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Modelling the distribution of *Galeorhinus galeus* and *Mustelus asterias* in the Greater North- and Celtic Seas to provide recommendations for improved shark management under the Marine Strategy Framework Directive

Bachelor Thesis

van hall larenstein
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Cover: *Galeorhinus galeus* (top) & *Mustelus asterias* (bottom) (Shark Trust, 2010)

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Summary

Sharks are ecological important inhabitants of most of the world's oceans and seas. Still their life-history, which is dictated by slow growth rates and late maturity, makes most species, especially demersal- and coastal sharks, prone to exploitation through target- and non-target fisheries. Another threat is represented by the degradation of marine habitat, including shallow coastal regions, which for many shark species harbor essential nurseries. Recently, threats towards sharks and the connected risks for ecosystem stability, including commercial stocks, find the more frequent attention of shark specific management. Managing marine species with habitats across national boundaries is intricate and requires the access to species specific habitat- and distribution data. This information however is lacking for most sharks, but could be supported by novel techniques in Species Distribution Modelling. Target species for such a model in this study were Tope (*Galeorhinus galeus*) and Starry Smooth-Hound (*Mustelus asterias*). Both are migratory sharks in EU waters and would benefit from the identification of important habitats such as nurseries and derived spatial conservation measures. How spatial information can be transformed into species distribution models and further be applied to devise management measures for the target species in EU waters is explored in this study. Focus in management is thereby put on currently central management instruments such as the Marine Strategy Framework Directive.

Using species presence records from DATRAS and IFI surveys, as well as several environmental parameters, MaxEnt models of the juvenile and mature life-stage, divided by season, were produced. Afterwards, extant EU management for sharks and the target species was reviewed and potential for adaptions in the light of recent developments under the Marine Strategy Framework Directive devised. Hotspot areas, describing habitats of high suitability for *G. galeus* and *M. asterias*, were derived from the species distribution models as a navigation for the appliance of management.

Results suggest, that juvenile *G. galeus* continuously inhabits coastal areas at the north-west-coast of Ireland, the Irish Sea, the eastern English Channel, and the southern North Sea. As matures were predicted to inhabit distinct habitats further offshore, this study supports the assumption that *G. galeus* uses dedicated nursery areas. Contrastingly, no extraordinary differences were found between the predictions of suitable habitat of juvenile and mature *M. asterias.* Therefore, the concept that the species uses dedicated nurseries could not be supported by this study. However, profound differences in the prediction of suitable habitat in different seasons suggest that *M. asterias* undergoes a north-south migration. In winter, the species finds habitat in the northern North Sea, and migrates down along the coasts of the UK and Ireland in spring, down to its summer habitats in the southern North Sea. In fall the pattern seems to reverse to a northward migration. Response curves indicated that the migration might be associated to changes in water temperature. Although a prominent migration pattern was visible, some marine areas were predicted to offer *M. asterias* suitable habitat throughout the year. These hotspots were predicted in the Irish Sea, the eastern English Channel and the southern North Sea.

Spatial management advice is directed towards Member States harboring these hotspots, and suggestions for measures to achieve an improvement of management for sharks within the set spatial and environmental goals, set under the MSFD are given. Advice given, included the introduction of additional spatial protection measures as required under the MSFD, primarily in the form of MPAs with regulated fishing activity to reduce mortality through by-catch.

Although this study ran into limitations caused by the scarcity or unavailability of data, the results are thought to give a valuable indication of the potential distribution of *G. galeus* and *M. asterias* in the Greater North- and Celtic Seas. Therefore, it was concluded that this study provided a sufficient modelling approach to delineate potential spatial distribution of the target species, and that recent developments in EU maritime management under the Marine Strategy Framework Directive provide opportunities to process this spatial information, and to give incentives for the protection and management of those sharks amending to current practices.

Given the limitations, these studies' findings should be validated. Further research into the distribution of the target species and the underlying mechanisms is strongly recommended. Furthermore, if the advised management amendments are adopted, they should be enforced, and the status of the populations should be monitored.

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Abbreviations

AUC	Area Under the Curve
CBD	Convention on Biological Diversity
CHL	Chlorophyll-a concentration
CFP	Common Fisheries Policy
CMS	Convention on Migratory Species
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
Community	European Community
DATRAS	Database on trawl surveys
DO	Dissolved Oxygen concentration
EC	European Commission
EEZ	Exclusive Economic Zone
EU	European Union
EUPOA	European Plan of Action (for the Conservation and Management of Sharks)
FAO	United Nations Food and Agriculture Organization
GES	Good Environmental Status
ICES	International Council for the Exploration of the Seas
IFI	Inland Fisheries Ireland
IMP	Integrated Maritime Policy
IPOA	International Plan of Actions (for the Conservation and Management of Sharks)
IUCN	International Union for the Conservation of Nature
MaxEnt	Maximum Entropy Model
Member State	European Union Member State
MSFD	Marine Strategy Framework Directive
MPA	Marine Protected Area
NEA	North-East Atlantic
PoMs	Program of measures
SBT	Sea Bottom Temperature
SDM	Species Distribution Model/Modelling
SST	Sea Surface Temperature
UNCLOS	United Nations Convention on the Law of the Sea

1. Introduction

Sharks, herein referred to as part of the elasmobranch class, including sharks, rays (and skates), have been persistent inhabitants of marine ecosystems for the last 400 million years (Worm *et al.*, 2013). By being a part of the upper and mid trophic levels of marine food webs, sharks comprise a key function in ecosystem trophic dynamics (Schlaff *et al.*, 2014). However, being K-strategists with late maturity and low fecundity, most shark populations express low growth rates and are highly vulnerable to habitat loss and exploitation, more so even than most bony fish (Martin *et al.*, 2012; Dulvy *et al.*, 2014). In extensively utilized marine regions such as the North Sea, pressures through the degradation of marine habitat, fisheries and climate change, have led to the decline and collapse of many large fish species (Sguotti *et al.*, 2016).

Currently, eight elasmobranchs, which are native to the Greater North Sea, are included as threatened or declining species under the Oslo-Paris Convention for the Protection of the Marine Environment of the North-East Atlantic (NEA) (OSPAR) (ICES, 2017a). The overall conservation status of elasmobranchs in European Union (EU) waters seems to be even worse than the one of species which are subject to target fisheries (Nieto *et al.*, 2015). However, only in recent years the recognition of the importance of sharks in their ecological role and in their value for commercial fisheries has led to an increasing amount of research with the aim to ascertain habitat use (Schlaff *et al.*, 2014) and to implement shark specific management measures (Sguotti *et al.*, 2016).

Marine management in the EU marine is implemented on Community level (EU) and/or regional level. The marine environment in the EU is divided among the EU Member States by their respective Exclusive Economic Zones (EEZs) (Figure 1), and is of interest for influential stakeholders, such as commercial fisheries and the shipping industry. Applied management within this marine region can be limited in its range of influence, across EEZs and like this also in spatial regard, which includes regions of special ecological interest such as the Wadden Sea. For this reason, management of mobile and often migratory marine species such as sharks is complex and calls for coherence of shark management among Member States or rather the spatial protection of specific regions and/or essential habitats to add to conservation objectives.

Current EU shark management is facilitated either through fisheries regulation or environmental management. Fisheries management, which includes the regulation of shark fishery activities, is applied either directly through the assignment of limits and quotas for targeted fish stocks as well as for by-catch, or indirect through regulations in gear, through discard-bans, and in limiting access to fishery grounds in spatial or seasonal regard. Environmental management concerning sharks can be species specific, specific to a group of species, or be concerned with the protection of habitats or habitats with benefits for specific species.

An early framework for specific shark management in face of increased pressure through fisheries, was developed through the United Nations Food and Agriculture Organization International Plan of Action for the Conservation and Management of Sharks (FAO, 1999), that acknowledged the deficiency in information for successful shark management. More recently, the derived European Community Action Plan for the Conservation and Management of Sharks (EC, 2009a) proposes a framework for the conservation and management of sharks in the EU, through the development of coherent legislative policy, while highlighting the key role of fisheries in managing the many depleted shark stocks affected by Community fisheries.

The need for cross sectoral coherency in an overarching agenda is currently addressed by the EU Integrated Maritime Policy (IMP) (EC, 2012). In that way, ambitions for sustainable development, represented alike by commercial stakeholders such as fisheries under the Common Fisheries Policy (CFP) (EC, 2013) as well as stakeholders representing environmental concern, like the Habitats Directive (EC, 1992) and Conventions such as OSPAR (OSPAR, 2010) currently find a common denominator in the environmental pillar of the IMP: The Marine Strategy Framework Directive (MSFD) (EC, 2012).

Adopted in 2008, the MSFD urges Member States to develop and implement National Marine Strategies to achieve 'Good Environmental Status' (GES) of the marine environment in the EU by 2020, by applying and adjusting a framework including GES descriptors which, among others, address *biological diversity* and *integrity of marine food webs*. The adaptive management approach followed by the MSFD allows for environmental targets and implemented measures to be reviewed and adjusted cyclical. The end of the first cycle was set for July 2018 and will provide a review of the current state of the environment, the definition of GES and the environmental targets formulated with means to achieve GES for each Member State.

For the Dutch Marine Strategy this review was conducted in 2017 and is currently in the last development phases. The current draft version of the adapted strategy states, that the status of elasmobranch communities in the North Sea is still worrisome, and recommends the facilitation of elasmobranch research, in combination with mitigating measures such as communication and education, improvement of survival, and the reduction of by-catch to improve the situation (Ministerie van LNV, 2018).

Similar priorities were identified by the Dutch Elasmobranch Society (NEV) (Walker & Kingma, 2016), which is an active member of the Working Group on Elasmobranch Fishes (WGEF). The WGEF developed stock assessments for the EC Action Plan for the Conservation and Management of Sharks, and is part of the International Council for the Exploration of the Sea (ICES), responsible for the regular evaluation of the state of shark populations in the ICES areas (Figure 1) and bi-annual fisheries advice to the European Commission (EC).

The NEV points out that there are still large differences in the management of sharks in the EU, and that the coordination of policy and research could help achieving goals set under the MSFD (Walker & Kingma, 2016).

Next to the need for improved coordination in EU policies, the management of sharks in European waters is hampered by a lack of scientifically profound knowledge, especially concerning population trends and core distribution areas (Sguotti *et al.*, 2016). Knowledge that can support the development of shark management can be provided by the identification of suitable habitat (Addison *et al.*, 2013). A scientific approach to describe habitat suitability of a species, is species distribution modelling (SDM) (Franklin, 2009). Through parallel advances in Geographic Information Systems (GIS), and data-analyses technologies, the range of applications for SDMs increased tremendously (Elith & Graham, 2009).

To predict the distribution of a species in an area of interest, SDMs associate environmental conditions, with known species occurrences (Elith *et al.*, 2011). For instance, research by Meyers *et al.* (2017) found that, by using an SDM on critically endangered angel shark (*Squatina squatina*), that the species occurrence is likely to be correlated to abiotic environmental factors such as sea surface temperature, chlorophyll, salinity and depth. The results of the study were used to support the development of the Angelshark Action Plan for the Canary Islands (Barker *et al.*, 2016). This shows, that the prediction of shark habitat, using a suitable SDM, can have direct implications for management and can aid conservation for specific shark species.

