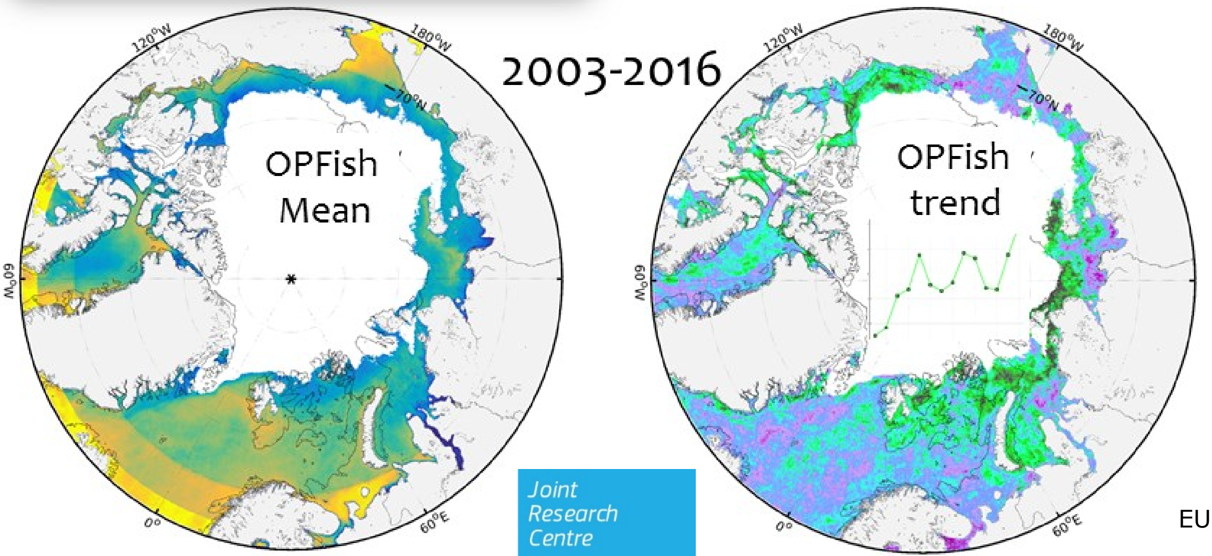
JRC SCIENCE FOR POLICY REPORT

Ocean Productivity index for Fish in the Arctic Ocean

Initial assessment of satellite-derived plankton-to-fish productive habitats

Druon Jean-Noël

2017



Joint Research Centre

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Abstract

The JRC explores the potentials of a satellite-derived index (the Ocean Productivity index for Fish - OPFish) at large scale to represent the production of high tropic level communities (fish) and its variability after currently observed climate change during the period 2003-2016 in the Arctic Ocean. The OPFish uses the daily detection of productive oceanic features (chlorophyll-a [CHL] fronts) from ocean colour satellite sensors at 1/24-degree resolution as a proxy for food availability to fish populations. These productive features, such as eddies or gyres, were shown to attract fish and top predators as they are active long enough (from weeks to months) to allow the development of mesozooplankton populations. Potentially eutrophic waters are excluded by removing high daily levels of surface chlorophyll-a contents (daily surface content above 10 mg CHL.m^{-3}).

The satellite monitoring of productive fronts associated with day length in the OPFish formulation provide insight on the overall capacity of the marine environment to sustain high trophic level communities. Time-series and trends of OPFish identify current climate change impacts on potential fish productivity, including seasonal deviations, which may affect fish growth and recruitment.

The annual climatology levels of OPFish between 2003 and 2016 were assessed setting zero value in months of permanent night (mostly from November to February) and monthly means of index values for periods of long-day duration (mostly from May to September) filtering out low coverage of CHL due to low-light levels, ice and clouds. The climatology of OPFish in the ice-free of the Arctic Ocean, an area mostly over the continental shelf and shelf-break, displayed lower levels and more uneven distribution than in temperate shelves (e.g. North-East Atlantic) with absolute values ranging from 20 to 50% compared to 45-55% respectively. The trends of OPFish on the 2003-2016 period showed about four-fold higher regional variability and levels in the Arctic compared to the North-East Atlantic shelf area. The general OPFish trend of the Arctic Ocean is the highest observed among the regional oceans, with +2.9% per decade (in absolute value) compared to +0.5% per decade for the global ocean. In relative change, this increase translates into +16% per decade in the Arctic compared to +2.1% per decade for the global ocean.

The OPFish is a plankton-to-fish index that represents the potential distribution of high trophic level (fish) productivity. Despite a necessary ongoing validation process using zooplankton and fisheries data in the Atlantic Ocean, the moderate absolute level of OPFish in the Arctic Ocean compared to temperate shelves and the substantial positive trend over 2003-2016 provide useful baseline information for future fisheries management. The high geographical disparities of level and trend of the potential fish productivity also emphasizes the necessity to take into account the spatial dimension when planing a sustainable exploitation of natural living resources.

Rationale

Information on the overall dynamics of marine ecosystems at large scale is scarce and especially in hostile environments such as the Artic Ocean. Satellite ocean colour may contribute to understand such dynamics through the identification of productive oceanic features and to provide insights on climate-driven changes in fish populations. The assessment of fish stocks is still nowadays suffering from large uncertainties since results of most stock assessment models depend exclusively on the quality of fisheries-related input data. Uncertainties are particularly large for short-lived exploited species (e.g. small pelagics) as their limited mobility make their recruitment and growth highly dependent on environmental conditions. Stocks of highly migratory species are also difficult to assess since their high mobility and opportunistic behaviour to explore new environments alter our knowledge of the population distribution. The environmental and spatial dimensions are therefore key aspects to understand the dynamics of many fish populations. The Arctic Ocean, bounded by the 66.6ºN latitude (Figure 1), is furthermore a hostile environment where sampling possibilities of fish populations are seasonally limited and were even more in the past decades due to the progressive retreat of the ice cover. Consequently, the Arctic Ocean has been so far very poorly exploited in terms of natural living resources and is the last relatively pristine and unknown ocean of the Earth.

Satellite remote sensing of ocean colour can help in filling these knowledge gaps by monitoring environmental-relevant features that describes the distribution of potential oceanic productivity available to fish at suitable time (daily to weekly) and spatial (1/24 degree) scales. Decadal time-series provide valuable indication on trends which is key information to evaluate the current impacts of climate change on the Arctic Ocean capacity to sustain high trophic level communities. The Ocean Productivity index for Fish (OPFish) represents a complementary and fisheries-independent source of information on the Arctic Ocean available for the necessary knowledge level that must be raised prior a sustainable exploitation of living resources could be foreseen.

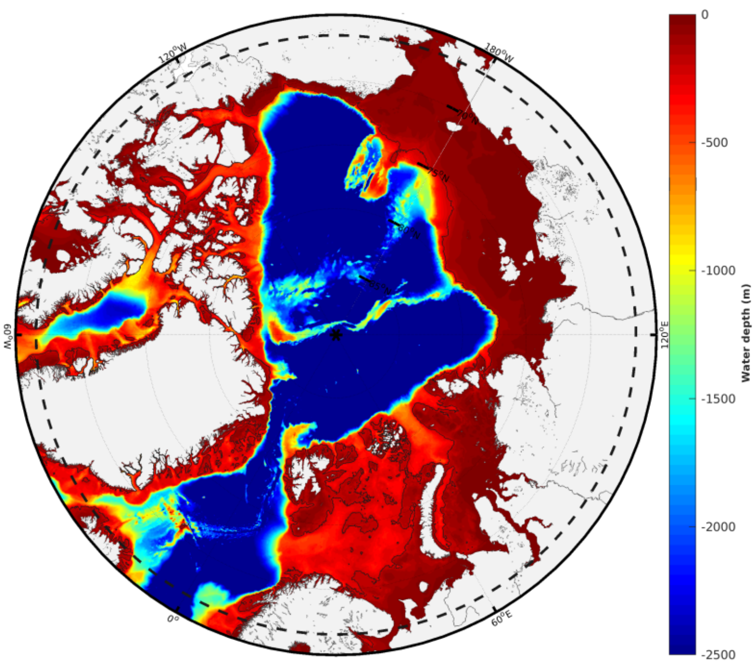


Figure 1 Bathymetry map of the Arctic Ocean (source GEBCO) bounded by the 66.6ºN latitude (dashed line). The 200 m depth contour is shown.

