Simulation of tag-recapture experiments in the Indian Ocean: A habitat based model applied to the Skipjack population

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Abstract

The IOTC will soon implement a large tagging program in the Indian Ocean in order to obtain the parameters needed to achieve reliable stock assessment for the target tropical tuna species, bigeye, yellowfin and skipjack. One of the first step of this work is the simulation of tag-recapture experiments. For that purpose, a habitat based tuna spatial dynamics model has been developed (Maury 2000).It allows to simulate tag spatial dynamics and recovery given climatological environmental parameters. This model has been first calibrated to match the distribution of the skipjack population. This paper presents an update of the simulation model with the latest available C/f data, SST, oxygen concentration and and the use of tuna forage index. Furthermore, scenarios of tagging mainly based on purse seine fishery seasonal activity have been prepared for discussion during the WPT. Once accepted by the WPT, they will be implemented in the spatial dynamics model and compared using a spatialized stock assessment model. The procedure will then be adapted to the two other target species.

Introduction

Tropical tunas in the Indian Ocean are experiencing high exploitation rate (Anon., 2001, 2002, 2003) which may not be sustainable in the long term (Fonteneau com pers.). A risk of overfishing for the yellowfin and bigeye stock is likely but unknown. In fact, no reliable stock assessment in this ocean can be realized at present because of the lack of knowledge of the main biological parameters. Scientists agreed that a large scale tagging program is the key stone tool needed for being abble to conduct realistic tuna stock assessments. The IOTC decided to organize such a large scale tagging program in the Indian Ocean: the IOTTP (Indian Ocean Tuna Tagging Program). This program has three main goals:

- ⇨ To estimate the key parameters : natural and fishing mortality, growth, migration
- ⇨ To evaluate the impact of the FAD fisheries (ecological trap?)
- ⇨ To determine the degree of interactions between the fisheries (longline, purse seine, artisanal)

Those estimates are crucial for all future stock assessments and hence are necessary for a sustainable management of the fisheries.

According to the terms of reference of the working party on tagging (Anon 99), prospective simulations are needed to help designing tag-recapture experiments. Several realistic tagging scenarii for the three tropical species (bigeye, yellowfin, and skipjack) have to be established and compared in order to select the optimal tagging schedule (time/zone) for reliable parameters estimation. A model of tuna spatial dynamics (Maury, 2000) based on habitat data, has been developed and tuned to simulate the tag-recapture experiments. A spatial stock assessment model is used to estimate the key parameters and compare the scenarii.

The aim of this paper is to present the simulation framework chosen, and its application to the skipjack stock and to propose some scenarii to be tested with the simulation model. This work is still under progress. The study has to be completed for the skipjack stock before September 2004 and will be extended to the two others species by the beginning of 2005 with IOTC fundings.

1. Overview of the method used

To design a tagging experiment, we must determine how many fish should be tagged and released, when and where, to achieve a chosen level of precision and accuracy in the key population parameters estimation (Xiao, 1996).
The general methodology has been presented in details by Maury (2000). It relies on three stages.

The first stage consists in simulating as realistically as possible tag-recapture experiments of tunas in the Indian Ocean. It is based on a species specific environmentally driven advection-diffusion-reaction model which represents the tagged fish spatial dynamics and their recovery according to a mean fishing effort spatio-temporal distribution. The simulations provide spatio-temporal recovery data sets according to various tagging scenarii.

The second stage consists in bootstrapping the simulated data set to incorporate stochasticity in the deterministically simulated tag recovery process. It gives a large number of “possible” recapture data set for a given tagging scenario.

The third stage corresponds to the assessment process, as it will be conducted when real tagging data will be available. Each bootstrapped recapture sample is analyzed with an observation model, which provides estimates of the desired population parameters (here, natural mortality, catchabilities and movement rates). Mean biases and standard errors of the parameters estimates are calculated for each tagging scenario studied to allow for comparisons.

Finally, the whole process enables to compare different possible alternative tagging scenarii to help designing the tagging strategy of the program.

1.1 Advection-diffusion-reaction model : use in the general case

An advection diffusion reaction model is used to describe fishes movements and mortality. In such a model, fish movement has two components: a random one, the diffusion term which characterizes « dispersive » movements, and a directed one, the advection term which describes directed movement. Both components are included in a partial differential equation (PDE) continuous in time and space (Okubo 1980, Bertignac et al. 1998, Sibert et al*.* 1999, Maury et al. 2001) which represents the spatial dynamics of one cohort of tagged fish :

$$\frac{\partial N}{\partial t} = D.\left(\frac{\partial^2 N}{\partial x^2} + \frac{\partial^2 N}{\partial y^2}\right) - \frac{\partial\left(\alpha.\frac{\partial(HSI)}{\partial x}.N\right)}{\partial x} - \frac{\partial\left(\alpha.\frac{\partial(HSI)}{\partial y}.N\right)}{\partial y} - (F + M).N$$