In conserving sharks, species with migratory tendencies deserve special attention when considering, that compared to the fourth (24%) of all shark taxa, that is considered to be threatened, 46% of data sufficient migratory sharks are at higher risk and an additional 21% under threat (Fowler, 2014). *Galeorhinus galeus* (Tope) and *Mustelus asterias* (Starry Smooth-Hound), both triakid sharks inhabiting the Greater North- and Celtic Seas, have migratory tendencies possibly related to seasonal shifts in environmental conditions and to parturition. Although the EU populations of *G. galeus* (International Union for the Conservation of Nature – Red list status: 'Vulnerable') and *M. asterias* ('Near threatened') in the North Sea are only partly threatened, and *Mustelus spp*. (including multiple species of the genus) populations seem to be experiencing growth (Ministerie van LNV, 2018), essential habitats such as nurseries have not yet been identified with scientific evidence. Hence, little is known about the ontogenetic distribution of those species in the Greater North- and Celtic Seas (Fransen & Zundel, 2017).

The protection of essential shark habitat, such as nursery areas, has become a popular tool to conserve sharks (Kinney & Simpfendorfer, 2009). Shark nursery grounds in the Greater North- and Celtic Seas are thought to include bays and estuaries, lacking predation by other pelagic species and are usually associated with high productivity. Like this, early survival of juveniles is increased and through an additional amount of potential prey items, growth is promoted (Grubbs & Musick, 2007).

Based on recent observations, the NEV assumes nursery areas of *G. galeus* and *M. asterias* in Dutch coastal areas (Walker, P. (NEV), personal communication, April 5th, 2018). This notion is supported by research, stating that *G. galeus* and *M.asterias* use certain coastal regions along the Dutch- and German coastline as a potential nursery (Brevé *et al.*, 2016; Leopold & Baptist, 2016; Fransen & Zundel, 2017). Assumptions include, that *M. asterias* chooses outer estuaries and large bays as nurseries and is considered to pup in the waters in front of the former Eastern-/Western-Scheldt Estuary (Brevé *et al.*, 2016; Fransen & Zundel, 2017). *G. galeus* also prefers discrete pupping areas and is expected to use the tidal inlets between the Dutch Wadden islands as a nursery area (Leopold & Baptist, 2016).

SDMs, which have the potential to identify and/or confirm assumed shark habitat, are missing for both species, therefore spatial information about the distribution in time and space is also not available for specific management measures. As *G. galeus* and *M. asterias* are the only migrating shark species assumed in the NEA that frequently use EU coastal regions (Walker, P. (NEV), personal communication, May 4th, 2018), the identification of habitat, including nursery grounds, can contribute to the compliance with current environmental ambitions under the MSFD (including parent policies) and to the therein mentioned need for conservation measures to be integrated into spatial protection such as MPAs (EC, 2008a, p.21).

1.1 Problem statement

The development of management for the shark species *G. galeus* and *M. asterias* in the Greater North- and Celtic Seas is hampered by a lack of knowledge about their distribution and habitat use. Therefore, the identification of this target species habitat, including essential nursery grounds, is necessary to improve current management.

1.2 Research Aim

The aim of this study is to produce species distribution models for *G. galeus* and *M. asterias,* in order to provide suggestions for possible spatial shark management in the Greater North- and Celtic Seas.

1.3 Research Questions

The aim of this research translates into the following main- and sub-questions:

1. Which areas provide the most suitable mature- and nursery habitat for *G. galeus* and *M. asterias* in the Greater North- and Celtic Seas*?*
    a) What is the distribution of mature and juvenile populations of *G. galeus* and *M. asterias* in the research area?
    b) Which environmental factors most significantly describe the distribution of *G. galeus* and *M. asterias* in the research area?
2. Which amending spatial management recommendations can be made for *G. galeus* and *M. asterias* in the Greater North- and Celtic Seas?
    a) How do EU policies, including the MSFD affect the management of sharks and *G. galeus* and *M. asterias,* in the research?
    b) How can the results of research question 1 be applied to amend management of *G. galeus* and *M. asterias* in the research area?

2. Material & Methods

2.1 Research Area

This study aims at providing details about the distribution and management of *G. galeus* and *M. asterias* in the Greater North- and Celtic Seas. The respective OSPAR Areas II and III were chosen as Research Area (Figure 1). The western border of OSPAR Area III follows the continental slope, and therefore provides a margin that corresponds to the depth preference of the target species. Furthermore, the available presence records were sampled, with very few exceptions, in this area.
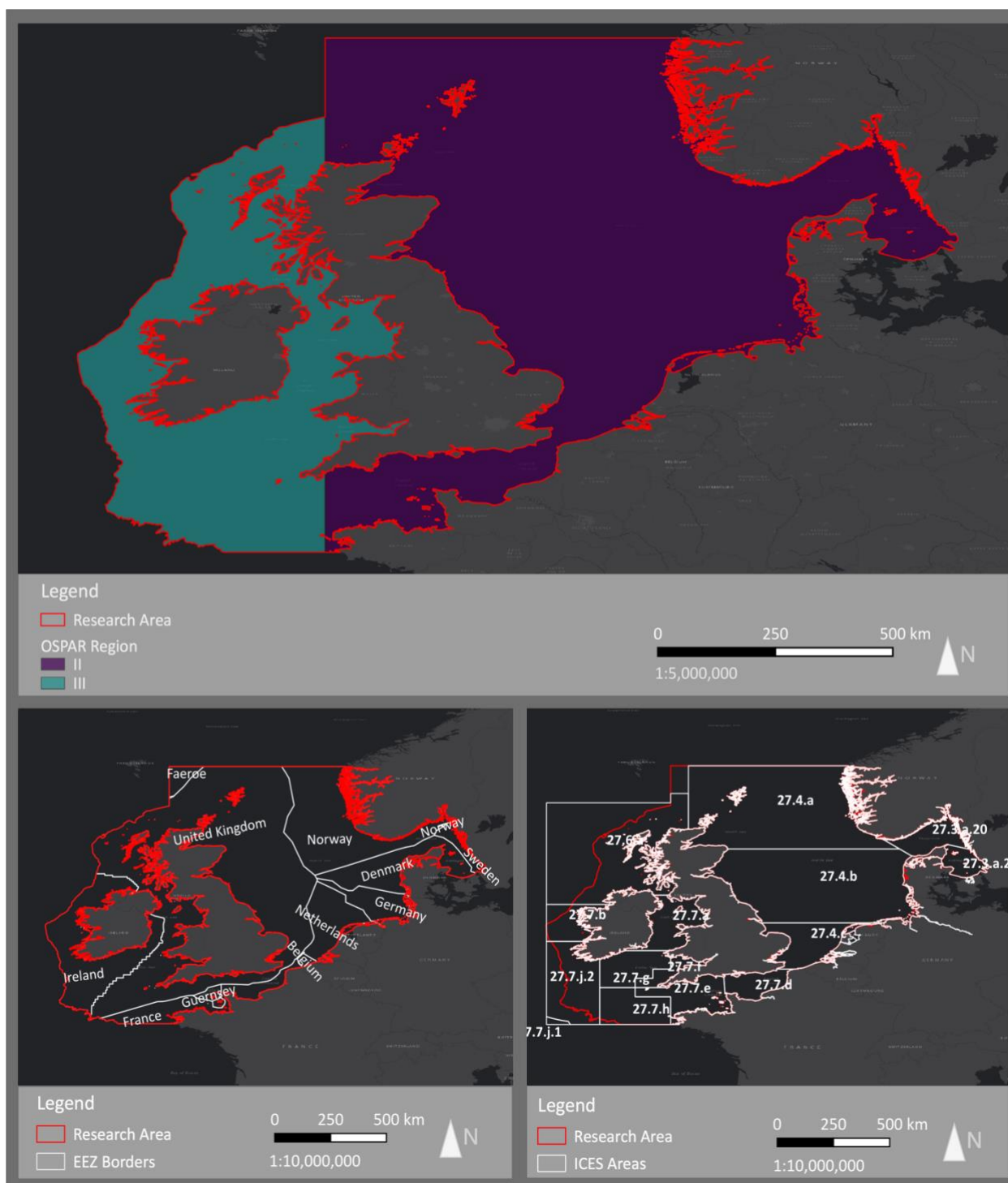

Figure 1: Research Area: OSPAR areas II (Greater North Sea) and III (Celtic Sea) at the top; the EEZs at the lower left, and ICES areas of the NEA at the lower right. Map data acquired from ICES, 2009; Vliz, 2014; OSPAR ODIMS, 2017 & ESRI et al., 2018.

2.2 Target species

2.2.1 Galeorhinus galeus (Tope)

Recently, the conservation status of *G. galeus* from 2006 (Walker *et al.*, 2006) was confirmed as category "*Vulnerable*" of the IUCN Red List (Nieto *et al.*, 2015), for European waters. The population of *G. galeus,* resident in the NEA ICES area is considered to be a singular individual stock (ICES, 2017b). *G. galeus* undertakes great migrations within the NEA. For example: Individuals tagged around the British Isles where recaptured as far North as Iceland and as far South as the Canary Islands (Walker *et al.*, 2006) (Appendix J).

While historically the species has been exploited throughout its range, today *G. galeus* is of low importance for commercial fisheries in the NEA and no target fisheries are currently active (with the exception of recreational angling) (ICES, 2017b). However, *G. galeus* is landed as by-catch of mixed demersal as well as pelagic fisheries, depending on its lifestyle. Trawl- and gillnets, as well as longlines pose the main threat towards the species. (Walker *et al.*, 2006; ICES, 2017b)

Juvenile specimen are usually associated with shallow coastal regions, mature *G. galeus* however are found down to depths of 800m, and alternating to a pelagic lifestyle.

The species is long-lived, reaching ages between 40-60 years, while growing to maximum sizes of around 200 cm in total length (Farrell *et al.*, 2015). Maturity in males is reached at sizes between 120-135 cm and in females between 134–140 cm, while fecundity is associated to increase with maternal size. Pups are born at a reported range of 26–40 cm, depending on the region (Walker *et al.*, 2006), likely around the April to June as reported from the Mediterranean. *G. galeus*, like other elasmobranchs, is supposed to use discrete pupping areas, such as bays and estuaries (Walker *et al.*, 2006). Still, concrete identifications of pupping and/or nursery areas in the NEA are not confirmed.

2.2.2 Mustelus asterias (Starry Smooth-hound)

M. asterias was reassessed from its 2006 IUCN Red List Category "*Least Concern*" (Serena *et al.*, 2009) to being "*Near Threatened*" (Nieto *et al.*, 2015).

Demersal *M. asterias* is dominant in NEA shelf regions up to 200m. The species abundance thins out towards the Mediterranean, where it is largely replaced by, in appearance similar, *M. mustelus.* Still, the species is considered to be a single stock throughout its range in the NEA (ICES, 2017b) (Appendix J).

While being of commercial interest in the Mediterranean, the shark is only of recreational attractiveness in the NEA and is usually discarded in commercial fisheries (Serena *et al.*, 2009) – with exceptions for some English Channel fisheries (Martin *et al.*, 2012). By-catch is facilitated mostly through trawl nets (including pups,) gillnets, as well as trammel and line gear (Serena *et al.*, 2009; ICES, 2017b).

Longevity differs between sex, with a recorded minimum of 13 year for males, and 18 years for females (max. 24 years). *M. asterias* reaches maximum lengths of 151cm and reaches maturity at approximately 80-85cm (Farrell *et al.*, 2015).

New born pups are born about 30cm in total length. For some females a biennial reproduction cycle is assumed, while pupping is described as occurring mostly between April and September (Farrell *et al.*, 2015), or as observed by McCully *et al.* (2015) in February in the western English Channel, and in June to July in the Eastern English Channel. Potential nursery areas are generally assumed in inshore areas such as bays and estuaries (e.g. Serena *et al.*, 2009), region-specific assumptions include in general the southern North Sea as well as the English- and Bristol Channel (Ellis *et al.*, 2005; ICES, 2017b).