1 Methods

The present methodology compiles information on feeding preferences of marine species in various environments to derive a general index of ocean productivity accessible to high trophic levels (OPFish). This productivity index is then extrapolated into the Arctic Ocean where information on ecosystem dynamics is scarce. The ecological traits of key marine predators that are known to influence its presence in the environment were identified from the equatorial to sub-polar latitudes. Productive fronts were generally described to be the main driver for feeding of numerous marine species and a major vector of oceans' productivity along the food chain (Belkin et al., 2009; Kirby et al., 2000; Le Fèvre, 1986; Olson et al., 1994; Polovina et al., 2001). Tunas species such as albacore (*Thunnus alalunga*), Atlantic bluefin (*Thunnus thynnus*) and skipjack tuna (*Katsuwonus pelamis*) are known to generally aggregate in the vicinity of CHL fronts (Druon et al., 2016, 2017; Royer et al., 2004) and may even create ecological bridges for migration (Briscoe et al., 2017). Other predators at various trophic levels such as fin whales or demersal fish nurseries (European hake) were also shown to be influenced by CHL fronts as a common driver of nutrition (Druon et al., 2012, 2015; Fossi et al., 2017). CHL fronts are generally a mesoscale feature that persist long enough (i.e., weeks to months) to sustain zooplankton production and thus, to attract upper trophic level species (Figure 2). An on-going study is furthermore linking high abundances of mesozooplankton to these productive fronts (Druon et al. in prep.). The OPFish index is exclusively derived from satellite CHL data, however its calibration was performed using extensive observation data from key marine species grouped by main trophic levels (mesozooplankton, small pelagic fish, tunas, sharks and marine mammals).

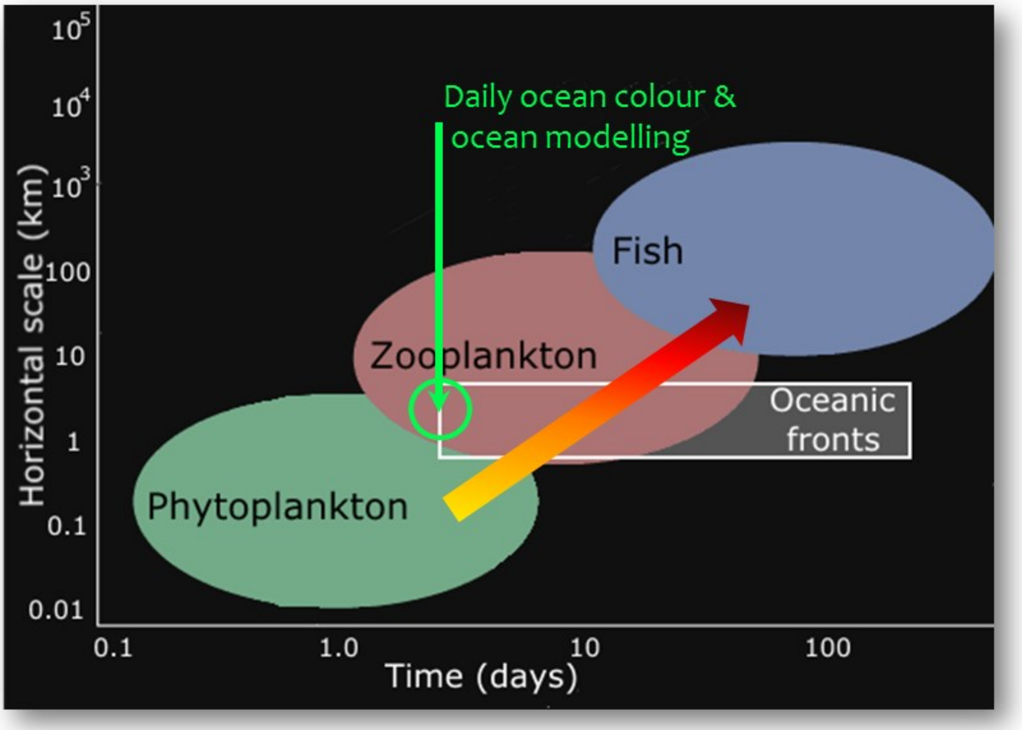


Figure 2 Time and horizontal scales associated to the dynamics of phytoplankton, zooplankton and fish. Scales of oceanic fronts allow an efficient transfer of the organic matter from plankton to fish and ocean colour sensors are suitable observation means to daily track productive fronts.

1.1 Data

1.1.1 Satellite chlorophyll-a content

Daily surface chlorophyll-a content (CHL, $mg.m^{-3}$) were obtained from MODIS-Aqua (2003 - 2016; 1/24° resolution) ocean colour sensor using the OCI algorithm (Hu et al., 2012). This product was extracted from the NASA portal (https://oceancolor.gsfc.nasa.gov/cgi/l3). CHL daily data in the Arctic at 1 km resolution from Marine Copernicus could not be used since multi-sensor data, if useful for increasing CHL coverage, is not suitable for front computation. The current methodology for habitat identification and OPFish index requires a sensor-specific calibration which takes into account the sensor optical characteristics to quantify CHL and the data spatial resolution. Once each satellite sensor is calibrated, daily habitat or OPFish can be derived for each sensor and merged habitat or OPFish can be performed for a greater spatial coverage.

Mesoscale CHL fronts were in this study identified using only daily MODIS-Aqua data. This CHL data were pre-processed using iterations of a median filter in order to recover missing data on the edge of the valid data, followed by a Gaussian smoothing procedure (see Druon et al., 2012 for details). CHL gradients were computed using a bidirectional horizontal gradient calculation within a window of 3-by-3 grid cells (Canny filter). CHL fronts were identified for CHL gradient values above a minimum threshold (see below).

1.1.2 Observations of key marine species

The generic ocean productivity index for fish results of a compilation of species-specific habitat studies covering various compartments of the ecosystem (zooplankton, small pelagics, tuna species, sharks and marine mammals). The presence-only or abundance-only data from these studies were used to define species-specific favourable habitat for feeding (Table 1). Preferences for CHL range and CHL fronts were identified for each species (Figure 3) using cluster analyses (see publications in Table 2 for details). The preference of a species for particular CHL fronts was formulated using a continuous function linking the horizontal CHL gradient to a daily habitat value from 0 to 1 (see orange line segments as an example for fin whale in Figure 4A). This formulation translates a value of CHL gradient in log scale into a daily habitat quality for feeding taking as a slope the maximum slope of the cumulative distribution function. This slope identifies the range of CHL gradient for which a species is sensitive.

Table 1. Characteristics of the observations (presence-only or abundance-only) by species used to derive the generic Ocean Productivity index for Fish from July 2002 to 2017 (MODIS-Aqua).

