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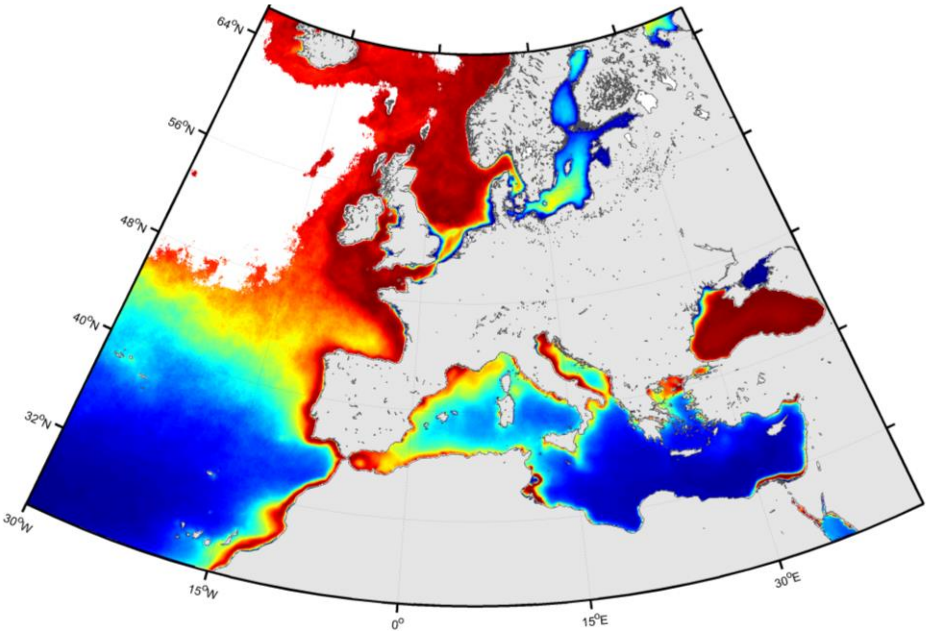
Monitoring pelagic habitats to support future EU Policies

Strategic view on how the daily monitoring of marine water-column habitats will support the future EU Integrated Maritime Policy (MSP, CFP, MSFD) to stimulate ecosystem health and blue growth.*

* *Maritime Spatial Planning, Common Fisheries Policy, Marine Strategy Framework Directive*.

Jean-Noël Druon

2014



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Content

Rationale

The marine area is increasingly perceived as a space that is capable of supporting important economic growth in the near future provided that the system is properly managed. The blue economy spans from transport and energy to the exploitation of natural resources. Fishery is a key sector of the maritime domain that relates to food security, cultural heritage and regional social cohesion. In waters deeper than ca. 30 m, exploited near-seabed and pelagic species strongly depend on the pelagic primary productivity, i.e. the production of organic matter by micro-algae in surface waters. While sea bed habitats have recently had the attention of research activities and have been mapped at least partially at European scale (EMODnet: http://www.emodnet-hydrography.eu/), pelagic habitats are still largely unknown mostly due to their high variability in time and space. When assessing fish stocks, fisheries science traditionally relies on population dynamics (variability of size and age classes) with little if any consideration of the spatial and environmental dimensions of the stocks. Understanding spatial patterns in population dynamics is however a necessary prerequisite to protect critical habitats and in ensuring sustainable management of fishery resources (Caddy & Carocci 1999, Berkeley et al. 2004). The development of Earth Observing Systems on marine productivity and advances in the physical ocean modeling (i.e Myocean project, www.myocean.eu) nowadays allow the monitoring of pelagic habitats. Such monitoring can be used to introduce the spatial and environmental dimensions of exploited stocks in fisheries science and management, both of which are a requirement of EU marine policies.

Maritime Spatial Planning, as a pillar of the EU Integrated Maritime Policy, is commonly understood as a public process for analysing and planning the spatial and temporal distribution of human activities in sea areas to achieve economic, environmental and social objectives (COM(2013) 133 final). Therefore as for any other maritime sector, appropriate spatial management of the European fisheries sector will need to be implemented to optimize blue growth and to safeguard both the fishing industry and ecosystems status. The spatial dimension has been progressively introduced in other parts of the world, notably by the U.S. Regional Fishery Management Councils which have decades of knowledge and experience in coastal and marine spatial planning (http://www.fisherycouncils.org/MSPFlier.pdf).

U.S. Regional Fishery Management Councils:
As the need for seafood grows, so do competing uses of the ocean such as marine aquaculture and ocean energy, and the future of marine spatial planning will play a pivotal role in maintaining and improving stewardship of the oceans.
The U.S. Regional Fishery Management Councils use sound science and are implementing ecosystem-based management to reduce conflicts among uses, and preserve critical ecosystem services to meet economic and social objectives.

