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UPDATE OF THE INDEX OF ABUNDANCE OF JUVENILE BLUEFIN TUNA IN THE WESTERN MEDITERRANEAN SEA UNTIL 2011

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SUMMARY

Here we present an update of the aerial surveys that have been carried out by IFREMER in the western Mediterranean Sea since 2000. This collection of data enables the monitoring of the bluefin juvenile population since the Gulf of Lyon is considered as a nursery for young individuals. The detections of juvenile bluefin tuna are carried out along the same transects between 2000-2003 and then 2009-2011 and are used to calculate a fishery-independent index of bluefin tuna abundance. This index can therefore be included in the stock assessment procedure as an abundance index of juveniles.

RÉSUMÉ

Nous présentons ici une mise à jour des données de suivis aériens effectués par IFREMER en Méditerranée occidentale depuis 2000. Ces données permettent le suivi de la population de juvéniles de thon rouge car le Golfe du Lion est considéré comme une nourricerie pour ces jeunes individus. Les détections de bancs de thon rouge sont réalisées le long des mêmes transects entre 2000 et 2003 puis de 2009 à 2011 et sont utilisées afin de calculer un indice d'abondance indépendant des données de pêche pour les juvéniles de thon rouge. Cette indice peut ainsi être inclus dans la procédure d'évaluation de stock en tant qu'indice d'abondance des juvéniles.

RESUMEN

Se presenta una actualización de los datos de prospecciones aéreas efectuadas por IFREMER en el Mediterráneo occidental desde 2000. Estos datos permiten el seguimiento de la población de juveniles de atún rojo ya que el golfo de León es considerado una zona de alimentación para estos ejemplares jóvenes. Las detecciones de los bancos de atún rojo se realizaron a lo largo de los mismos transectos entre 2000 y 2003 y posteriormente de 2009 a 2011 y se utilizan para calcular un índice de abundancia independiente de la pesquería para los juveniles de atún rojo. Este índice puede así incluirse en el procedimiento de evaluación de stock como índice de abundancia de juveniles.

KEYWORDS

Atlantic bluefin tuna, Thunnus thynnus, aerial survey, index of abundance, Gulf of Lyon, strip transect

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1. Introduction

The paucity of fisheries information in the Mediterranean has been identified as an important limitation of the scientific advice about the Atlantic bluefin tuna (ABFT) stock status (ICCAT 2008). In addition to this recurrent difficulty, the ABFT rebuilding has considerably modified fisheries strategies and effort mostly because of increasing size limit and severe reduction in the both the fishing season and TAC (ICCAT 2010). Consequently, fisheries-dependent information from the East Atlantic and Mediterranean ABFT stock is not only incomplete, but is also strongly affected by new management regulations (ICCAT 2010). Such a situation is challenging, especially to estimate the performances of the ABFT rebuilding.

Information from fisheries-independent surveys may be particularly useful in such context because scientific surveys are usually unaffected by management regulations and could be therefore more reliable to detect management-driven changes in abundance. We here present an update of the aerial surveys that have been carried out by Ifremer in the Western Mediterranean Sea since 2000 (Fromentin *et al*. 2003; Bonhommeau *et al*. 2009) as well as the corresponding index of abundance for the western juveniles ABFT from 2000 to 2003 and 2009 to 2011.

2. Materials and method

2.1 Data acquisition

Aerial surveys have been carried out over the period June-October in the Northwestern 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.

The protocol has remained the same since 2000. The flights were conducted with a small aircraft at 1000 feet above sea level. The aircraft included a pilot and 2 scientific spotters (i.e. the authors of the manuscript as well as Henri Farrugio up to 2009). 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. Four 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 and are surveyed within 4 to 5 hours. Each route is surveyed within a day/flight. The number and date of the routes that have been surveyed each 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. 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 Index of abundance: Estimates of density using the distance sampling theory

The estimation of density to compute the index of abundance 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, *D*, and the associated variance of the year *j* from the *r* replicates may be approximated as follow:

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

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

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 number of detections must exponentially decrease with the perpendicular distance from the route while the objects directly on the transect must be detected with a probability of 1. 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_i, L and w are accurately measured.

We here implemented a "strip transect" because this approach is simpler to implement, more robust and more relevant for our dataset (see Fromentin *et al.* 2003). In such an approach, *w* is fixed and directly determined from the histogram of the perpendicular distances (see also Bonhommeau *et al*. 2009).
A krigging method was then applied to the data of each year to get a visual representation of the density of detected schools. To do so, as 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.