Species (eventually by size class or sex)	**Observation type**	**Area covered**	**Number of available observations**	**Publication**	**75th percentile distance (km) to favourable habitat (number of observations with suitable CHL coverage)***
Mesozooplankton	abundance > 0	North Atlantic	24,847	In preparation	-
Sardine	abundance above third quartile	Mediterranean Sea	6,500	Unpublished	-
Anchovy	abundance above third quartile	Mediterranean Sea	8,719	Unpublished	-
Hake nurseries (hake below 15 cm total length)	Abundance above third quartile	Mediterranean Sea	7,579	Druon et al., 2015	1 km *(n=178)*
Skipjack tuna	Presence-only	Central eastern Atlantic (AO) and western Indian Oceans (IO)	110,486	Druon et al., 2017	Sets on free-swimming schools: 90 km-AO / 5 km-IO *(n=7,110/4,304)* Sets on fishing aggregating devices: 200 km-AO / 22 km-IO *(n=3,455/26,958)*
Atlantic bluefin tuna (juveniles and adults)	presence-only	Gulf of Mexico, North Atlantic, Mediterranean Sea	26,184	Druon et al., 2016	Juvenile/adult feeding: 0.7 km/6.5 km *(n=952/6,270)* Spawning: 13.9 km *(n=582)*
Blue shark (juveniles, adult males and females)	presence-only	Mediterranean Sea, Atlantic and Indian Oceans	2,426	In preparation	-
Fin whale	presence-only	West Mediterranean Sea	3,039	Druon et al., 2012, Fossi et al., 2017	4 km *(n=1,505)*

* *Distance (km) for which 75% of observations are closer to favourable habitat (and corresponding number of observations with suitable habitat coverage).*

1.2 OPFish computation

Data on CHL fronts obtained from species preference were grouped by main trophic levels (mesozooplankton, small pelagics, tuna species, demersal nurseries, sharks, mammals) in order to identify, for the MODIS-Aqua sensor, an objective distribution of preferred CHL fronts among all groups (Figure 4B).

In addition to the horizontal gradient of CHL, the OPFish index includes a preferred CHL content (weight value of 0 or 1) that refers to the minimum and maximum preferred CHL levels among the studied species, i.e. 0.08 $mg.m^{-3}$ for mesozooplankton and blue shark and 10.04 $mg.m^{-3}$ for mesozooplankton respectively (Figure 3). This upper level of CHL content aims at excluding potentially eutrophic waters from the daily OPFish. This value corresponds to the upper CHL limit for all studied species, i.e. to the percentile 99.1^{th} of the mesozooplankton abundances and 99.7^{th} of all species.

Daily value of OPFish was defined in each grid cell from:

- the horizontal gradient of CHL (values from 0 to 1 as above),
- an overall preferred range of CHL content (weight of 0 or 1) and
- a relative day length duration (weight from 0 to 1 values) derived from date and latitude.

The OPFish index has daily values from 0 to 1 following the equation:

$$\mathrm{O}PFish_{0\ to\ 1} = gradCHL_{linear\ function_{0\ to\ 1}} * CHL_{min/max_{0\ or\ 1}} * \frac{\mathrm{DayLength}}{24}_{0\ to\ 1}$$

The OPFish index is therefore bounded, at its lower limit, by a minimum CHL gradient that defines a minimum size of influential productive front and by a minimum CHL content and, at its upper limit, by a maximum CHL content (Figure 3) while being weighted by day length. The OPFish index relates to a notion of productivity as extreme differences of duration of day light exist between seasons and from the equator to the poles. Day length was preferred to the Photosynthetically Available Radiation (PAR) for estimating light limitation because PAR is even less available than CHL at high latitudes (no PAR data above 65ºN from October to February) and because phytoplankton cells tend to adapt their CHL content to the available light so that the effective duration of day light is likely to be more determinant for near surface productivity than the corresponding light energy.

Subsurface productivity was not presently accounted for because these deeper environments are considered to be a substantially lower source of potential nutrition for the food chain compared to surface productive fronts following the exponential decrease of light with increasing depth. Deep CHL maximum are however considered to be of upmost qualitative importance to maintain basic level of biological activity and restart plankton productivity after a long period of stratification. Furthermore, subsurface productivity plays a major role in the oligotrophic environments where permanent stratification occurs. Because this satellite-based methodology does not detect subsurface productivity, the OPFish index slightly underestimates productivity levels of oligotrophic environments, i.e.

near null values of OPFish. However, low-CHL productive fronts (low CHL gradient values) in oligotrophic environments are detected.

Consequently, the present index focuses on marine hotspots from oligotrophic to eutrophic environments where primary productivity occurs near the sea surface as a result of a frontal activity. The OPFish index also highlights areas where light is mostly not a limiting factor during day time and neither nutrient since productive fronts correspond to resurgences of deeper waters. In near permanent-night periods where day light is limiting near the surface (e.g. in March, Figure A. 1), phytoplankton may increase their CHL content and, if the low-light level allows the ocean colour detection, the OPFish will detect the frontal activity but the daily index value may be overestimated.

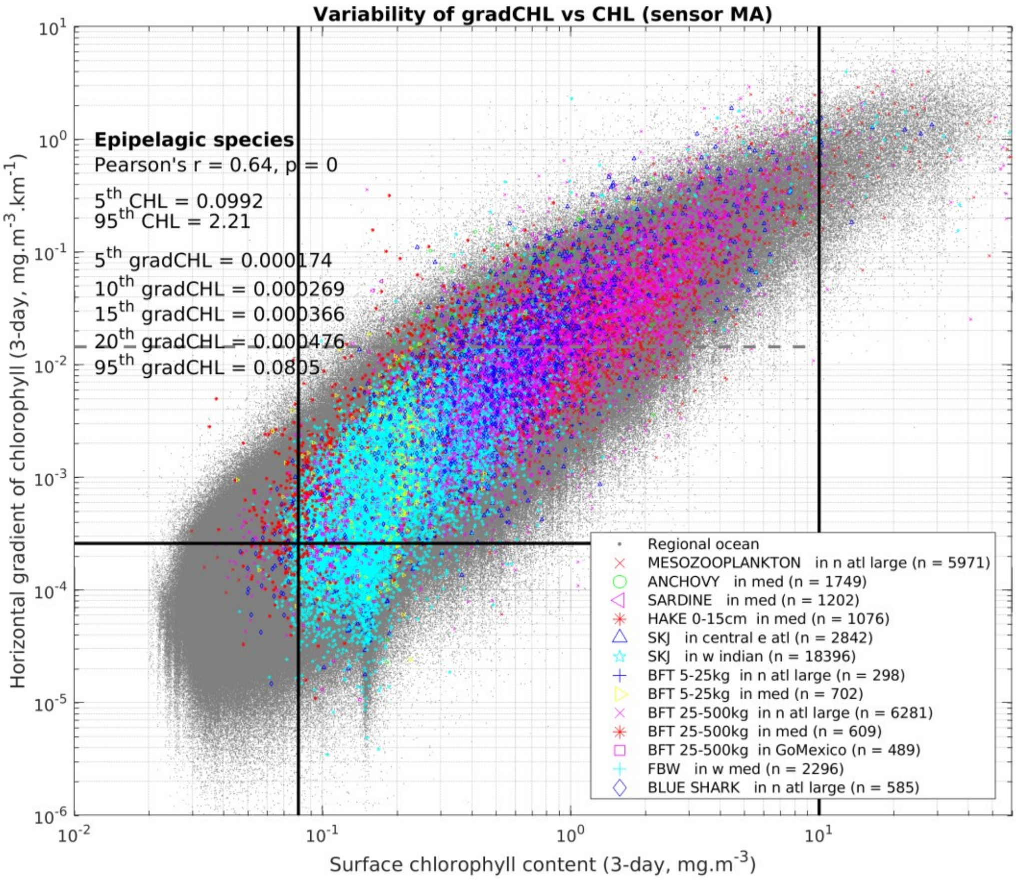
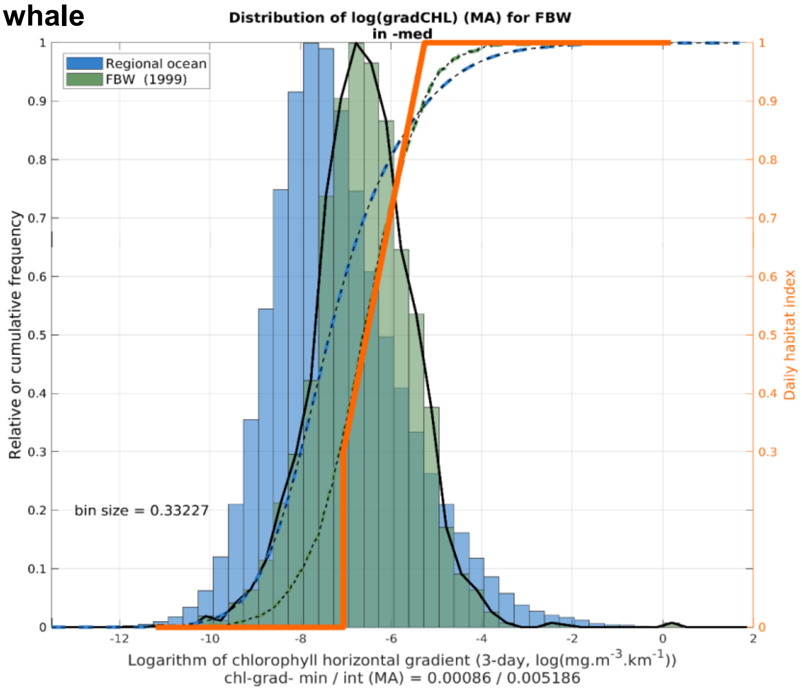