Spatial management of fisheries is required because current fishing practices affect marine resources in differing ways. For example, demersal trawling that severely impacts the sea bed habitats can change the structure, composition, diversity and productivity of biota (Jennings & Kaiser 1998). Size selective fishing can affect the resilience and the sustainability of fish species by reducing their average size, their size at age and their genetic diversity (Botsford et al. 1997). But the environment also strongly impacts the ecosystem. The availability of prey species has a direct effect on recruitment. Annual changes in weather and events at the spatial scale of individual fish during critical larval and juvenile stages can have major implications on the structure and biological productivity of many stocks (Curtin & Prellezo 2010). In addition, regime shifts of the environment including climate change are now accepted as occurring at decadal time spans which can lead to shifts in the structure of whole ecosystems (e.g. Abella et al. 2008, Coma et al. 2009, D'Onghia et al. 2012).

The daily monitoring of our seas and the characterization of pelagic habitats are therefore medium-term key areas of research that could substantially improve our knowledge on fish population dynamics in support of EU marine policies and particularly within the Horizon 2020 Program for research and innovation. Horizon 2020 will provide strong support to the Integrated Maritime Policy, as well as the priorities of the EU's initiatives for the Atlantic Strategy and Blue Growth.

Classification of pelagic habitats: fill the gaps of knowledge

Pelagic habitats refer to an ecological area of the surface water-column and, specifically hereafter, to species-specific water depths, e.g. the upper 50 m for the Atlantic bluefin tuna or the water column for depths in the range 30-350 m for hake nurseries. Pelagic habitats are characterized here by biotic factors (chlorophyll fronts and chlorophyll content), seen as a proxy for marine productivity, and abiotic factors (temperature, current velocity) which are perceived as physical tolerance limits of the species under study.

For the oceanic waters of the Mediterranean Sea, a general classification of pelagic habitats based on surface chlorophyll levels was selected following a proposal from the JRC (see Report UNEP/MAP 2013). Such a classification emphasizes the importance of productivity in describing marine ecosystems and of food availability as key element in characterizing pelagic ecosystems prior to chemical and physical components. Indeed, only specific assemblages of chemical and physical conditions will generate phytoplankton productivity in the surface ocean.

Two types of pelagic habitats can be derived considering that productive oceanic features (chlorophyll fronts) are the main vectors of the oceans' productivity along the food chain (Le Fèvre 1986, Olson et al. 1994, Kirby et al. 2000, Polovina et al. 2001, e.g. Belkin et al. 2009, Druon et al. 2011, 2012): pelagic habitats related to general ecosystem productivity and those related to a specific species. Figure 1 shows on one hand an example of European productive ecosystems where the absence or excess of productivity (eutrophication) are both limiting factors of an healthy food chain, and, on the other hand, the favourable Mediterranean feeding grounds for the Atlantic bluefin tuna (Figure 2) and hake recruits (Figure 3). These maps are derived from daily chlorophyll-a content and front identification and by the ecological niche occupied by each species which is derived by particular preference or tolerance to productivity levels and hydrological characteristics.

