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AERIAL SURVEYS OF BLUEFIN TUNA IN THE WESTERN MEDITERRANEAN SEA: RETROSPECTIVE, PROSPECTIVE, PERSPECTIVE

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SUMMARY

While the current stock status of bluefin tuna (BFT) has been considered as declining, there remain considerable data limitations for its stock assessment in the Mediterranean Sea. The collection of fishery-independent data reveals to be crucial to compensate for the lack of Mediterranean purse seine CPUE indices as well as to overcome a potential halt in the bluefin tuna fishery that would impede the monitoring of the stock and the comparison to reference points. Here we present a retrospective of aerial surveys that have been carried out since 2000. It includes the protocol as well as a retrospective of temporal and spatial distribution of detected schools. We then propose several perspectives that could improve the data collection method itself and the statistical method. By coupling information on bluefin tuna ecology, e.g. location and size of schools, with biotic and abiotic data (thermal and primary production fronts, prey distribution and abundance), perspectives offered by aerial surveys are particularly interesting in the framework of the Ecosystem Approach to Fisheries that has to be applied by 2012.

RÉSUMÉ

Bien que l'état actuel du stock de thon rouge (BFT) soit considéré comme étant en déclin, il reste de nombreuses limitations dans les données utilisées pour l'évaluation de stock de cette espèce en Méditerranée. La collecte de données indépendantes des captures se révèle déterminante pour compenser le manque d'indices de capture par unité d'effort (CPUE) des thoniers senneurs de la Méditerranée, ainsi que pour faire face à un potentiel arrêt de la pêcherie de thon rouge qui empêcherait de pouvoir mener un suivi du stock et la comparaison de points de référence. Dans cette étude, nous présentons une rétrospective des prospections aériennes qui ont été menées depuis 2000 qui inclut le protocole utilisé ainsi qu'une rétrospective de la distribution spatio-temporelle des bancs détectés. Nous proposons par la suite plusieurs prospectives qui permettraient d'améliorer la méthode de collecte de données et leur analyse statistique. En associant les informations sur l'écologie du thon rouge, par exemple la position et la taille des bancs, aux conditions biotique et abiotique du milieu (fronts thermiques et production primaire, distribution et abondance des proies), les perspectives offertes par les prospections aériennes sont particulièrement intéressantes dans le cadre de l'approche écosystémique des pêches qui doit être appliquée d'ici à 2012.

RESUMEN

Aunque actualmente se considera que el estado del stock de atún rojo (BFT) es que está disminuyendo, siguen existiendo considerables limitaciones en los datos para la evaluación de las poblaciones en el Mar Mediterráneo. La recopilación de datos independientes de la pesquería es crucial para compensar la falta de índices de CPUE de cerco con jareta del Mediterráneo, así como para hacer frente a una posible suspensión de la pesquería de atún rojo que impediría el seguimiento del stock y la comparación con puntos de referencia. Aquí se presenta una retrospectiva de las prospecciones aéreas que se han llevado a cabo desde el año 2000. Incluye el protocolo, así como una retrospectiva de la distribución temporal y espacial de los cardúmenes detectados. A continuación, se proponen varias prospectivas que podrían mejorar el método de recogida de datos en sí y el método estadístico. Juntando la información sobre la ecología del atún rojo, por ejemplo, ubicación y tamaño de los cardúmenes con datos bióticos y abióticos (frentes de producción térmica y primaria, distribución y abundancia de presas), las perspectivas ofrecidas por las prospecciones aéreas son especialmente interesantes en el marco del enfoque ecosistémico de la pesca que se ha de aplicar en 2012.

KEYWORDS

Atlantic bluefin tuna, aerial survey, index of abundance, Gulf of Lions, strip transect

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1. Introduction

Bluefin tuna (*Thunnus thynnus*) western and eastern stocks are estimated to be strongly overfished and considered as overexploited. The 2006 stock assessment even suggests a substantial risk of fisheries and population collapse (ICCAT 2007). The point estimates which are referred to for stock assessment, i.e. the available data mainly stem from commercial catches. These fishery-based data are often standardized for use as an index of relative abundance, particularly in fisheries where a regular resource survey has not been feasible (Hilborn & Walters, 1992; Maunder & Punt, 2004). Different factors such as changes or variations in catchability (e.g. changes in fleet composition and effort creep within vessels) may however be incorrectly concluded to be due to changes in abundances (Bishop *et al*., 2008). In particular, Mediterranean purse seine CPUE indices could be questioned with respect to this reliability all the more so different management decisions have affected the fishery for the last years (e.g. reduction in the fishing season). As a matter of fact, a potential halt in the fishery resulting from the listing in Appendix I of the Convention of International Trade of Endangered Species (CITES), would imply that there would be no ways to assess the stock thereafter. Here we ask how we can get a reliable index to follow the evolution of the stock.