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- $N=N_{x,y,t}$: fish density of the considered cohort at point (*x, y*) at time *t*
- **D** : diffusivity coefficient,
- $HSI=HSI_{x,y,t}$, : habitat suitability
- α : proportionality coefficient,
- **M** **:** natural mortality rate
- $F=F_{x,y,t}$ local fishing mortality rate

To be realistic the heterogeneity of the tuna distribution must be linked to the environmental heterogeneity. In the simulation model, the advective component of the movement is related to the local gradient of an habitat suitability index (HSI), which depends on the functional response of tuna to environmental factors. Then due to the environmental forcing, the model transports the tagged fish population towards the most suitable places for fish living, according to the habitat temporal evolution. According to Hutchinson (1957) niche definition, the *HSI* is defined as an hypervolume whose *n* dimensions corresponds to the *n* environmental factors considered to determine fish habitat:

(2) $$HSI = \prod_{i=1}^{n} (ba_i)^{p_i} \quad \text{with} \quad \begin{cases} ba_i = f_i(e_i) \\ R \xrightarrow{f_i} [0,1] \end{cases}$$

With ba_i the biotic affinity for the environmental factor e_i, p_i its associated weight and f_i the functional response (non-linear in the general case) of tuna to the environmental factor e_i.

A numerical solution of equation (1) is obtained using an ADI numerical scheme (« alternating-direction implicit method ») (Press et al. 1994) with a one day time step on a 1°x1° square grid which lay from 20°west to 130°west (longitude) and 40°south to 30° north (latitude) (Fig. 2). Closed reflective boundaries (Neumann conditions: $\frac{\partial N}{\partial x} = \frac{\partial N}{\partial y} = 0$ at boundaries) are used to model impassable frontiers and shores. The initial tagged population distribution (the time and place of the fish release) is user defined and can be chosen anywhere in the grid.

1.2 The observation model : estimation of the key population parameters

For computing time reasons, a simple compartment model is used. The methodology is summarized in below.

Table 1: evaluation model: brief overview

Equation	
$$\begin{cases} \frac{dN_{1,t}}{dt} = \sum_{i=2}^{n} T_{i\to1,t} N_{i,t} - (q_1 f_{1,t} + M + \sum_{i=2}^{n} T_{1\to i,t}) N_{1,t} \\ \vdots \\ \frac{dN_{j,t}}{dt} = \sum_{i=1,i\neq j}^{n} T_{j\to i,t} N_{i,t} - (q_j f_{j,t} + M + \sum_{i=1,i\neq j}^{n} T_{j\to i,t}) N_{j,t} \\ \vdots \\ \frac{dN_{n,t}}{dt} = \sum_{i=1}^{n-1} T_{i\to n,t} N_{i,t} - (q_n f_{n,t} + M + \sum_{i=1}^{n-1} T_{n\to i,t}) N_{n,t} \end{cases} \quad \begin{cases} \frac{dC_{1,t}}{dt} = q_1 f_{1,t} N_{1,t} \\ \vdots \\ \frac{dC_{j,t}}{dt} = q_j f_{j,t} N_{j,t} \\ \vdots \\ \frac{dC_{n,t}}{dt} = q_n f_{n,t} N_{n,t} \end{cases}$$	*Ni,t*: number of tagged fish in the zone I at time t $T_{i\to j,t}$: transfer rate q_i : catchability coefficient in zone i *M* :mortality rate $f_{i,t}$:fishing effort
The system is integrated numerically using a semi-implicit scheme on a 10 days time basis. Given the short time basis used, fish movements are restricted to occur only between spatially adjacent zones during one time step.12 spatial zones are distinguished in the case of the skipjack tuna population (figure 8). Given this spatial division, 661 parameters are defined (54x12 transfer rates, 12 catchability coefficients and one natural mortality rate) and must be estimated.	
Parameters estimation	
$$L = P\left(C_{g,z,m} \Big/ \hat{C}_{g,z,m}, f_{z,m} \right) = \prod_g \prod_z \prod_m \left(\frac{\hat{C}_{g,z,m}^{C_{g,z,m}} . e^{-\hat{C}_{g,z,m}}}{C_{g,z,m}!} \right)$$	Observed numbers of tag returns are related to predicted numbers of tag returns by a Poisson likehood function
$$-\log(L) = \sum_g \sum_z \sum_m \left[\hat{C}_{g,z,m} + \sum_{i=1}^{C_{g,z,m}} \ln(i) - C_{g,z,m} \ln(\hat{C}_{g,z,m}) \right]$$	Maximum likehood parameter estimates are obtained by minimizing the negative loglikelihood with the ADMB software
Quality of the parameter estimates	
$$\begin{cases} RB_{\hat{p}} = \frac{1}{p}\left[p - \mu_{\hat{p}}\right] = 1 - \frac{1}{np}\sum_{i=1}^{n} \hat{p}_i \\ RSE_{\hat{p}} = \frac{1}{p}\sqrt{\sigma_{\hat{p}}^2} = \frac{1}{p}\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(\hat{p}_i - \frac{1}{n}\sum_{j=1}^{n}\hat{p}_j\right)^2} \end{cases}$$	Given the n bootstrap replicate, relative biais and error can be calculated for each parameters to measure the accuracy and precision to be expected from a given tagging scenario (Xiao, 96,00)