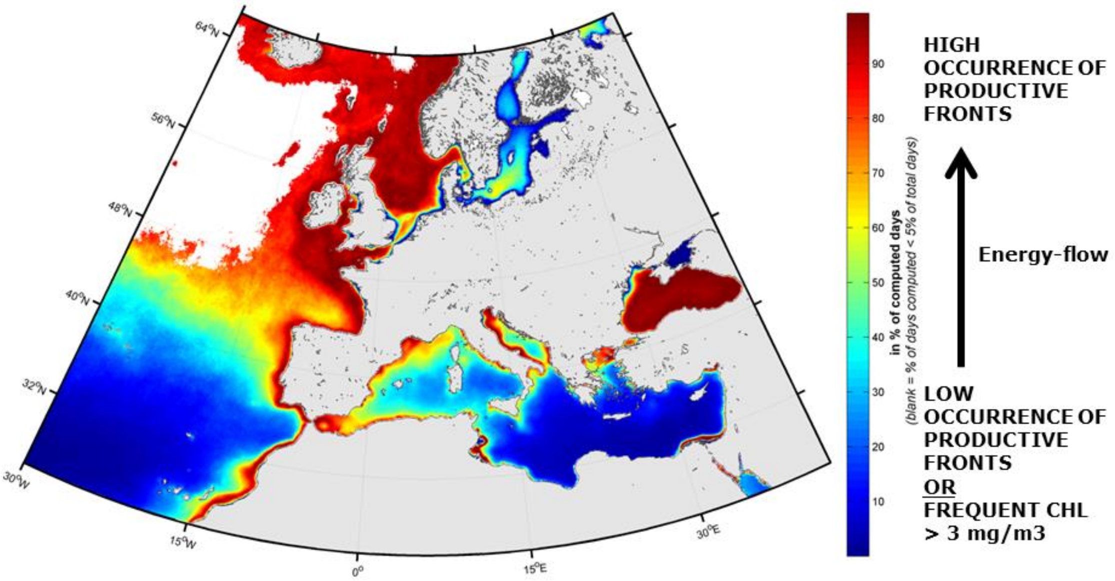

Figure 1 *Productive oceans: occurrence of favourable pelagic habitat for feeding (1998-2013) derived from the daily identification of chlorophyll-a fronts and maximum level of chlorophyll-a content and excluding potentially eutrophicated areas derived from SeaWiFS (1998-2010) and MODIS-Aqua (2002-2013) sensors.*

The used thresholds defines two levels of productive habitats – a low level (daily value of 0.3) and high level (daily value of 1):
Low daily productivity (MODIS-Aqua):CHL gradient > 0.36 10^{-3} $mg.m^{-3}.km^{-1}$ and 0.10 < CHL content < 0.23 $mg.m^{-3}$
High daily productivity (MODIS-Aqua): CHL gradient > 2.95 10^{-3} $mg.m^{-3}.km^{-1}$ and 0.23 < CHL content < 3.0 $mg.m^{-3}$

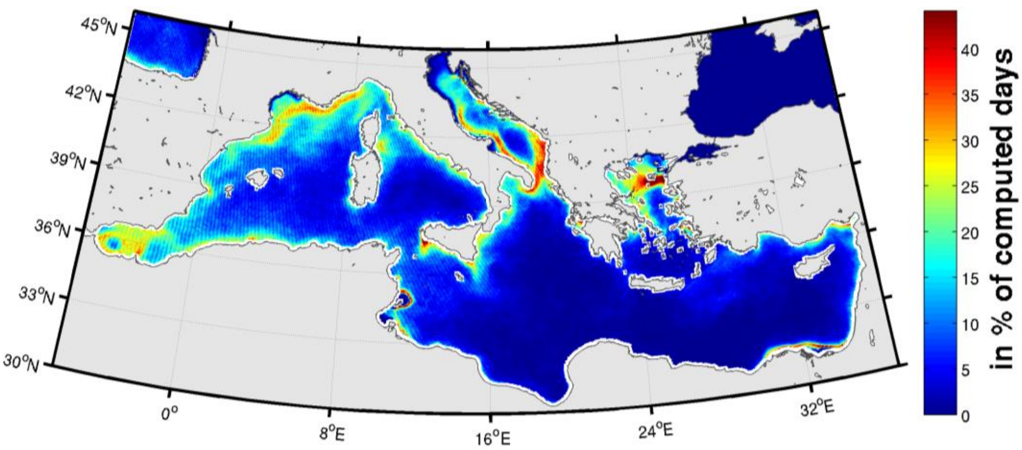

Figure 2 *Potential feeding habitat of the Atlantic bluefin tuna in the Mediterranean Sea (2003-2012): yellow/red areas represent on average the most frequently favourable habitat for bluefin tuna nutrition.*

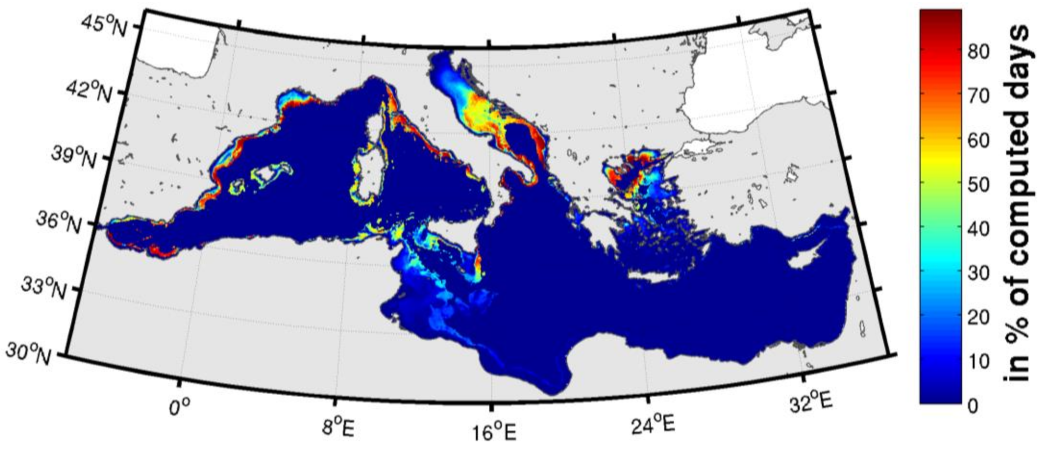

Figure 3 *Potential hake nurseries in the Mediterranean Sea (February to June 1999-2011): yellow-red areas represent the most frequently favourable habitat for the young-of-the-year hake (expressed in relative frequency of occurrence).*

