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NOTE ON THE STOCK STRUCTURE OF PACIFIC BIGEYE TUNA TO BE USED IN STOCK ASSESSMENTS

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Note on the stock structure of Pacific bigeye tuna to be used in stock assessments

By Alain Fonteneau[1] and Javier Ariz[2]

Summary

This paper reviews and discusses the stock structure of Pacific bigeye tuna in relation with the prospects of stock assessment analysis of this population. The analysis of fishery data, mainly the spatio temporal bigeye catches by gear and by sizes, indicates that the present 150°W frontier based on historical and administrative results does not appear to be a convenient biological frontier. Our conclusion is that the present lack of significant tag recoveries across the 150°W frontier should not be considered as being significant, due to the limited numbers of bigeye presently tagged and to the great distances between present tagging locations. North South movements of adult bigeye are also a potential source of mixing between eastern and western bigeye populations. It is hypothetized that there could be an increased net flow of juvenile bigeye towards the WCPO due to the increased number of FADs in the western EPO. Our conclusion is that all the bigeye stock assessments by WCPFC and the IATTC should preferably be conducted in a unified best model and at a Pacific wide scale. A large scale tagging programme covering the distribution area of the entire bigeye population and fully coordinated between WCPFC and IATTC would be necessary to obtain realistic and age specific movement patterns at a Pacific wide level. Management actions of the bigeye stocks should also be fully coordinated between the Western and Eastern stocks, because of the probably weak biological frontier and also because of the bigeye long life span. The long term management benefits or failures will probably be shared by WCPFC and IATTC.

1-Introduction

This paper is based on a definition of population and stock that are given in annex 1. In this definition, a stock is basically a **geographical management unit** chosen by fishery scientists to assess stock status and to manage the stock.

A legal frontier has been *de facto* established in the Central Pacific around 150° W separating Western and Eastern Pacific stocks, these stocks being later independently used for the assessment and management by WCPFC and the IATTC (and using different models). This limit between stocks may be a “reasonable” one for skipjack and for yellowfin, but it

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appears to be widely questionable for bigeye tuna, at least for tuna scientists working in the Atlantic and the Indian oceans. Surprisingly the biological validity of this quite artificial/questionable legal frontier has never been thoroughly evaluated nor discussed by scientists from IATTC of from WCPFC: all the IATTC stock assessment reports confirm that there is a strict frontier at 150°W (few assessments being done on the Pacific wide population), but to our knowledge, the biological validity of such a frontier has never been actively studied nor questioned in any of the past scientific reports. This paper, written by "external" scientists, will examine the data in favour or against such a frontier, and it will discuss the potential movement patterns of juvenile and adult bigeye in the central Pacific.

2- A pending question: is there a bigeye frontier at 150°W?

2-1 What frontier between Western & Eastern Pacific bigeye stocks?

Most bigeye stock assessments done in the Pacific have been conducted in the hypothesis of a strict W-E frontier at 150°W (keeping in mind that some of the SPC assessments were interestingly done at a Pacific wide scale, without being a best case study for WCPFC and IATTC). The origin of such a frontier was primarily historical and legal ones: this 150°W limit has been used since 1950 and the creation of the IATTC, an implicit western frontier of the IATTC competence area. Such a frontier was later well accepted in the WCPFC and IATTC bigeye stock assessments, mainly because of the rarity of transpacific bigeye recoveries. It should also be noticed that this 150°W frontier split the Pacific Ocean between 2 areas that have been producing nearly identical bigeye yearly catches since the early sixties: this striking similarity of yearly catches being observed for both total catches (figure 1) as well as for catches of adult bigeye taken by longliners (figure 2). The lack of significant transpacific tag recoveries is of course real, but it is widely the consequence of the present weakness of past bigeye tagging programs in the Pacific. Furthermore, the limited taggings of bigeye have been done very far from the 150°W frontier, and this fact constitutes a major limitation to reach a firm conclusion upon the 150°W frontier. We consider that even if bigeye tuna resources sometimes tend to be highly viscous ones, as it has been well demonstrated by the limited movement shown by the recent IATTC bigeye recoveries (Schaefer and Fuller 2005), these results cannot be, in our opinion, a real scientific proof that there is a real biological frontier at 150°W. In the same way, the present limited bigeye tagging cannot be a proof that bigeye tunas born in the Equatorial areas do no migrate to the Northern Pacific towards their feeding zones that are perfectly well identified in the North Pacific between 20° and 40°N (as it was concluded by the IATTC staff, see annex 1, 3rd point).

On the other hand, there is a global and legitimate consensus among tuna scientists that when a tuna population covers an entire wide ocean, and in some cases a very wide ocean like the Pacific Ocean, there is most often a need to manage the resources at a smaller geographical scale, possibly at the scale of large economical zones (Hilborn and Sibert) . This geographical choice of a management unit corresponds to the artificial but legitimate choice of given stocks (cf annex 1).

The choice of these frontiers between tuna stocks have been established world wide based on various criteria:

1) Lack of mixing demonstrated by **tagging/recovery** results, by an heterogeneity in the regional **genes** (for instance Mediteranean albacore and swordfish),
2) **Environmental heterogeneity** may often create biological barriers limiting the tuna movements between 2 fishing zones: this is for instance the case for Northern

and Southern temperate tunas (albacore, bluefin), that have limited movements across the equatorial areas.

3) **Larges distances**: tunas have been classified by lawyers (Caracas law of the Sea, article 64) as being "highly migratory species": this is sometimes true (as it was recently shown by various tagging results, such as the frequent wide scale recoveries observed during the Indian Ocean tagging and on northern and southern bluefin), but most often, tunas stocks could be better classified as being "viscous" resources (Mac Call, Sibert, Fonteneau et al 1998): these tunas doing only limited scale movements compared to their very wide geographical habitat. In such a context of tuna stock viscosity, a large distance between two fishing zones will most often tend to correspond to a low or to a very low mixing rate between individuals inhabiting these two remote areas. In such a case, these remote fractions of stocks should preferably/necessarily be assessed and managed as being independent stocks, simply due to a distance factor, and to the quite limited movements of these tunas. This conclusion may be valid one, even if the environment is quite homogeneous between these remote stocks.
4) **Legal frontier,** for instance the frontier between two tuna commissions or any EEZ limit: there is an unknown but real risk that such a legal limit may not be well identified nor followed by the tunas during their migrations.

The analysis of environmental data in the Pacific Ocean shows that there is no significant environmental barrier restricting the E-W potential movements of juvenile nor of the adult bigeye at 150°W in the equatorial areas (cf Longhurst areas, Figure 7). Keeping in mind that there is some environmental discontinuity (but not a barrier) between the EPO waters and the warm pool in the WPO, the adult bigeye habitat is clearly continuous across the entire Pacific ocean, two factors that are not in favour of creating such a frontier between stocks. It should also be kept in mind that the great distances across the Pacific Ocean (about 10.000 nautical miles between Indonesia and the American coast) is also a major factor limiting the full mixing of tunas between these two remote areas. The following paragraphs will examine the distribution and potential movements of juvenile and adult bigeye fished in equatorial and in temperate waters of the Central Pacific Ocean.