3. Results

As previously noted, ABFT schools were mainly concentrated in the southwestern part of the sampling area, except in 2001 (**Figure 2**). Note, however, that weather conditions and practical issues have led to a more important sampling of the western route in 2003 and 2009, which may slightly bias these spatial distributions.
Since 2009, the detected schools covered a wider area compared to the 2000-2003 years (**Figure 2**). There is a clear extension towards the coasts (that has been confirmed by numerous observations), which seems to be concurrent with higher abundance (see below). The main kernels of density (green to red color) were interestingly located on the break of the continental shelf where the oceanic floor plummets from 100m to 1000m.

Since 2009, important concentrations of ABFT schools (a high number of ABFT schools within a given and limited area) have been observed. As it was difficult for the observer to accurately count the number of school in such area, it has been decided to delineate an area rather than a number. For the density kernel calculations, a weight of 12 has been allocated to these areas of ABFT concentrations.

As expected with the distance sampling theory, the number of detected schools decreased exponentially with the perpendicular distance (**Figure 3**). 75%, or more, of the schools were detected at a perpendicular distance < 2nm. Secondary detections can easily be identified on such a plot, taking place mostly from 2.5 nm to 5 nm (sometimes up to 8 nm). These results thus clearly confirm the adequacy of a strip transect with a width at 2nm (as calculated before).

The strip transect of 2nm thus only takes into account the schools detected at a perpendicular distance < 2nm. The results indicate a clear contrast between the former and the latter period (**Figure 4**). Densities over the period 2000-2003 varied between 0.0040 and 0.0068 schools/nm^2. From 2009, there is a sharp increase in the index values, with densities at around ~0.025 schools/nm^2, i.e. densities being 4-5 times higher than this of the 2000-2003 period. **Table 1** synthesized the main results for the calculation of the density of bluefin schools.

4. Discussion

As discussed in details in Bonhommeau *et al.* (2009), aerial surveys can provide a synoptic and reliable estimation of ABFT abundance, but there are some limitations. For instance, weather conditions can affect ABFT detectability as well as the total number of flights in a given year. The 2010 surveys were carried out with the same place as previously, but we performed the 2011 survey with a more sophisticated aircraft equipped with a gyroscopic camera and computing facilities onboard. Doing so, we could keep a full record of each survey and further use the camera to focus and zoom on each detected school. This camera allowed us to measure ABFT schools locations with higher precision (without moving off the route) as well as to get, on some spots, better information on the size of the fish and size of the schools. In 2012, the survey will use the same technology as in 2011 and should further expand the survey area, especially East of Marseille.

The sharp increase in ABFT density since 2009 is obviously the most striking result from these aerial surveys. In 2009 and 2010, ABFT densities were about 4-fold those of the 2000-2003 period. The last survey (i.e. 2011) displayed the highest density ever observed since the beginning of this survey, with a value up to 4.7 times the mean of the 2000-2003 period. The results of the 2012 survey would be thus of peculiar interest to see if this rapid and sharp increasing trend holds or not.

Note that our results are in agreement with observations from commercial and recreational fishermen who also confirm a sharp increase in ABFT abundance in the Gulf of Lions over the last years. As this area is a known and recurrent feeding ground for juveniles BFTE (Fromentin and Powers 2005, Druon *et al*. 2011), it is likely that this increase results from the BFTE rebuilding plan, more specifically from the increasing minimum size limit (30 kg) that was implemented in July 2007. This regulation has indeed banned the purse seine fleets (mostly French, but also Spanish and Italian), which used to catch fish < 30 kg in this area because most the fish caught became under the size limit (and later on, outside of the purse seiner fishing season). Note that the purse seine fleets used to catch about 30,000 to 250,000 juveniles BFTE/year during the early 2000s (i.e. before 2007). So, the 30kg minimum size limit allowed a substantial accumulation of juvenile BFTE in this (up to a million individuals).

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Table 1. Summary of the main features of aerial surveys and results.

Year	Number of transects per year (-)	Number of transects with observations per year (-)	Mean number of detected schools per transect (-)	Mean density (# school. nm^{-1})	Coefficient of variation of the density (%)
2000	6	5	9.7	0.0068	44.6
2001	8	5	7.9	0.0056	43.5
2002	9	5	5.8	0.0041	55.4
2003	11	10	9.5	0.0066	26.2
2009	8	8	35.0	0.0253	35.4
2010	5	5	34.0	0.0237	47.5
2011	8	8	37.6	0.0271	25.7