In the case of BFT, few scientific or fisheries-independent data are available. When the use of acoustic or trawl surveys are hardly conceivable, aerial surveys have proved to be a good alternative where techniques previously mentioned cannot be applied. For example, since 1993, aerial spottings are regularly carried out along the Southern Australian coasts to compute an index of abundance of juveniles of Southern bluefin tuna (e.g., Cowling & O'Reilly 1999). Some surveys and a framework for fishery-independent aerial assessment have been also tested on large Atlantic bluefin tuna (BFT) of the West Atlantic (Lutcavage & Kraus 1995, Lutcavage & Newlands 1999). In the same manner, here we investigate the potential use of aerial surveys in the Mediterranean Sea to get a reliable "abundance" index for BFT and monitor the evolution of the Eastern stock.

For 4 years (2000-2003) and in 2009, aerial surveys have been carried out from June to October in the western Mediterranean Sea, the Gulf of Lions. These aerial surveys were one of the aims of the EU project named STROMBOLI (2000-2002) and subsequent surveys (2003 and 2009) were funded by the Agriculture and Fishing Minister and IFREMER to monitor the BFT Mediterranean stock (see Fromentin *et al*. 2003). Although a 5-year hole in the data (2004-2008) precludes their use to compare with other abundance time-series, collected data are substantial enough to initiate some preliminary investigations.

This retrospective of aerial surveys first presents the data collected during the different years, i.e. the spatial and temporal distributions of the detected BFT schools. From then, a first statistical approach stemming from the theory of distance sampling is developed to illustrate the potential applications such as the estimation of a density, i.e. a number of schools per square nautical miles per year. We then provide some prospectives of improvements that could be gained both in terms of data collection and statistical approach and get closer to an abundance index. We finally discuss the perspectives offered by this data collection such as their linkage to environmental conditions, to prey abundance and distribution and fishery spatial effort.

2. Materials and method

2.1 Data acquisition

Aerial surveys have been carried out from 2000 to 2003 and thereafter in 2009 over the period June-October in the Western Mediterranean Sea, i.e. the Gulf of Lions. This period and location correspond to where young BFT were traditionally caught by the French purse seiners. About 20 flights per year were conducted, depending on weather conditions, with a "push pull" aircraft at 1000 feet above sea level. This kind of aircraft has the advantage to have the wings above the lateral windows which offers a better overview for the observers (pilot plus 1 or 2 of the authors).

When possible, trained spotters also participated to the surveys (information obtained with and without trained spotter has not been mixed to avoid inconsistency). Aerial surveys have been conducted at the same time of day (around noon when the sun is at its highest) and during favorable weather conditions, i.e. sunny sky and low wind speed (<10nm/h), which limits the possibility to conduct aerial survey outside of the summer season.

4 different routes have been defined at the beginning of these surveys **(Figure 1a-d)**. These routes have a length of 360, 350, 313, and 378 nautical miles respectively. Each route can be surveyed within 5 hours, including distance between airport and transect. For each route, the number and date of surveys per year is given in **Table 1**.

One crucial point of the distance sampling theory is to obtain reliable perpendicular distances, i.e. accurate locations of the route and detected schools. This can be easily obtained with a GPS and data were gathered at the end of each flight. The detection of tuna is possible when fish jump and/or swim rapidly at the surface, probably in relation to feeding and/or foraging activity. Each detected school was termed as "tiny", "small", "medium", "large", "very large" or "aggregation" for high concentrations of schools and rough estimates of the size of fish was written down if possible.