Figure 3 *Scatter plot of the horizontal gradient of chlorophyll-a (gradCHL) vs chlorophyll-a content (CHL) for the regional ocean (Mediterranean Sea, Atlantic and West Indian Oceans, grey dots) and for the different studied species. The black lines correspond to the minimum and maximum CHL levels and the minimum gradCHL value used in the ocean productivity index for fish (OPFish) while the grey dashed line is the intermediate value of gradCHL above which OPFish has a value of 1 (see also Figure 4).*

Cloud coverage, that hampers the detection of CHL, is variable by region and season (winter *vs* summer). Monthly maps of OPFish were thus computed using the frequency of occurrence of daily index, i.e. the number of effective daily identifications by grid cell over the corresponding month weighted by the daily index value. Longer time composite products were computed using monthly means in order to overcome eventual seasonal disparities of cloud coverage providing the same weight for each month when possible. A daily value of zero is attributed to the OPFish index when day length value is zero independently of CHL data and cloud coverage.

A) Fin whale



B) OPFish

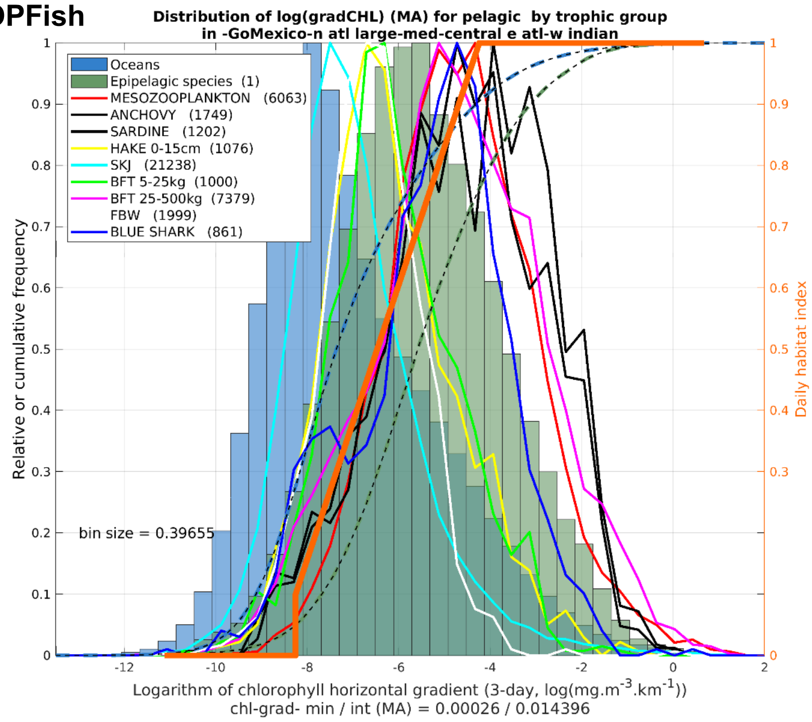


Figure 4 *Definition of the daily favourable feeding habitat (orange line segments) for fin whale (A) and for the Ocean Productivity index for Fish (B) taking into account the characteristics by main trophic group (mesozooplankton, small pelagics, tuna species, demersal nurseries, sharks and mammals) based on the distribution of horizontal chlorophyll-a gradients (green histogram) at the species' locations. These chlorophyll-a gradients represent small and large productive surface front features, as detected by MODIS-Aqua sensor. The cumulative frequencies and distributions of horizontal chlorophyll-a gradients in the regional Oceans (blue dashed line and blue histogram) are also plotted for comparison. The min. chlorophyll-a gradients values that defined a daily habitat value of zero (lower value of the orange line segments) corresponds to the percentile 5th of all species observations reconstructed by group, while the slope between the zero and one values was defined by the maximum slope of the cumulative distribution (green dashed line).*

2 Results – OPFish in the Arctic

2.1 Seasonal characteristics

The Arctic Ocean is highly seasonal with the near-absence of day light in Autumn and Winter and the near-permanence of day light in Spring and Summer (Figure 5 and Figure 6). As a result, the ice-free waters of the Arctic Ocean are very contrasted in terms of productivity for fish between the two main seasons from April to September (Figure 6 A-B) and from October to March (Figure 6 C-D). Peak of OPFish levels are reached in June with about 80% of sea area associated with productive fronts (Figure 5). Blank areas in Figure 6 C-D from October to March (above about 80ºN) correspond to areas where daily CHL was undetected for the entire mission of MODIS-Aqua (from July 2002 to September 2017). This area therefore likely corresponds to the permanent ice cover during that period and not to the actual ice cover during cold months. The blank areas during warm months (Figure 6 A-B) correspond to the low availability of OPFish (below 1%) due to low-light preventing CHL detection or to cloud or ice cover.

Maximum levels of OPFish values (above 75% of occurrence of productive fronts) occurred in Spring at about 70-75ºN except from 20ºE to 60ºW where values are in the range from 50 to 75%. Maximum values in summer mostly occur from 75 to 80ºN and from 0 to 150ºE except in the area from 30 to 65ºE.