From the daily Earth Observation to the improved understanding of pelagic ecosystems

Eutrophication monitoring

Eutrophication can be defined as a process driven by enrichment of water nutrients, especially nitrogen and/or phosphorus compounds, leading to increased growth, primary production and biomass of algae, changes in the balance of organisms and water quality degradation (Ferreira et al. 2011).

Following the Marine Strategy Framework Directive (MSFD), EU Member States must achieve or maintain Good Environmental Status (GES) of their marine and coastal waters by 2020 according to 11 descriptors among which eutrophication is one of these and reported in Annex 1 of the Directive as:

"Human-induced eutrophication is minimised, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algae blooms and oxygen deficiency in bottom waters."

The frequency of chlorophyll-a fronts within an intermediate range of chlorophyll-a content identifies the productive features that attract top-predators, i.e. areas of efficient energy transfer between trophic levels outside of low and high chlorophyll levels. High chlorophyll levels potentially correspond to eutrophicated areas where the food chain is disrupted and primary production is not available to upper trophic levels. Although not all |European Seas are equally sensitive to eutrophication (Druon et al. 2004, Djavidnia et al. 2005), it is monitored by ocean colour sensors at high time and space resolution so that its impact on fish productivity can be identified.

Refinement of stock assessments (standardization of Catch Per Unit of Effort - CPUE)

In the frequent cases where the geographical distribution of a fish population is insufficiently described by the available data (e.g. for migrating species), the mapping of favourable habitats permits to spatially extrapolate the catches per unit of fishing effort (CPUE) in order to refine the assessment of stocks.

However routinely-used stock assessment models are rarely designed or can be adapted for an analysis of spatial management measures such as evaluating the impact of a spatio-temporal fishery closure. Most fishery assessment models are indeed designed only to make predictions of how changes in fishing mortality will impact harvest and biomass levels of individual species. They are not easily adaptable to explore the consequences of changes in fishing mortality that may result from management measures that shift effort spatially. Using spatial management measures effectively requires new models and data (Holland 2003). Some examples already exist such as the Spatial Ecosystem And Population Dynamics Model (SEAPODYM) to estimate the spatial distribution of tuna-like populations in the Pacific Ocean using the modelling of pelagic habitats as a forcing variable (Lehodey et al. 2008, Abecassis et al. 2011, 2012). SEAPODYM is an age-structured spatially explicit population dynamics model.

It is worth noting that the spatial dimension is particularly required for migratory species which have a large (often unknown) distribution and for short-lived species (e.g. sardine or anchovy) for which the important stock variations are largely influenced by the environmental conditions for reproduction and not so much by the population structure.

Adjustment of fishing quotas to the natural variability of the stocks (i.e. under the influence of variable environmental conditions)

The observed seasonal and inter-annual variability of pelagic habitats is high (see for instance from ±50 to 75% in Figure 4) so that growth of fish populations may substantially be influenced by the availability of food (Figure 5). The link since 2003 of the young-of-the-year (age-0) mean biomass with total landings one year later in Figure 5 suggests a higher relative catch of younger specimens (age-1) than previously and an increase in overfishing of hake following the sharp decrease in landings after the mid-1990s. In addition in 2010 and 2011 substantially less-favourable conditions for hake recruits (shown in Figure 4 by the two red lines) coincident with lower levels of biomass (Figure 5) indicate that stocks of juvenile hake available for fishing in 2012 and 2013 are likely to be negatively impacted. Indeed, hake landings for Spain, Italy and France decreased by 28% in 2012 compared to 2010 (STECF[1]). This observation suggests that high fishing pressure combined with an environmental pressure may have strongly limited the availability of food for recruits. From year-to-year, the fishing quotas could therefore be adapted by taking into account the suitability of essential habitats and stock size estimates, to ensure that catch levels are appropriate and fisheries are sustainable.