2.2 Method

Spatial and temporal distribution of detected school

Each detected school is plotted to illustrate their spatial distribution each year. As these schools have been reported as having different sizes, we arbitrarily attributed a weight for each size. These weights were 1, 2, 3, 6, 9, and 12 for tiny, small, medium, large, very large schools and aggregation respectively. A krigging method was then applied to the data to get a visual representation of the density of detected school. The function *kde2d* from the R package *MASS* was used to this end (Venables & Ripley, 2002).

Estimates of density using the distance sampling theory

The analysis of the data from aerial surveys is based on the theory of the distance sampling (Buckland *et al*. 1993). The lines or routes are defined within a given area, along which each object of interest (here a tuna school) is recorded. The route is surveyed several times within a given period. The density of the replicate *i* may be approximated as follow:

$$\hat{D}_i = \frac{n_i}{2wL}$$

where D_i is the density estimate (number per unit area) of replicate *i*, n_i is the number of tuna schools detected in the replicate *i*, *w*, the width of detection from the line of the transect and *L*, total length of the transect. The mean density, $\overline{D}$, from *r* replicates may be approximated as follow:

$$\overline{D} = \frac{1}{r}\sum_{1}^{n}\hat{D}i$$

and the variance between replicates as:

$$var(D) = \frac{1}{r(r-1)}\sum_{1}^{n}\left(\hat{D}i - \overline{D}\right)^2$$

Several constraints must be respected to obtain a reliable index. First, the objects must be detected at their initial position, prior to any movement in response to the presence of observers. Second, the detectability must decrease with the perpendicular distance from the route and the objects directly on the transect must be detected with a probability of 1. Finally, the perpendicular distances from the route must be measured accurately (the track of plane and the locations of the detected objects must be as precise as possible). The theory allows that some, perhaps many, of the objects remain undetected and that variation in detection due to environment or observer could occur, as soon as *n*, *L* and *w* are accurately measured. According to the line transect theory, *w* is estimated through a detection function, which is a model that fits the histogram of the perpendicular distances of the detections (e.g., Buckland *et al*. 1993; Chen 1996). This method, which is currently used for bird surveys, is elegant, but imply a minimum size sample of ~60-80 detections and can be further easily biased in areas of high density.

Here we used "strip transects" to estimate the density as this method is simpler to implement (*w* is fixed and directly determined from the histogram) and more robust than the line transects. They have further advantages: (i) they do not require a minimum number of observations, (ii) they do not imply the distinction between primary and secondary detection and (iii) they are easy to poststratify. Note that Cowling & O'Reilly (1999) have recently recommended the implementation of a strip transect method for index of abundance of SBT.

3. Results

3.1 Spatial distribution of detected school

Although the sampling covered a wide area of the Gulf of Lions, some spatial and temporal patterns of detected school can be observed as well as differences regarding the size of school **(Figure 2)**. In particular, detected BFT schools were mainly concentrated in the southwestern part of the sampling area during 2000, 2003, and 2009 while they were located in the southeastern part during 2001 and 2002 surveys. It is noteworthy the sampling effort might influence this results. Although a strong focus has been held about a random sampling, weather conditions and practical issues have led to a more important sampling of the western route in 2003 and 2009 **(Table 1)**. When accounting for the size of the detected schools, the krigging method reveals that the dots were more dispersed during 2000, 2003, and 2009 than in 2001 and 2002. The schools detected in 2009 covered a particularly wide area compared to previous years. The main kernels of density (green to red color in **Figure 2**) were interestingly located on the continental shelf where the oceanic floor plummets from 100m to 1000m. As in 2003, the year 2009 has been marked by observations of important concentrations, especially in the southeastern part of the Gulf of Lions. These concentrations implied that it was not possible for the observer to accurately count the number of school. Therefore, it has been decided to delineate an area rather than a number. For now, these areas have not been evaluated and a weight of 12 has been allocated to them for the density kernel calculations in **Figure 2**.

3.2 Detectability of schools

As expected with the distance sampling theory, the number of detected schools decreased exponentially with the perpendicular distance **(Figure 3)** and 75% of the schools were detected at a perpendicular distance < 2 nautical miles. A secondary weaker peak seems to occur from 4 nautical miles and even a tertiary peak at a distance of 6 nautical miles in 2003 and 2009. This may be linked to secondary observations resulting from spotting from a previously detected school. To remove this potential bias and strictly apply the strip transect, we removed the schools further than 2 nautical miles from the route. Similarly, empirical experience of observers proved this distance to be consistent with detection threshold (for example, by calculating the distance between the GPS position of the furthest fixed object, such as a ship, and the current position of the aircraft).