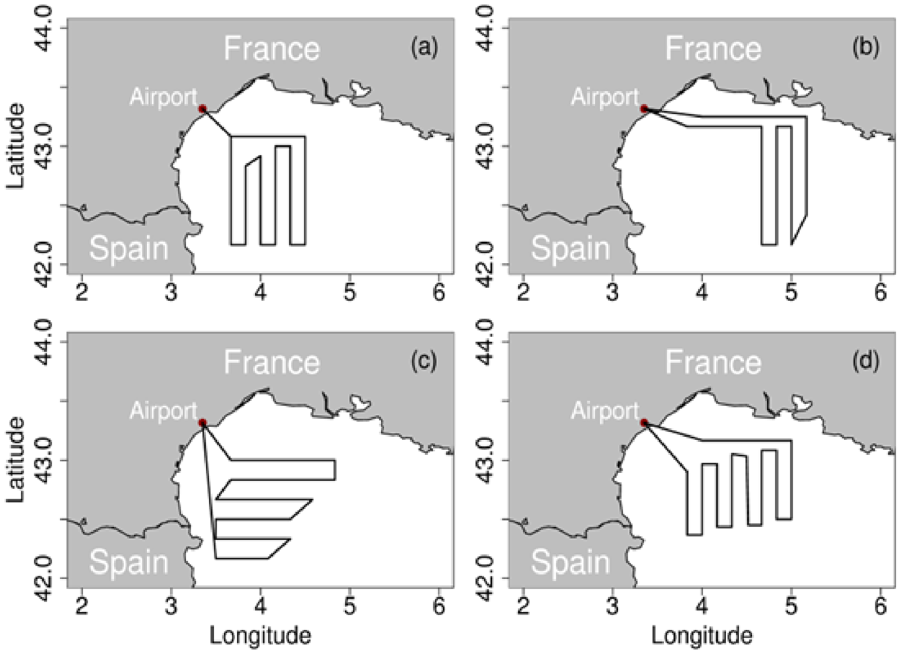

Figure 1. Maps of the different routes used to carry the aerial surveys out in the Mediterranean Sea, Gulf of Lions.