2.3 Species Distribution Modelling

In this study, the open-source software MaxEnt 3.4.1 (Phillips *et al.*, 2006; Phillips *et al.*, 2017a), which relies on the theory of Maximum Entropy, was used to produce SDMs as it is able to outperform many other models, in terms of predictive accuracy, if only presence data is available (Phillips *et al.*, 2006; Hernandez *et al.*, 2006). Furthermore, MaxEnt is user-friendly and has shown to be relatively robust when dealing with small sample sizes and data-poor situations (Pearson *et al.*, 2007; Wisz *et al.*, 2008).

To fit an SDM, MaxEnt requires two data inputs (Phillips, 2017b):

1) Species presence points (geographical observations).
2) Environmental GIS layers of factors which are likely to govern the niche of the target species.

In this sub-chapter, the utilized data inputs for MaxEnt are described, and the execution of the SDM process is illustrated.

2.3.1 Species Presence Data

The majority of the presence points for the target species, *G. galeus* and *M. asterias,* originate from the ICES Database of Trawl Surveys (DATRAS) (ICES, n.d.).

The DATRAS dataset includes data from several fishing surveys, conducted from 1988 through 2017 (and ongoing) (ICES, n.d.). The surveys cover most of the northern European seas. Consequently, presence points are numerous, even for species of low abundance.

The datasets feature 1327 presence points of *G. galeus* and 26793 presence records of *M. asterias*, in total. More information about the surveys can be accessed via the DATRAS survey description portal and its sub-sites (http://datras.ices.dk/Home/Descriptions.aspx).

For *G. galeus,* the data retrieved from the DATRAS dataset were complemented with presence data from tagging surveys carried out by Inland Fisheries Ireland (IFI) from 1970 through 2016 (and ongoing). The available dataset contained only presence points of *G. galeus* with a length shorter than 120cm (juveniles). In total, the DATRAS dataset could be complemented with an additional 938 presence records. More information about the tagging program can be accessed via the fish tagging website of Inland Fisheries Ireland (http://www.fisheriesireland.ie/Tagging/tope.html#tagging-results).

In both, the DATRAS and the IFI dataset, several metadata are stored alongside the geographical information of a sample. Using these metadata, the presence points were subset by season, and the juvenile and mature life-stage of *G. galeus* and *M. asterias* (Table 1)*.*

Following Farrell *et al.* (2015), all individuals of *G. galeus* with a total length of less than 120cm were considered juvenile, and all samples with a length of more than 140cm as mature.

For *M. asterias*, all individuals shorter than 80cm were considered as juvenile, and all larger than 85cm as mature (Farrell *et al.*, 2015). As the sex of many samples was not identified, the earliest and latest points of maturation were chosen to subset the datasets by life-stage. This approach led to the loss of some presence data, but reassured the correct allocation of the species' life-stages.

As the target species are presumed to undergo seasonal migrations, and some of the environmental variables used change considerably over the course of a year (e.g. Sea Surface Temperature), presence records were subset by season, as defined in Table 1. Due to the unequal sampling effort within the years, the subsets for each season yielded different sample sizes (Table 1). Microsoft Excel (Microsoft, 2018) was used for processing the presence records.

Table 1: Number of presence records of juvenile and mature G. galeus and M. asterias, per season.

Season		G. galeus Juvenile (≤120cm)	G. galeus Mature (≥140cm)	M. asterias Juvenile (≤80cm)	M. asterias Mature (≥85cm)
Spring	**(March – April)**	56	9	284	35
Summer	**(May – August)**	855	28	409	176
Fall	**(September – November)**	708	146	3903	849
Winter	**(December – February)**	22	12	1163	162

2.3.2 Environmental Parameters used to model the Distribution of G. galeus and M. asterias

The environmental variables which were used to estimate the distribution of *G. galeus* and *M. asterias* in the Celtic- And Greater North Sea are (Figure 4):

- Sea Surface Temperature (SST)
- Sea Bottom Temperature (SBT)
- Salinity
- Chlorophyll (CHL) concentration
- Dissolved Oxygen (DO) concentration
- Bathymetry (Depth)
- Energy at the Sea Bottom
- Substrate Type
- Distance to Coasts

While from these nine variables the first five vary over time, the last four are static, meaning they do not change significantly within the time frame of this research. To model the distribution of juvenile and mature *G. galeus* and *M. asterias,* it was necessary to produce 16 MaxEnt SDMs: One per season and life-stage, for both species (Figure 4).
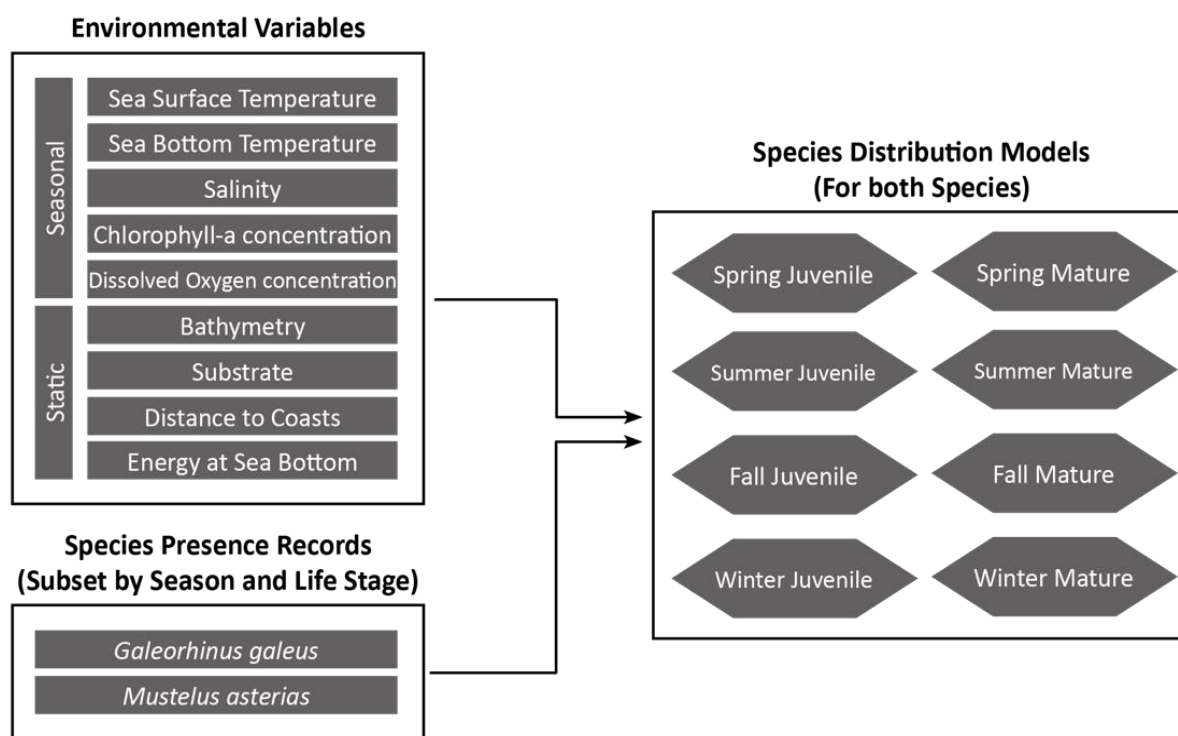

Figure 4: Conceptual Model of the MaxEnt Modelling

2.3.3 Environmental Data Sources

The Copernicus Marine Environment Monitoring Service (CMEMS; http://marine.copernicus.eu) provides various (GIS) datasets, covering a multitude of ocean monitoring variables. This study made use of this service and used two of these datasets as input for the variable environmental factors. The physical variables SST, SBT and Salinity were taken from the "Northwestshelf_Reanalysis_Phys_004_009" dataset (CMEMS, 2018a), and the biogeochemical variables CHL and DO were acquired from the "Northwestschelf_Reanalysis_Bio_004_011" dataset (CMEMS, 2018b). Both datasets were compiled by the MetOffice and feature a re-analysis of various input data to provide GIS datasets about the physical and biogeochemical environment in the NEA over a period of 28 full years (1985-2013) (CMEMS, 2018a; CMEMS, 2018b). The GIS datasets have a resolution of 0.111*0.067 degrees (WGS84) and are available as daily and monthly means. Considering all 28 years of data, seasonal averages of all variables were calculated. Seasons were defined in the same way as for the species presence points (Table 1, page above).

The European Marine Observation and Data Network (EMODnet; www.emodnet.eu) centralizes and distributes marine data from several disciplines (EMODnet, 2017a). Two of the EMODnet data products are a high-resolution bathymetry layer and the EUSeaMap (a digital map showing broad-scale habitat types and their descriptor variables in European waters). The bathymetric data were acquired through the EMODnet Bathymetry Portal (www.emodnet-bathymetry.eu) and have a resolution of about 0.002*0.002 degrees (EMODnet, 2017b). The substrate data is a habitat descriptor layer (polygon) within EUSeaMap, and was accessed via the EMODnet Seabed Habitats portal (www.emodnet-seamaphabitats.eu, EMODnet, 2016).
Similar to EMODnet, ICES (www.ICES.dk) also centralizes and distributes marine data, and their services include the provision of some marine environmental variables as GIS layers. As a proxy for the current strength at the sea bottom, a layer indicating the kinetic energy (N m^2/s) at the sea bottom was included (ICES, 2017c). The raster layer comes at a resolution of 0.003*0.003 degrees and approximately covers the research area.
Using a shapefile with the worlds' coastlines (OpenSteetMapData, 2018), a raster layer, indicating the shortest possible distance from every cell of the layer to the coasts (Euclidean distance), was produced.

For the use in MaxEnt, all environmental variables were "clipped" to the extent of the research area and resampled to the cell-size of the layer with the highest resolution (= bathymetry).

All geoprocessing was executed using ESRI ArcGIS Desktop 10.6 (ESRI, 2018; hereafter referred to as ArcGIS), QGIS 3.2 (QGIS Development Team, 2018), and the ArcGIS extension SDMtoolbox 2.2c (Brown, 2014). A detailed flowchart and description of the data preparation process can be found in Appendix A.

2.3.4 Accounting for Sampling Bias

MaxEnt requires that the input species datasets are free of sampling bias. If this is not the case, the resulting models are rather a prediction of sampling effort than an estimate of species presence. MaxEnt offers the possibility to import a sampling bias file in order to automatically adjust for sampling bias through weighted background selection. (Phillips *et al.*, 2009)
Using ICES' DATRAS presence records of all elasmobranchs, a bias file was created using a gaussian kernel density estimation (Appendix B). Without further reclassification, the bias file was directly

used in MaxEnt to account for sampling bias in the models of *M. asterias* and mature *G. galeus*. As the juvenile *G. galeus* presence records originate from two datasets (ICES & IFI), a second bias file was created using only the presence points of juvenile *G. galeus* (Appendix B). Both bias files were produced using the "MASS" (Venables & Ripley, 2002), "raster" (Hijmans, 2017) and "rgdal" (Bivand *et al.,* 2018) packages in RStudio (RStudio Team, 2016).

2.3.5 MaxEnt Settings

When starting up MaxEnt, the settings to run a basic model are already activated. Settings, other than standard (Figure 5) were chosen as following:

- "Response curves" where activated to explore the preference of the species for a category or range in the environment variables.
- "Jackknife tests" were used to assess the contribution and importance of every variable used in the model (in terms of training gain).
- The function "Pictures of predictions" was utilized to get preliminary visual results of the models.
- "Remove duplicate presence records" was de-selected as, due to the nature of sampling, many of the presence records were overlaying each other.
- "Random test percentage" was chosen at 25% to validate the model. If the number of presence records was below 25, a test percentage of 0% was used minimize the loss of presence points to testing.
- "Write plot data" was used to retrieve data for further plotting of results with the statistical software suite RStudio (RStudio Team, 2016) and the package "ggplot2" (Wickham*,* 2016).