2-2- Movement of juvenile bigeye across the frontier: effect of FADs?

The following facts should be recognized concerning this 150°W frontier:

- ✓ There is clearly around 100°W an area where juvenile bigeye tend to be more abundant in the EPO (see figure 8), probably the major area of bigeye concentration in the EPO,
- ✓ But juvenile bigeye are significantly caught in all the equatorial waters in the WCPO and EPO, and there is no environmental frontier in these equatorial waters at 150°W (figure 7).
- ✓ Furthermore, since there is a dominant westward surface current[3] (Figure 9) in the area, a fraction of the FADs that are seeded south of 4°N could easily move to the western Pacific, and possibly "carry" a fraction of the EPO bigeye biomass associated to FADs (keeping in mind that these tunas may well come back later to the EPO, for instance if the adult bigeye show a homing behaviour). This potential westward drift

[3] The westward drift of FADs tend to be dominant in the EPO, but the westward drift of FADs would need to be confirmed by direct observations, as some of these FADs may move towards the north or the south, or also drift eastwards, at least seasonally, for instance in the equatorial counter current.

could easily transfer FADs over large distances and within short durations, as a FAD drifting at a speed of 1 knot (an average speed for the equatorial current in the EPO), will move from the center of the main IATTC bigeye FAD area ("El Coralito") to the western Pacific frontier at 150°W in only 4 months.

It should thus be envisaged that young bigeye can easily do east to west movements in the equatorial areas (or the opposite) and then cross the 150°W frontier. It should also be envisaged that **if the ecological trap hypothesis could be confirmed**, i.e. if bigeye tunas are firmly associated with the network of drifting FADs (as it was proposed by Marsac et al 2000 and recently widely(?) confirmed by Hallier and Gaertner 2008), the movement pattern of juvenile bigeye would be different nowadays: FADs now producing a dominant output flow of juvenile bigeye from the EPO to the Central Pacific due to the dominant westward drift of FADs in the equatorial current (Figure 9).

This ecological trap hypothesis is still somewhat controversial, but in this hypothesis, juvenile bigeye that are often showing a firm association with FADs (of course not under a given FAD, but associated to a network of drifting FADs) would have a net(?) movement towards the WCPO. On the other hand, it could be envisaged that the tagging of tunas associated to anchored FADs (as the recent IATTC bigeye tagging) could have underestimated the "real" movement rates and pattern of the bigeye tagged in the area.

As a conclusion, it could then be hypothesized:

(1) that juvenile bigeye are now easily and increasingly crossing the 150°W "legal frontier", especially when they are associated to a network of FADs drifting westward.
(2) that this amount of bigeye tuna moving westward may have been increasing during recent years (since the mid nineties), due to the increased use of FADs in the EPO.

It should then be of prime importance to better recognize these potential movements and to plan a research program allowing to estimate these potential movement patterns, as they could produce a potential loss of juvenile bigeye tunas in the EPO, and a corresponding gain in the WCPFC area. If young bigeye are moving out from the modelled area, these potential movements of young bigeye recruits could of course be of great importance in stock modelling, as they would limit the validity of all the estimated recruitments obtained by a biased closed model. The Pacific wide tagging programs that are presently developed or planned by WCPFC and the IATTC would of course be the ideal way to evaluate these movements. Furthermore, *had hoc* tagging programme targeting bigeye associated to FADs in the central areas of the Equatorial Pacific should also be planned. It should also be fully recognized by WCPFC and by the IATTC that these future tagging programmes of bigeye tuna in the Pacific ocean should be fully integrated: targeting bigeye tagging in the west, central and East Pacific, as well as in the Northern areas.

2-3- East West movements of spawners?

All the transpacific equatorial areas E and W of 150°W are potential spawning zones for bigeye (Taiwanese observer data) (see Figure 3). These catches of adult bigeye have been permanently observed east and west around the 150°W frontier since 1960 (always caught in warm waters), in an area that has permanently been the core of the bigeye distribution of adults in the Pacific Ocean. This fact is well shown by monthly fishing maps of longliners in the area (these 630 maps have been done, and they are available upon request) a diagram of the monthly catches by longliners around the IATTC frontier (between 120°W and 180°W),

by longitudinal zones of 5°, show permanent movements of the longline fishery E and W of the 150°W frontier (Figure 5). We consider that there is a high probability that such a geographical mobility of the catches and the longline fisheries do correspond to fish movements (as in this case, the bigeye tuna concentrations are permanently followed and targeted by longliners). This hypothesis that the movement of the longline fishery corresponds to a biological movement of bigeye tunas, should at least be envisaged and analysed, preferably using 1° squares or set by set data.

This question should be fully recognized and a tagging program on large bigeye tunas, preferably using archival tags, would also probably be the best way to solve this major uncertainty.

2-4- What North South movements of preadult and adult bigeye?

Furthermore, it is quite clear from the longline fishery data, that major feeding zones of bigeye tuna are located in the North Pacific between 20° and 40°N (see figures 3 and 4). It should also be kept in mind that the total distance between Asia and America at 30° North is much smaller than at the Equator:

- 5000 nautical miles at 30°N (only 1/4th of this distance being in the EPO),
- 10000 miles at the Equator.

The smaller size of this northern area, and its character of a feeding zone, should increase the probability for a mixing of fishes born in the Eastern and/or the Western Pacific. This area could for instance be similar to the North Atlantic Gulf Stream waters, where bluefin tunas born in the Mediterranean Sea and in the Gulf of Mexico, feed in the same temperate waters.

Furthermore, this potential seasonal movement of adult bigeye toward their northern feeding zones is also well suggested by the seasonality of the northern fisheries. Figure 10 shows the higher northern longline CPUEs of bigeye during the 1st and last quarter of each year, when on the opposite the equatorial CPUEs of bigeye tend to be quite stable (similar observations can be done worldwide for all the bigeye stocks).

3- Discussion:

3-1- Overall question of the 150°W frontier

Our present conclusion is that the present 150°W frontier should not be kept as a closed frontier between two independent Eastern and Western Pacific bigeye stocks. We consider that none of the 3 parameters given by the IATTC as a support for the validity of such 150°W frontier (see annex 3) could be considered as being convincing ones:

(1) We consider that if the present tagging programs of bigeye are of course interesting, they remain widely insufficient, in terms of their limited numbers/recoveries of tags, of their limited geographical distribution (Coral Sea and EPO tagging in limited areas), and of their potential bias (tagging on anchored buoys), to correctly evaluate the real bigeye age specific movements at the scale of the Pacific Ocean.