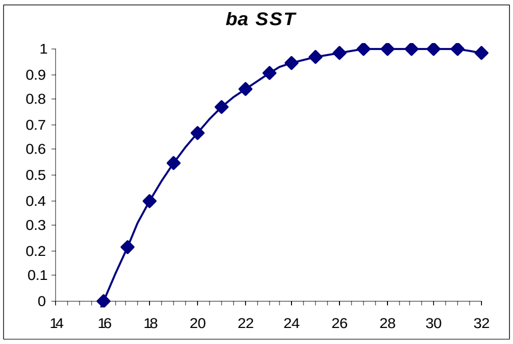
2. Simulation of the population and catch distribution

2.1. tuning of habitat parameterization

The advection-diffusion-reaction model is tuned according to environmental preferences knowledge to obtain a realistic distribution of the tuna population. To choose the best value of the parameters the simulation outputs (population and catch distributions) are compared to captures map and tested against expert knowledge of tuna population distribution and movement.
The model is tuned through the habitat index, and the biotic affinity to the environmental factors. The diffusivity coefficient D and the natural mortality M are fixed using estimates from the Pacific Ocean (Bertignac et al. 98, Sibert et al. 99). To characterize the skipjack habitat, we assume that sea surface temperature, oxygen tolerance and forage are the main parameters to be taken in account.

2.1.1 Functional response to the temperature

A dome shaped function allowing the definition of an optimal and a lethal temperature is used (Figure 1):



$$ba_{SST} = 1 - \frac{|sst - sst_{opt}|^{\gamma}}{|sst_0 - sst_{opt}|^{\gamma}} \quad if \ sst > sst_0$$
$$= 0 \quad if \ sst < sst_0$$

SST_{opt}= 29°C
SST_{lim}= 16°C
γ = 3 (tuned)

Fig. 1 : Functional response to the SST used in the case of the skipjack population

This parameterization drives the skipjack population to warm waters between 24°C and 30°C (Barkley & al.78, Brill 94, Bertignac et al.98) (Figure 2).

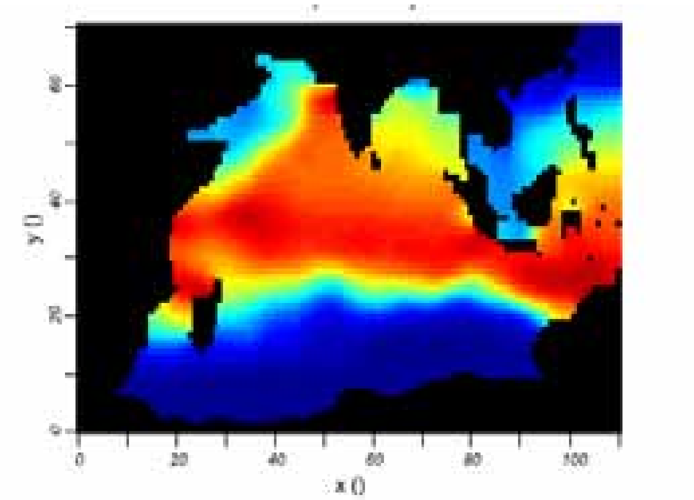
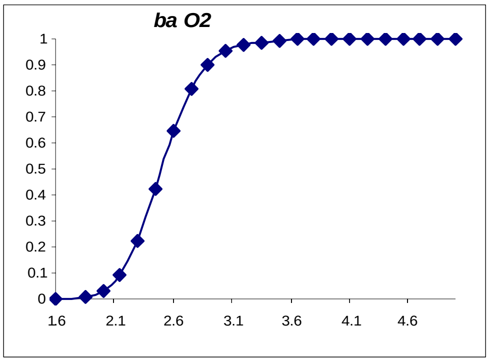


Fig. 2.: Skipjack distribution in march forced only by temperature

2.1.2 Functional response to the oxygen



$$baoxy = \frac{[O_2]^{\gamma}}{[O_2]^{\gamma} + [O_2]_{\lim}^{\gamma}}$$

$[O_2]_{lim}$= 2.5ml/L (Marsac 93)
$\gamma = 15$ (tuned)

Fig. 3 : Functional response to the O_2 used in the case of the skipjack population

We choose to force the model with dissolved O_2 concentration at 100m depth, even if Skipjack live preferentially in surface, because O_2 concentration at the surface is not limiting at all over the whole ocean. To force the model with oxygen concentration ensures to limite the distribution principally in the north of the Indian Ocean (Figure 4).