3.3 Estimates of the density

Considering a strip transect with a width of 2 nautical miles, densities of juveniles BFT in the Gulf of Lions exhibit stable values over the period 2000-2003 while a sharp increase (more than doubling) occurs in 2009 (**Table 2**, **Figure 4**). The variance of the density between years appears to be stable which is satisfactory. Previous estimates of Fromentin *et al*. (2003) are in agreement with the present analysis. Although small divergences may arise from data reprocessing, the values obtained were not significantly different. It should be noted that the number of schools solely was used to calculate the density. The size of the school was not accounted for which may imply a bias in the analysis. This was however the sole manner to keep an homogeneous way to assess the density since the estimation of the size of a school may be prone to temporal variations (depending on whether a small or a large number of schools are detected for a given day) and to an observer effect.

4. Discussion

Results of aerial surveys are encouraging to provide a synoptic estimation of the evolution of BFT abundance. They also suggest aerial surveys could be an appropriate and complementary approach to CPUE data. Some limitations such weather conditions can however affect the detectability and the number of flights. With respect to the detection of BFT schools, it is noteworthy north and north-west winds decrease the detectability because either creating whitecaps at the sea surface or changing BFT depth range or area. The use of aerial surveys to provide an abundance index is achievable but still needs improvements for estimating biomass (and not only school density) and calibrating aerial detectability. However it can already be considered as robust and used as a semi-quantitative / qualitative index of the abundance.

4.1 Prospectives

The experience gained during the 5-year surveys suggested several improvements that can be achieved to increase the detectability, the accuracy of estimates, and the statistical method. Here we develop several leads.

4.1.1 Data acquisition

− Expand the covered area

So far, 4 routes in the western part of the Mediterranean Sea have been explored. Other routes could be sampled in the Eastern part of the Gulf of Lions, especially from Marseille to Nice and along Corsica shelves where BFT have also been reported. This could be easily implemented but request additional time and funding to be carried out.

− Account for the size of the school and fish for density estimates

As mentioned above, the size of the fish/school was not accounted for in the density calculations. The qualitative approach to determine the school size could however be used to provide additional information in the estimation of the density. For instance, it may be possible to set a corresponding value to the size of the school as it has been done in the present study **(Figure 2)**, e.g. tiny school equals to 1 and large one equals to 6. To go further, the help of professional of aerial surveys might enable the determination of a number of fish per school as well as the size/weight of fish. This could really promote the data collection and enable us to get closer to a "real" abundance index (i.e. a biomass). Be as it may, a validation would be needed, e.g. by comparing aerial estimates with acoustic evaluations. An interesting calibration method would be to hire fishermen boats or research vessel (acoustic) to compare the estimates of the number of fish with "actual" values. So doing, it would also be possible to get information about the size of the fish in the school which is a prerequisite to an abundance index.

− Compare to other aerial surveys and exchange information with neighboring countries

To assess the reliability of the method, exchanges of observers with other institutes that carry out such surveys could be undertaken. It could enable the inter-calibration of the method and get more consistent and reliable estimates of the density at a wider scale in the Mediterranean Sea.

4.1.2 Method

− Towards a "classical" transect method

Although the strip transect method used in the present study is particularly robust and provides useful information, it could be possible to apply the distance sampling theory by fitting a model to the histogram of the distance of detection **(Figure 3)**. A statistical method such as generalized linear model could even account for environmentally-linked detectability to correct the fitted model.

− Use of imagery like picture and image analysis

One of the main drawbacks of the use of aerial surveys is that they are linked to the observers as well as the experience they gained during their flights. Inter-comparison could be performed to assess this effect and observers could fly together but not interact during the survey. The results can be compared thereafter. This does not preclude the possible lack of continuity in the time-series since observer can change and the experience can be lost without being transferred. A potential alternative to this issue would be to develop a method based upon pictures taken during the flight. So far, it is hard to assess the number of schools and the size of fish from a picture as could do an experienced observer. The possible use of other wavelength of the light may help to untangle the gleam of the light. For instance, as BFT have a inside temperature higher than water, infrared could be used. The strong light attenuation at this wavelength might however impede the detection of BFT in deeper water than the first meters. We could also use the weak attenuation of light in sea waters in the ultraviolet bands (near 365nm) to take pictures of BFT schools. Image analysis could then be performed to provide estimates of the number of fish and their size.