(2) We consider that the availability of a large biomass of food in a given area, a reference to the EPO in the IATTC document, either a feeding or a spawning zones, does not provide any useful information upon the previous or subsequent movement patterns of tunas that are temporarily feeding in a given area.

(3) We consider that the North-South migration of bigeye between their equatorial nurseries, their temperate feeding zones at northern latitudes (in a range between 20° and 40°N) and their subsequent spawning in equatorial areas (between 15°N and 15°S) should be considered by every tuna scientist as being the best hypothesis explaining the geographical latitudinal distribution of bigeye in the Pacific Ocean (as in all the other oceans). This hypothesis is for us a very strong one, even if it has not yet been confirmed by tagging/recoveries, simply due to an insufficient tagging and also possibly to poor reporting rates of tags by longliners.

On the opposite, we consider that there is a very high probability that significant movements of bigeye tuna do occur across the 150°W frontier at all ages of the exploited life of bigeye tuna in the Pacific: juvenile, pre-adults as well as adults. These movement patterns could of course introduce significant bias in the stock assessment if there are net flows of tunas in/out from the EPO or WCPO areas (and worse if these input/output are variable over time, for instance due to increasing use of FADs or to environmental effects).

3-2- Assessment and management implications of the 150°W frontier

It is easy to recognize that the present 150°W frontier does not play a major role to drive the present conclusion of the bigeye stock assessments: this is simply because both Eastern and Western stocks have been increasingly exploited and in parallel, showing first a similar increase of longline fisheries (figure 2). Furthermore, the recent increase of FAD associated purse seine catches of small bigeye was also observed + or - simultaneously in parallel in the 2 areas. Then it should not be a surprise of a proof that the 2 stocks are isolated to conclude that the stock status diagnosis in the Eastern and Western Pacific are quite convergent.

However, it should also be recognized and fully explained to the managers of the Eastern and Western bigeye stocks that the 150°W frontier may very well have, in the long run, (for instance at the 10 to 15 years horizon, a reasonable delay for bigeye) major management implications. Two examples can easily be given as a support of this conclusion:

- If the IATTC decides to protect juvenile bigeye, for instance permanently closing the area where a majority of small bigeye have been taken by purse seiners, there is for us an unknown but possibly large probability that the 15 years of benefits of this closure will be shared by the WPO and the EPO.
- In the same way, if WCPCF decides to reduce fishing mortality of bigeye spawners closing the equatorial spawning area between 180° and 150°W, there is also a high probability that the benefits of such a measure would be shared in the long run by WCPFC and the IATTC fishing countries (for instance if the movements of adult bigeye tuna suggested by figure 5 are real ones).
- It should then be recognized that any management measure could have its benefits split between the 2 areas, and on the contrary, a critical lack of management in one area, for instance leading to the collapse of one of these 2 stocks, would probably have a highly negative impact on the other stock (as the overfishing of Mediterranean bluefin has a negative impact on the western Atlantic stock, even with a low and strict quota).

4- Conclusion

Taking into consideration the previous facts and its connected hypotheses, the present uncertainties in the bigeye stock structure and its full implications should be better recognized by WCPFC and the IATTC.

- ✓ To fully recognize the potential movements of Pacific bigeye across the 150°W frontier and their potential importance in the assessment and management of the bigeye population,
- ✓ To plan and to do an ad hoc research programme to better evaluate them: the best way to solve these uncertainties would be to conduct a fully realistic large scale tagging programme, targeting a wide range of bigeye sizes, in the Northern and Equatorial areas, and especially in the areas West and East of the 150°W frontier, for instance between 120°W and 180°W (an emphasis being(???) for instance be given to French Polynesia tagging), in order to evaluate the age specific transfer rates of bigeye around this 150°W frontier.
- ✓ In the short term, an in depth analysis of the time and area "apparent" movements of bigeye tuna fished by longliners, based on their spatial and temporal patterns of high fishing efforts targeting bigeye, and of high bigeye catches and CPUE (preferably done at the 1° squares level) should also help to better evaluate the potential movements of adult bigeye (for instance around the 150° W frontier, but also at a wider geographical scale, estimating both E-W and N-S movements).
- ✓ To use assessment models that can well handle these geographical units and the age specific movements of biomass (Such models being already used for bigeye assessment, for instance MF-CL, but being still based on highly unrealistic movement patterns that are not age specific). In the short term, our conclusion is that all the bigeye stock assessments by WCPFC and the IATTC should preferably be conducted using a Pacific wide scale, as it was tentatively done by Hampton et XXX when using a full scale MC-CL model covering the entire Pacific Ocean. If such models are well parameterized and well handled, they should allow to obtain more realistic stock assessments of the bigeye resources exploited in the EPO and in the WCP. However, it should be recognized and kept in mind that the results from such Pacific wide geographically stratified models, would be fully realistic only if the movement patterns at age of the Pacific wide population are realistic ones and as a function of age(repeté?). It should also be noticed that this fully integrated stock assessment model at the scale of the entire Pacific would not be in contradiction with the legal status and responsibilities of the IATTC and WCPFC, the two bodies that are responsible of tuna stock conservation in their own areas of competence. In this prospect of a single Pacific wide assessment model of the bigeye population, all the results (local biomass trend, local MSY, local Fishing mortality, etc…) would still be available and fully valid in each of the 2 areas (WCPFC and IATTC). The subsequent management actions should then be taken by each of these two RFO, based on the stock status in their own area of competence. Our conclusion is that such fully integrated analysis would be much better than two independent analyses. The results obtained from such an analysis for each of the 2 stocks (in the WCPFC & IATTC areas) would be provided for each of these stocks. The management responsibility of these 2 stocks by WCPFC and the IATTC would of course be unchanged.

- ✓ To envisage and to implement management actions of the bigeye stocks that would be fully coordinated between the Western and Eastern stocks

Bibliography

Aires-da-Silva A. and M. N. Maunder, 2007. Status of Bigeye tuna in the eastern Pacific Ocean. Inter-American Tropical Tuna Commision. 8th Meeting of the Scientific Working Group. 99p.

Fonteneau A., Gascuel D. et Pallares P., 1998. Vingt cinq ans d'évaluations thonières de l'Atlantique : quelques réflexions méthodologiques. J. Beckett Ed. Actes du symposium ICCAT de Punta Delgada. ICCAT Collective volume of scientific papers, Vol. L(2), 523-562.

Hallier, J.P., Gaertner, D., 2008. Drifting fish aggregation devices could act as an ecological trap for tropical tuna species. Marine Ecology Progress Series, Vol. 353, 255–264,

Hilborn R. and J. Sibert, 1986. Is international management of tunas necessary?. South Pacific Commission Newletter 38, p31-40.

Hampton J., P. Kleiber, Y. Takeuchi, H. Kurota and M. Maunder, 2003. Stock assessment of bigeye tuna in the western and central Pacific Ocean, with comparisons to the entire Pacific Ocean. SCTB 16 Working paper, 81p.

