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The environment drives Atlantic bluefin tuna availability in the Gulf of Lions

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Abstract :

Atlantic bluefin tuna (ABFT) is a migratory species whose exploitation is affected by its migratory behaviour. ABFT can be found the whole year round in the Gulf of Lions (GoL), with the exception of the May/June/July spawning season. The date at which ABFT fishing resumes in the GoL after spawning is variable and affects both the summer longline fishery and the local aerial survey used to derive a fisheries-independent index of abundance used in the stock assessment. We investigated whether environmental conditions could explain inter-annual variability in ABFT availability in the GoL. We focused on Sea surface temperature (SST) and northern wind events looking at changes in the ABFT summer longline fishery start date and quota completion date. Years with weaker northern wind events displayed a higher SST and were associated with a delay in ABFT catch by up to more than one month, whereas the bulk of the catch was completed earlier. A scale-dependent analysis of the densities of ABFT schools detected during the aerial survey show consistent associations between the short-term fluctuations in northern wind and SST and the densities of ABFT schools detected. When considering the trends these effects appeared reversed, higher SST and weaker northern wind being associated with an increase in ABFT school density. The implication of these results on the aerial survey and for the exploitation and conservation of ABFT are discussed in the light of the literature on its migratory behaviour in the context of climate change.

Keywords : aerial survey, Atlantic Bluefin Tuna, availability, environmental effect, exploitation, Gulf of Lions, index of abundance, migration

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INTRODUCTION

Atlantic bluefin tuna (ABFT, *Thunnus thynnus*) is an emblematic large pelagic migratory species of high commercial value and large geographical repartition (Fromentin and Powers, 2005). This species has been exploited for centuries, primarily in the Mediterranean where more than 60% of the catch still occurs today (Ravier and Fromentin, 2001; ICCAT, 2017). ABFT is managed by the International Commission for the Conservation of Atlantic Tunas (ICCAT) as two stocks, the Western Atlantic stock and the Eastern Atlantic and Mediterranean stock. The Eastern Atlantic and Mediterranean stock is the larger of the two and represents about 90% of the ABFT total catch (ICCAT 2017).

A salient aspect of ABFT migratory patterns is that a substantial, but unknown, fraction of all ABFT adults enter the Mediterranean in spring to breed in spawning grounds around the Balearic Islands, North of Sicily, South of Malta and near Cyprus (Fromentin and Powers, 2005; Rooker *et al.*, 2007). ABFT then leaves the Mediterranean after reproduction to forage in the northeast Atlantic, but it is also known to cross the Atlantic and some can even reach Canada and the Eastern US coast (Block *et al.*, 2005). However, tagging studies in other areas, such as the northwestern Mediterranean, have shown that some ABFT individuals are also resident in the Mediterranean Sea all year long and do not exhibit any migration outside of the Mediterranean (Fromentin and Lopuszanski, 2014;

Cermeño *et al.*, 2015). Migrations in and out of the Mediterranean are thus complex and the underlying mechanisms are still unknown, although some hypotheses date back a long while (Neuparth, A.E., 1925; Mather, F.J. *et al.*, 1995; Ravier and Fromentin, 2004).

Within the Mediterranean, the Gulf of Lions (GoL), the Ligurian Sea, the Adriatic Sea and the Gulf of Gabes are the main ABFT nursery areas, where young ABFT individuals are found most of the year (Mather, F.J. *et al.*, 1995). These nursery areas were heavily exploited until 2007, when the ICCAT rebuilding plan was implemented and the minimum size limit increased to 115 cm and 30 kg (Fromentin *et al.*, 2014). France is one of the biggest exploiters of ABFT and its fleets operate primarily in the Mediterranean and secondarily in the North Atlantic. ABFT purse seining in the Mediterranean is responsible for the highest proportion of catches, with more than 80% of the French quota (ICCAT, 2017). New regulations on ABFT exploitation in 2009 following the ICCAT rebuilding plan helped stop the French purse seiners operating in the GoL and focus on larger fish exploited in the spawning grounds off the Balearic Islands, Malta and, in certain years, as far as the Levantine basin. In 2007, a few French artisanal boats started to use the traditional longline technique and, between 2009 and 2011, this GoL operating fishery developed up to about 50 licensed boats.

Electronic tagging studies carried out in the GoL and, more generally in the northwest Mediterranean, also suggest ABFT's strong fidelity to the area for most of the year, except in May/June/July, during which they also seem to join the spawning areas (Fromentin and Lopuszanski, 2014; Cermeño *et al.*, 2015). The high residency and abundance of young ABFT makes the GoL a valuable area for a fisheries-independent index of abundance. For this purpose, an aerial survey has been carried out since 2000 during the months of August and September (Bauer *et al.*, 2015). The index of abundance obtained from this survey provides a substantial contribution to the international stock assessment of ABFT since 2012, as it is the only fisheries-independent information available for juveniles in the Mediterranean (ICCAT, 2017). Within this context, the timing at which ABFT comes back in the GoL around late July can affect the aerial survey, but also the artisanal longline fishery, which mostly operates from February to April and July to November.