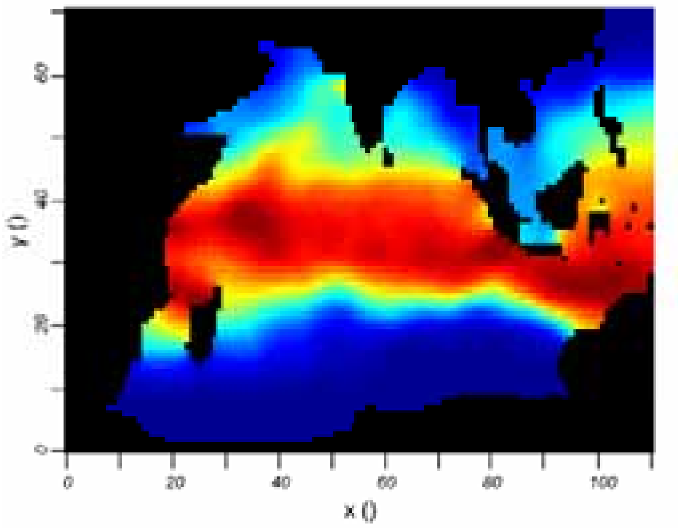


Fig. 4 : Skipjack distribution in march forced by temperature and oxygen data

Until now the fish distribution has been forced only by these two environmental parameters. We assigned the most important weight to the temperature (p_i = 20), and a much lower weight (0.01) to oxygen.

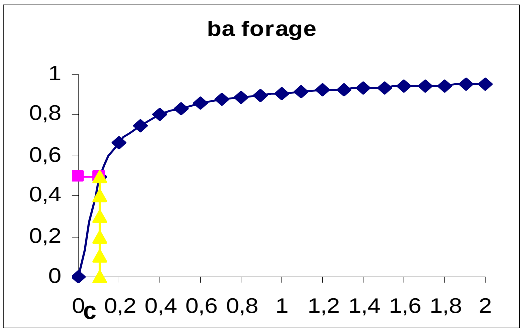
2.1.3 Functional response to the forage

Tuna forage encompasses many different species (from small mesopelagic fishes to cephalopods and pelagic crustaceans) whose spatial distribution is not well known and poorly documented in the litterature. To obtain the expected distribution of the tuna forage, which is a key parameter driving tuna movements, a size-structured model has been developed (Maury, unpublished). In this model, observed phytoplankton (seawifs data) is used as the source term of a partial differential equation representing the entire ecosystem dynamics with a single state variable which experiences growth and mortality.

Various determinant features are taken into account in the model:**Active and passive movements** (currents) of the organisms;

- Fully explicit **size-structured trophic interactions** (predation, competition) ;
- **Energy explicit growth and reproduction** (assimilation of energy, maintenance);
- **Temperature-dependent metabolic rates** of organisms;
- **Size-dependent natural non-predatory mortality**.**Predation is supposed to be opportunistic** and only controlled by the **ratio of size** between organisms so that all organisms can

be predators and preys at the same time, depending on their relative size: predation is supposed to occur if the predator to prey length ratio ranges between two extreme values.A Holling type II functional response is used to model the response of tuna movement to the food density (Figure 5).



$$ba_{forage} = \frac{F}{c+F}$$

Fig. 5: Functional response to the forage used in the case of the skipjack simulation

We have begun to force the model with forage data during the meeting. The first results are preliminary but already interesting. (Figure 6)

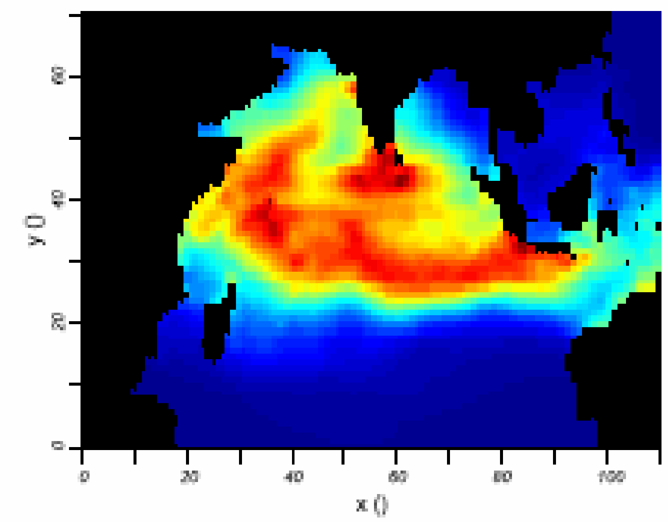


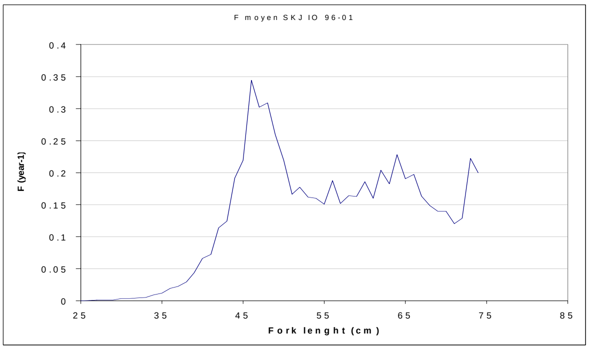
Fig.6 : Skipjack distribution in march forced by temperature oxygen and forage data : preliminary results