Laloe, F., 1989. Un modèle global avec quantité de biomasse inaccessible dépendant de la surface de pêche. Application aux données de la pêche d'albacores (*Thunnus albacares*) de l'Atlantique est. Aquatic Living Resources, 2, 231-239.

Lehodey, P., 2001. The pelagic ecosystem of the tropical Pacific Ocean: dynamic spatial modelling and biological consequences of ENSO. Progress in Oceanography, 49, 439–468

Mac Call, A., 1990. Dynamic geography of marine fish populations. Book in recruitment fishery oceanography. University of Washington press. 153p.

Marsac, F., Fonteneau, A., Ménard F. , 2000. Drifting FADs used in tuna fisheries: an ecological trap? In Pêche thonière et dispositifs de concentration des poissons. Le Gall, Cayré et Taquet Ed., Editions IFREMER, 537-552.

Schaefer, K.M. , Fuller, D.W., 2005. Conventional and archival tagging of bigeye tuna (*Thunnus obesus*) in the Eastern equatorial Pacific Ocean. ICCAT Collective volume of scientific papers, Vol. 57(2), 67-84.

Sibert, J.R., Fournier, D.A., 1994. Evaluation of advection-diffusion equations for estimation of movement patterns from tag recapture data. FAO Fisheries Technical paper 336. Vol. 1, 108-121.

Annex 1: Stock and population

The 2 terms of stock and population are used in this paper following these definitions:

- ✓ **Population**: all individuals from a given species living in a given area. *All individuals of bigeye living in the Pacific ocean belong to the same population.*
- ✓ **Sub populations**: fractions of population that are sharing a common and peculiar genetic structure and peculiar biological, movement and behavioural patterns; each of these sub populations may have its origin in a peculiar time and area strata, and a majority or all fishes from this group may tend to show peculiar movement patterns and also a homing behaviour, for instance potentially spawning in their birth area.
- ✓ **Stock**: a stock is a geographical management unit chosen by fishery scientists to assess stock status and to manage the stock. The ideal case is when the limits between these stocks correspond with well identified sub-populations, with low mixing rates between tunas fished in these areas. Such limits between stocks should be seen by scientists as being only temporary frontiers used as working hypothesis.

Annex 2

The IATTC diagnosis explaining the validity of its bigeye frontier at 150°W (May 2008)

"Extensive tagging of bigeye in the equatorial EPO during 2000-2005 with archival and conventional tags has demonstrated that fish, including those over 3 years of age and those at liberty more than one year, show restricted movements within the equatorial EPO. Recent bigeye tagging studies in the central Pacific around the Hawaiian Islands, and also in the Coral Sea, have also demonstrated that the movements of bigeye are restricted, with very few individuals moving more than about 1,000 nm.

The horizontal movements and spawning patterns of bigeye in tropical and subtropical regions are similar to those of yellowfin and skipjack, and different to the migratory movements and spawning patterns of albacore and bluefin tunas. Bigeye feed primarily on organisms that inhabit the deep-scattering layer, such as squid and mesopelagic fishes. The concentrations of these organisms in the equatorial EPO is very high, as documented in numerous oceanographic surveys, including EASTROPAC.

There is no evidence from tagging or any other source to indicate that there is movement of bigeye spawned in the equatorial EPO to feeding zones north of 20°N at any age".