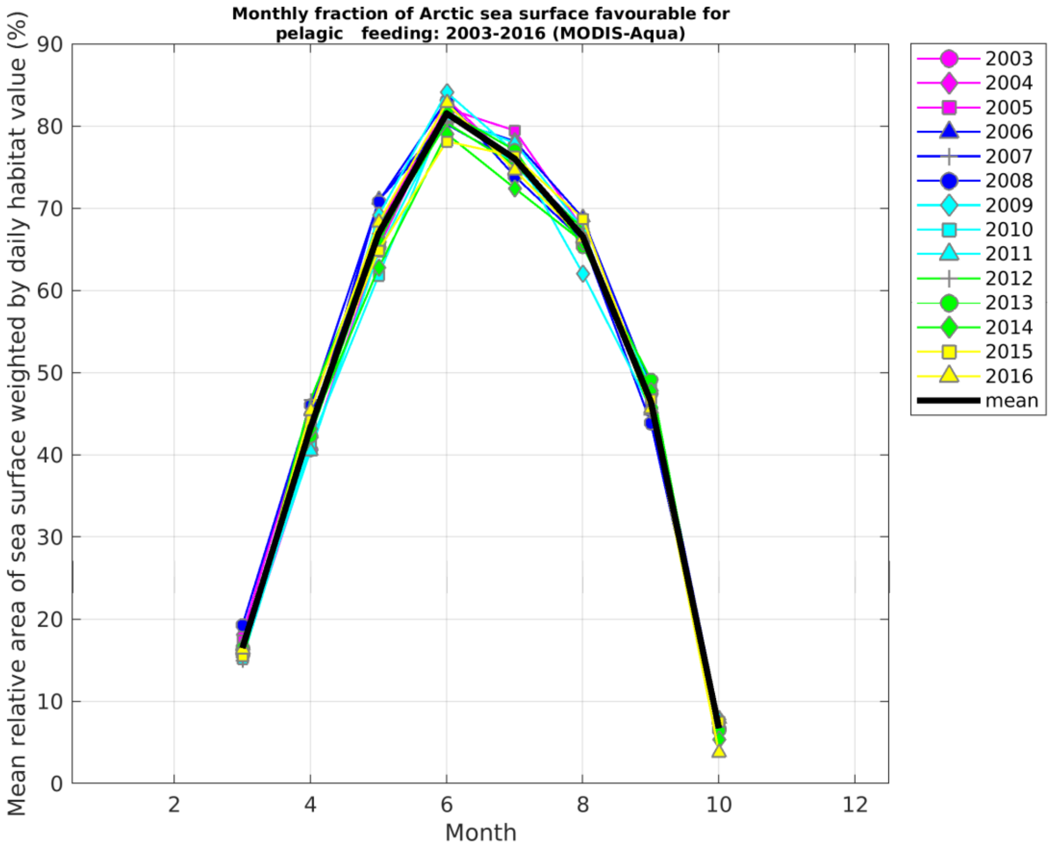


Figure 5 Monthly size indices of Ocean Productivity index for Fish (OPFish) for the 2003-2016 period. Value of OPFish from November to February is zero due to the absence of day light.

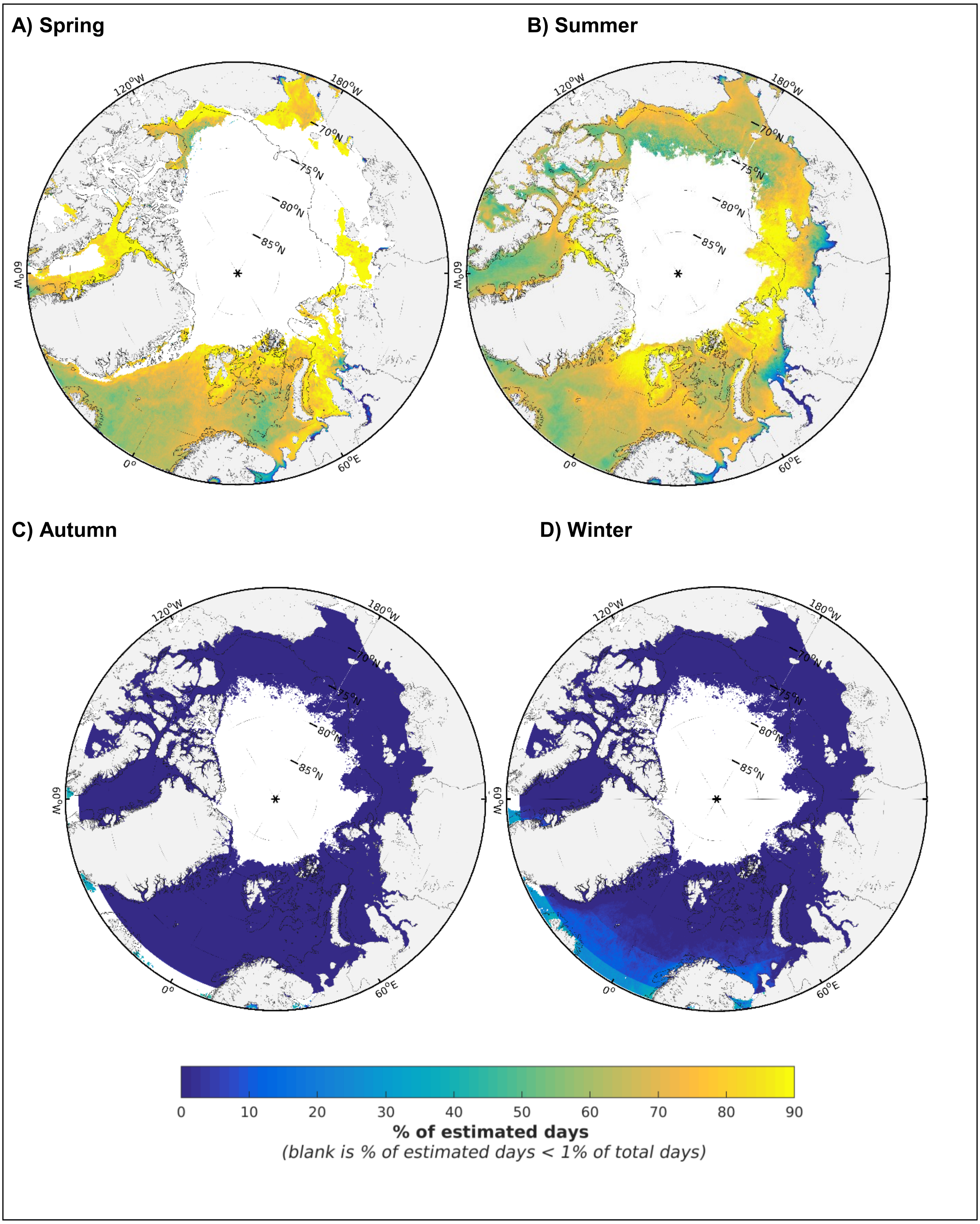


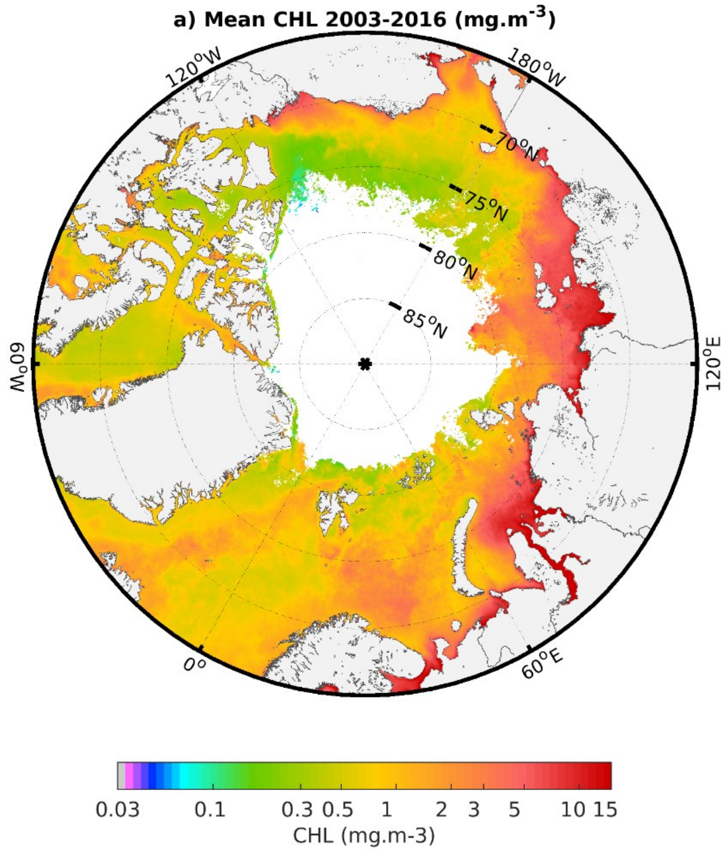
Figure 6 Ocean Productivity index for Fish (OPFish) for the 2003-2016 period *(*A) from April to June, (B) from July to September, (C) from October to December and (D) from January to March. High OPFish values represent a high frequency of occurrence of large productive fronts. The blank areas correspond to sea ice cover or index occurrence below 1% of the total number of days in the considered time period.