Environmental conditions are known to be a strong driver for ABFT migratory behaviour and its spatio-temporal distribution at the large scale (i.e. over the whole Atlantic and adjacent seas, see e.g. Humston *et al.*, 2000; Schick and Lutcavage, 2009; Golet *et al.*, 2013; Fromentin *et al.*, 2014; Druon *et al.*, 2016). The environment has also been documented to affect different facets of ABFT spatial distribution at a smaller and more local scale. In the GoL, ABFT schools distributions appear to be strongly affected by the vicinity of oceanic features such as fronts (Royer *et al.*, 2004), whereas the seasonal dynamics of the water stratification has been shown to affect its vertical distribution (Bauer *et al.*, 2017).

In a context of climate change, understanding how environmental conditions affect ABFT availability in the GoL is not only important for the exploitation and conservation of ABFT, but it also has practical implications for the aerial survey carried out in the area. A potential yearly change in ABFT spatial distribution or in its vertical behaviour would affect its detectability through the survey and thus the resulting index of abundance, ultimately affecting the stock assessment. This is especially critical as this abundance index is the only one available for young ages (2-5 year-old group) of the Eastern Mediterranean stock. This issue pertains to the long-standing line of research aiming at accounting for the variable environment in fisheries-dependent and independent abundance indices. A change in the availability of fish to a given fleet (or scientific survey) due to the environment can be misinterpreted as a change in abundance and impact stock assessments (Frisk *et al.*, 2008; Link *et al.*, 2011). This has often been addressed through incorporating climatic indices in a standardisation process (Teo and Block, 2010). In the case of the aerial survey, establishing the link between environmental variations and change in availability in the GoL would provide an abundance index robust to yearly -- and short-term -- changes in environmental conditions. As the longliners operating in the GoL target the same fraction of population as the survey, identifying a link between the environment and the availability of ABFT to the fishery would provide a first step in correcting the index for such environmentally-induced inter-annual variations.

To correct the index for annual variations in ABFT summer migrations in the GoL (both in the timing and amplitude), the present study aims to better understand the role of environmental variations in yearly ABFT availability, more precisely (i) whether the timing of the summer longline fishery is affected by environmental variables and (ii) whether the identified environmental variables affect the aerial survey carried out in the GoL. Detailed catch statistics of the longline fishery were compiled and analysed to estimate yearly changes in the fisheries linked to ABFT availability and independent from the yearly increase in quota. These changes were then compared to yearly variations in key environmental variables over the GoL. By separating the long-term from the shorter-term fluctuations, data on sightings from the French aerial survey was also used to identify whether the environmental variables affect ABFT school density, which ultimately will allow the improvement of the robustness of the abundance index obtained from the survey.

MATERIALS AND METHODS

French longline fishery data and analyses

The fishing season for the french longliners operating in the GoL begins as soon as administrative aspects allow it, often in February or March. It ends at the end of the year, or when the quota has been completed. The activity of the longline fishery in the GoL changes over the year depending on the quantity of fish available, the demand and the weather. The February-April period is often favourable for catches, but the demand is not at its highest and the fishermen tend to keep some quota available for the rest of the season. From May-July, during the spawning season, almost no ABFT is landed, mainly due to its absence from the area. ABFT starts to show up again in the landings of the GoL longliners during July, which marks the beginning of an intense exploitation period as holidays and tourism create a strong demand for ABFT. The exploitation then continues until the quota is finished. To analyze the changes in activity of the fishery from one year to another, detailed catch data for the longliners in the GoL over the period 2011-2019 were obtained from the national statistics database. The daily number of fish caught were added up each week every year starting on the 1st of January. Weekly catches were then used to compute two indicators, deemed independent of increasing quotas, to characterise changes in availability to the longline fishery in the GoL.

The first indicator (D_{summer}) is the week at which the summer longline fishery re-started every year since 2011. This indicator was designed to capture potential changes in availability during the summer period. As the summer demand for ABFT in the French market is high, fishermen tend to start fishing as soon as fish come back in the GoL. Its computation was made as follows. For each year, the cumulated sum of the weekly catches (in number of fish) was divided by the yearly total catch. This formed a standardised time series of cumulated catches for each year, representing the share of the yearly catch made each week. Such standardisation allowed for an easier analysis of cumulative catch and, even though the quota of the longline fleet continuously increased over years, D_{summer} was insensitive to yearly changes in quota. Any period with zero catch (such as June-July) is characterised by a plateau. The beginning of the summer longline fishing season (D_{summer}) can then be easily estimated as the breakpoint between the end of the plateau and the following increase, through a segmented regression using the *segmented* function from the R package *segmented*. Here, the segmented regression was applied to the cumulated catch series reduced to the period over which the shift was observed (i.e. Summer-Autumn) to only estimate one breakpoint.