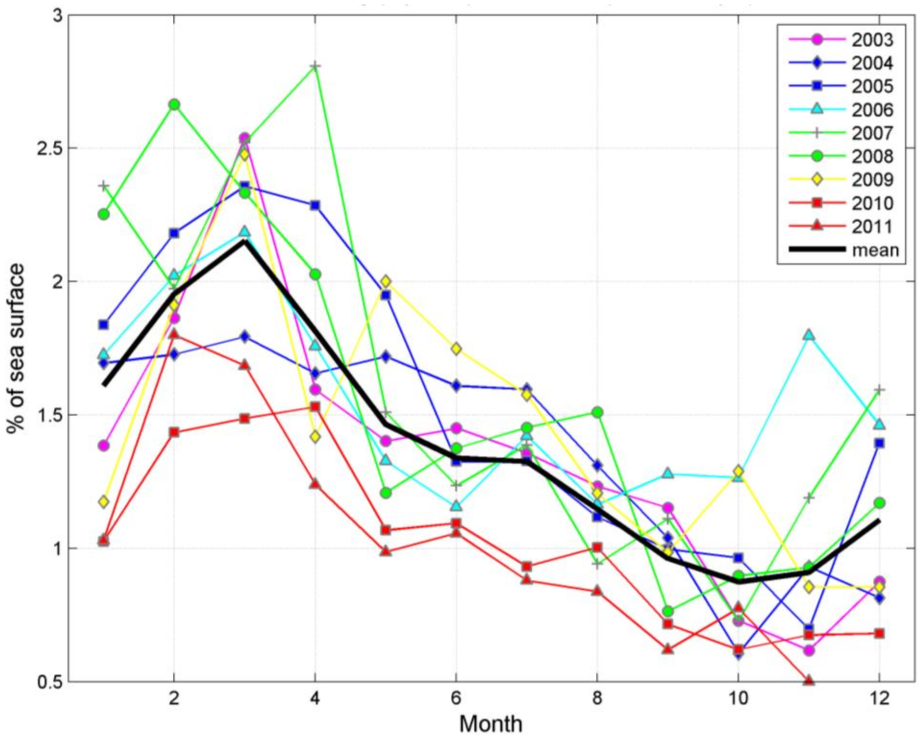

Figure 4 *Seasonal and inter-annual variability of preferred habitat for young-of-the-year hake (2003-2011, in percent surface of the Mediterranean Sea). Note the substantially lower favourable habitats in 2010 and 2011 (in red) which affected the young-of-the-year hake biomass (see below) and likely the 2012-2013 catches.*

[1] https://fishreg.jrc.ec.europa.eu/web/datadissemination/home

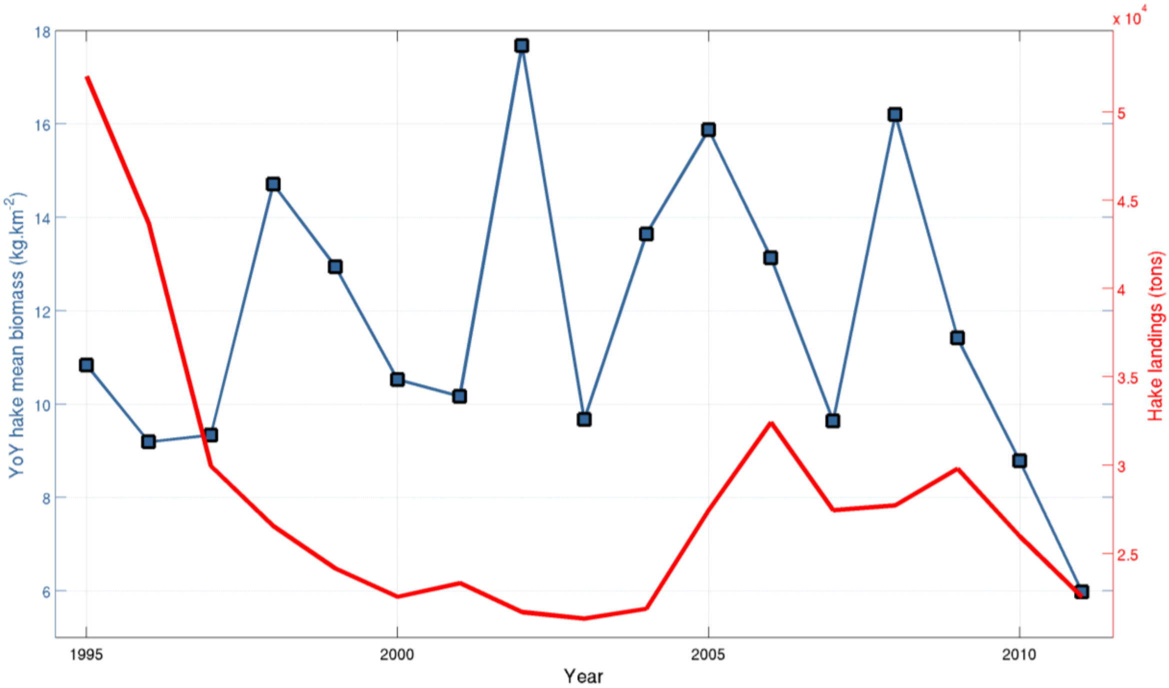

Figure 5 *Annual mean young-of-the-year hake biomass (MEDITS data) and total hake landings (General Fisheries Commission for the Mediterranean, http://www.gfcm.org/gfcm/topic/17105/en) in the Mediterranean Sea (1995-2011).*