2.2 OPFish annual climatology over 2003-2016

The extreme seasonal conditions of day length, sun light and cloud cover resulted in highly variable CHL coverage which was overcome by an additional filtering for the computation of the annual climatology of OPFish. Grid cells where CHL coverage was lower than 1% (see Figure 7 B: North of 72ºN towards 180ºW and North of 82ºN towards 60ºE) were filtered out to compute the annual climatology of OPFish to avoid spatial inconsistency. Temporal consistency was reinforced by using monthly means of OPFish in the annual climatology composite. An example of spatial and temporal inconsistency is shown in Figure 7 A where the CHL annual climatology computed from daily data over-represents summer concentrations, and especially at high latitudes, due to extreme seasonal conditions of day length and cloud cover (see in Figure 7 A especially where CHL coverage is below 1% in Figure 7 B).

OPFish is far more defined than CHL during cold months since permanent night areas were set to zero value when day length has a zero value. This means that no potential fish productivity is attributed when day light is unavailable. Low OPFish coverage due to high cloud cover (low CHL cover) was overcome using a minimum threshold of 1% for both the index and CHL coverage (for spatial consistency) and using monthly mean in the annual climatology computation (for temporal consistency). The use of monthly means to compute the annual climatology of OPFish explains the discontinuities at sub-polar latitudes (one per month for January and February, Figure 8 and Figure A. 1). The low coverage of CHL (most areas are from 1 to 10%, Figure 7 B) should not hamper the detection of the mean OPFish levels because the monthly mean index is defined most of the year, i.e. except during about three months of night-day transition. For instance, the OPFish values of about 20-30% between 70ºN and 73ºN result of monthly values from May-June to September and from November to February (see monthly climatology in Figure A. 1) which provides a fair level of seasonal information.

The annual climatology of OPFish in the Arctic Ocean (2003-2016) shows decreasing levels from sub-polar latitudes to poleward (from about 50-70% to 20-40% frequency of occurrence, Figure 8). Because the daily index takes day length into account, OPFish is a productivity-related index and the annual climatology links to the overall potential fish productivity.



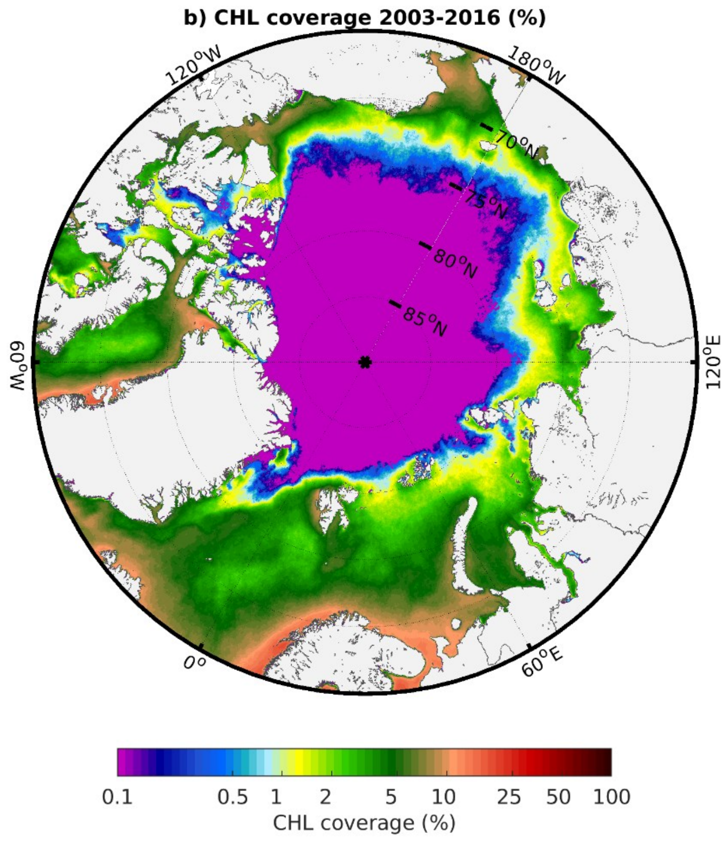


Figure 7 Annual climatology (2003-2016) of surface chlorophyll-a data (CHL) A) surface content (mg.m^{-3}) and B) coverage (%) in the Arctic Ocean derived from daily data (MODIS-Aqua sensor). Note the area with chlorophyll-a concentrations (CHL) coverage below 1% which is filtered out from the OPFish annual climatology on **Figure 8**.

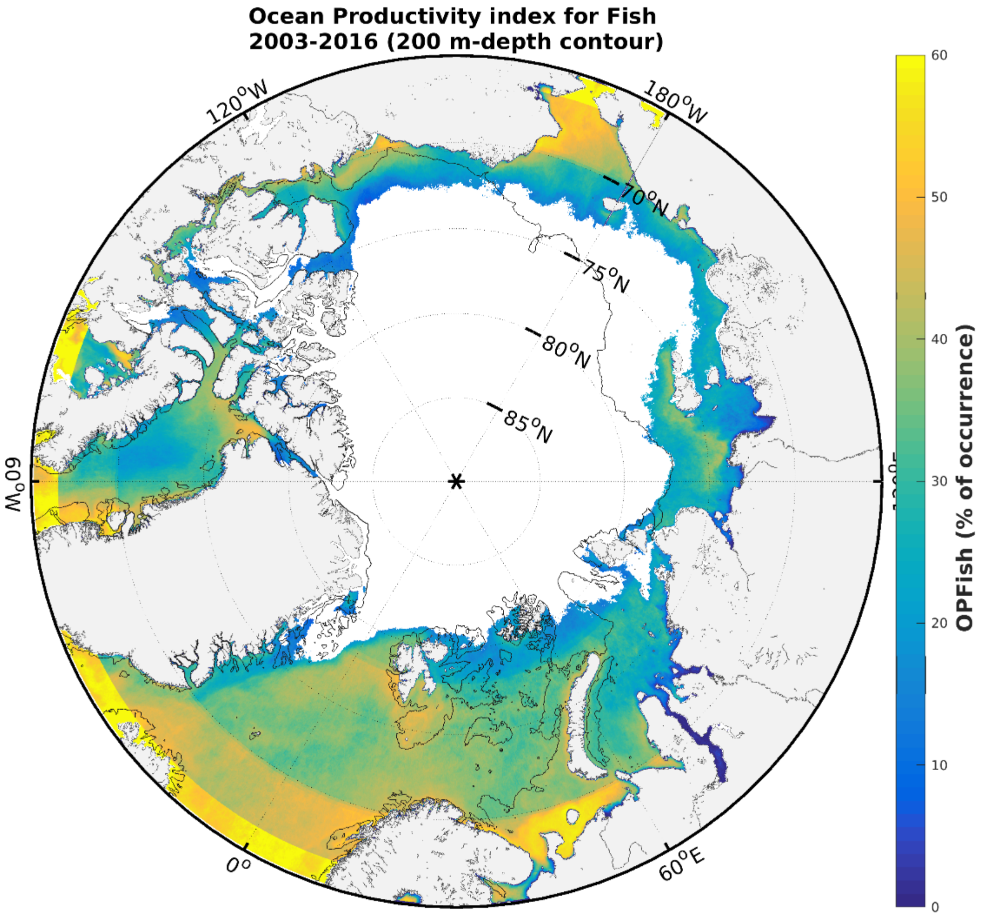


Figure 8 Ocean Productivity index for Fish (OPFish) for the 2003-2016 period computed from monthly means. High OPFish values represent a high frequency of occurrence of large productive fronts. Latitudinal discontinuities result from the use of monthly means (**Figure A. 1**) to derive the annual climatology (see text for details). The blank areas correspond to sea ice cover, or to index or chlorophyll-a concentrations (CHL) occurrence below 1% of the total number of days in the considered time period.