4.2 Perspectives

While it remains to early to be able to provide a real abundance index (i.e. biomass estimates) from aerial surveys, the present study illustrates their potential use in providing semi quantitative / qualitative indices of BFT abundance. The evolution of the density of a detected school, illustrated in **Figure 4**, shows that the abundance of BFT was higher in 2009 than in the other sampled years. Such results already provide insights to assess the response of the stock to management decisions.

Aerial surveys can also provide substantial information about BFT ecology as this sampling method enables the determination of the preferred locations of BFT. Such information could be coupled to environmental data (e.g. temperature fronts, retention areas) or biotic conditions (e.g. chlorophyll concentration) to determine the favorable conditions for BFT survival and growth.

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Table 1. Number of flights per year for each route. The date (DD/MM) of each flight is indicated in brackets. Note that all flights lasting more than 2h30 are here counted even when BFT schools haven't been detected. ND= not defined at that time.

		Route 1	*Route 2*	*Route 3*	*Route 4*
2000	#	2	2	2	ND
	dates	06/09, 09/09	08/09, 13/09	23/09, 24/09	
2001	#	2	3	1	ND
	dates	21/09, 26/09	13/09, 27/09, 08/10	20/09	
2002	#	1	2	0	1
	dates	12/09	22/08, 16/09		21/08
2003	#	8	5	0	2
	dates	23/06, 22/07, 05/08 21/08, 27/08, 15/09 18/09, 25/09	13/06, 26/06, 23/07 07/08, 18/08		26/09, 29/09
2009	#	7	3	2	2
	dates	17/06, 18/06, 24/06 29/06, 27/08, 08/09 23/09	30/06, 03/07, 01/09	19/06, 10/09	07/09, 11/09

Table 2. Estimates of the density of BFT schools for each year.

Year	*Mean density*	*Standard deviation*
2000	0.0073	0.0003
2001	0.0083	0.0002
2002	0.0082	0.0004
2003	0.0068	0.0002
2009	0.0202	0.0002

