 1 shedding at less than 2% and type 2 shedding between 0.015 (per year for SKJ , and 0.041 for YFT**
- Tag shedding rates have been also estimated by SPC scientists.

(9) An overview of tuna tag reporting rates estimated world wide by species & gear

- Tag reporting rates are a statistical parameter of key stone importance
- Very low reporting rates, or worse totally unknown rates, are a severe limiting factor to estimate movement rates, natural mortality and exploitation rates
- Reporting rates have been sometimes (for instance in the Indian Ocean) but quite rarely, estimated for purse seine fleets based on systematic **tag seeding** done during the fishing operation by observers or by selected crew members,
- Tag seeding results may be hampered or biased by various limiting factors, but they remain of key interest to estimate reporting rates
- Reporting rate for purse seiners in the WPO has been estimated by Hampton 1997 to be approximately 60% and at 94% by Anganuzzi et al 2012 in the Indian Ocean
- Maunder et al concluded on the EPO BET that there is little information about the tag reporting rates, when Schaefer & Fuller 2009 estimated the reporting rates bigeye caught in the estern Pacific by longliners with dart tags at a low rate of 10%.
- Atlantic very low reporting rates <1% estimated by Carruthers for most fleets
- Longline reprting rates for the major LL fleets have been also estimated at **5% in the Indian Ocean** (Carruthers et al 2012), & this is probably a strong result that has been well anchored on the measured Reporting Rates of PS.
- Longline fleets that are of great importance world wide because of their very wide fishing zones and of their key stone importance in all tuna stock assessments are showing most often very low reporting rates of dart tags.

- These reporting rates of longliners have been also indirectly estimated comparing the ratio of tagged fishes/total catches of longliners and purse seiners & doing this calculation only on large tunas caught by the 2 gears.
- Relative reporting rates of PS & LL should ideally be estimated using detailed tagging and fishery data, well stratified by flag, time & area strata, and by size of fishes, but these basic data are not available in the public domain
- However, the global ratios of tags reported by each gear as a function of their average catches of large YFT & BET may be indicative of their relative reporting rates

Total **numbers of recoveries** declared by species, by ocean and by gear

Big **Yellowfin** numbers of recoveries

Ocean	PS	LL
EPO	1 038	14
WPO	427	86
Atl	62	7
IO	4 102	92
Total	5 630	199

Big **Bigeye** numbers of recoveries

Ocean	PS	LL
EPO	3 395	48
WPO	35	274
Atl	18	61
IO	474	253
Total	3 922	636

Numbers of tagged large tunas recovered & declared by longliners are much lower than for PS:

- Only 636 BET declared by LL vs 14.936 for PS
- Only 199 YFT declared by LL vs 27.109 for PS

But these numbers should be put in relation with the average total catches caught by each gear

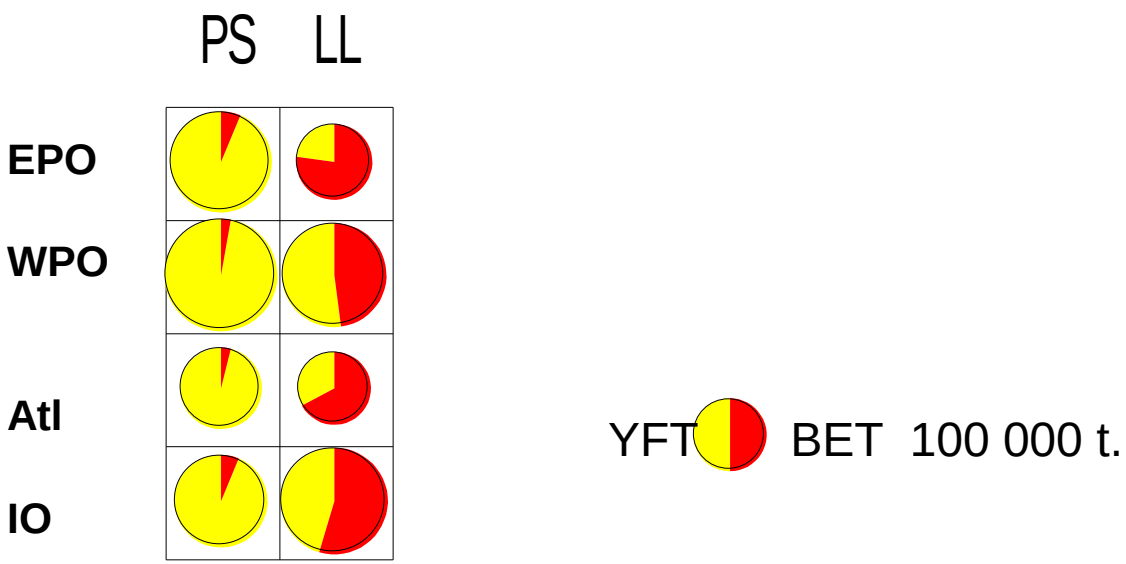
Average yearly catches by gear (in t.) of large tunas >90 cm during the periods of main recoveries (periods are variable beween oceans)

Big Yellowfin average catches (tons)

Ocean	PS	LL
EPO	125 466	17 419
WPO	87 000	84 000
Atl	83 432	21 029
IO	105 567	66 906
Total	401 464	189 354

Big Bigeye catches

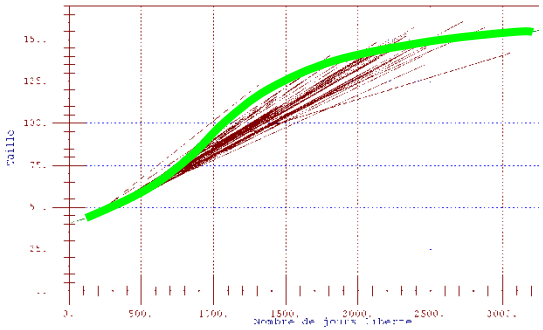
Ocean	PS	LL
EPO	**8 370**	**27 000**
WPO	**3 625**	**56 900**
Atl	**3 358**	**48 563**
IO	**7 102**	**80 272**
Total	**22 455**	**212 736**