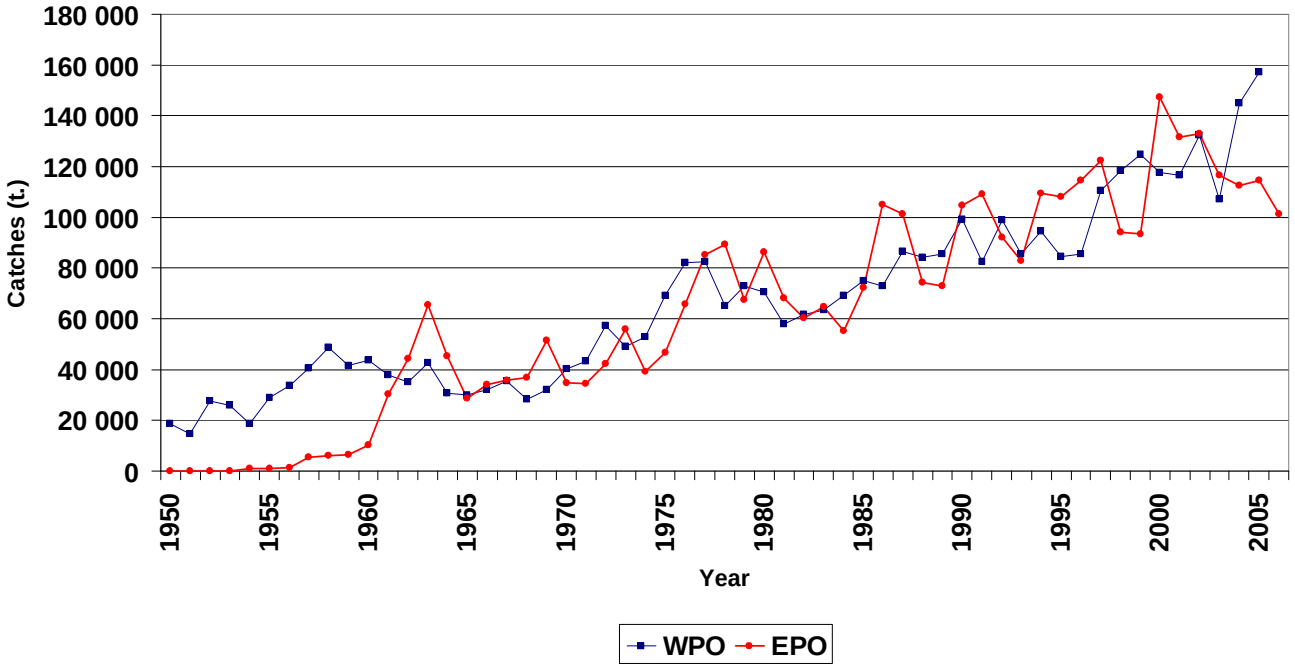

Figure 1: Yearly bigeye total catches taken in the EPO and in the WPO

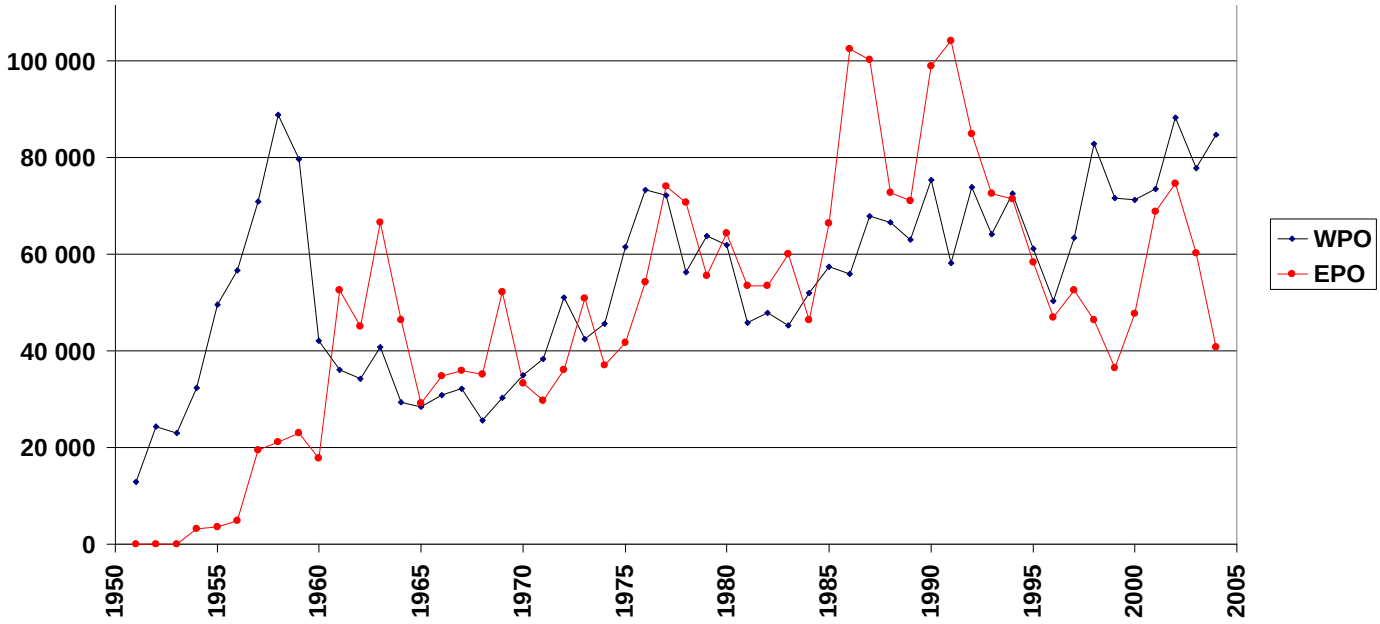

Figure 2: Yearly bigeye catches taken by longliners in the EPO and in the WPO

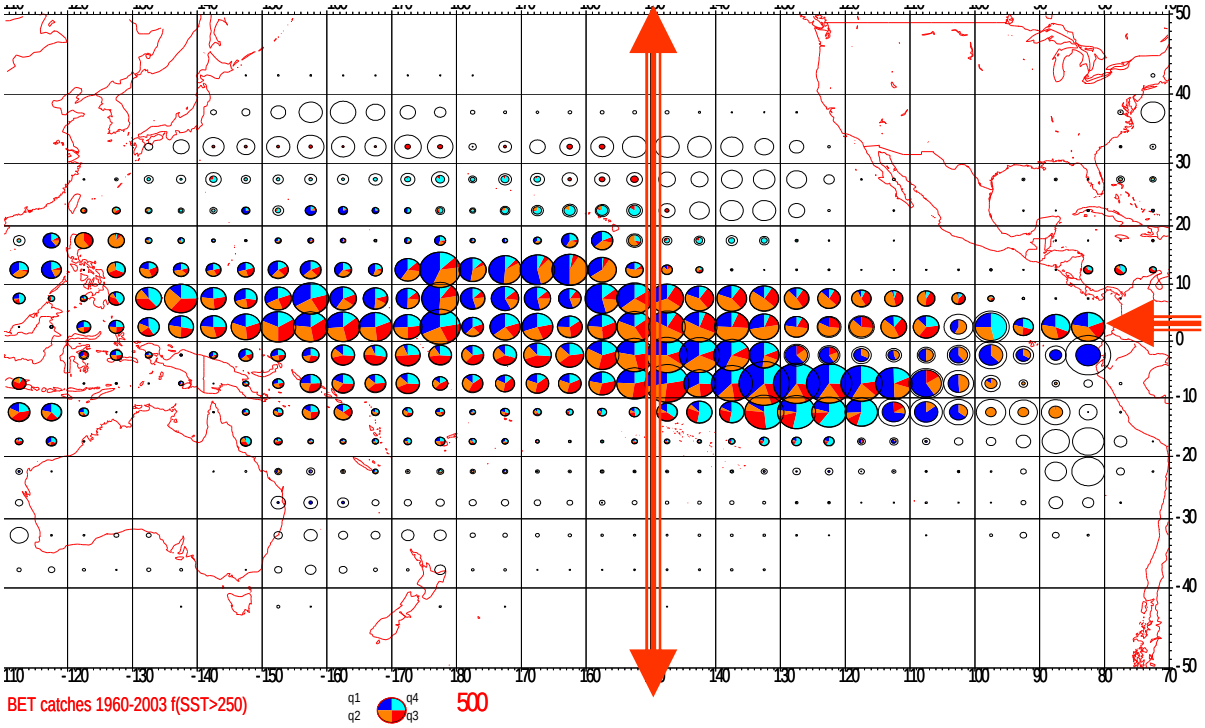

Figure 3: Average fishing map of quarterly catches of bigeye tunas taken in the Pacicfic Ocean during the 1960-2004 period by longliners in warm waters with SST > 24°C (in each 5°squares and quarter, coloured pies as a function of the quarter during which the catch was taken).and in cold waters (<24°C) (white pies)