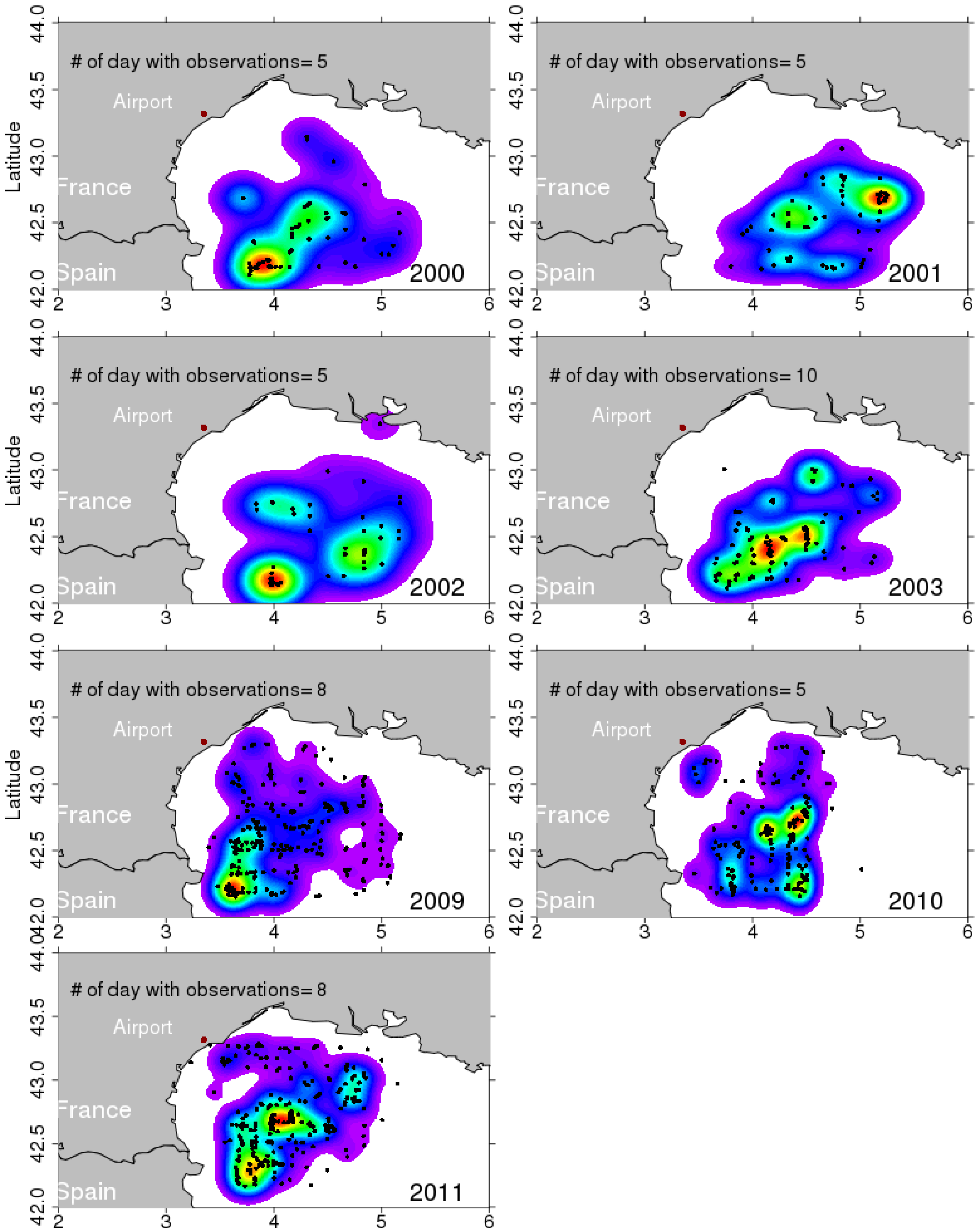

Figure 2. Spatial distribution of detected schools of BFT during aerial surveys led between 2000 and 2003 and between 2009 and 2011. Each panel represents a year and the number of flights where detections have been done is indicated on the top-left corner. As different size of schools could be detected, 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).

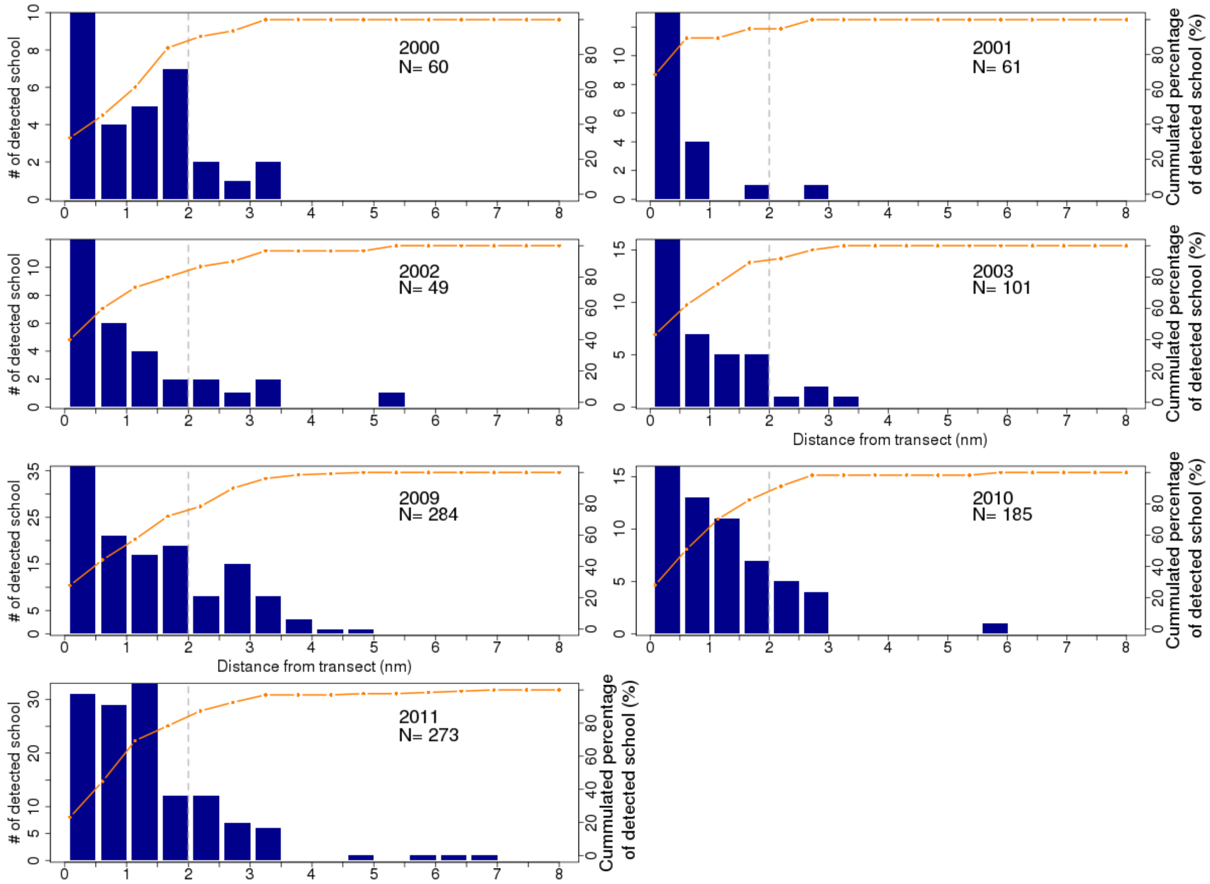

Figure 3. Histograms and cumulative percentage (orange line) of the number of schools being detected for each class of perpendicular distances to the route. The grey dashed line indicates the 2 nautical miles distance.