The second indicator (D_{90}) is the date at which 90% of the yearly catch was completed. While D_{summer} captures the week when the fish starts to be available during the summer season, D_{90} indicates how quickly the bulk of the catch is completed over the year. Compared to D_{summer}, D_{90} reflects the amount of fish being available to the fishing activity during a given year, with the assumption that the season finishes earlier if more fish is available. This is reasonable because there is a strong incentive for fishermen to finish the fishing season as early as possible to avoid the risk of not completing the quota and of landing fish when the demand and prices drop following the end of the tourist season. D_{90} has been preferred over other statistics such as the percentage of total catch or number of fish caught per week, which are more likely to be affected by the increase in quota. Indeed a given percent of catch does not represent the same amount of fish each year. D_{90} was also preferred to the duration of the fishing season, which can be affected by yearly changes in regulations, such as changes in the beginning of the season due to administrative aspects. D_{90} has been computed over the whole year and not only after the beginning of the summer season (D_{summer}) so that it would remain an independent variable insensitive to the amount of catch made before and after D_{summer}. This was tested by comparing D_{90} to the share of the total catch fished up until the last week of June using the Spearman correlation. However, D_{90} could be sensitive to an increase in quota, as one still expects that a higher quota would delay the completion of 90% of the catch. Therefore, the series of D_{90} estimates was checked for a positive trend, and an increased delay, that could reflect the yearly increase in ABFT quota over the years 2011-2019. The absence of an increasing trend suggests that the indicator is not driven by changes in quota and that it captures to some extent the changes in ABFT availability.

Aerial survey data

Aerial survey over the GoL started in 2000 to provide a fisheries-independent index of abundance for juvenile ABFT (Bauer *et al.*, 2015; Rouyer *et al.*, 2019b). This survey is still continuing with the same protocol, but no data was acquired over 2004-2008. About 10 to 12 flights are made each year from the beginning of August to mid-October following predefined routes that cover the full GoL (Bauer *et al.*, 2015). The altitude of a flight is always 1000 feet above sea level and the speed is about 200km/h. They take place around noon on days with a sunny sky and low wind speed (20 km/h) to achieve optimal detection conditions for the spotters. Up to 3 scientists embark to spot ABFT schools, which are classified into different size classes. Here, the aerial survey data was used to derive the yearly log densities of schools (number of schools spotted over the surveyed area, $D_{logAerial}$) over the 2009-2019 period that overlaps with the fishery data. Although the number of flights for the year 2013 was low, i.e. 2 flights against 8-12 in other years, the data has been kept to use a continuous time series of density estimates even though this value is less robust than the others.

Environmental data

This study focuses on the impact of northern winds and SST, which were assumed by several scientific spotters to capture a substantial variability in ABFT availability. Further variables could have been considered, but multiplying comparisons for a relatively short data series would have been likely to produce a more complex, but not more demonstrative, picture. The northern wind is also a key driver of the local oceanography, as it affects the structure of the water column, the temperature and the productivity of the whole area. Strong bursts of northern winds ("*Mistral*" and "*Tramontane*") blow throughout the year and activate the productivity in the GoL through local upwelling cells (Millot, 1990; Brossier and Drobinski, 2009). In the summer, such events cool down the water and break the stratification of the water column, which has already been associated with a change in ABFT behaviour (Royer *et al.*, 2004; Bauer *et al.*, 2017). SST is commonly assumed to have a large spectrum of effects on marine ecosystems. In the present study, SST can either affect ABFT dynamics as an environmental cue for migrations and/or feeding (Walli *et al.*, 2009; Druon *et al.*, 2011). The base data supporting the study was downloaded from the E.U. Copernicus Marine Service Information website (http://marine.copernicus.eu/). The Global Ocean Wind L4 Reprocessed 6 Hourly Observations dataset at 0.25 x 0.25 degree resolution was used to extract the northern wind ($m.s^{-1}$) while the Mediterranean Sea High Resolution L4 Sea Surface Temperature Reprocessed daily mean dataset was used for SST. However these datasets did not cover the year 2019, for which the Global Ocean Wind L4 Near Real Time 6 Hourly Observations dataset and the Mediterranean Sea High Resolution and Ultra High Resolution Sea Surface Temperature daily mean dataset for the wind and the SST were respectively used.

The data for both wind and SST were limited from 0°E to 10°E in longitude and from 40°N to 44°N in latitude, for years 2009-2019. This area is large enough to capture the environmental characteristics in the GoL plus neighbouring areas such as the Catalan sea and the Gulf of Genoa. For each year, an average over the daily values and over the whole area was computed for the month of July, resulting in a yearly time series of averaged northern wind (*NWind*) and averaged sea surface temperature (*SST*).

Statistical analyses

Both series of *NWind* and *SST* were compared to series of D_{summer} and D_{90} visually as well as using Spearman correlations, which are considered to be more robust than the Pearson correlations for short time series. The fisheries data availability limited the length of the period studied (2011-2019), which in turn limited the amount of techniques and analyses that could have been performed.

The effect of the environmental variables on $D_{logAerial}$ obtained from the aerial survey was investigated through a time-scale decomposition. This allowed for the separation of long-term changes in abundance from shorter-term changes in availability. First, a *loess* was fitted to $D_{logAerial}$, *NWind* and *SST* data over the 2009-2019 period to estimate the trends. The *loess* function in R, with a span of 3 was used to capture the trends in the time series, which were compared visually. Second, the residuals of the loess predictions -- the detrended signal -- were extracted and compared through Spearman correlations.