"Cloglog" was chosen as output format, because it is the most appropriate transformation for estimating probability of presence and has a stronger theoretical justification than the logistic transform (Phillips *et al.,* 2017a).
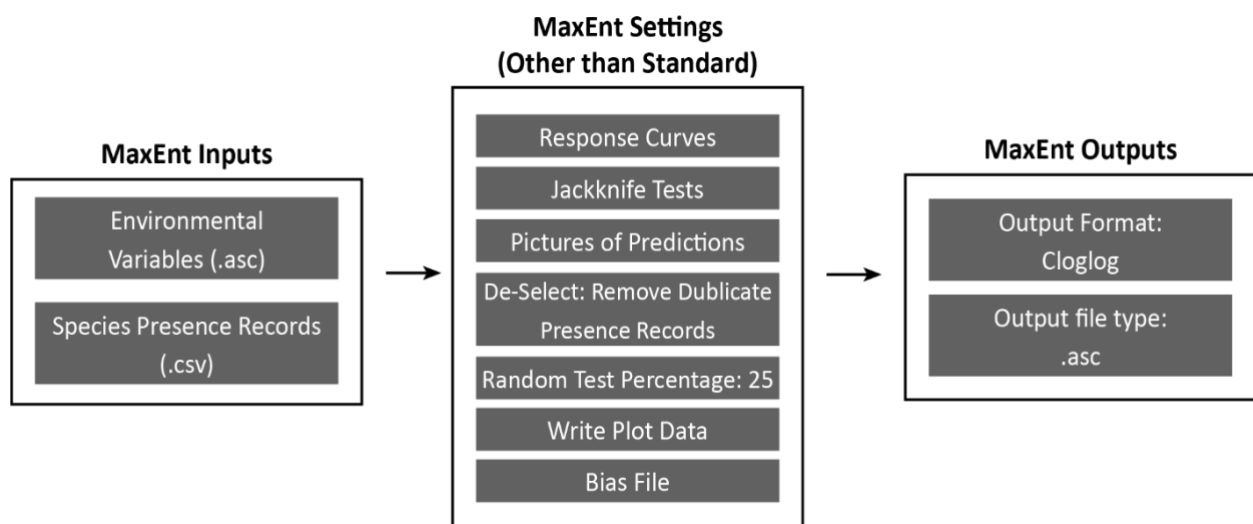

Figure 5: Utilized MaxEnt Settings

2.3.6 Interpretation of Results

The MaxEnt output includes a model summary, showing all model statistics. Part of these statistics are the Area Under the Curve (AUC) graphs and calculations, which are indicators for the model fit. By definition, an AUC value of 0.5 describes a prediction that is no better than random, and values close to 1 indicate a powerful prediction (Tobeña *et al.*, 2016). In MaxEnt research, the definition which AUC value indicates which model quality often varies considerably (Merckx *et al.*, 2011). Here, AUC values smaller than 0.7 are considered to deliver a poor predictive performance, while AUC values between 0.7 and 0.8 are regarded as moderately good, models with an AUC between 0.8 and 0.9 are assumed to be good, and models with an AUC higher than 0.9 are regarded as excellent (Figure 6; Merckx *et al.*, 2011; Tobeña *et al.*, 2016).

AUC:	≤ 0.7: Poor	0.7 – 0.8: Moderate	0.8 – 0.9: Good	≥ 0.9: Excellent

Figure 6: AUC interpretation scale

2.3.7 Model Selection

The full models (with all environmental variables) were reduced, so that they were as simple as possible while still being powerful. An AUC loss of up to 0.025 was considered to be acceptable to achieve simpler models with improved interpretability.

To achieve this, only the environmental variables that contributed strongly to the model and showed a high importance in terms of training gain and AUC loss (Jackknife tests) were selected. Furthermore, environmental variables with high collinearity were removed from the model (as much as possible) to improve the interpretability of the response curves.

Collinearity between the environmental input variables was assessed and visualized using the packages "SDMTools" (VanDerWal *et al.*, 2014), "Hmisc" (Harrell Jr *et al.*, 2018), and "ggcorrplot" (Kassambara, 2016) in RStudio (RStudio Team, 2016). A correlation matrix can be found in Appendix C.

2.4 Literature Research

To establish the current status of shark management, including that of the target species, in EU waters a literature research is conducted. Focus was put on the identification of shark management, exclusively applicable for the EU, Member States, and on regional level, as the target species are considered to represent individual stocks in that region. To attain further information about shark distribution and habitat preferences, as well as about applications of habitat modelling in shark management, topic related scientific studies were included in the literature research.

The accumulation of available literature prefered peer-reviewed literature and grey literature from renowned sources (e.g. by the Commission and advisory bodies such as ICES and the IUCN). As management is subject to constant change, the most recent policy amendments were consulted with preference.

The terms and catchphrases, used in combination, to identify literature are found on the following page in Table 2:

Concerning shark management:		
EU shark management	Marine conservation	Shark fisheries
EUR-lex	Marine Strategy Framework	Regulation
EU Marine Policy	Directive	Agreement
EU fishery management	NEV	Directive
Common Fisheries Policy	ICES	Provision
Marine spatial management	Shark conservation status	Convention
Greater North Sea	Celtic Seas	Wadden Sea
Concerning shark biology and behavior:		
Tope/ *G. galeus*	Habitat	Environment factors
Starry smooth-hound/ *M. asterias*	Nursery	Biotic/Abiotic
	Distribution	Ecological niche
Bottleneck	Elasmobranchs	Juveniles/Neonates
Life history	Season	
Concerning SDMs used in shark management:		
Shark habitat modelling	Spatial conservation	Implications
Species Distribution Modelling	Distribution	Distribution data
Niche	Occurrence	Presence

2.4.1 Review of EU Shark Management

The review included example management of the target-, and on genus level related species.

Based on the preceding literature research, extant or near-future developments in shark management with relevance for EU waters and the research area (Chapter 2.1) were identified in an inventory (Appendix G). Based on the from the management and species review derived information, potential for adaptations in shark management is assessed and the possible role of the MSFD therein identified.

For reasons of applicability, reviewed management should be as relevant as possible, in regard to the target species and the research area.

2.4.2 Applying the SDM Results to provide Advice for Improvements in EU Shark Management

Finally, it was evaluated how the results of this sub-study, including the spatial information extracted from the SDM approach (Chapter 3.1, 3.2), can be applied to devise possible management measures for the target species in the research area. Results were translated into specific advice for shark management, under aspects of conservation and sustainable use. Advice focused on the juvenile population of *G. galeus* and *M. asterias,* and on the protection of habitats with importance for those populations. Although adult populations were additionally mapped, this was first and foremost used to be able to distinguish habitat use between juvenile and mature specimen and secondly to draw assumptions over possible migration patterns.

Derived advice was formulated as specific as possible, in regard to the target species, also to account for differences in species behavior and biology, as well as to the identified spatial information and identified target species hotspots.

3.   Results

3.1   Species Distribution Maps: *G. galeus*

Eight MaxEnt models were produced to model suitable habitat of juvenile and mature *G. galeus* in the Greater North- and Celtic Seas – one for each life-stage and season. Except for the two winter models, all models yielded good to excellent results, with an AUC in the range between 0.897 and 0.988 (Table 3). As the AUCs of the winter models, with a value of 0.793 for the juvenile and 0.684 for the mature model, were not satisfying, the associated habitat suitability maps should be considered with caution.

The Salinity and the SBT are the two environmental variables which were included in every model and could not be omitted without considerable drops in model performance. Furthermore, the bathymetry, the distance to coasts, and the energy at sea bottom were important predictor

Table 3: Used Environmental Variables and the achieved AUC of the *G. galeus* SDMs, per life-stage and season.

Juvenile	Spring	Summer	Fall	Winter
Bathymetry	✓	✓	✓	✓
Distance to Coast	✓	✓	✓	✗
Energy at Sea Bottom	✓	✓	✓	✓
Salinity	✓	✓	✓	✓
SBT	✓	✓	✓	✓
SST	✗	✗	✗	✗
DO concentration	✗	✗	✗	✗
CHL concentration	✗	✗	✗	✗
Substrate				✓
AUC:	0.984	0.952	0.921	0.793

Mature	Spring	Summer	Fall	Winter
Bathymetry	✗	✓	✗	✓
Distance to Coast	✓	✓	✗	✓
Energy at Sea Bottom	✓	✓	✓	✗
Salinity	✓	✓	✓	✓
SBT	✓	✓	✓	✓
SST	✗	✗	✗	✗
DO concentration	✗	✗	✗	✗
CHL concentration	✗	✗	✗	✗
Substrate	✓	✗	✓	✓
AUC:	0.897	0.988	0.911	0.684

variables in the majority of the models. The substrate type was of particular importance in the winter model of juvenile *G. galeus*, and the majority ($^3/_4$) of the mature models. (Table 3)

In all models, the CHL concentration, the DO concentration, and the SST could successfully be omitted without causing serious AUC losses. Considering the strong correlation among these variables, and the Salinity and the SBT (Appendix C), it becomes evident that the former depend on the latter. (Table 3)

Stacked bar-charts, showing the contribution of the utilized environmental variables to the individual models (Appendix F), indicate that the most important environmental predictors to model suitable habitat of juvenile and mature *G. galeus* differ between life-stages.

For juveniles, the SBT, the bathymetry, and the salinity were the factors which contributed most to the models. Only in the winter model, the substrate type was a very important predictor.

For matures, the energy at sea bottom, and the distance to coast (which was not included in the juvenile models) were more prominent predictors. The substrate type contributed most in the spring and winter models.

A distinctive pattern aligns with the high importance of the substrate type predictor in models where the number of presence records was low (n<25). In the winter model of juvenile *G. galeus* the substrate type had a contribution of 47.8% to the model. With a contribution of 93.9% to the spring model and 91.4% to the winter model of matures, this pattern is even more prevalent. The

result is, that the habitat suitability maps for these models (Figure 7 & 8) mainly depict a certain substrate type as suitable.

Response curves, illustrating the suitable range within an environmental variable for all seasons and life-stages can be found in Appendix E.

The response curves for the SBT indicate that juvenile as well as mature *G. galeus* have, with a range between 12° and 27°C, a relatively broad temperature tolerance. The predictions of suitable SBTs differ vastly between seasons, but show similar patterns in juveniles and matures. In spring, waters with temperatures between 19° and 22°C are suitable, while in summer warmer waters with temperatures between 23° and 27 °C are predicted as such. In fall, lower temperature between 12° and 15°C are predicted to be suitable. In winter, the predictions differ between juveniles and matures. While temperatures below 19°C are considered to be suitable for juvenile *G. galeus*, all temperatures throughout the range are predicted to be suitable for matures.

Suitable salinity is predicted in the same range throughout the seasons, but differently between life-stages. While juveniles can be found in waters with a salinity between 33 and 36 parts per thousand (ppt), suitable habitat of mature *G. galeus* is predicted in areas with slightly higher salinities in the range between 35 and 38ppt.

The depth predictor was not of importance in the spring and fall models of mature *G. galeus* and was therefore excluded from the models. For juveniles and matures, the suitable depth is predicted to vary by season in a similar pattern. While in spring (only juveniles) and summer depths of less than 60m are predicted to offer suitable habitat, the range extends into deeper areas in fall, with suitable depth predicted down to 150m (only juveniles). Contrastingly, in winter depths below 50m are predicted to offer the most suitable habitat.

The distance to coast predictor was excluded from the winter model for juveniles, and the fall model for mature *G. galeus.* A prominent pattern shows, that mature *G. galeus* are predicted to find suitable habitat not only close to the coast, but also in areas further offshore. While Euclidean distances of less than 1 are predicted to be most suitable for juvenile *G. galeus*, Euclidean distances of up to 2 are considered as such for matures in spring and winter. In fall, a Euclidean distance of less than 0.5 is predicted to be unsuitable for matures, and therefore contrasts the prediction for juveniles.