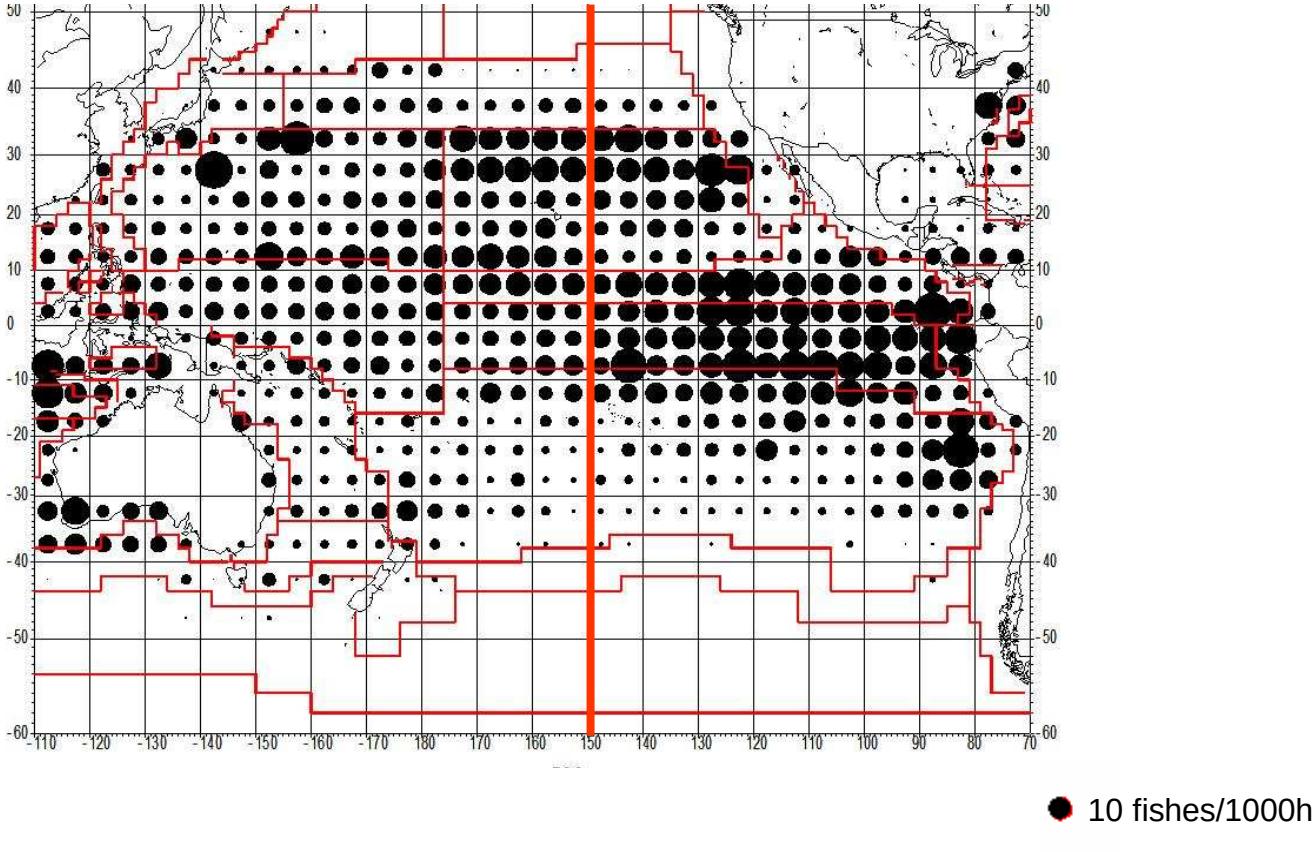

Figure 4: Map showing the highest 5°-month CPUEs observe d during the 1952-2004 period in the Japanese longline fishery and Longhurst 1998 areas.

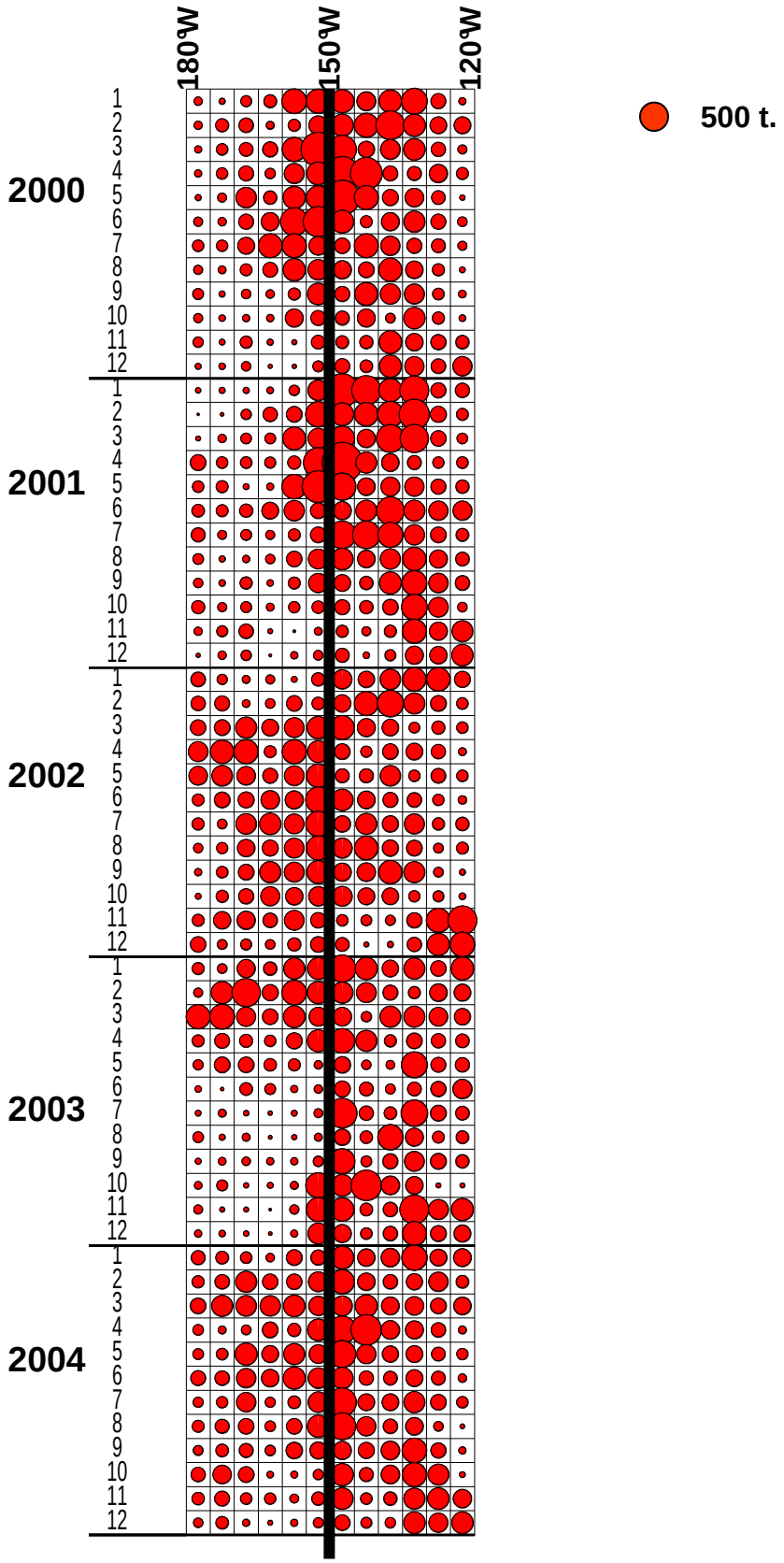

Figure 5: Diagram showing during the 2001-2004 period, taken as an exemple, the total monthly bigeye catches by slices of 5° of longitude, taken by longliners in the are a between 15°N and 15° S (the main fishing gear of longlin ers). *This figure shows that the area around 150° W, the tradi tionnal frontier between the 2 assumed Western and Eastern bigeye stocks, is during each year and all year round, a major fishing zone for adult bigeye. These monthly patterns of catches as a function of longitude also suggest that this figure may correspond to E-W movements of adult bigeye.*