RESULTS

The standardised cumulated catch time series all displayed a similar shape, which reflected the different phases of exploitation over the year (Fig. 1). On each of the cumulated catch series, the May-July period of no exploitation was clearly apparent, but its length varied between years. The indicator D_{summer} varied by more than a month across years, between early July in 2011 (week 25, Table 1) and late August in 2018 (week 30, Table 1). D_{90} also displayed substantial variations, ranging between early October in 2016 (week 37, Table 1) and late November in 2013 (week 44, Table 1). Comparing D_{90} to the percentage of fish caught from the beginning of the year up until D_{summer} did not show any relationship (r=-0.05, p=0.897). As the ABFT quota for France increased over the studied period and as the number of longline licenses has remained stable since 2014, any link between D_{90} and the yearly total catch of the fleet should translate into an increase in D_{90}, as a larger catch would be expected to be associated with an extended fishing period. However, no obvious relationship between D_{90} and the total yearly catch of the fleet could be detected (r=0.244, p=0.527, Table 1), suggesting that the variability in D_{90} was influenced by other processes.

Very different northern wind conditions in July were found between the years over the course of the 2011-2019 period. The years 2013, 2015 and 2018 appeared to have been characterised by weaker *NWind*, whereas 2012, 2014 and 2016 appeared to have experienced stronger *NWind* (Fig. 2). In addition, the years 2013, 2015 and 2018 also experienced warmer *SST* in July, whereas 2011, 2012, 2014 and 2016 displayed relatively colder *SST* (Fig. 2). This was reflected in the time series of *NWind* and *SST* computed between 2011 and 2019, which displayed opposite fluctuations, as did D_{summer} and *NWind* (Fig. 2). The relationships between the two fishing indicators

(D_{summer} and D_{90}) and the two environmental variables (*NWind* and *SST*) were rather clear: D_{summer} and D_{90} were negatively related to *NWind*, but positively to *SST*. In other words, later summer fishing seasons and longer fishing seasons, such as in 2013 and 2018, occurred when *NWind* was low and *SST* high, whereas earlier or shorter fishing seasons, such as in 2011 and 2016, occurred when *NWind* was high and *SST* low (Fig. 3). However, the relationship between D_{summer} and *NWind* (Spearman's r=-0.65, p=0.063) appeared stronger than the relationship between D_{summer} and *SST* (Spearman's r=0.40, p=0.291). The relationship between D_{90} and *NWind* appeared particularly strong (Spearman's r=-0.94, p=0.0001), as did the relationship between D_{90} and *SST* (Spearman's r=0.65, p=0.059).

The trends extracted from $D_{logAerial}$ and *SST* displayed very similar increasing patterns, whereas the trend in *NWind* displayed a decrease (Fig. 4). However, the trends represented between 17% and 35% of the total variance, which was dominated by higher frequency fluctuations. The detrended time series of $D_{logAerial}$ and *NWind* displayed similar patterns, also opposed to those of *SST* (Fig. 4). The Spearman correlation between the detrended series of *SST* and $D_{logAerial}$ was strong (r=-0.84, p=0.0026), but was even stronger between the detrended series of *NWind* and $D_{logAerial}$ (r=0.92, p<2.2e-16). The relationships between the detrended variables were consistent to those obtained between the environmental variables and the D_{summer} and D_{90} indicators. In essence, years with stronger northern wind events and cooler SST were associated with an earlier summer fishing season, a faster completion of the bulk of the catch and also higher densities of schools spotted during the survey. These results suggest that years with strong northern wind events and cooler sea surface temperature in July were characterised by a higher ABFT availability for the fishery in the GoL.

DISCUSSION

As for many fish species, the spatial distribution of ABFT varies depending on the season due to migratory events related to feeding and spawning. Such migrations are often triggered by changes in environmental conditions, which set the seasonal timing of such events (Wilson *et al.*, 2001; Miller *et al.*, 2009; Block *et al.*, 2011). Our results suggest that environmentally-driven migrations occur in the GoL, with a substantial impact on the aerial scientific survey and fishing activities taking place in that location. Both inter-annual variations in the timing of the fishing activity and the density of schools detected through the aerial survey appeared to be affected in a consistent way. Results also show that years with a delayed summer fishing activity and later completion of the yearly catch consistently correspond to years with lower densities of tuna schools detected through the aerial survey. Those years are characterised by lower northern winds and higher SST.

The northern winds are a key driver of the GoL oceanography, as they are associated with a higher productivity in the GoL due to the activation of local upwelling processes, which break the stratification of the water column and cool down the upper water layers (Millot *et al.*, 1979, 1990). This process together with the Rhone river discharge and high meso-scale activities make the GoL a hotspot of marine productivity within the Mediterranean (Agostini and Bakun 2002; Hu *et al*., 2011), which attracts top predators, such as ABFT and marine mammals (Druon *et al*., 2011). The GoL is even considered as a key and recurrent nursery area for young ABFT, where they spend a major part of the year (Fromentin and Lopuszanski, 2014). Our results show that the beginning of the summer fishing season was delayed and that the density of ABFT schools was lower in the GoL during the years characterised by weaker northern winds during July. A hypothesis is that weaker northern winds could decrease the relative attractiveness of the GoL for ABFT because of lower productivity. An alternative hypothesis is that, as July marks the end of the reproduction period in the Western Mediterranean (Rooker *et al.*, 2007), changes in the phenology of the post-spawning migration back in the GoL are captured by the northern wind and the sea surface temperature in the GoL. Investigating the timing of migration through other areas/fisheries might help test the generality of these hypotheses, whereas looking into other environmental variables such as Ocean Heat Content might help to identify through what process the timing of migrations is being affected (Luo *et al.*, 2015).