The energy at sea bottom predictor was excluded from the winter models of mature *G. galeus.* In spring, summer, and fall habitats with a relatively low energy of less than 1600N m^2/s are considered to be suitable for juveniles. Contrastingly, all energy levels, except very low-energy environments (< 300N m^2/s), are predicted to offer suitable for matures in summer and fall. In spring, the whole range of the energy at sea bottom variable is predicted to be suitable.

The substrate type predictor was included in the spring, fall and winter models of mature *G. galeus*, and in the winter model of the juveniles. Matures show similar patterns for all modeled seasons, indicating a primary preference for mixed sediment and a secondary preference for sandy bottoms (spring and fall only). Contrastingly, juveniles show a preference for mud to muddy sand and sand.
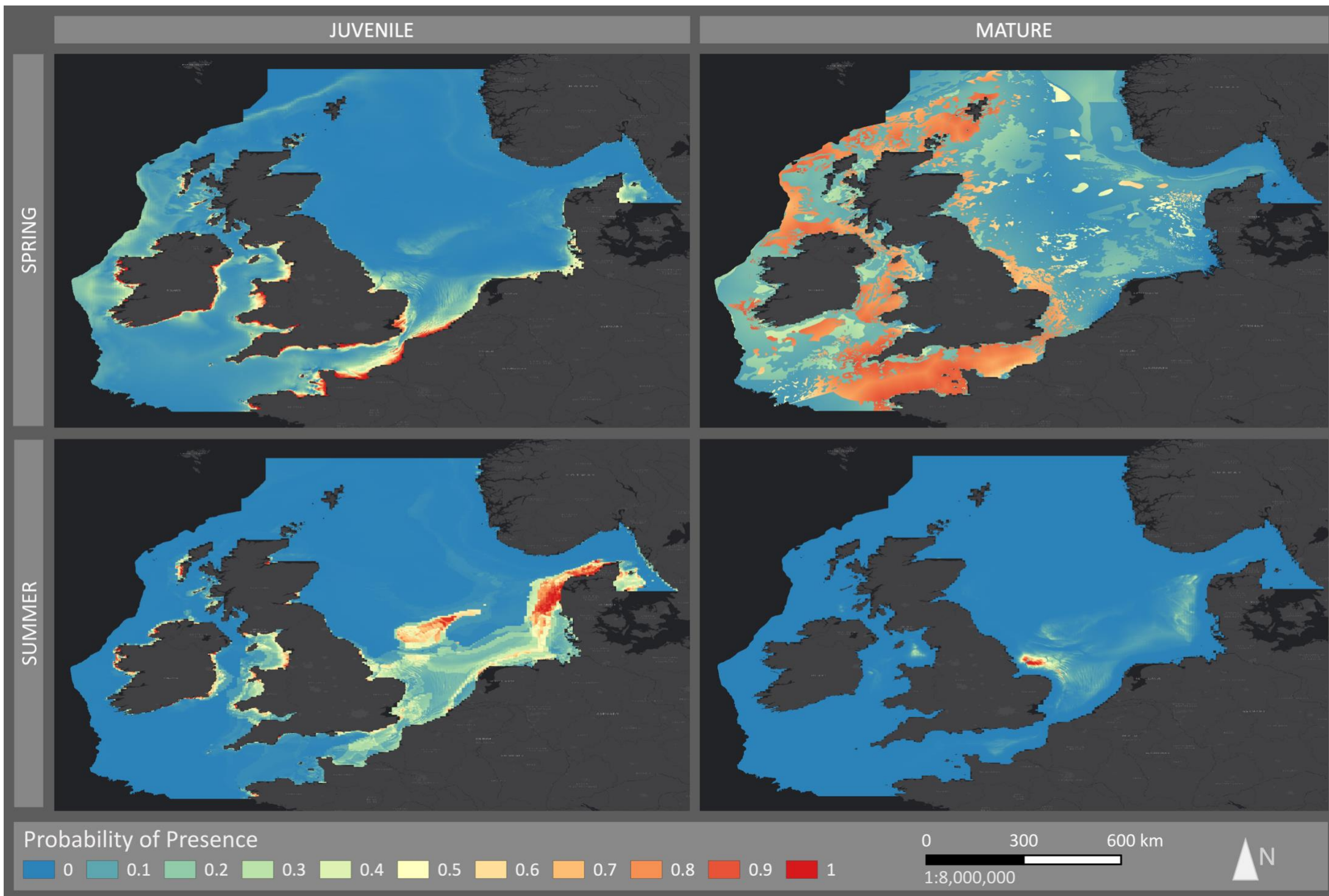
Figure 7: Species Distribution Maps of juvenile and mature G. galeus, split up by Season (Spring & Summer). Basemap by ESRI et al., 2018.
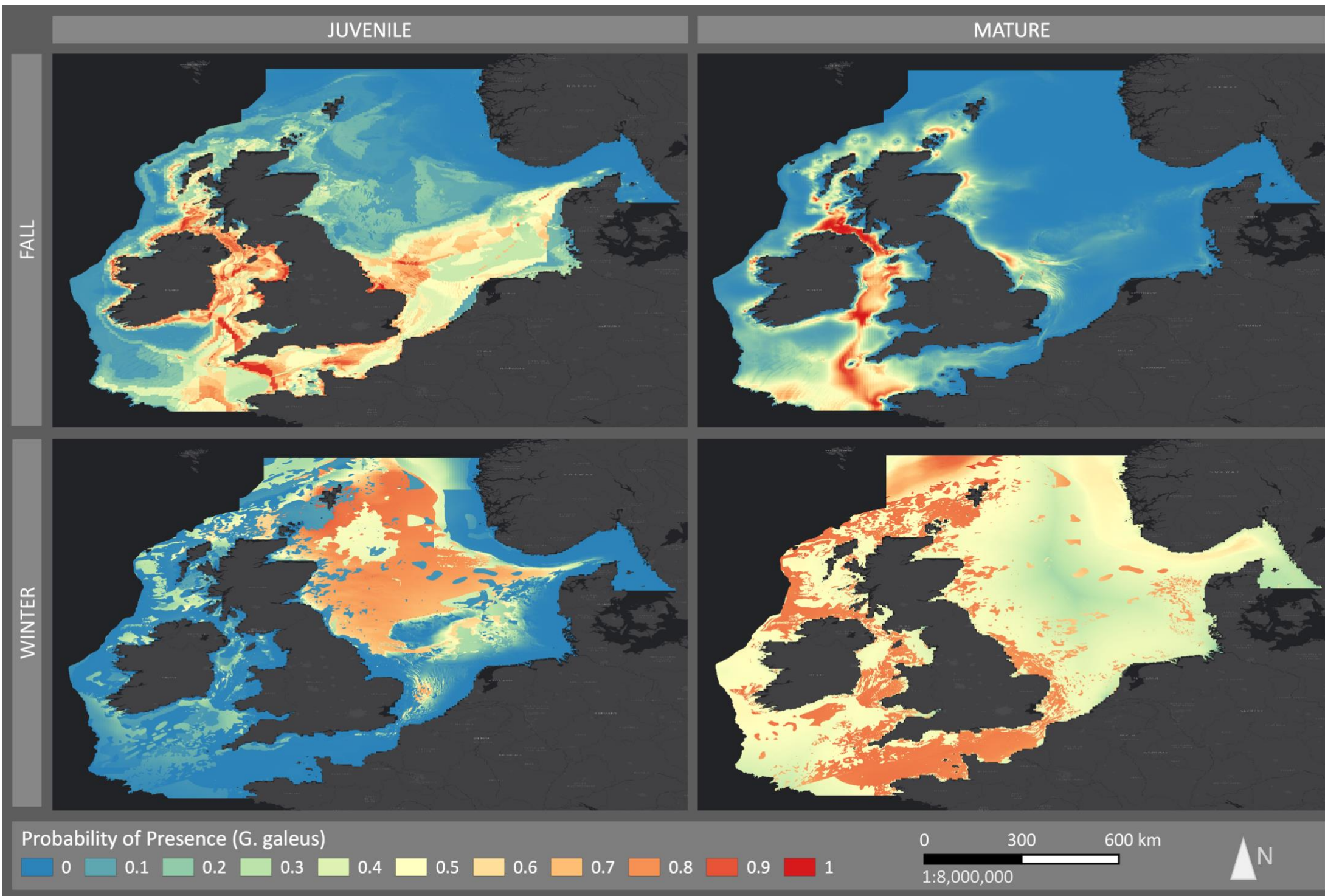
Figure 8: Species Distribution Maps of juvenile and mature G. galeus, split up by Season (Fall & Winter). Basemap by ESRI et al., 2018.

During spring, suitable habitat for juvenile *G. galeus* is generally predicted in close proximity to the coast. Suitable areas of high probability can be found along large stretches of the coast of Ireland, Southern England, Wales, Northern France, Belgium, the Wadden Sea, and near the Wadden Islands. The prediction of shallow depths (< 60m) and close distances to coasts as suitable habitat is reflected in the restriction to coastal areas. Mature *G. galeus*, on the other hand, are predicted to be find suitably habitats further offshore, in large areas between England and France, Ireland and England, and around Northern Ireland and Scotland. Also, their presence is predicted in smaller areas, scattered throughout the North Sea. It is noteworthy, that the predicted suitable areas coincide with the mixed sediment substrate type. The reason for this prediction can be found in the strong contribution of the substrate type predictor to the spring model, and the estimated preference for mixed sediments.

In summer, suitable habitat for juvenile *G. galeus* is predicted on the Dogger Bank, in large areas along the Danish coast, in the Southern North Sea, parts of the Wadden Sea, and in coastal areas all around Great Britain and Ireland (especially bays and estuaries). Similar to the spring model, the prediction of shallow depth and short distance to coast as suitable supports these findings. In contrast to the relatively wide spread of suitably areas for juveniles, suitable habitat of mature *G. galeus* is limited to a small area west of The Wash and the Humboldt Estuary in England. However, the Dogger Bank, as well as larger, offshore, parts of the southern North Sea are also predicted to be inhabited by mature *G. galeus* at a lower probability of presence. (Figure 7)

In fall, the predicted suitable area for juvenile *G. galeus* is especially widespread. It stretches from Birdlington Bay in Great Britain through the whole Southern North Sea over to Denmark, and includes large areas in the English Channel, as well as the seas around Ireland. Presence in the Wadden Sea is predicted with moderate probability. It is noticeable, that shallow as well as offshore habitats are predicted to be inhabited by juvenile *G. galeus.* The predicted suitable habitat for mature *G. galeus* coincides in some areas with the one for the juveniles. Suitable areas of high probability can be found in the Irish Sea and in the areas extending south from there, down to northern France. Furthermore, suitable habitat is predicted along the British west-coast, and with lower probability on the Dogger Bank (Figure 8).

In winter, the predicted suitable habitats of juvenile and mature *G. galeus* contrast each other. While suitable habitat of juveniles is predicted in large parts of the central and northern North Sea, habitat of matures is estimated to be found in similar areas as in spring (see above). Given the strong contribution of the substrate type predictor to both models, the high contrast is due to different substrate types being preferred by juveniles and matures. While juveniles are considered to find suitable habitat in areas with mud to muddy sand or sandy bottoms, matures are associated with mixed sediments (Appendix E). This explains the similarity with the spring model, where mixed sediments were also the preferred substrate type of mature *G. galeus.* (Figure 8)

A general pattern that differentiates suitable habitat between juvenile and mature *G. galeus* is the prediction of coastal areas as suitable areas. While suitable habitat for juveniles is usually predicted in proximity to the coast and in coastal water bodies like bays and estuaries, mature individuals are generally estimated to find habitat further offshore. (Figure 7 & 8)

The response curves support this finding by showing that shallower depth, and shorter distances to coasts are more suitable for juveniles. Furthermore, slightly higher SBTs (especially in summer) and lower salinities, compared to matures, indicate the general suitability of coastal areas. (Appendix E)

However, it needs to be kept in mind that offshore habitat is not estimated to be exclusively suitable for matures but instead also for juveniles (as predicted by the fall and winter models).