2.3 Trend of OPFish over 2003-2016

The trend map of OPFish over 2003-2016 was processed using a linear trend based on monthly means of each grid cell independently of one another. Note that showed trends are absolute changes, the OPFish index being expressed in percentage of daily occurrence of productive fronts (%). Relative change of OPFish over the time-series have substantially higher levels.

Regional variability of absolute trend is high from above +17% per decade to about -12% per decade (Figure 9). The mean absolute trend of OPFish in the Arctic Ocean is +2.9% per decade, which is about six-fold the observed global ocean trend (+0.5%, result not shown). This positive trend appears to be consistent over the period 2003-2016 with however relatively low levels in 2008-2010 and 2013-2014 and high levels in 2007 and 2011-2012 (Figure 10). This increase of productive front occurrence corresponds, in terms of ocean surface area, from about 20% of year-round ice-free waters of the Arctic Ocean in 2003 to about 25% in 2015-2016 (Figure 10 left). This absolute OPFish increase over the period 2003-2016 matches the increase in relative values of about +16% per decade (Figure 10 right). A fraction of this overall increase of OPFish over the 2003-2016 period could be linked to the increase surface of free-water, however the comparison of summer

2003-2005 with 2014-2016 (Figure 11) shows that most of recent free-water areas correspond to relatively low OPFish levels (between 130ºW and 160ºE).

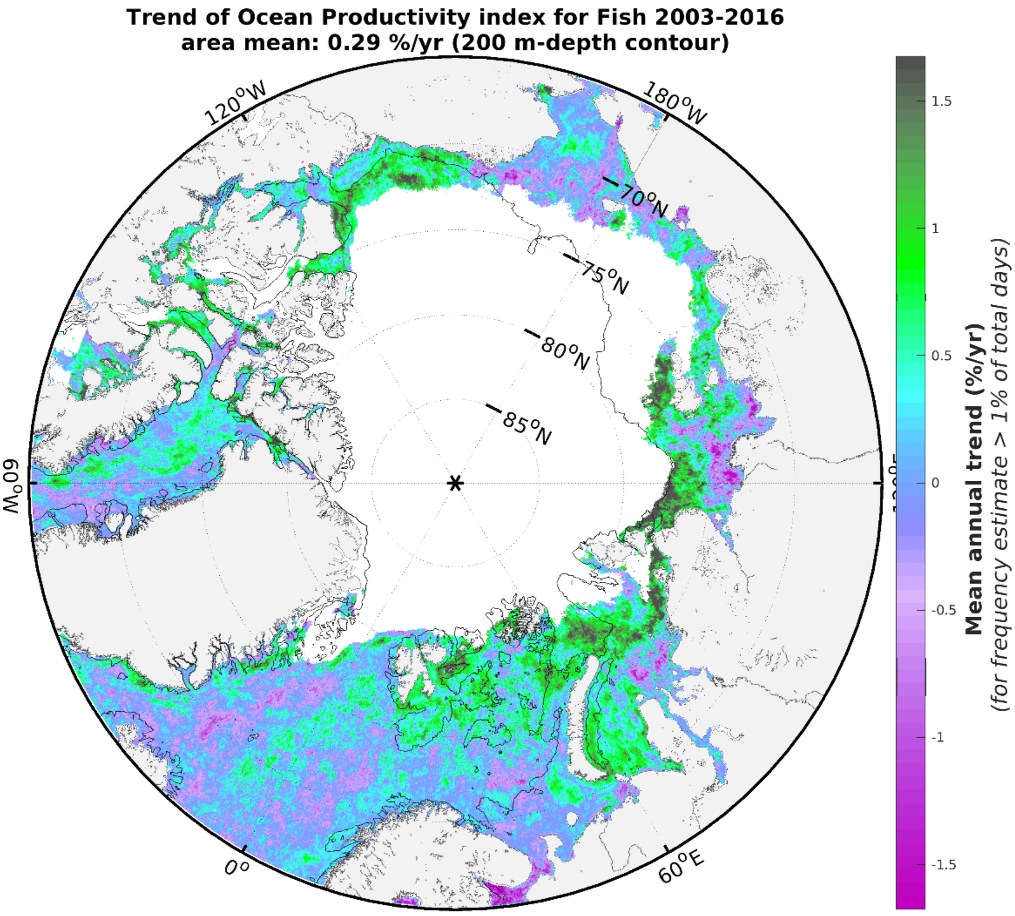
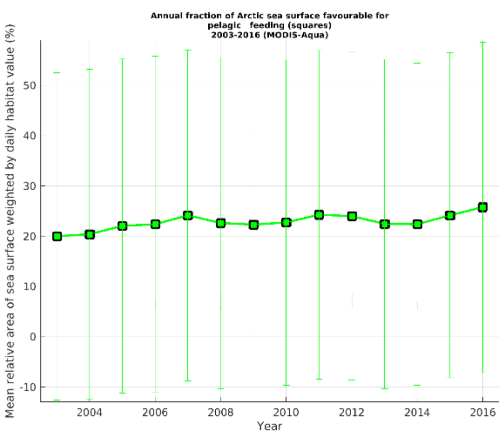


Figure 9 Trend of Ocean Productivity index for Fish (OPFish) for the 2003-2016 period computed from monthly means. Positive trends (green) represent an observed increase frequency of occurrence of productive fronts. The mean absolute trend of OPFish in the Arctic Ocean is +2.9% per decade. The blank areas correspond to sea ice cover, or to index or CHL occurrence below 1% of the total number of days in the considered time period.



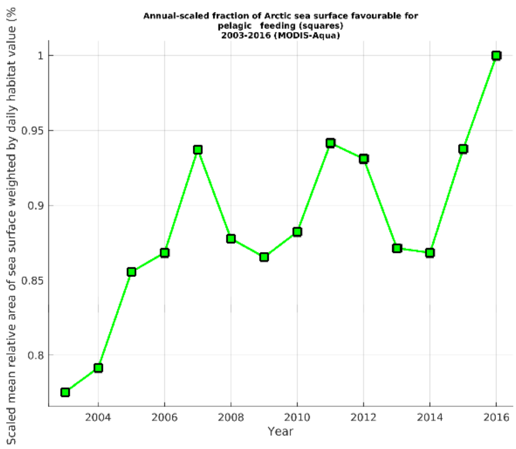


Figure 10 Annual size indices of Ocean Productivity index for Fish (OPFish) for the 2003-2016 period in absolute values (left) and scaled to the maximum values in the time-series (right). Absolute trend levels are of +2.9% per decade which corresponds to about +16% per decade in relative values.

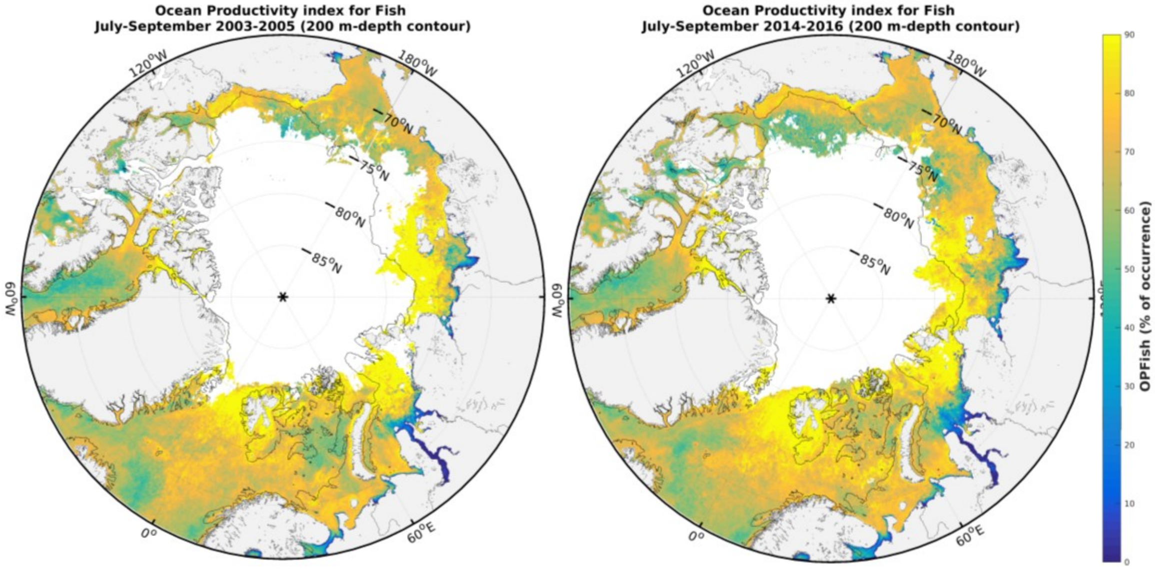


Figure 11 Map of Ocean Productivity index for Fish (OPFish) for July-September 2003-2005 (left) and 2014-2016 (right). The change in minimum ice cover between these summer periods is likely represented by changes of the central blank areas (less than 1% detection over the three-month period).