The long and short-term response of ABFT to a changing climate might not be trivial as several different processes are at play at different time scales in the GoL. For instance, our results show that the long-term increase in SST corresponds to a positive trend in *DlogAerial*, whereas year-to-year variations in SST and *DlogAerial* are negatively related. This apparent inconsistency might actually be explained if we assume that long-term fluctuations are mostly related to changes in ABFT abundance, which is known to increase at the population level (ICCAT 2017), whereas short-term variations mostly reflect changes in the migratory behaviour of ABFT. Such a result is important from a stock assessment perspective, as it indicates that fisheries-independent indices, such as the ABFT aerial survey, may actually reflect both changes in abundance and in availability or migration. A clear path to provide a robust and reliable abundance index is therefore to remove the effect of changes in availability to only retain the signal related to changes in abundance. Appropriate standardisation of fisheries-dependent indices for the varying environment might help to deal with this aspect, providing that the right processes are appropriately detected and dealt with (Teo and Block, 2010; Forrestal *et al.*, 2019).

Our results identify that inter-annual variations in ABFT availability in the GoL are associated to *NWind* and *SST*. This suggests that with years characterised by stronger northern wind events and lower SST in July, the overall quantity of ABFT in the GoL is relatively higher. This effect appears to be substantial and should be then accounted for by the modelling framework used to provide the index of abundance. A way to include this aspect could be to adjust the detection probability within the distance framework used to produce the index of abundance, or to explicitly model it using a hierarchical approach (Buckland *et al.*, 2005; Miller *et al.*, 2019). Using data describing the diving behaviour of ABFT acquired through electronic tagging could also allow to account for seasonal changes in the stratification of the water column, which affects the vertical behaviour of ABFT in the GoL and ultimately its detectability (Walli *et al.*, 2009; Galuardi and Lutcavage, 2012; Bauer *et al.*, 2017).

Electronic tagging seems a valuable approach in refining the observations made in this study. This approach has shed a large amount of light on ABFT ecology (Block *et al.*, 2005; Galuardi *et al.*, 2010) and could offer fruitful perspectives in understanding the responses of its migrations to environmental forcing and to unravel the processes at play at different time scales. For instance, a residency time study could help understand whether the changes in primary productivity and in the dynamics of the small pelagics community in the GoL affect the relative attractiveness of the area for young bluefin (Feuilloley et al., 2020). At a shorter time-scale, tagging studies could also be used to identify whether the timing of post-spawning migrations in the GoL is associated with more direct changes in the physical environment of ABFT at the individual level caused by northern wind events (Teo *et al.*, 2007). Lastly, tagging of ABFT before or during the spawning season would also help to identify the environmental triggers involved in the timing of spawning migrations in the Mediterranean and the GoL (Fromentin and Lopuszanski, 2014; Cermeño *et al.*, 2015; Rouyer *et al.*, 2019a).

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

AUTHOR CONTRIBUTION STATEMENT

T. Rouyer, S. Bonhommeau, J.-M. Fromentin and O. Derridj acquired the data. T. Rouyer conceived the study. T. Rouyer, S. Bonhommeau, J.-M. Fromentin and G. Bal ran the analyses and wrote the manuscript.

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TABLES AND FIGURES

Table 1: Estimated timing (week) for the beginning of the summer fishing season (D_{summer}), date at which 90% of the yearly catch (D_{90}) is completed for the longline fishery in the Gulf of Lions and yearly catch (tonnes).