When comparing the predicted presence by season, shifts in habitat become obvious (Figure 7 & 8). The predicted suitable areas for juveniles extend from narrow bands along the coastlines of Great Britain, France, Belgium, The Netherlands, Germany and Denmark in spring further out into the open ocean in summer and fall, until offshore areas become prominent in winter. However, it can be seen that, except in winter, often similar sea areas are predicted to be suitable for juvenile *G. galeus,* only with a different extent into the offshore. These juvenile "hotspots" areas, with seasonally re-occurring suitability, are found along the coasts of the southern North Sea, the English Channel and Ireland, as well as in "The Wash" in England, and in the Bristol Channel. (Figure 11)

When looking at the changes in predicted presence of mature *G. galeus*, a very prominent detail is the similarity between the spring and winter map. This is due to the fact that in both models, mixed substrate and sand was the preferred substrate type, and the variable contributed strongly to the models (Appendix E & F). In these seasons, large areas around Great Britain, coastal as well as oceanic, have a high probability of presence. For the summer and fall models, the presence prediction shows no apparent patterns. (Figure 7 & 8)

3.2 Species Distribution Maps: *M. asterias*

Eight MaxEnt models were produced to model suitable habitat of juvenile and mature *M. asterias* in the Greater North- and Celtic Seas – one for each life-stage, per season.

All models yielded good to excellent results, with an AUC in the range between 0.846 and 0.988 (Table 4).

The salinity, the SBT, and the bathymetry were the environmental variables which were included in every model and could not be omitted without considerable drops in model performance. The distance to coasts predictor was important for modeling suitable habitat of mature *G. galeus*, but was not necessary in the juvenile models. The energy at sea bottom was an important predictor in all, but the fall model of mature *M. asterias*. The substrate type was of importance in the fall and winter models of the matures. (Table 4)

Similar to the *G. galeus* models, the CHL concentration, the DO concentration, and the SST could successfully be omitted in all models without causing serious AUC losses.

Table 4: Used Environmental Variables and the achieved AUC of the M. asterias SDMs, per life-stage and season.

Juvenile	Spring	Summer	Fall	Winter
Bathymetry	✓	✓	✓	✓
Distance to Coast	✗	✗	✗	✗
Energy at Sea Bottom	✓	✓	✓	✓
Salinity	✓	✓	✓	✓
SBT	✓	✓	✓	✓
SST	✗	✗	✗	✗
DO concentration	✗	✗	✗	✗
CHL concentration	✗	✗	✗	✗
Substrate	✗	✗	✗	✗
AUC:	0.977	0.972	0.846	0.979

Mature	Spring	Summer	Fall	Winter
Bathymetry	✓	✓	✓	✓
Distance to Coast	✓	✓	✓	✓
Energy at Sea Bottom	✓	✓	✗	✓
Salinity	✓	✓	✓	✓
SBT	✓	✓	✓	✓
SST	✗	✗	✗	✗
DO concentration	✗	✗	✗	✗
CHL concentration	✗	✗	✗	✗
Substrate	✗	✗	✓	✓
AUC:	0.958	0.988	0.979	0.938

Stacked bar-charts, showing the contribution of the utilized environmental variables to the individual models (Appendix F) indicate, that suitable habitat of juvenile and mature *G. galeus* is defined by similar environmental parameters.

The SBT is, for juveniles and matures alike, one of the most important predictors in all models. The contributions of the bathymetry, the salinity, the energy at sea bottom, and the distance to coasts predictors vary significantly between seasons and life-stages. However, there is no apparent pattern to these changes. The substrate type predictor, used in the fall and winter models of mature *M. asterias,* contributed with 2.6 and 0.1% (respectively) not substantially to the models.

Response curves for *M. asterias*, illustrating the suitable range within an environmental variable for all seasons and life-stages, can be found in Appendix D.

Similar to *G. galeus*, *M. asterias* shows, with a range between 14° and 29 °C, a great tolerance to changes in temperature. While the predicted suitable temperatures are similar for the juvenile and mature life-stage, there are considerable changes between seasons. In spring, temperatures around 18 °C are predicted to be most suitable. In summer, these temperatures are predicted to be much higher, with values ranging from 26° to 29 °C. In fall, colder temperatures in the range between 14° and 17.5 °C are estimated to be suitable. Controversy, in winter similar temperatures to those in spring are predicted to be suitable for both, juveniles and adults. This makes fall the season in which the coldest waters are predicted to offer suitable habitat.

The suitable salinity is predicted to range from 33 to 38 ppt for both, juvenile and mature *M. asterias.* Overall, juvenile and mature response curves show similar patterns with slightly lower

suitable salinities being predicted in summer (33-34 ppt) and fall (34-35 ppt) than in spring (36-37 ppt) and winter (35.5-36.5 ppt).

The depth preference of *M. asterias* is predicted to be similar between seasons, but not between life-stages. While depths from 25 down to 160m are predicted to be most suitable for juveniles, depths from 50m down throughout the range are estimated to be suitable for matures.

The response curves of the distance to coast show similar patterns for juveniles and matures, but differences between seasons. While areas in proximity to coast are most suitable for *M. asterias* in spring, summer and fall, habitats with two to three times the distance are predicted to be suitable in the winter models.

The energy at sea bottom predictor was excluded from the fall model of mature *M. asterias.* Habitats with low-energy conditions of less than 1600N m^2/s are predicted to be suitably for juveniles in all seasons. For mature *M. asterias,* low-energy habitats with less than 1000N m^2/s are predicted to be suitable in spring and summer, while high-energy habitats of more than 300N m^2/s are estimated as suitable in winter.
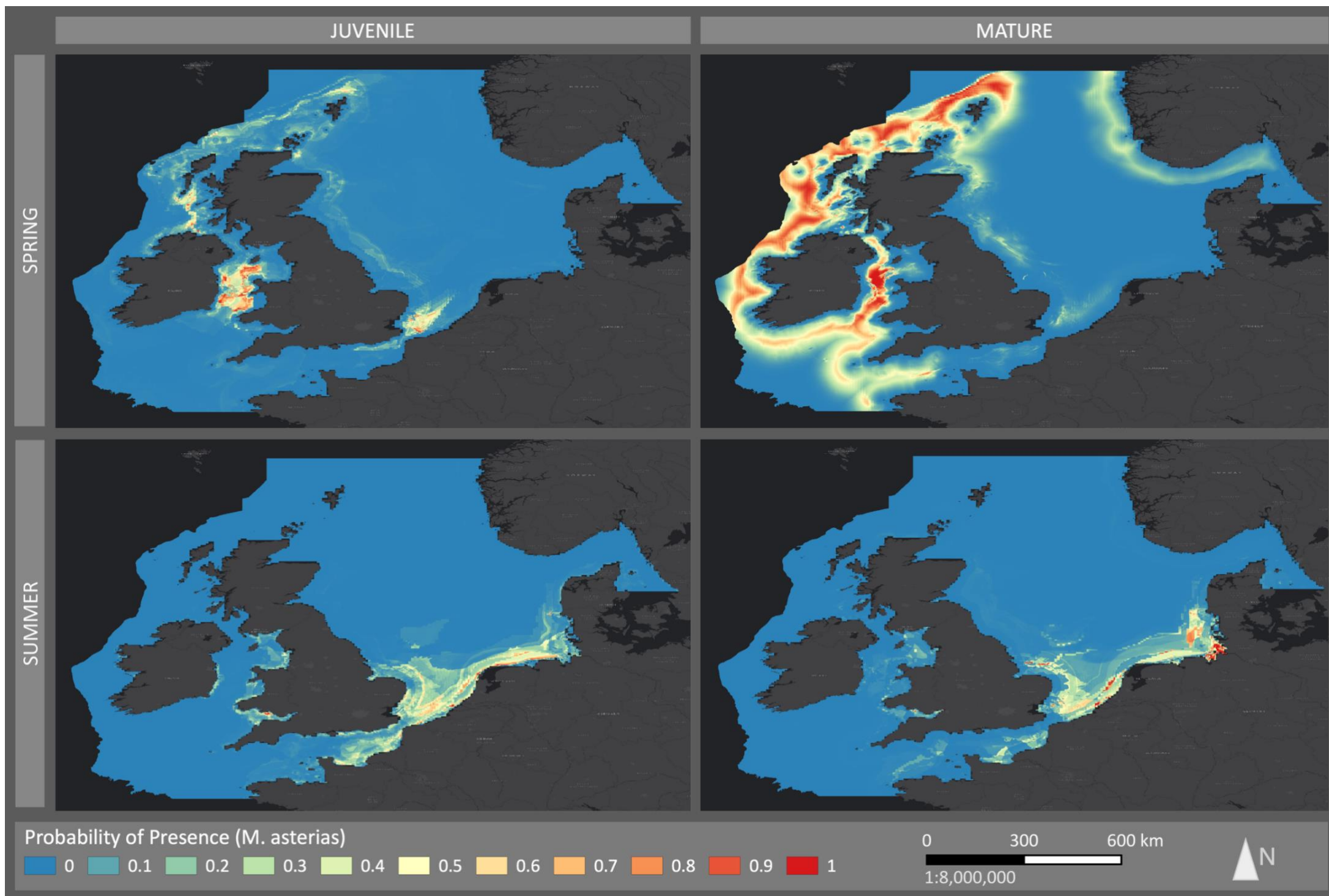
Figure 9: Species Distribution Maps of juvenile and mature M. asterias, split up by Season (Spring & Summer). Basemap by ESRI et al., 2018.
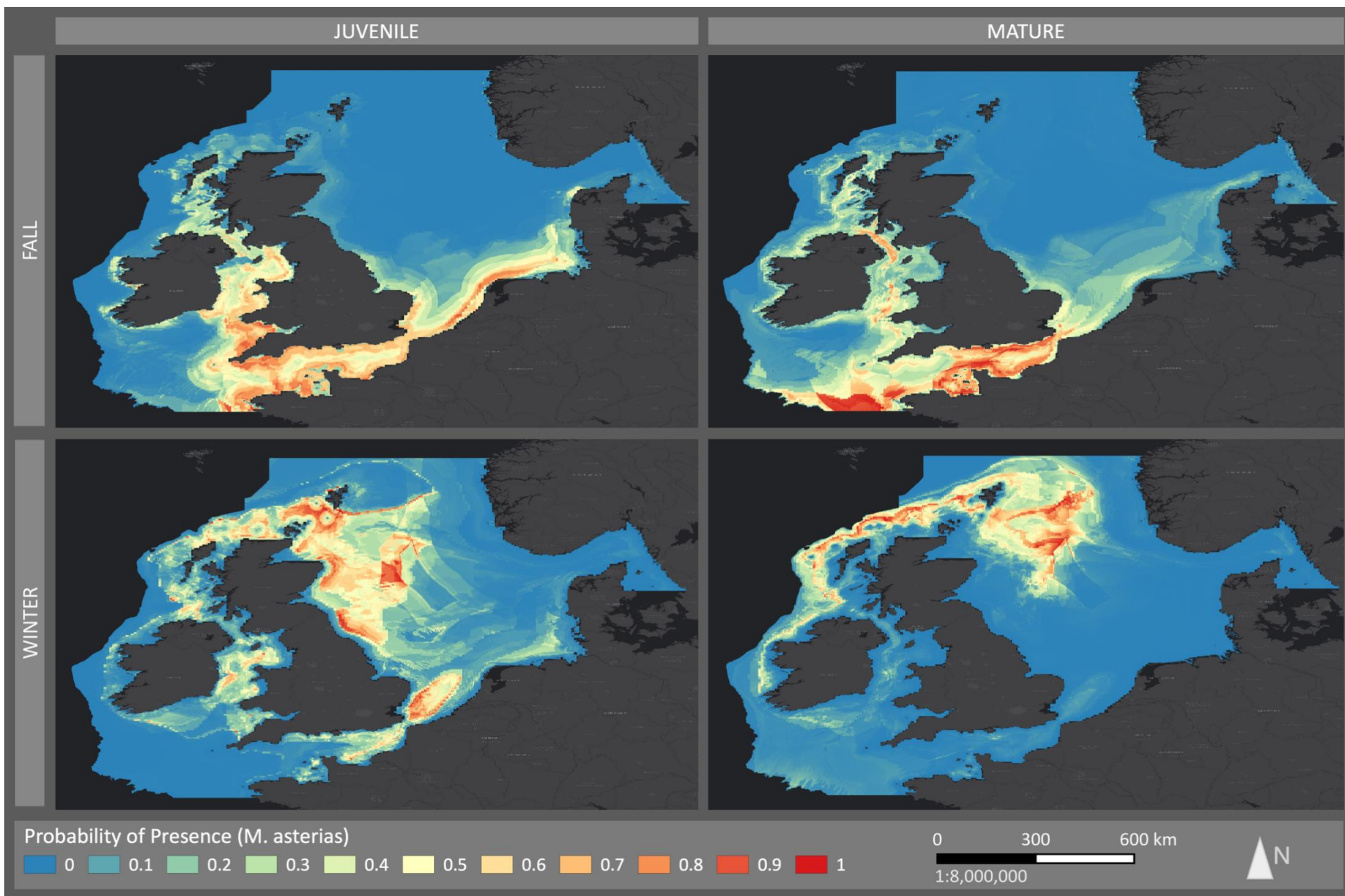
Figure 10: Species Distribution Maps of juvenile and mature M. asterias, split up by Season (Fall & Winter). Basemap by ESRI et al., 2018.