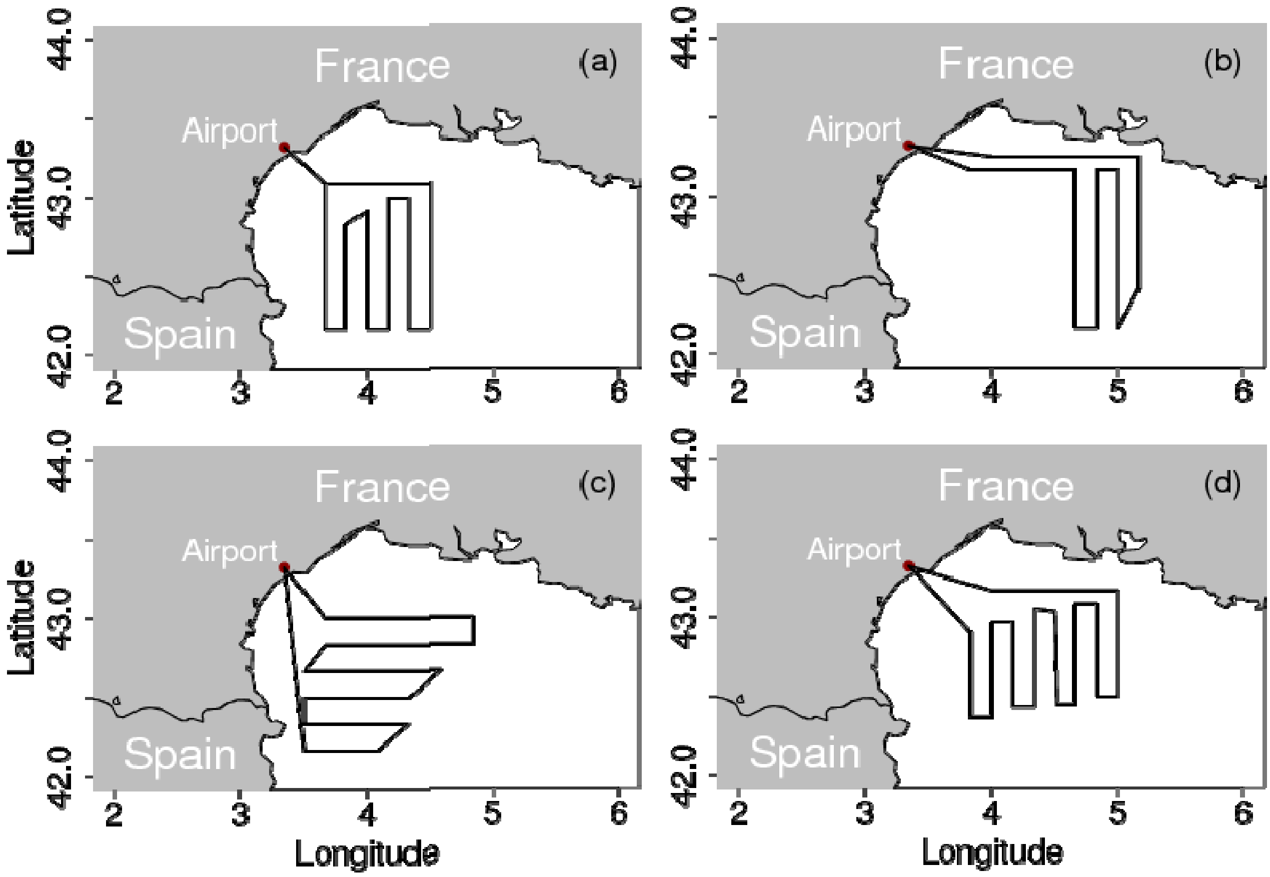

Figure 1: Maps of the different routes used to carry the aerial surveys out in the Mediterranean Sea, Gulf of Lions