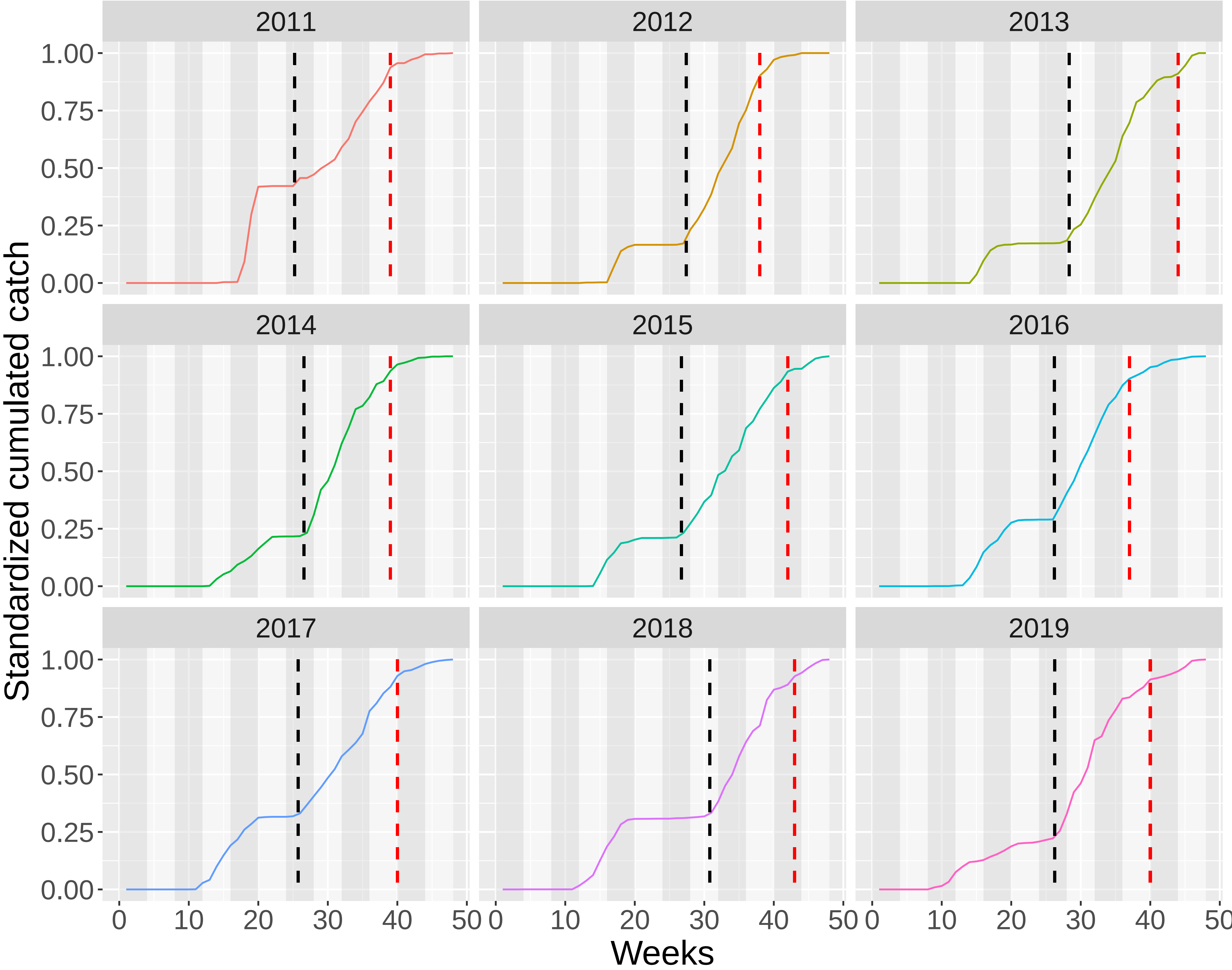
Year	**Date beginning of summer season (week)**	**Date 90% of catch (week)**	**Total catch (tonnes)**
2011	25.2	39	98
2012	27.4	38	89
2013	28.3	44	176
2014	26.6	39	233
2015	26.7	42	196
2016	26.2	37	262
2017	25.7	40	272
2018	30.8	43	319
2019	26.3	40	327

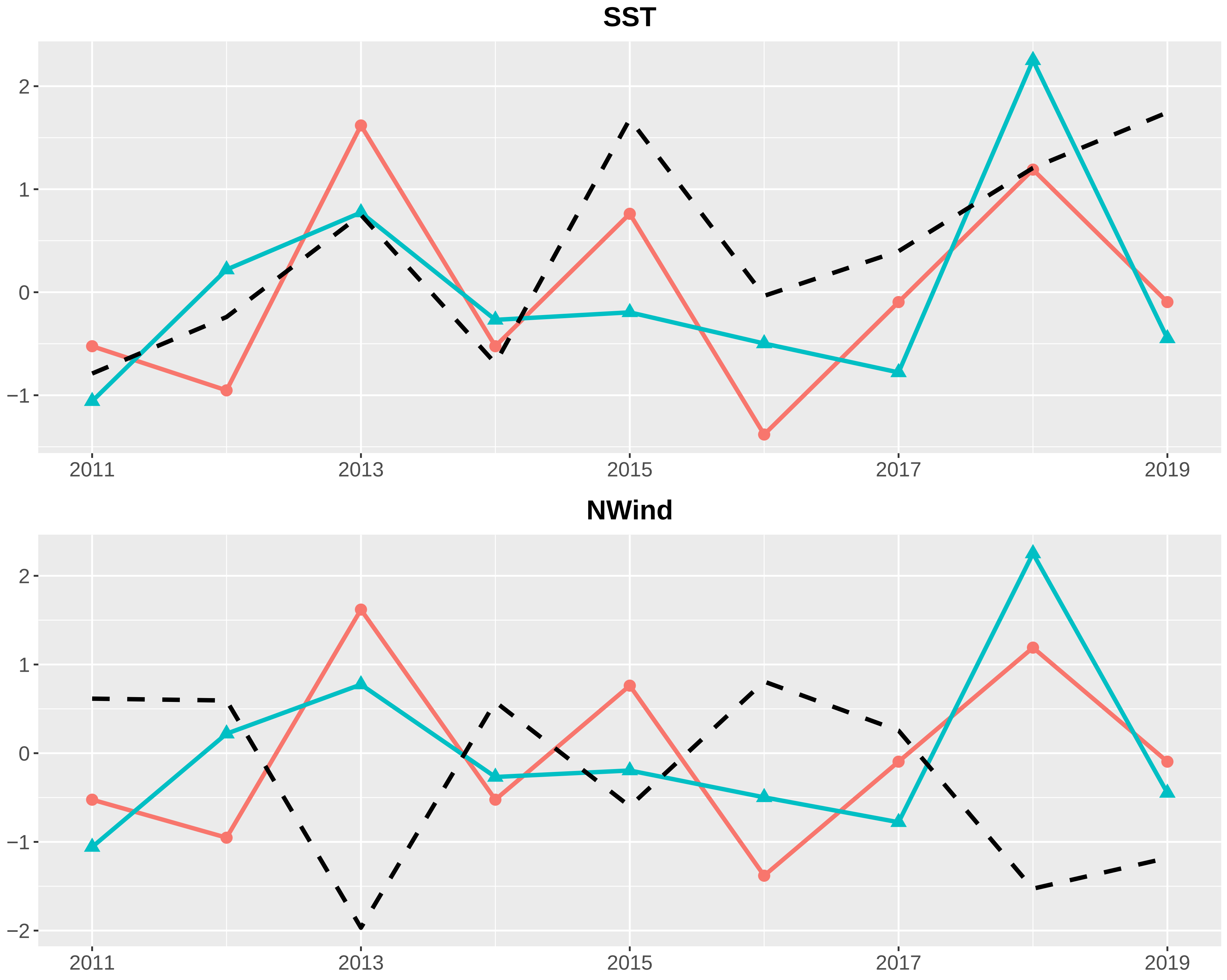
Figure 1: Standardised cumulated catch (number of fish) of the French longliner throughout the year and over the weeks, estimated beginning of the longliner summer fishing season (D_{summer}, black dotted line) and date at which 90% of the catch was completed (D_{90}, red dotted line) for each year. Grey/white vertical rectangles indicate successive months.