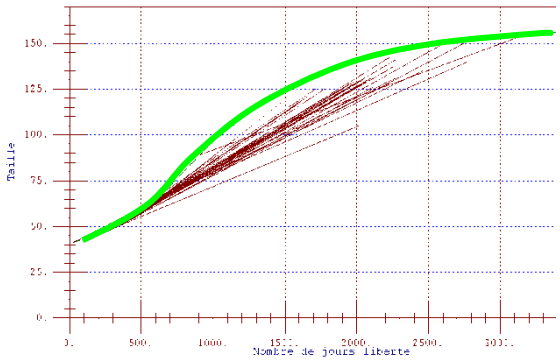
- Due to the low reporting rate of tags for the major longline fleets, it should be considered, as stated by Pollacheck 2006, that low return rates from longline vessels should not be used as an indication of potential for interactions between surface and longline fisheries without a careful assessment on reporting rates.
- Or an indication that adult tunas tagged in equatorial areas are not significantly moving in the temperate or remote fishing zones that are exploited world wide mainly by longliners.

(10) An overview of tuna recoveries by sex obtained world wide by the various RFOs

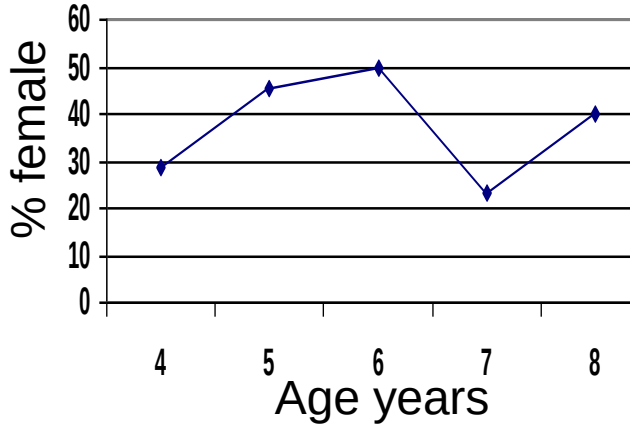
- It is of great interest to obtain the sex and the exact sizes of large YFT & BET recovered, as the sex ratio and growth of the 2 sexes allow to estimate **growth and natural mortality of adult male or female YFT & BET**
- These 2 parameters are of major importance in all today analytical stock assessment works done by RFOs on these 2 species that are showing a declining % of females at adult sizes.
- Sex of recovered tunas have been very seldom obtained by scientists, but ositive results have been obtained by the IOTC tagging for adult YFT & BET: a sample of 85 YFT and BET well observed by scientists, they strongly indicate
- A lower infinity of female YFT & BET; a result probably valid worlwide?
- A similar natural mortality of male & female bigeye



Growth of male BET following the 2008 IOTC growth curve



female BET growing at a slower rate than the 2008 IOTC model



A quite stable sex ratio at age of recovered old BET

Discussion of the main results of this analysis of world tagging results: A gold Medal given to the Indian Ocean tagging programme

In this year 2012 of Olympic Games, a gold medal should be given to the IO tagging program: coming late, but providing multiple unexpected and highly valuable results. A great success due to cascading positive factors such as:

- its strong and well planned framework,
- its very efficient management by the IOTC & its IOTTP team,
- the very good cooperation of many fishermen and the very good follow up by scientists of most Seychelles landings and other secundary ports in the area.
- Efficient tag seeding on purse seiners
- A very high rate of well-documented recovery data, generating a lot more data than most of the other tagging programmes.
- also some unprogrammed luck: IOTTP done just before the today large extension of piracy…Tanzanian tunas cooperative & abundant, efficient P&L fishing, tagging far from PS fishing zones, efficient MAC tagging using pole & line with & without bait, large scale & fast tuna movements in the IO.

- **This program also reinforces/confirms the major interest of results that can only be obtained from large scale & well handled dart tag tagging programs,**
- Electronic tagging are of course also necessary, but solely in addition of dart tags
- And also the **great interest to simultaneously tag large numbers of the 3 tuna species, and to estimate well the reporting rates of all major gears, & to obtain scientific measurements of most recoveries, & preferably by sex for large tunas.**

Several common characteristics appear to exist in the results between oceans and between species, while startling differences remains unexplained,

In the spirit of the Kobe process, there would be a great interest to create a common world data base of detailed tagging & recovery data, dart tags & electronic tags, as well as a data base containing the basic statistical information on the catch at size by gear & by time & area strata, and to conduct in depth statistical analysis of these tagging results, an analysis also incorporating the environment & its heterogeneity..

- This comparative analysis & overview of the multiple results obtained from dart tags tuna tagging done worldwide shows the major importance of these results that can solely be obtained by large scale dart tag programs:

These results have been providing the best/only estimates of **longevity** and **natural mortality at age, growth (by sex), exploitation rates, tuna movements and potential interactions between fisheries.**

It should be recognized that the results of these large scale dart tag tagging programs are today the backbone of all modern stock assessment analysis done by tuna RFOs, in addition of course of the basic C/E & CAS statistics.

Fishermen & national scientists of all fishing countries should fully cooperate with scientists in the recovery of tags

There is also clearly a deep need to develop from time to time, for instance **every 10 years**, these apparently old fashioned multispecies large scale tagging programs, as they are still essential today & in the future to monitor changes in resources and in fisheries.


Thank you for your attention!