2.2. Fishing mortality and catchability parameterization for the Skipjack stock

Simulating tag-recapture experiments require to determine fishing mortality. Fishing mortality parameterization is a key point to obtain realistic tag recovery simulations. Calculating the local fishing mortality by 1 degree square requires the calculation of catchabilities and so the calculation of a mean annual fishing mortality and a surface stock (Maury, 1998, 2000).

$$q_s = \frac{F_T \bar{S}_T}{f_T S_s}$$

To get an estimation of the annual fishing mortality applied to the stock, a length-based VPA (Jones method) was conducted on mean catch size data on the period 1996-2001 (Figure 7).The Von Bertalanffy parameters have been chosen according to the last estimation of the WPTT working on skipjack (IOTC 2003).



Most of the skipjack caught have a length comprised between 45 and 55 cm: so total fishing mortality is assumed to be equal to 0.25 yr^{-1}

Fig. 7 : Fishing mortality applied to the Skipjack stock estimated with length-based VPA

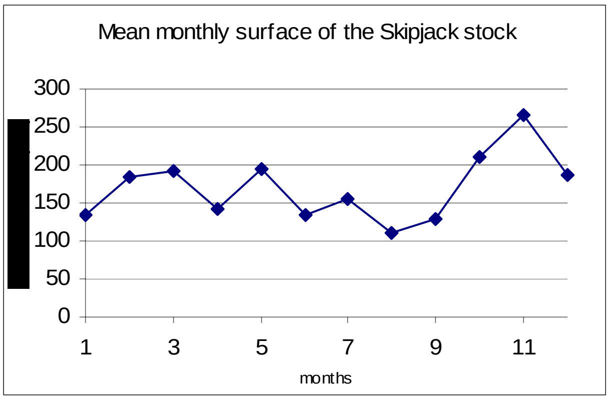


Fig. 8 : Estimated monthly stock surface

The surface stock (exploited fraction of the population), is mostly a theorical concept.
We defined it as the surface where 95% of the catches occurred. (Marshall & Frank, 1994; Swain & Sinclair, 1994). We deduced the mean monthly surface from the calculation of the cumulative distribution of catch versus surface for 12 mean months (99-02). The annual average is 170 one degree square (Figure 8).

Two main fisheries exploit the skipjack stock. Hence, two catchability coeffcients have been distinguished. Most of the catches come from the purse seine (French and Spain in majority) and the maldivian bait boat fisheries. So according to the catch level of the two fleets we attribute 55% of the total fishing mortality to the seiners and 25% to the bait boat. The stock surface is supposed to be the same for the two fisheries. It allows to calculate two coefficients of local catchability using the equation presented above (Maury, 2000):

$$qps = \frac{F_T \bar{S}_T}{f_T S_s} * \% ps = \frac{0.25 * 170}{12826 * 1} * 0.55 = 0.0018 \quad searching \quad days^{-1}$$

$$qbb = \frac{F_T \bar{S}_T}{f_T S_s} * \% bb = \frac{0.25 * 170}{1997 * 1} * 0.25 = 0.0053 \quad searching \quad days^{-1}$$

3. Choice of the *scenarii* to be tested: criterion of selection and proposals

The scenarii of tagging, that we want to test and compare, have to be chosen. Propositions are made in this chapter which must be discussed during the meeting.

3.1. Constraints

Two Spanish bait boat have been chosen to realize tagging (feasibility final report IOTC 2003). It seems that they must operate together for security and efficiency reasons. Tagging experiments will last two years and half. The three species target are yellowfin and bigeye mainly, and skipjack. It appears that it will be difficult to tag adult bigeye tuna with pole on line vessel. Adult bigeye are indeed swimming in deep water and are hardly accessible for pole on line.

The operations of tuna pole and line vessels are totally dependant on a continual and adequate supply of live bait: this is the main constraint, which limit the tagging range of vessels. We consider that boats have approximately an autonomy of fifteen days. The real viability of live bait during a so long period has to be proven, we retain this hypothesis as a first guess. Five places where live bait might be available are used as a starting point: Madagascar-Mayotte (MM), Seychelles(S), Tanzania-Kenya (TK), Oman-Yemen (OY), Chagos-Maldives-Laccadives (CML). The availability of suitable baitfish grounds is related to different factors: bait resources, species available, access to different areas, ways to get the bait. The stop over of the boat is also given as an approximate indication.

It is difficult to predict the number of tags that will be released in reality. According to the constraints above, we consider that boats will tag fishes twenty days in one month: five days corresponding to the travel time, five another days to the supply of live bait. In one year, we can assume that there will be about 240 days of tagging. Finally, we estimate that at least 80 000 tags are expected to be released during the two years and half of the project.