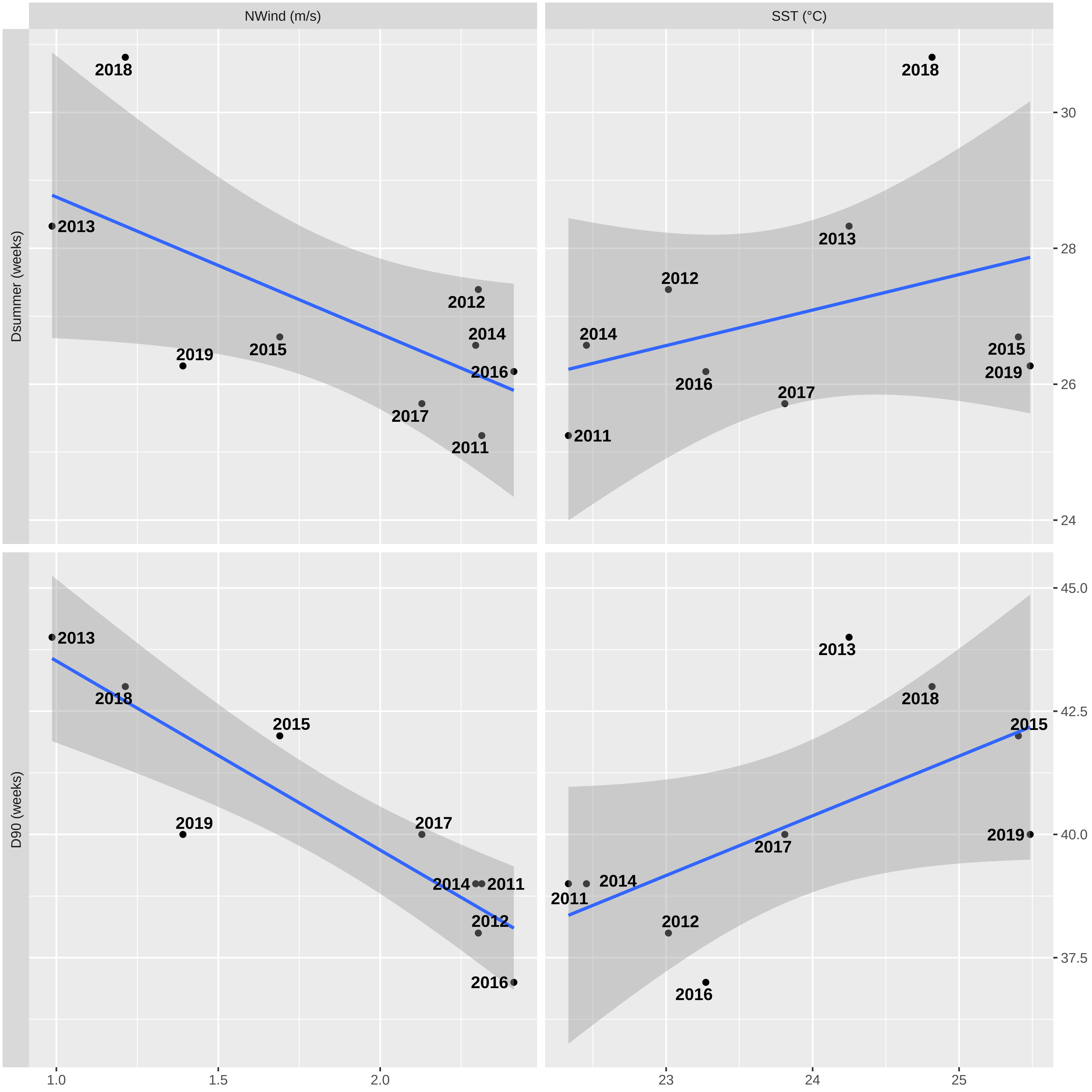
Figure 2: Standardised time series of D_{90} (red line and filled circles) and D_{summer} (blue line and filled triangles) over the 2011-2019 period, compared to standardised time series of Sea Surface Temperature (*SST*, dashed line, top panel) and Northern Wind (*NWind*, dashed line, bottom panel).