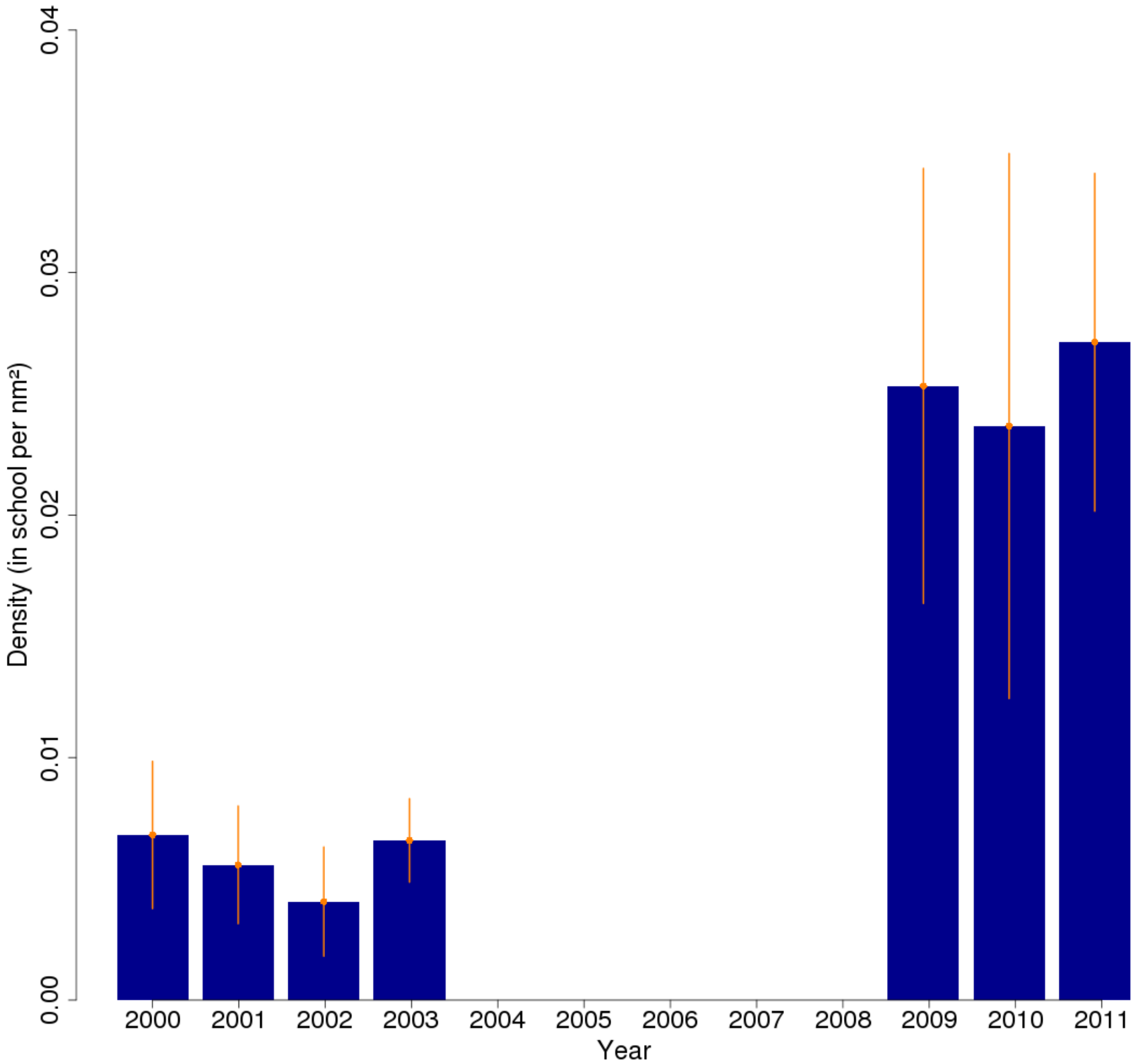

Figure 4. Evolution of the density of detected school along the routes between 2000 and 2011. Orange dots indicate the value of the density and orange segments, the 95% confidence interval.