When looking at the predictions of suitable habitat for *M. asterias* (Figure 9 & 10), a general pattern shows that juvenile and mature habitat has spatial similarity in all seasons. However, differences in habitat among seasons are substantial.

In spring, *M. asterias* can be found in the central Irish Sea, along the northern coast of the UK, and from the English Channel extending into the southern North Sea. While suitable areas between juveniles and matures overlap, matures are predicted to find suitable habitat in a more widespread area than juveniles, including all waters around Ireland, and offshore areas extending down to northern France. (Figure 9)

In summer, suitable habitat is predicted to be found in coastal proximity in the Irish Sea, in the English Channel, and in the southern North Sea. Here, the Dutch and German coastlines (in front of the Wadden Islands) are predicted with high probability as suitable habitat. (Figure 9)

In fall, the prediction of suitable habitat is similar to summer, but shifts further down from the southern North Sea into the English Channel. Furthermore, Welsh waters, as well as great parts of the Irish Sea and the waters extending up north along the Scottish coastline are predicted to offer suitable habitat for *M. asterias.* (Figure 10)

In winter, suitable habitat is predicted further north, and to differ marginally between juveniles and matures. Generally, *M. asterias* can be found around Ireland, off the Scottish north-coast, and around the Shetland Islands. While matures are predicted to find habitat in the central northern North Sea, juveniles are expected to also use waters in closer coastal proximity to the British west coast, down to the Humboldt Estuary, as well as the English Channel and waters extending from there into the southern North Sea. (Figure 10)

Response curves (Appendix D) of the distance to coasts support the prediction by showing that in winter habitats further offshore are predicted as suitable than in other seasons. While most parameters show similar suitability ranges for juveniles and matures, differences can be found in the energy at sea bottom variable. While juveniles are estimated to find habitat in low-energy areas with forces lower than 1500N m^2/s, mature *M. asterias* are estimated to tolerate high-energy conditions throughout the range.

When comparing the predictions of suitable habitat for juvenile and mature *M. asterias* in each season, there is no striking difference in habitat usage between the life-stages. Generally, similar sea areas – varying by extent – are used by both, juveniles and matures.

However, even though seasonal differences in the prediction of suitable habitat are very prominent, some suitable areas show overlap in all seasons. These annual "hotspots" can be found in parts of the southern North Sea, the English Channel, and the Irish Sea (Figure 12).

3.3 Review of EU Shark Management and related Parent Policies

3.3.1 Management of G. galeus

The global population of *G. galeus* is assessed as *'Vulnerable'* by the IUCN Red list (Walker *et al.*, 2006). The species was historically exploited throughout its range and stock collapses in e.g. California and South America shed light on the proneness of the species to over-exploitation. Nowadays, *G. galeus* is only of low importance for commercial fisheries in the NEA, but is regularly caught as by-catch of demersal as well as pelagic fisheries, especially in the English Channel. Furthermore, the species is popular in recreational fisheries (ICES, 2017b). Main threat to *G. galeus* as by-catch is seen in gillnets, whose by-catch with smaller mesh size also frequently includes juvenile specimen, and longlines as well as on a secondary note also by trawl fisheries.

Data on *G. galeus* used to be generalized and often identification grouped the species together under dog- or houndfish-like species. Biological data in the early part of the century were generally limited (Walker *et al.*, 2006), but is increasingly available for EU waters by means of ICES stock assessments.

At the CITES Conference of the Parties 13 in 2004, the CITES Animals Committee had specific recommendation regarding *G. galeus* (Walker *et al.*, 2006), as to ensure that international trade does not affect the status of the species in a harmful manner.

Fisheries regulations for *G. galeus* partly exist for EU waters, currently amended by the Council Regulation (EU) 2018/120, still features a 0-TAC for *G. galeus*.

> **Box 1: ICES Advice**
> In 2012, ICES provided advice on the allegedly single *G. galeus* stock in the NEA:
> *"Based on ICES approach to data-limited stocks, ICES advises that catches should be reduced by 20%. Because the data for catches of tope are not fully documented and considered unreliable (due to the historical use of generic landings categories), ICES is not in a position to quantify the result. Measures to identify pupping areas should be taken"* (ICES, 2017b)

However, this only takes effect when caught by longline within ICES regions division 2 a and subarea 4 as well as in the waters of ICES subareas 1, 5, 6, 7, 8, 12 and 14 (EC, 2018a).
Exclusively for British fisheries, the '*Tope Order'* limits fishing gear for *G. galeus* to rod and line, and introduces a by-catch limit for commercial fisheries (Sea Fisheries England, 2008).
International fisheries regulation for *G. galeus* can be found in Australia (Box 2), where the species is managed for several years, also under the aspect of exploitation.

> **Box 2: Australian *G. galeus* (vernacular: School shark)**
> Next to Australia and New Zealand, there are only few provisions made for the protection or the regulated exploitation of the species. Conservation of *G. galeus* in Australia has history and was recently revised by the Stock Rebuilding Strategy 2015 (AFMA, 2015). The strategy was built around measures such as the closure of areas important for pups and breeding *G. galeus*, the reduction of fishing- and by-catch limits, gear restrictions as well as the improvement of knowledge, data collection and monitoring.
>
> Throughout the development of the strategy fishing pressure was identified as one of the main threats. *G. galeus* have proven to be prone to gillnets and incidental by-catch. Next to fisheries, habitat degradation ought to have contributed further to the decline in *G. galeus'* recruitment and recovery. Biomass in Australia was assessed based on the number of annual pups (up to one year of age). However, focus was put on large breeding age females to promote stock recovery. Pupping grounds, identified through research, were consequently closed to fishing. Later on,

additional areas were closed for specified gear (e.g. were gillnets banned from depths deeper than 183m and automatic longlines in waters shallower than 183m). Other gear restrictions for specific regions included shark longline and shark hook gear. Mesh sizes of 152 to 165mm were assessed to safely deflect larger specimen such as breeding females and smaller sharks, however not middle-sized individuals. By-catch in longlines was tackled with gradually reducing line hooks (max. 15,000 hooks per vessel). TACs were established for *G. galeus*, and other shark fisheries where the species is a frequent by-catch. Further, retaining sharks of less than 450mm was prohibited to prevent the targeting of juveniles.

The recent revision notices, that measuring abundance and thus monitoring the rebuilding strategy remains a challenge. It is acknowledged that depending on the targets rebuilding a stock could take several generations.

3.3.2 Management of M. asterias

The population status of *M. asterias* is assessed as '*Least concern*' by the IUCN Red list (Serena *et al.*, 2009) but for EU waters was revised for 2015 as '*Near threatened*' (Nieto *et al.*, 2015). The species is of commercial interest, especially in the Mediterranean, but is often discarded in the NEA. The species, which is considered to be a single stock in waters north of Spain, is often taken as seasonal by-catch by trawl and gill nets. However, *M. asterias* is also of commercial interest, as well as recreational interest in sport fisheries throughout the broader English Channel.

Besides protection measures for the Balearic Island marine reserve for *Mustelus spp.*, no species-specific measures for *M. asterias* are in place (ICES, 2017b).

> **Box 3: ICES Advice**
> ICES advice for the years 2012, 2013 and 2014 (which was also suggested in 2015): *"Based on ICES approach to data-limited stocks, ICES advises that catches should be reduced by 4%. Because the data for catches of smooth-hounds are not fully documented and considered highly unreliable (due to the historical use of generic landings categories), ICES is not in a position to quantify the result".*
> The lack of data prompted ICES to explicitly advice for a precautionary approach to fishery limits concerning starry smooth-hound. (ICES, 2017b)

3.3.3 Review of EU Shark Management and the MSFD

A complete inventory about policies directly and indirectly affecting shark management in the EU can be reviewed in Appendix G.

On international level there are several multilateral conventions to which the EU or Member States are contracting- or signatory party, which put sharks (usually on class level) under protection. Thereunder, the United Nations Convention on the Law of the Sea (UNCLOS), the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), the Convention on the Conservation of Migratory Species (CMS), and the Convention on Biological Diversity (CBD). Shark species are further included in provisions made by the Convention on the conservation of European wildlife and natural habitats (Bern Convention), the for EU waters most relevant Regional Fisheries Management Organization (RFMO), and the International Commission for the Conservation of Atlantic Tuna (ICCAT) which stands in close cooperation to the United Nations Food and Agriculture Organization (FAO) and deals with records and reports of fisheries data as well as the protection of tuna and tuna like stocks, including sharks. Species protected under those and other agreements are summarized in Appendix H.

However, the majority of the current species protected or listed under those multilateral agreements are often large oceanic species with highly migratory behavior. Moreover, although those often binding conventions are in force for many years, they are rarely enforced in its entire potential, and neither put much emphasis on regional regulation, nor comprise distinct shark populations for specific regions or at all list many coastal- or demersal sharks species.

Nevertheless, since the exploitation of marine resources has become a universal problem through the degradation of marine environments and resources, the need for sustainability in fisheries, and the need for science to enable management (Cowan *et al.*, 2012) was increasingly acknowledged throughout currently amending agreements and regulations in both, industry and environmental protection policies. Therefore, regarding the use and exploitation of biological resources, an ecosystem- and/or precautionary approach is advised in most of the recent EU policies, including the recent CFP reform. Hereby, the cross sectoral coherency in order to implement successful integrative maritime policy (IMP) under the overarching goal of the EU IMP stands central. Currently, in unifying ambitions for environmental development across most sectors of marine policy, the MSFD is deemed as instrumental and could provide a platform to integrate adaptions to current shark management.

Management of shark species, whose ecological role in EU waters is acknowledged, can and should have a part within this broad ambition.