3 Conclusion

The Arctic Ocean is a hostile and relatively unknown environment. Further knowledge on the dynamics of this last relatively pristine ocean must be acquired as ice-free waters are expanding and before fishing activities could potentially be developed. Despite its highly seasonal character due to permanent night or day and a relatively high cloud cover, optical satellite sensors provide useful and consistent information on marine productivity through the daily identification of CHL fronts on which the Ocean Productivity index for Fish is based. Because the OPFish takes into account the day length and hotspots of potential productivity available to high trophic levels (CHL fronts), the annual climatology composite provides insights on the potential fish biomass. This analysis is however preliminary and further validation of OPFish using fisheries and zooplankton data are ongoing in the North Atlantic area.

The ice-free Arctic Ocean is mostly composed of relatively shallow waters with about half of its surface above 200 m water depth and 70% above 500 m. The usual high productivity levels of shelves and shelf-break areas is however moderated by the extreme seasonality of light availability for primary production with several months of permanent night and day. The OPFish values in the Arctic show relatively lower levels (from about 20 to 50%, Figure 8) and larger regional disparities compared to sub-Arctic and temperate shelf areas (e.g. in the North-East Atlantic shelf with 45 to 55%, result not shown), so that the expected fish biomass in the Arctic Ocean is likely to be lower than on temperate continental shelves.

In terms of trends however, the Arctic continental shelves show about four-fold higher regional variability (absolute OPFish changes from -12% to +17% per decade) compared to temperate shelves in the North-East Atlantic (absolute changes from -3% to +4% per decade, not shown). The overall positive trend of OPFish in the Arctic during 2003-2016 period (absolute change of +2.9% per decade and relative change of +16% increase per decade) is several fold higher compared to the global ocean (absolute OPFish change of +0.5% per decade and relative change of +2.1% increase per decade, result not shown). Likely under the effect of warming after climate change, oceans appear to be generally more dynamic favouring the resurgence of nutrient-rich waters within frontal systems. The drivers of this increased hydrodynamics could be unusual wind events and increased evaporation or precipitation which may affect the thermo-haline circulation. The Arctic is the regional ocean that records the highest positive trend of OPFish as a result of satellite observation over the period 2003-2016.

Even if the OPFish index requires further validation, the overall observed positive trend of the index and related frequency of productive fronts already provides a first reliable tendency of the effect of climate change on the ocean productivity available to high trophic levels. The distribution of this positive trend is however spatially very uneven so that regional tendencies should be carefully analysed for suitable management.

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Review

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Annex

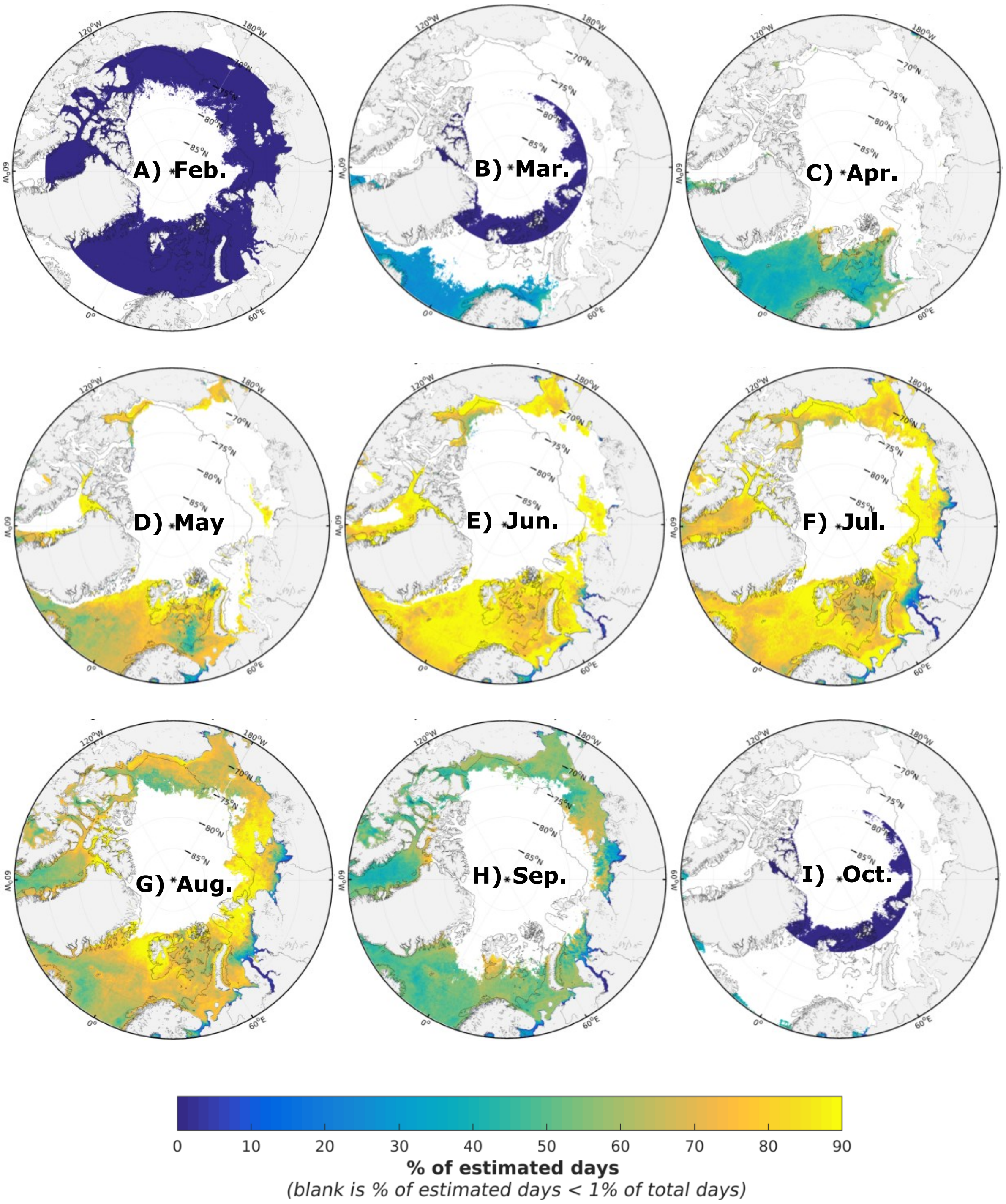

Figure A. 1 Monthly climatology of Ocean Productivity index for Fish (OPFish) for the 2003-2016 period from February to October (A-I). November OPFish map is equal to February and January and December maps are equal showing zero values down to about 66ºN. High OPFish values represent a high frequency of occurrence of large productive fronts. Zero values represent permanent night months of chlorophyll-a concentrations (CHL) permanently above 10 $mg.m^{-3}$.The blank areas correspond to sea ice cover, or to index occurrence below 1% of the total number of days in the considered time period.

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