Identification and protection of nurseries to optimize recruitment (fisheries closure or MPAs)

The identification of essential habitats for a given species linked to either reproduction or growth, including their year-to-year variability, permits the identification of the most appropriate spatio-temporal fishery closures. The monitoring of hake nurseries in the Mediterranean Sea for instance emphasizes the location of persistent areas suitable for hake reproduction at basin and regional scales as well as the most relevant period (winter and spring). Temporary closure to bottom trawling within these nurseries would therefore allow for optimization of the sustainable catch of larger specimens in subsequent years and contribute to the avoidance of overfishing. The implementation of Marine Protected Areas could be foreseen for key habitats that require permanent protection (no take zone).

Minimize by-catch by differentiating target from non-target species habitats

In other cases, the monitoring of pelagic habitats in near real time or model forecast offers the possibility to guide fishing fleets outside of non-targeted species to minimize by-catch. CSIRO in Australia (Hobday et al. 2010, Hartog et al. 2011) for instance uses a habitat-prediction model, combining data from an ocean model and pop-up satellite archival tags to define habitat zones that identify habitat overlap between yellowfin tuna (target) and southern bluefin tuna (by-catch). Scenario modeling of habitat change in response to e.g. climate change may also assist in informing future fishery management decisions.

In the meantime, the reformed CFP (COM 1380/2013) aspires to make fishermen more selective and new tools to achieve that objective are anticipated. So far the introduction of the landing obligation has been seen as contributing to achieving better selectivity but habitat monitoring could also help in the future to avoid by-catch (i.e. increase species-selectivity).

From science to policy

The assessment of the spatio-temporal distribution of key marine habitats may substantially reduce the uncertainties in stock estimates, especially for migratory and short-lived species. If fishing mortality at the Maximum Sustainable Yield (F_{MSY}) and moreover the spawning stock biomass at MSY (B_{MSY}) are more accurately estimated, the appropriate management measures (including spatial measures) will be facilitated. It is highly preferable to monitor the environment and make reasonable short-term predictions of environmental impacts on the stocks within a spatial population dynamics framework than, as currently performed, making predictions based on fishing mortality with large uncertainties on fish stocks (often driven by poor data) and without taking any environmental influences into consideration. In other words, spatial and environmentally-driven management measures could guide the Total Allowable Catches (TAC) rather relying solely on uncertain biomass and fishing mortality-driven calculations. The efficiency offered by spatial and environmental management measures and the reduction of uncertainties on the fish stocks will place fisheries closer to (a) the real boundary between precautionary approach and the Maximum Sustainable Yield and (b) to regular profitability. Indeed, the identification of key habitats in space and time for fish reproduction and/or growth will fill the gaps of knowledge to provide for and implement time-efficient fishery closures or MPAs and optimize recruitment.

The continuous monitoring of pelagic habitats (Figure 6) may allow in some cases to coarsely estimate the level of fishing opportunities in near real time and up to one year (e.g. hake nurseries, short life-span species) similar to what is done for crop prediction on land (JRC-IES, MARS Unit, AGRI4CAST). Such monitoring should also allow the progressive understanding and evaluation of the impact of medium to long-term climate changes on fish yields and of the adaptations required by the fishing industry.