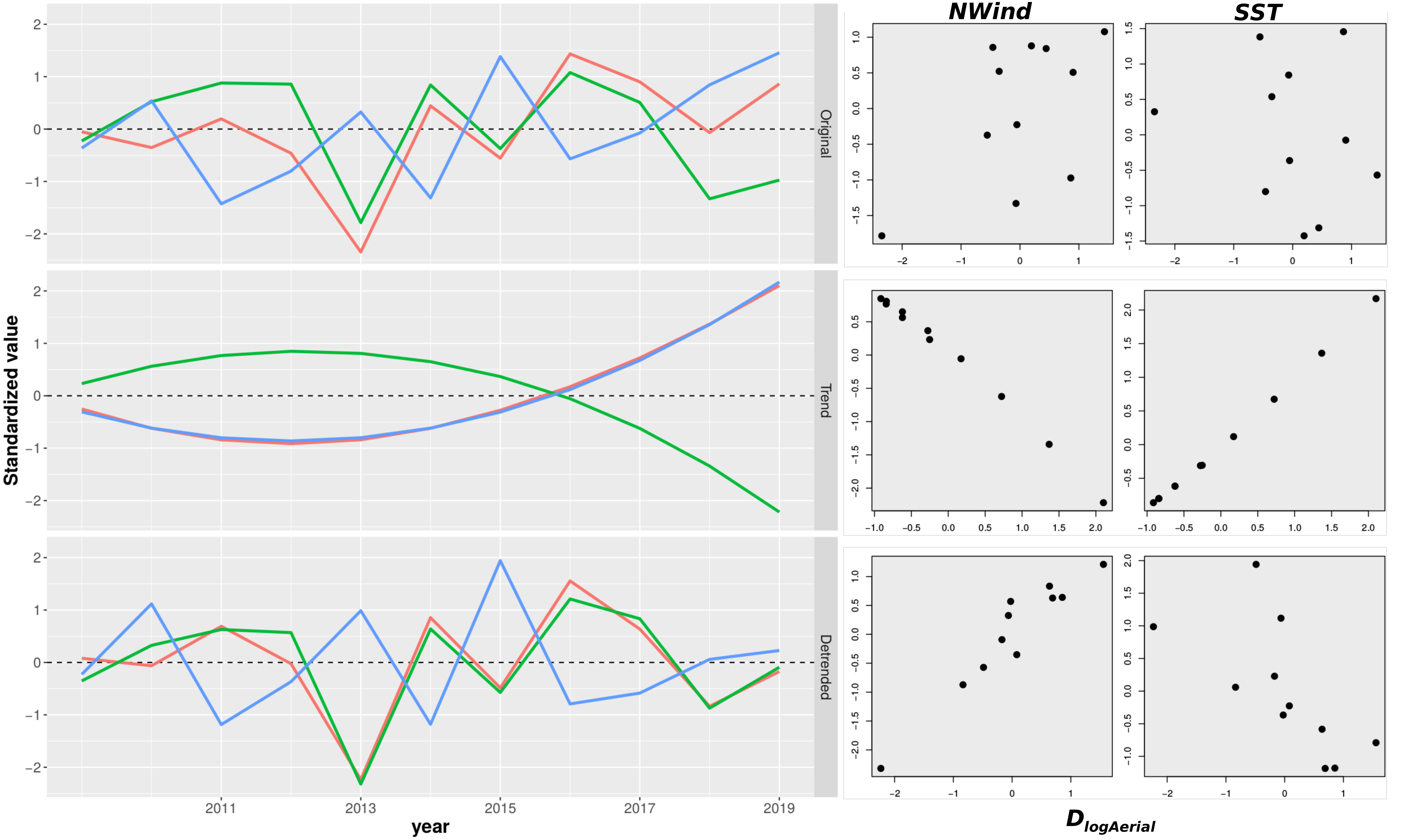
Figure 3: Scatterplots for the fisheries indicators D_{summer} and D_{90} against *NWind* and *SST*. The blue line is a linear regression and the grey area is the 95% confidence interval associated to it.

Figure 4: Time series (left panels) for the original (top panel), estimated trend (middle panel) and detrended (bottom panel) standardised time series for $D_{logAerial}$ (red line), the *NWind* (green line) and *SST* variables (blue line). The central and right panels display the scatterplots of NWind versus $D_{logAerial}$ (central panel) and SST versus $D_{logAerial}$ (right panel), for the original (top panel), estimated trend (middle panel) and detrended (bottom panel) standardised values of these variables.


2011
2012
2013
2014
2015
2016
2017
2018
2019
Standardized cumulated catch
1.00
0.75
0.50
0.25
0.00
Weeks
0
10
20
30
40
50


SST
2
1
0
−1
2011
2013
2015
2017
2019
NWind
2
1
0
−1
−2
2011
2013
2015
2017
2019


NWind (m/s)
SST (°C)
Dsummer (weeks)
D90 (weeks)
2018
2013
2012
2014
2019
2015
2016
2017
2011
30
28
26
24
45.0
42.5
40.0
37.5
1.0
1.5
2.0
23
24
25


NWind
SST
Original
Trend
Detrended
Standardized value
year
2011
2013
2015
2017
2019
−2
−1
0
1
2
$D_{logAerial}$