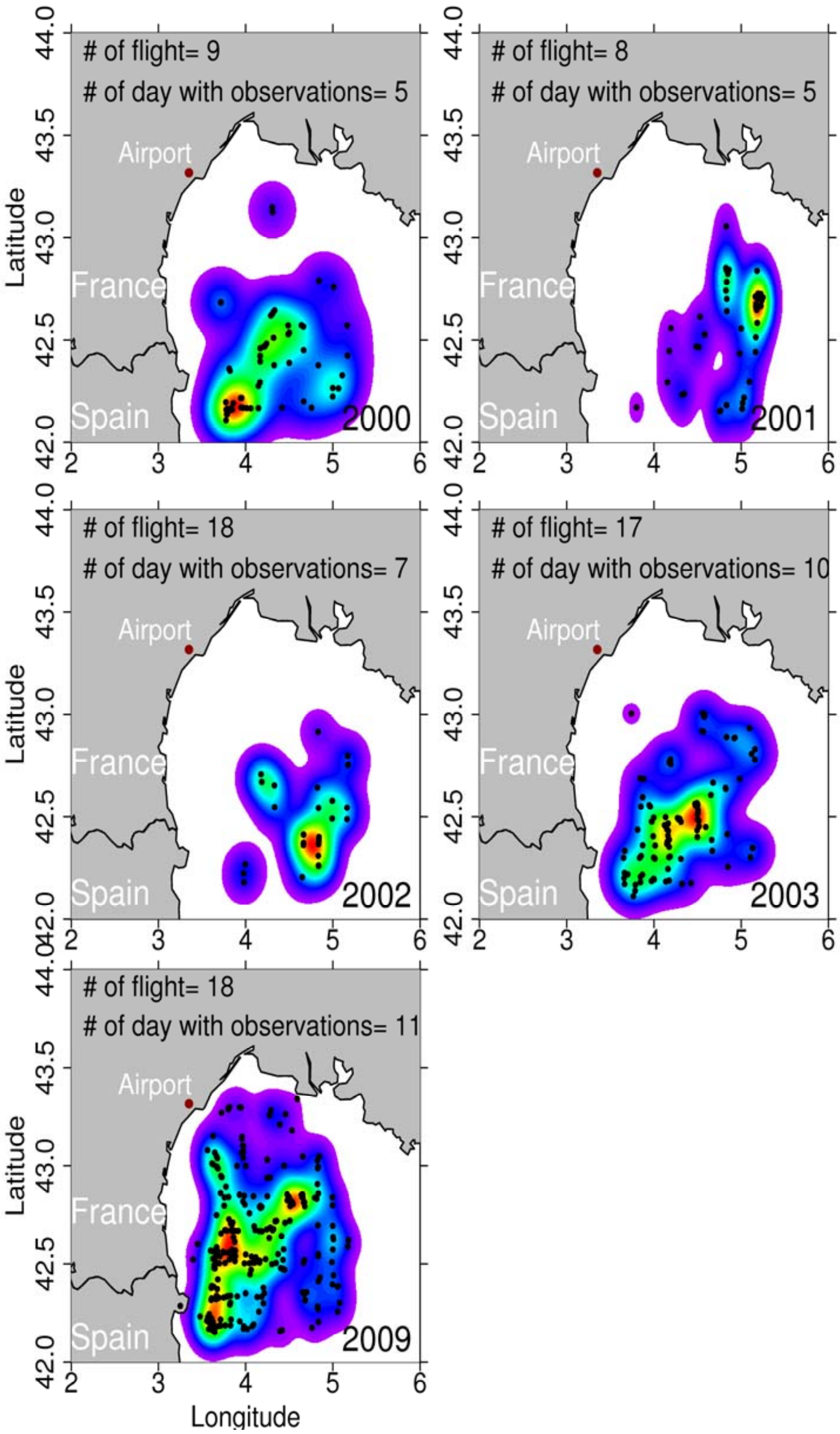

Figure 2: Spatial distribution of detected schools of BFT during aerial surveys led between 2000 and 2003 and in 2009. Each panel represents a year and the number of flights and the number of days where detection have been done is indicated on the top-left corner. As different size of school could be detected, a weight is allocated for each school and a kernel density (krigging method) is calculated to illustrate the relative density observed. (colors are dimensionless and for illustration purposes only).