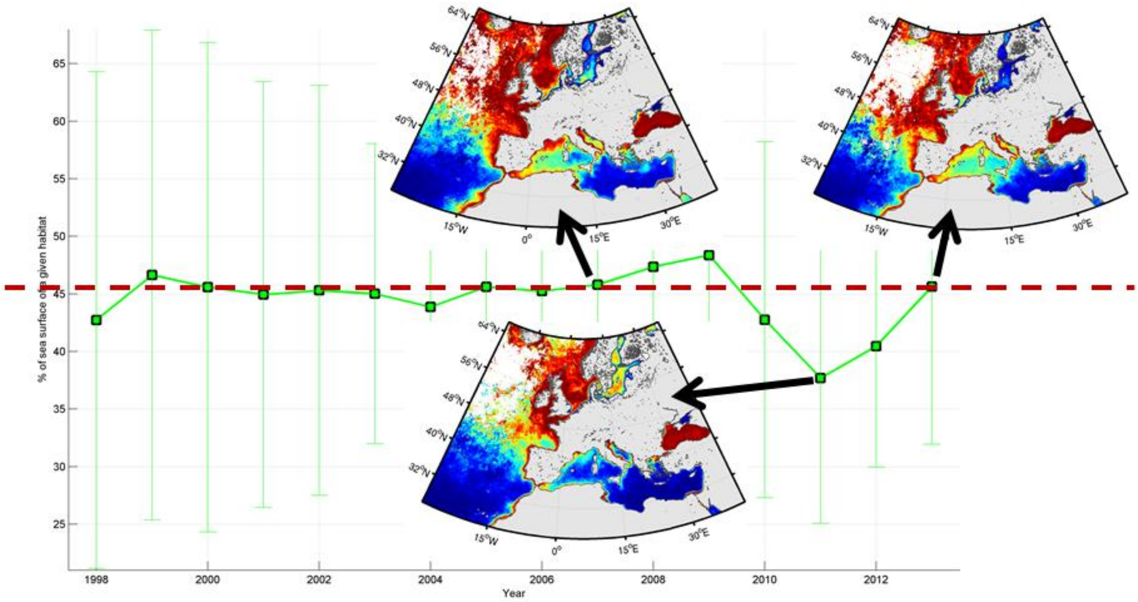

Figure 6 Inter-annual variability of favourable pelagic habitats in European Seas (1998-2013, in % of sea area). Note that the 2010-2012 negative anomaly mostly occurred simultaneously in the Mediterranean Sea and off the continental shelf of the North Atlantic.

Overall, information on the spatial aspects of population ecology and interactions with relevant ecosystem components are needed to implement an Ecosystem Approach to Fisheries Management (EAFM). The implementation of the Marine Strategy Framework Directive requires Member States to apply a broader 'ecosystem approach to marine management' (including in the development of conservation measures on populations of commercially exploited fish and shellfish) as a recognized fundamental principle underpinning the revised Common Fisheries Policy. Moreover Council Regulation (EC) 1967/2006 concerning management measures for the sustainable exploitation of fishery resources in the Mediterranean Sea specifically requires the establishment of fishing protected areas in order to protect nurseries. Maritime Spatial Planning shall apply an ecosystem-based approach to facilitate the co-existence and prevent conflicts between competing sector activities in marine waters and coastal zones, and shall notably aim to contribute to fostering the sustainable development and growth of the fisheries and aquaculture sectors (European Commission COM(2013) 133 final). The spatial-based fisheries management is therefore justified from both the scientific and policy perspectives.

Future and other use of pelagic habitat mapping

Depending on what species are targeted, the monitoring of pelagic habitats may serve other purposes than fisheries within the Integrated Maritime Policy. Applied to fin whales (Druon et al. 2012), this approach was used in combination with maritime traffic data to identify areas of high potential risk of collision with large vessels (Vaes & Druon 2013, Figure 7) and to guide the management of the PELAGOS Marine Mammal Sanctuary. The disturbance by marine noise as described in the MSFD may also be similarly studied. The overlap between species habitats shall also help to improve the understanding of the ecosystem structure and functioning and particularly the distribution of predators as regards to their prey as well as potential competition for the same resource.