For the purpose of the study and taking into consideration the seasonality of the fishery (Figure 10 et 11), nine main tagging areas have been chosen: West Seychelles (WSe), Seychelles (Se), East Seychelles (ESe), Maldives-Chagos(MC), Mozambique channel (M), West Somalia (WSo), East Somalia (ESo), Arabian Sea (ArS), Lacaddives (L) (Figure 9).

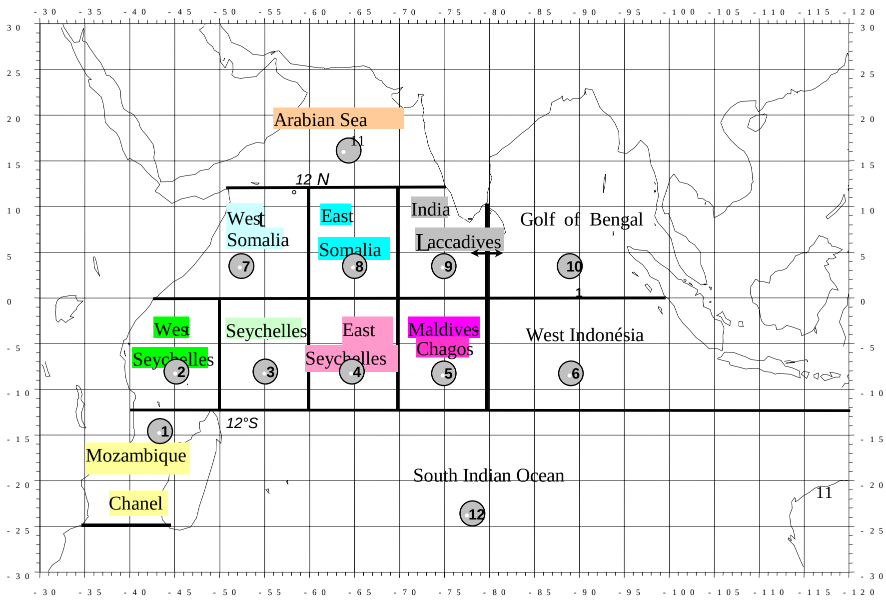


Fig. 9 : tagging zones

We used the purse seine seasonal distribution of catches to build the scenarii (Figure 10 and 11).On the one hand, we can't take the risk to send the bait boat in regions where the probability to find tuna is too low, if we want to have a good efficiency. But one the other hand tagging exactly where purse seiners are fishing will increase the probability of having earlier recapture. The compromise will be to stay near the purse seine but to avoid being too close. Furthermore, we have considered that there are no main meteorological constraints for bait boats (particularly no wind forcing). But, weather conditions may have more effects on bait fishing capability and may be limitant in certain areas.

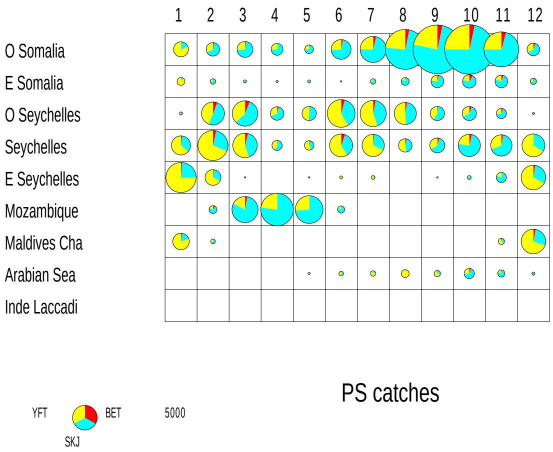


Fig. 10: mean monthly purse seine catches in each tagging region (93-02 period)

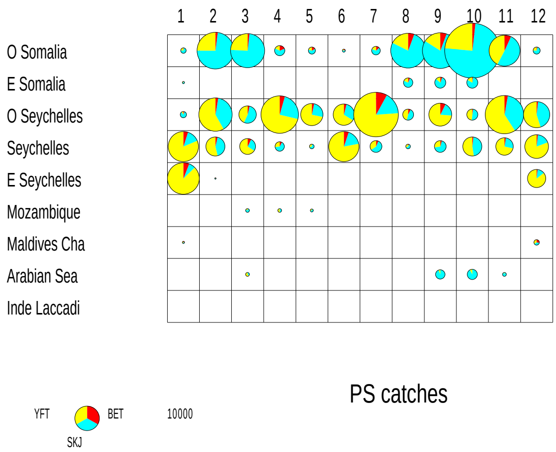


Fig. 11 : mean monthly purse seine catches in each tagging region (year 03)

3.2 Proposition

3.2.1 Basic scenario

The two years are the same: boats mirror roughly the mean seasonal purse seine distribution. There are no strong constraints. This simple scenario should be realizable in any case; there should not be problems of live baits availability. We will use it as the first year of the other scenarii (scenarios 4-7).