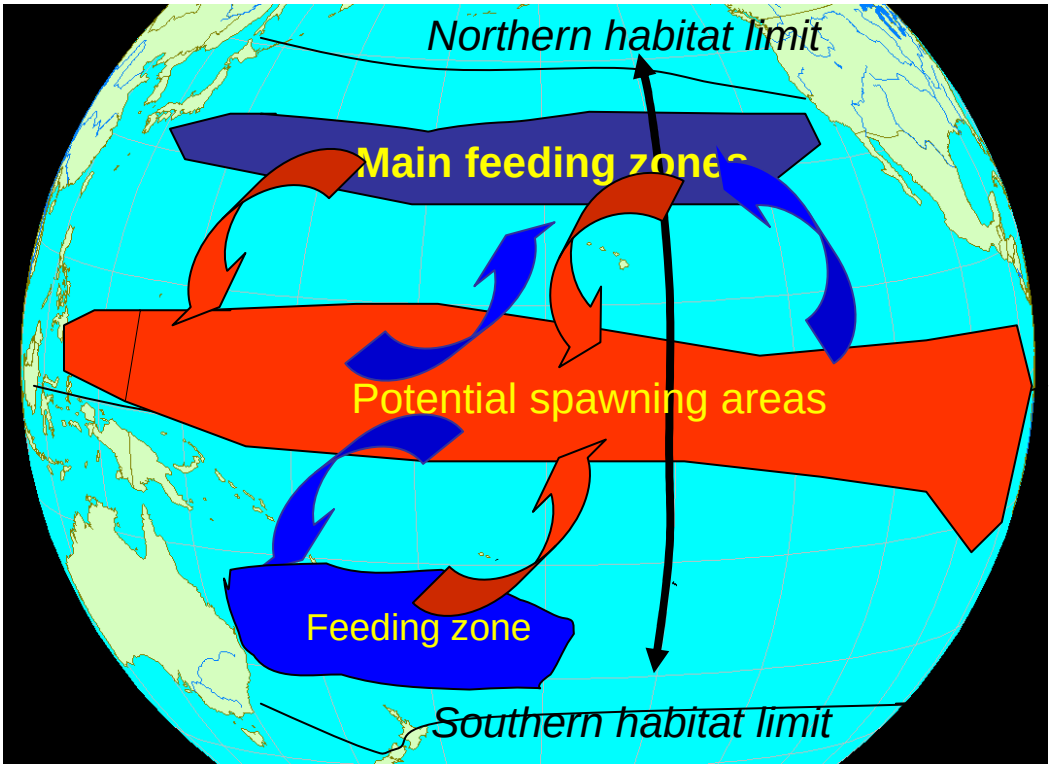

Figure 6: A conceptual overview of the main potential spawning and feeding zones of bigeye tuna in the Pacific Ocean, and the logical movement patterns of this species between these areas.

KURO: ***Kuro Shio Current***
NPST.W and E: ***North Pacific Subtropical Gyre West and east***
OCAL ***Offshore California Current***
SPSG: ***South Pacific Subtropical Gyre***
SSTC: ***South Subtropical Convergence***
CAMR ***Central American Coastal***
SUND ***Sunda-Arafura Seas Coastal***
NPTG: ***North Pacific Tropical Gyre***
PNEC: ***North Pacific Equatorial Countercurrent*****.**
PEQD ***Pacific Equatorial Divergence***
WARM ***Western Pacific Warm Pool***
ARCH ***Western Pacific Archipelagic Deep Basins***