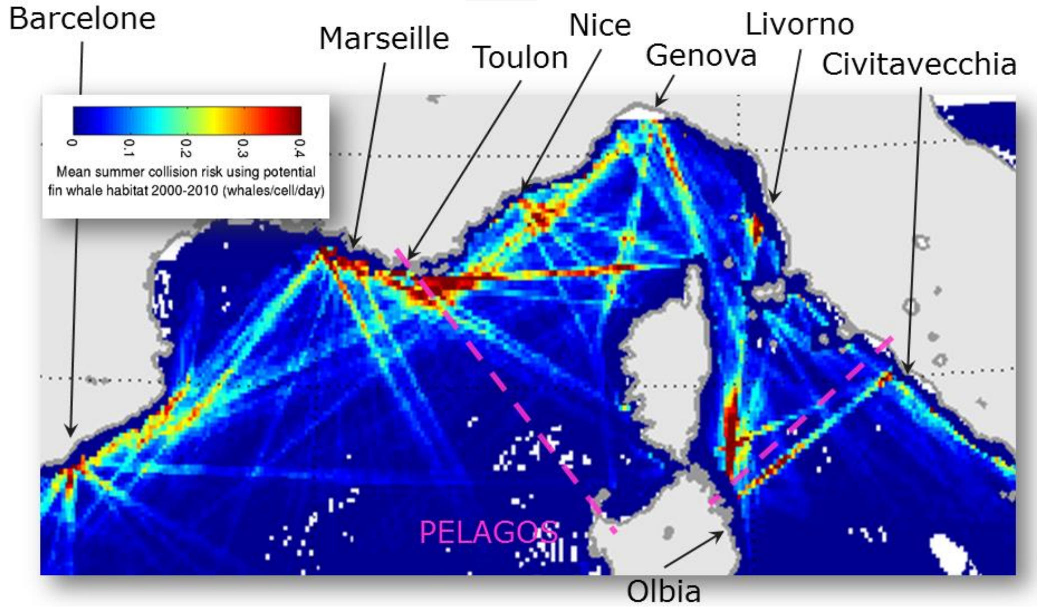

Figure 7 Map of potential ship strike risk with fin whales in the north-western Mediterranean Sea for the period summer 2000-2010 stating a constant maritime traffic density as of July 2009.

The future monitoring in near real time of our seas may also be used to increase fishing efficiency through the identification of favourable grounds under strict compliance conditions. Such methods have been already used in India to highlight potential fishing zone (PFZ) and help to reduce search time by up to 70% (and fuel consumption by the same amount) and to drastically increase catches per unit effort from 1.7 to 14.1 folds (Platt et al. 2008, Forget et al. 2009). The Indian operational system[2] is however not being used to promote sustainable fisheries since catches have drastically dropped. In the European context, the future use of near real time habitat mapping would support the economic and ecological sustainability of the fisheries sector by decreasing the fishing effort and footprint together with increasing profit for the same catch. Such implementation would however must require strict compliance with fishing regulations because past technological assistances in Europe always led to an increase of catches or effort. Compliance should improve through improved control scheme technology and notably through the increasing availability of vessel positional information (satellite VMS and AIS[3]). But fishers' compliance may also partially be obtained through higher responsible behavior where a "private" use of a given sea area is assigned. The allocation of sea areas to fishers such as is done with farmers on land, would promote long-term productivity and, thus, more responsible behaviors. This scheme would be particularly appropriate for small-scale fisheries or industrial fisheries with a limited number of companies such as in Iceland. Again here the spatial component of management is fundamental.

Conclusion

This strategic view describes how the daily monitoring of pelagic habitats, through the assessment of their spatial and environmental dimensions, may contribute to the sustainable exploitation of natural living resources. Fisheries will need to be spatially assessed and managed (a) to be properly integrated in future EU policy schemes as for any other maritime sector, (b) because the environmental forcing substantially influences marine ecosystems and their productivity and (c) because spatial management measures are increasingly put in place to protect marine ecosystems and exploited species. It is worth noting that in contrast with aquaculture and agriculture, fisheries relies on wild resources that need to be appropriately managed and monitored since the control of their growth and reproduction is extremely limited or absent. The monitoring of pressures and impacts on such fish populations both from natural and anthropogenic sources is a requirement for suitable knowledge and management, and is spatial by essence.

[2] http://www.incois.gov.in/Incois/PFZForecast?Mode=Initialize&strLanguageID=0

[3] Vessel Monitoring System and Automatic Identification System.

The spatial and environmental management of fisheries is an integrated approach that necessitates the development of new models and a common understanding by fishery and environmental scientists. Even if these two fields of science have traditionally been separated mostly due to limited knowledge, our increasing understanding of marine systems and developments in observation and computing capabilities should allow integration of both disciplines. This scientific challenge is a prerequisite for the proper implementation of the spatial and environmental fisheries management that will substantially increase the catches and profitability of the fishery sector while ensuring an improved understanding and management of marine ecosystems. The monitoring of pelagic habitats is therefore expected to play a substantial role in the future EU's Integrated Maritime Policy encompassing such aspects as blue growth, marine data and knowledge, maritime spatial planning and sea basin strategies.

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Abstract

This report is a prospective document which aims at showing the potentials of marine productivity and fish habitat monitoring to support the EU Integrated Maritime Policies. The main proxy for marine productivity relies on the daily tracking of productive frontal systems of the surface ocean (chlorophyll-a fronts) and of the hydrological tolerance of a specific species by physical ocean models.
The monitoring of pelagic habitats allows to introduce the still lacking spatial and environmental dimensions in the fisheries management to a) improve stock assessments, b) adjust fishing opportunities to the productivity of marine ecosystems, c) identify in space and time the essential fish habitats to preferably protect for sustainable catches and d) limit by-catch by differentiating target from non-target species habitats.
Other applications such as the risk of ship strike with large cetaceans or the eutrophication detection illustrate the capacities of the pelagic habitat monitoring to support the integration of multiple human activities within the EU Maritime Spatial Planning. The policy exploitation of this field of research requires the integration of the fishery and environmental scientific disciplines.

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