J	F M	A M	J J	A S O N	D
Ese	Se	M	Wse	Wso	ESe

Fig. 12: tagging planning 1

3.2.2 Basic scenarios

The scenarii are based on the purse seine activity but more details are introduced in the scenarii which take into account more tagging zone. Furthermore, it seems that the purse seine fishery distribution has changed these last years (2003, beginning 2004) so we defined two scenarii. The first one corresponds to the fishery of these last twenty years, the second one to the 2003 "anomalous" year which may potentially be a new configuration of the fishery.

These scenarii allow to tag all the length classes (Figure 13):

Somalia season: young fishes of the three species (bigeye, yellowfin, skipjack)
East Seychelles season: yellowfin spawning period (large fish)
Arabian sea- Laccadives: yellowfin intermediate sizes

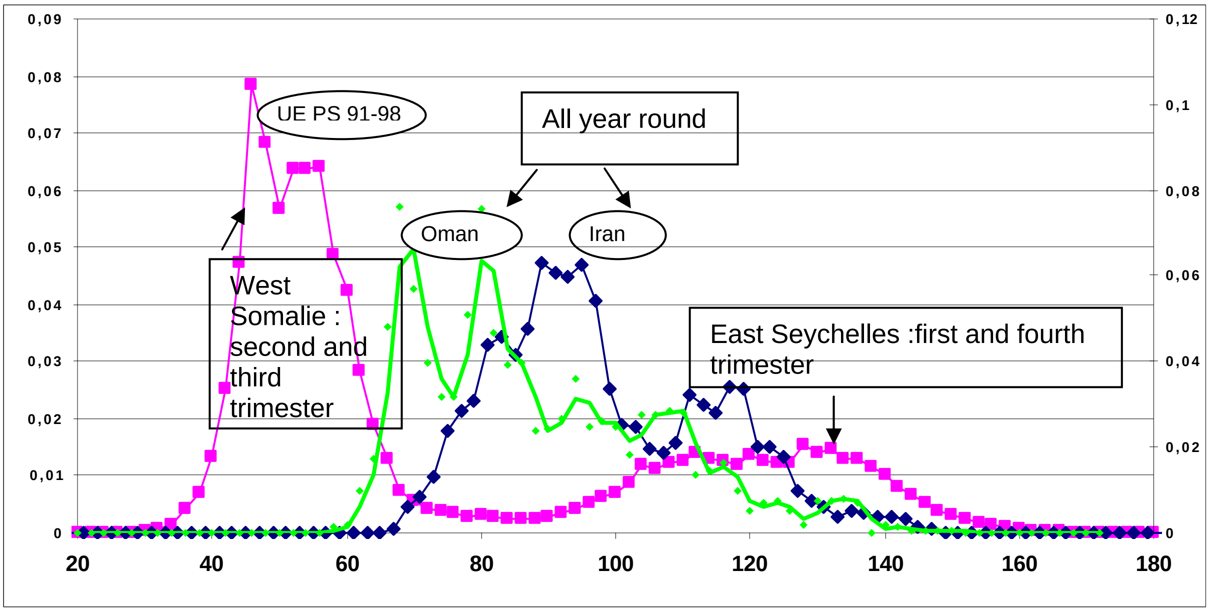


Fig.13.: yellowfin length frequencies for UE purse seine, Oman, and Iran fleets

Furthermore, these scenarii are targeting zones like the Mozambique Channel, where the origin and the future of tuna are not well known. So it is interesting to tag fishes in those regions to estimate transfert rates and better understand fishes migrations during their life cycles. The same is true for tuna in the West Seychelles region since large concentration of tunas (especially yellowfin) have been fished between Seychelles and Tanzania especially in 2003 and in the first part of 2004.
Finally, the small-scale tagging operations are in progress and are planned during the large scale tagging programme. Those operations will cover some areas like Maldives and Laccadives. However, as tagging is done from local artisanal platforms, tagging will mainly occurred close to shore. Consequently, some tagging operations by the large pole-and-line vessels of the IOTPP are planned in some of the scenarii but will only concern the off-shore areas of these zones.

- Purse seine fishing activity for a typical last twenty year : "classic Scenario "

Consequently the first year is based on the basic scenario while new tagging zones are prospected during the second year.

	First year												Second year											
Month	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Zones	ESe	WSe	Se		M	WSe	Se	WSo				Ese	MC	ESe	L		WSe	WSo			ArS			L
Baiting stop	Se	Se	MM		MM	TK	Se		TK		Se	Se	CML	Se	CML	Se	Se	TK	TK	OY	OY	OY	CML	

Fig. 14: tagging planning 2: "classic scenario"

- Purse seine fishing activity in an "anomalous" year : "Scenario 2003"

2003 has shown three main characteristics:

- Boats stayed in the Somalia zone a large part of the year since the beginning
- They ignored the Mozambique Channel
- Some catches can be observed in the Eastern Somalia region. The possibility of tagging in this region is questionable because there are no live bait points closes, but as a first guess we include it in a scenario

Consequently, tagging is ignoring Mozambique Channel and the zones to the East (Maldives-Chagos and Laccadives).