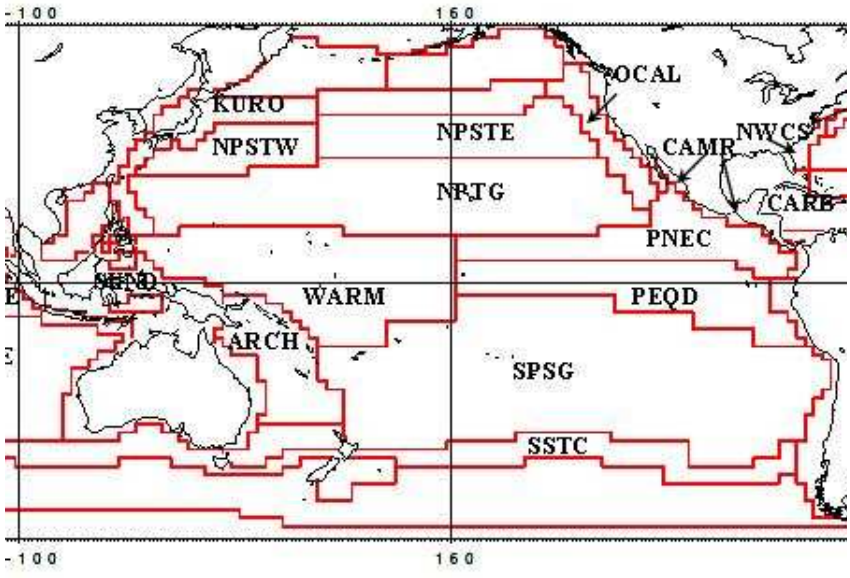

Figure 7: Map of the Longhurst 1998 areas in the Pacific Ocean

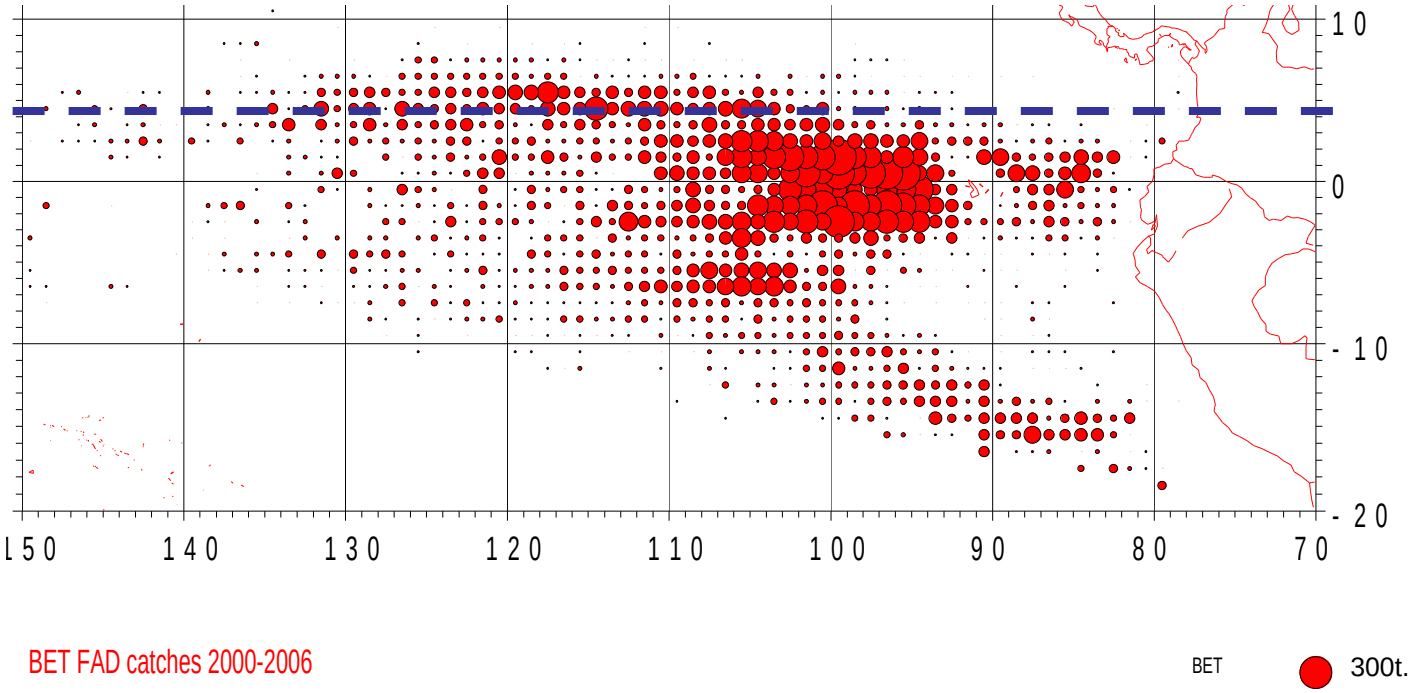

Figure 8: Average bigeye catches taken under FAD, by 1°squares, during the 2000-2006 period and 4°N approximate environmental limit *(surface current below this latitude being permanently dominated by a Westward flow: in the hypothesis that small bigeye are consistently associated with drifting FADs, such potential westward drift of FADs could produce a westward flow of the juvenile fraction of the bigeye fraction of stock).*

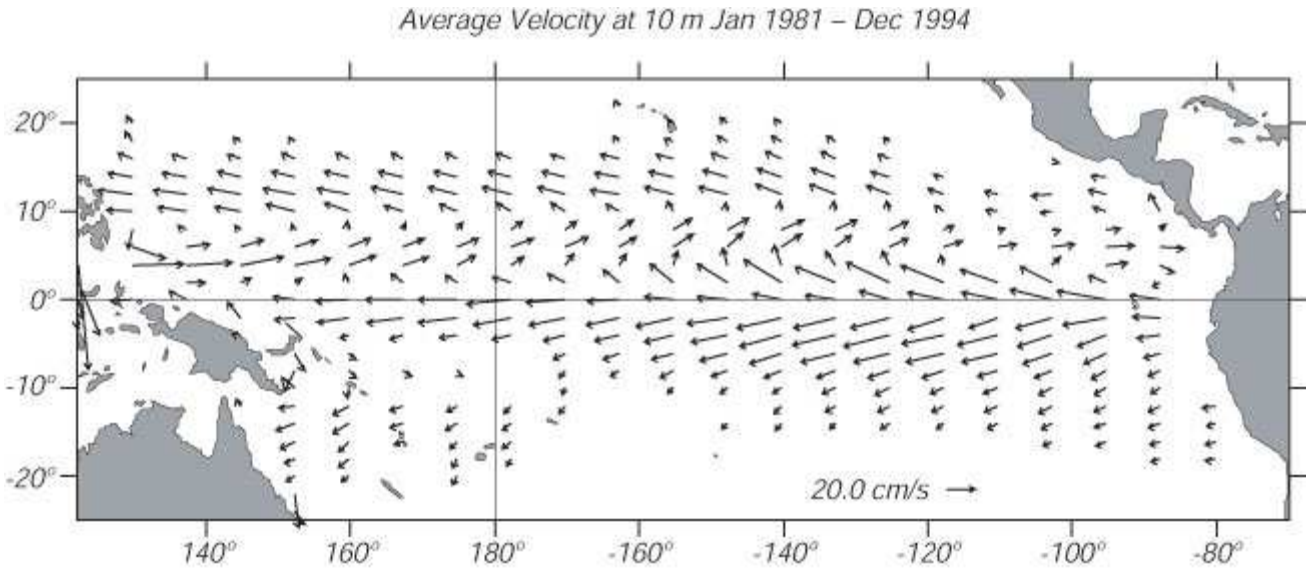

Figure 9: Average currents at 10m calculated from the Modular Ocean Model driven by observed winds and mean heat fluxes from 1981 to 1994. From Behringer, Ji, and Leetmaa (1998).
It can well be assumed that drift of FADs is predominantly following this westward water flow between 3°N and 8°S, the main bigeye FAD areas.

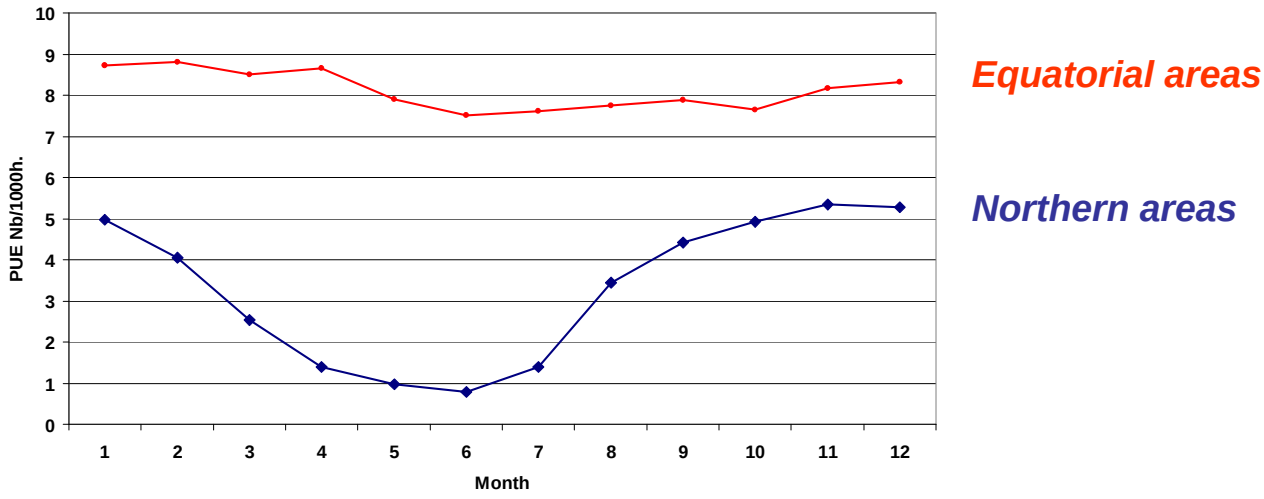

Figure 10: Average monthly levels of the bigeye nominal Bigeye CPUEs of Japanese longliners in the equatorial Pacific, (10°N-10°S) and in the North ern areas (North of 10°N)