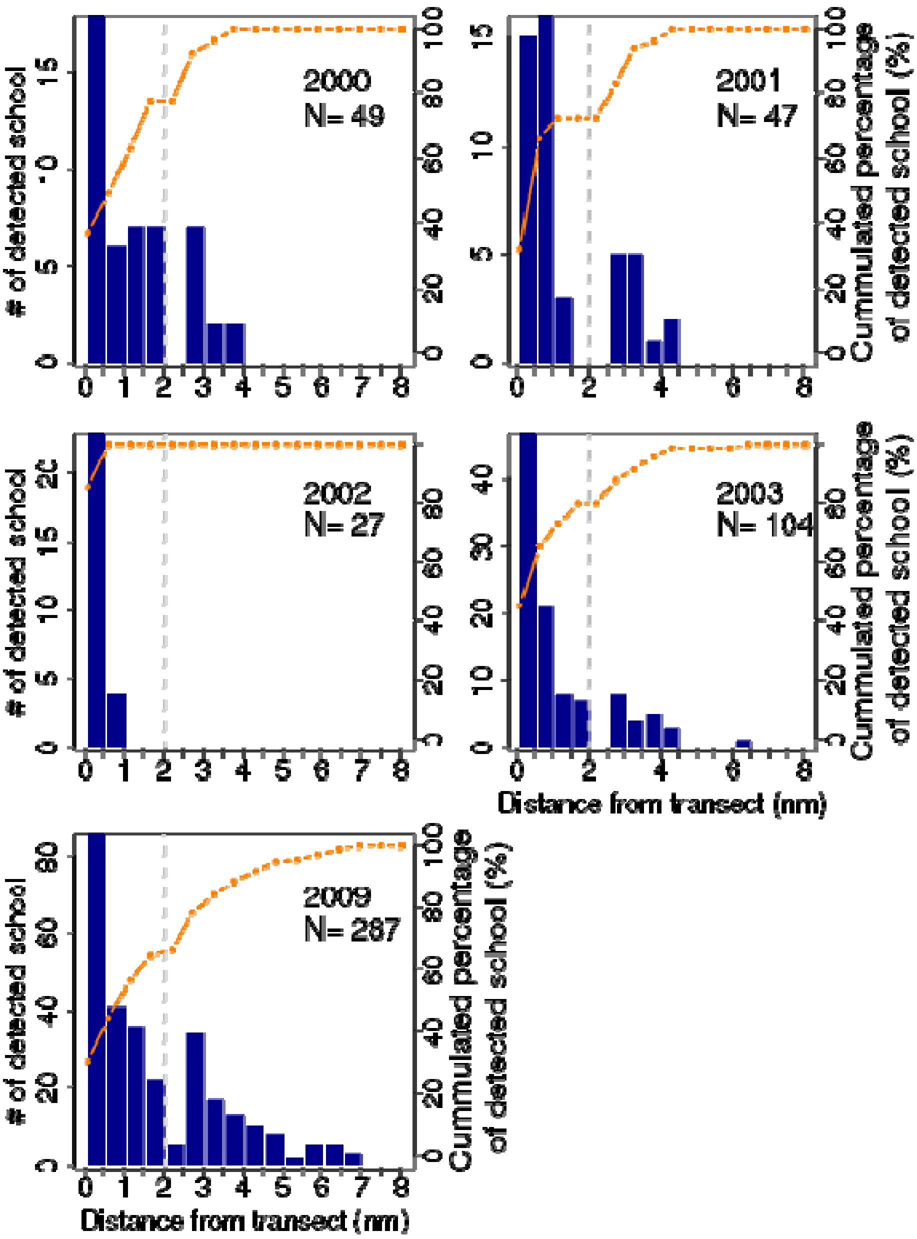

Figure 3. Histograms and cumulated percentage (orange line) of the number of schools being detected for each class of perpendicular distances to the route. The grey dashed line indicate the 2 nautical miles distance

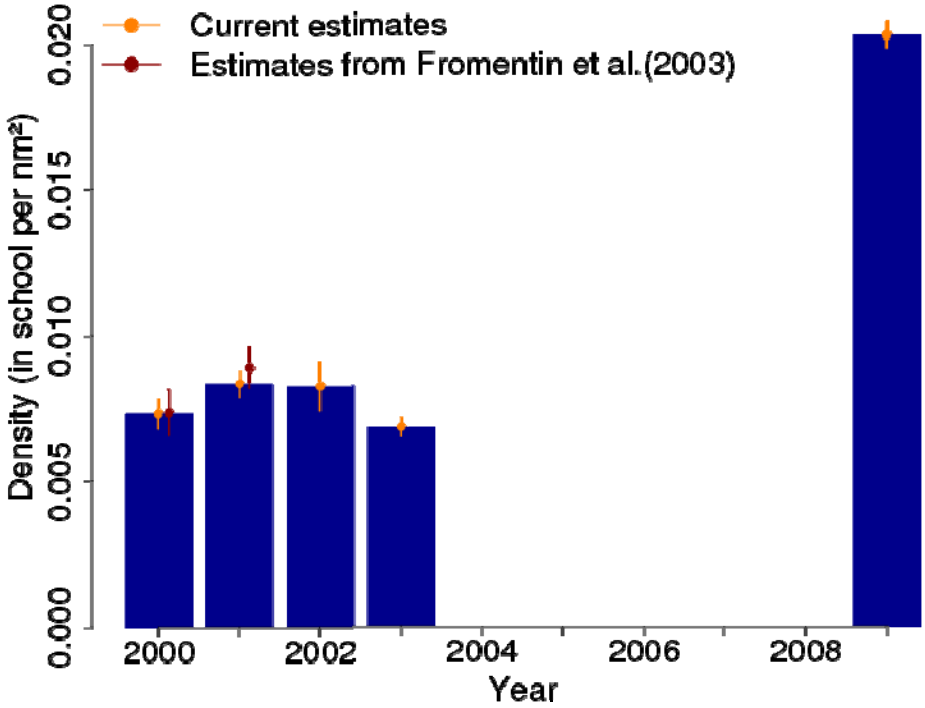

Figure 4. Evolution of the density of detected school along the routes between 2000 and 2009.

Orange dots indicate the value of the density and orange segments, the 95% confidence interval. The same goes for the red dots and segments which stem from the value obtained in Fromentin *et al*. (2003)