	First year												Second year											
Months	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Zones	Se	Wso		WSe		Se	WSe	WSo	ArS		ESo	Ese		Se		Wse				WSo			Wse	Se
Baiting stop	Se	TK	TK	TK	Se	Se	TK	OY	OY	OY	Se	Se	Se	Se	Se	TK				TK			Se	

Fig. 15: tagging planning 3 : "scenario 2003"

These two scenarios are theoretically realizable but a few uncertainties exist and could compromise them. For example, (Hallier, com.pers.), it is not sure that boat will be able to go in the north part of the West Somalia zone and in the Arabian Sea. It depends on the real availability of baits in Oman or in Yemen and their real conservation time. So it will be interesting to test the real gain of sending boats in this region (see below scenario 4 and 5).

3.2.3.Scenario which allows to test many hypotheses

The first year of this scenario is the same and corresponds to the scenario 1. The second year is use to test the effect of tagging in one precise region.

- <u>gains of tagging in the Arabian Sea and in the Laccadives : scenario 4 and 5 (Figure 16, 17)</u>

As already stated, there is still a lot of uncertainties regarding bait availability in the North West part of the Indian Ocean. So we test in these scenarii the advantages, in term of accuracy of the estimates, of tagging fishes in the Arabian Sea (Figure 15) and in the Laccadives (Figure 16).

J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Ese	Se		M		WSe		WSo				ESe	ESe	Se		M		WSe		WSo	ArS			
Se	Se	Se	MM	MM	TK	TK	TK	or	OY		Se	CML	Se	Se	MM	MM	TK		Se	OY			

Fig. 16 : tagging planning 4

J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Ese	Se		M		WSe		WSo				ESe	L			M		Wse		WSo				ESe
Se			MM		TK						Se	CML			MM		Se		TK				Se

Fig. 17 : tagging planning 5

- <u>gains of tagging in Seychelles scenario 6 (Figure 18)</u>

The purpose of this scenario is to test the lost of information if the tagging boats stay in Seychelles, their home base, the largest part of the year. It should be recalled that bait availability in Seychelles remain uncertain.

J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
ESe	Se		M		WSe		WSo				ESe	Se			M		Se		WSo				ESe
Se							TK				Se	Se											Se

Fig. 18 : tagging planning 6

- <u>gains of tagging in Somalia in the first part of the year : scenario 7(Figure 19)</u>

It could be interesting to tag fishes in the Somalia region before the upwelling season. Tagged fish will have time to mix with the rest of the local population before purse seine arrival. It will limit the risk of having premature recapture. Furthermore, considering the catches in 2003, a reasonable tagging effort can be expected with small risks not to find enough tuna. This scenario emphasizes the small fish categories.

J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
ESe	Se		M		WSe		WSo				ESe		WSo				WSe		WSo				ESe
Se							TK				Se		TK				Se		TK				Se

Fig. 19 : tagging planning 7

The scenarii presented above must be discussed during the meeting of the tagging working group. Propositions and critiques are needed and will be welcome. The objective is to define precisely during the meeting all the scenarii to be tested with the simulation model.

Conclusion

This work is still under progress. The simulation framework is now operational. Parameterization must be completed using forage estimates. Then we will have to test the scenarii selected during the present WPT meeting and compare them.
The next step will be to tune the model to the two other species: yellowfin and bigeye. The length-based VPA have already been made (Figure 20). Two length groups will be introduced, not only because they are not targeted by the same fisheries (purse seine and longliners) but also because small and large tunas do not have the same sensitivity to environmental parameters (adult bigeye are able to dive and do not stay in the surface layer as skipjack and yellowfin do).

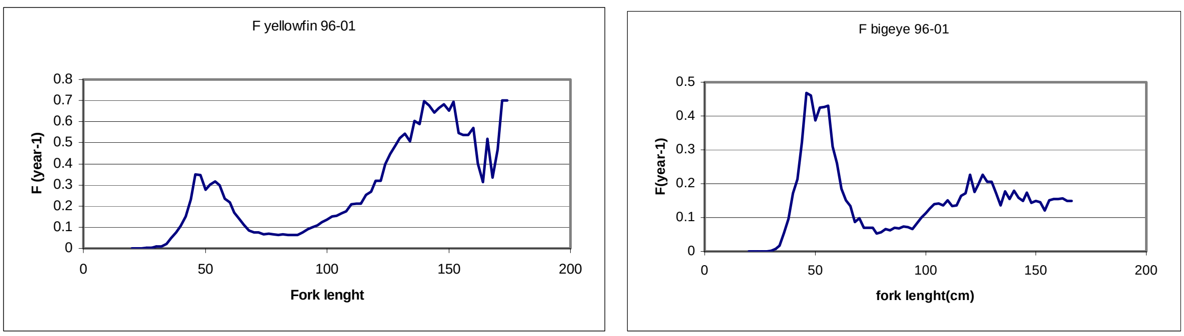


Fig.20: Fishing mortality applied to bigeye and yellowfin stock estimed with length-based VPA

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