To this day, finding shark specific management within these ambitions to a coherent and sustainable approach for EU marine environmental management is hard because sharks are rarely represented. For example: Although the EC Habitats Directive and derived policies are far reaching instruments in EU environmental policy, the provisions are rarely fully implemented. Most concerning, no threatened shark species are mentioned in any of the annexes of the Directive. Further is the implementation of 'favorable conservation status' for species and habitats, mentioned as overarching aim of the Directive, still be progressed.

The limited success of past management approaches for sharks through the United Nations Food and Agriculture Organization International Plan of Action Sharks (Fischer *et al.*, 2012) shows, that implementation of successful management depends on a range of factors. A lack of scientific data considering shark specific biology and stock status, as well as the absence of shark-specific measures in national fisheries management, coupled with too costly measures, and inadequate political attention to shark conservation in general, hampered the implementation of a successful frame work for shark conservation. In the EU, the complete implementation of the derived EU Action Plan for the conservation and management of sharks (EUPOA) represents another challenge in enforcing science-based limitations for shark fisheries and protecting endangered species (Fischer *et al.*, 2012).

Shark fisheries management within the EEZs and the high seas represents one of the most important conservation tools for shark populations (Fowler, 2014). Limiting fishing effort (through the reducing of annual TACs on specific species and/or by-catch fisheries) can play a key role and immediate measure for gradually reducing incidental catches. Similar importance should be given to fishing selectivity and the adaption of fishing gear, as well as to regulations regarding the handling of by-catch and incidental boarded shark species. Fisheries regulations considering sharks exists, and few 0-TACs were established. OSPAR, however, criticizes the applied by-catch measures as not effective, and points out that the awareness and catch identification regarding sharks is unsatisfying (OSPAR, 2010). This is a common issue which is also addressed e.g. by EUPOA sharks and which can facilitate the commercialization of threatened species under false assumption or pretense. It has however to be acknowledged, that data on shark species is barely available, and in

sufficient scale only accessible through cooperation with commercial fisheries. This situation still impedes certainty about shark distribution.

It has to be noted that EU shark fisheries management might be most deciding in top shark fishing Member States, for which (in the EU) Spain is the most accountable (EC, 2016). The ecosystem approach to fisheries of the CFP is, however, still prone to critic. Although several stocks experienced recovery after the introduction of the Maximum Sustainable Yield (MSY), up until recently still 40% of the fish stocks, notably for which sufficient data is available, are fished at capacities exceeding MSY goals (Salomon *et al.*, 2014). This attenuates the CFPs ambitions for establishing sustainability also in line with expressed goals, pursued to contribute to achieving GES under the MSFD.

The way to a meaningful reduction of shark fisheries in a major industry such as the Spanish one might be steep, but the conservation of species through spatial protection of important habitats, such as nurseries, could have a positive effect for the targeted shark stocks by increasing population stability and reproductive capacity.

Protecting marine space as essential habitats for specific species is an integral part of an ecosystem-based approach and such measures are pursued by both, the Habitats Directive and (more recently) the MSFD. Therefore, the achievement of the overall objective of the Directive – a GES of the European marine environment – has to be facilitated also by the use of spatial protection measures such as MPAs. The MSFD can be considered as the most potent instrument to provide initial improvements for EU shark management, as it unifies ambitions for the development of EU environmental management across the marine sector.

> **Box 4: MSFD-spatial protection**
> *"It is crucial for the achievement of the objectives of this Directive to ensure the integration of conservation objectives, management measures and monitoring and assessment activities set up for spatial protection measures such as special areas of conservation, special protection areas or marine protected areas" (EC, 2008a, p. 21)*

Establishing and increasing the amount of MPA surface in the EU by means of integrating essential shark habitat within those ambitions could comply with these environmental and community goals. Prerequisite however, for benefits for shark, or sharks as part of a functional ecosystem group such as elasmobranchs would be the integration of such in GES ambitions of the MSFD.

Complementing ambitions for EU spatial management can be reviewed in Appendix I.

3.4 Advice for the development of shark management under the MSFD

The MSFD (Appendix G) requires Member States to develop National Marine Strategies, which assess the current status of the marine environment, provide definition of national GES, and lay down a set of environmental targets as well as pressures that have to be tackled to devise sound Marine Strategies. These definitions are then adopted in national "Program of Measures" (PoMs), which lay down the strategy to achieve a GES. The Directive hereby explicitly urges the integration of spatial protection measures within National PoMs to contribute to a network of MPAs, as well as to special areas of conservation.

According to the Commission Assessment on National Marine Strategy development (EC, 2008a, Article 12), sharks are mentioned specifically or as part of elasmobranchs only by The Netherlands and Spain within the 'environmental targets and indicators' as "*fish species with a long-term negative trend in population size and fish species with a low reproductive capacity (i.e. skates, rays and sharks)",* and by the UK as being a functional group and acknowledged representative for the lack of higher trophic level organisms within the national strategy. (Dupont *et al.*, 2014)

Besides that, Member States rather made use of qualitative assessments and often retained GES definition on descriptor level as provided by the Directive instead of formulating nation specific and measurable goals. Although a major goal of the Directive was to establish a coordinated framework, only little coherence was found in the first development phase of the MSFD throughout the NEA marine region. This also covers the coherence among national strategies, concerning the definition of GES in regard to Biodiversity descriptors (D1), which is assessed as low (Dupont *et al.*, 2014).

Nevertheless, a more recent review of the national PoMs under Article 16 of the Directive (Dupont *et al.*, 2017a,b; Dupont *et al.*, 2018a,b,c,d) specifically addressed the implementation of spatial protection areas and marine protected areas. As a point of advantage, it has to be noted that all Member States (BE, FR, NL, IE, UK, GER) with direct relevance for identified juvenile hotspots mention spatial management in their PoMs. Above all, also five (BE, FR, NL, IE, UK except for GER) from the six Member States with direct relevance for seasonally important habitat, mention sharks, mostly as part of elasmobranchs or top-predators, in their PoMs (Table 5). This delineates sharks to some degree as an indicator for a 'good marine environment' for 'biodiversity descriptors' (D1, 4, 6) under the MSFD.

Table 5: Irish and UK ambitions for spatial protection and sharks within national 'program of measures'

Member State	Spatial targets	Shark targets
Belgium (BE)	Belgium has devised several measures that affect its MPAs thereunder considering sandbar habitats and a ban on fishing with entanglement nets on the beach. (Dupont *et al.*, 2017a)	Belgium formulated a measure 'Specific approach to sharks and rays under descriptors of D1, 4 and D3, encompassing the reduction of biological disturbance, extraction of species and to conserve marine ecosystems. (Dupont *et al.*, 2017a)
France (FR)	France aims to increase their MPA coverage to an overall 20% in 2020. This has to be achieved through the assignment of new areas representing ecological coherency. The aim is to protect endangered species and habitats including those under the Habitats Directive, OSPAR and IUCN Red List. (Dupont *et al.*, 2018d)	France does not mention sharks specifically, however refers to top predators and under Food web descriptor D4 to preserve the top predators in the trophic chain, indicated by the generalized performance of key predator species as well as considering trends in species abundance or biomass. (Dupont *et al.*, 2018d)
Ireland (IE)	Ireland appoints itself to its extant network of MPAs for the importance to achieve 'biodiversity' targets. While not planning on specific extension of network, Ireland aims at developing fisheries management measures within the six nautical mile limit and outside that range as well as to ensure that the current network is coherent and representative. (Dupont *et al.,* 2018a)	Irish measures aim to further develop actions against shark finning practices (M054) at sea and unspecified other measures for the conservation of sharks. Measure M064 aims to further support effective shark conservation in alignment with the EUPOA. Both are addressed under the 'biodiversity' descriptors D1, 3 and 4, applicable for Irish coastal, territorial and continental shelf waters. (Dupont *et al.*, 2018a)

United Kingdom (UK)	The UK aims to identify new spatial protection measures in scope of the MSFD, in order to contribute to a coherent network of MPAs. (Dupont *et al.*, 2018c)	Sharks under biodiversity descriptors D1 and 4. Including measures that address human impact on fish communities, the reduction of fish biomass and distribution and the combination of MPA and fishery measures to target sensitive species such as sharks. Therefore, the UK refers to Shark Action Plans, current finning regulations and international conventions such as the CMS. (Dupont *et al.,* 2018c)
Germany (GER)	Germany deems current coverage of MPAs as sufficient to comply with the MSFD and no added areas are planned. Nevertheless, Germany addresses the development of new spatial protection measures under the environmental descriptors 'biodiversity' and 'food webs' in order to protect migratory species in the marine environment by means of restricted or priority areas for (amongst other) migratory marine fish. (Dupont *et al.,* 2017b)	Sharks are not mentioned by Germany's PoMs to achieve a GES, but Germany generally refers to the expand of its marine protected areas as sufficient to achieve GES. (Dupont *et al.,* 2017b).
The Netherlands (NL)	The Netherlands put emphasis on further developing protection measures for Natura2000 sites and areas protected under the Habitats Directive, especially to limit human impact. Also, they put focus of spatial protection on seabed habitats and associated trawling disturbance through seabed fishing. (Dupont *et al.,* 2018b)	Environmental targets (Target 1b) address 'biodiversity' and 'marine food webs', stating to improve size, quality and distribution of vulnerable fish species including species with a low reproductive capacity such as sharks and rays. Another target (1i) addresses the reduction of human intervention on trophic level interactions, which considering that sharks play an essential role within those dynamics should specifically be relevant for large predators such as the target species. A third target (1c2), refers to sharks which are fished in the EU and whose stocks should be rebuild or be recovering in line with the EUPOA. Here, it is explicitly mentioned that the range of this target is cross-national. <u>Indicator</u> for all targets are assessed through population size, distribution, and condition of sharks and migratory fish. (Dupont *et al.,* 2018b).

Overarching to this advice stands the assumption of mere potential habitat, as uncertainty in the modelled distribution has to be acknowledged.

On a first note, sharks as integral part of marine environment and food webs should be considered in a healthy marine environment and thus be mentioned on species or class level within the goals of the MSFD for reaching a GES of the marine environment. This can be achieved by including population status of specific species, or species under a functional group as indicators for reaching environmental targets for MSFD Descriptors such as D1: Biodiversity (which for many Member States includes D4: Food web- and in cases D6: Sea bed integrity), with preference by means of

quantitative goals. On the basis of MSFD ambitions to achieve a GES, and including sharks by means of the addressed targets and measures it is assessed that sharks are only covered sufficiently by the Netherlands to develop immediate management measures. Therefore, the Dutch Marine Strategy is seen as vantage point for ambitions in shark management throughout the EU. The strategy should, in regard to shark management, as far as possible be adopted by all here concerned Member States (BE, FR, IE, GER, UK), for reasons of coherency in management of shared coast lines and coastal waters.

Acknowledging that overall coherency in developed National Marine Strategies is highest in the implementation of developing spatial protection measures and marine protected areas, spatial protection is the focal point of the given advice.

Advice for spatial protected areas and MPAs:

Based on the modelled spatial distribution of juvenile sharks, including ecological assumptions and spatial management ambitions of the spatially involved Member States, it is suggested to introduce protected areas or MPAs. The created hotspot maps delineate essential habitat for five (BE, FR, IE, NL, UK) of the six Member States with seasonal habitat importance.

For *G. galeus,* this includes displayed coastal hotspot habitat (Figure 11) of high probability of presence (>0.75 or 75%) in territorial waters of IE, UK, FR, BE and some extend NL.

Hotspots for juvenile *G. galeus* are found in coastal proximity in ICES subareas: The Southern North Sea (4c), the Eastern English Channel (7d), the Irish Sea (7a) and the West of Ireland (7b).
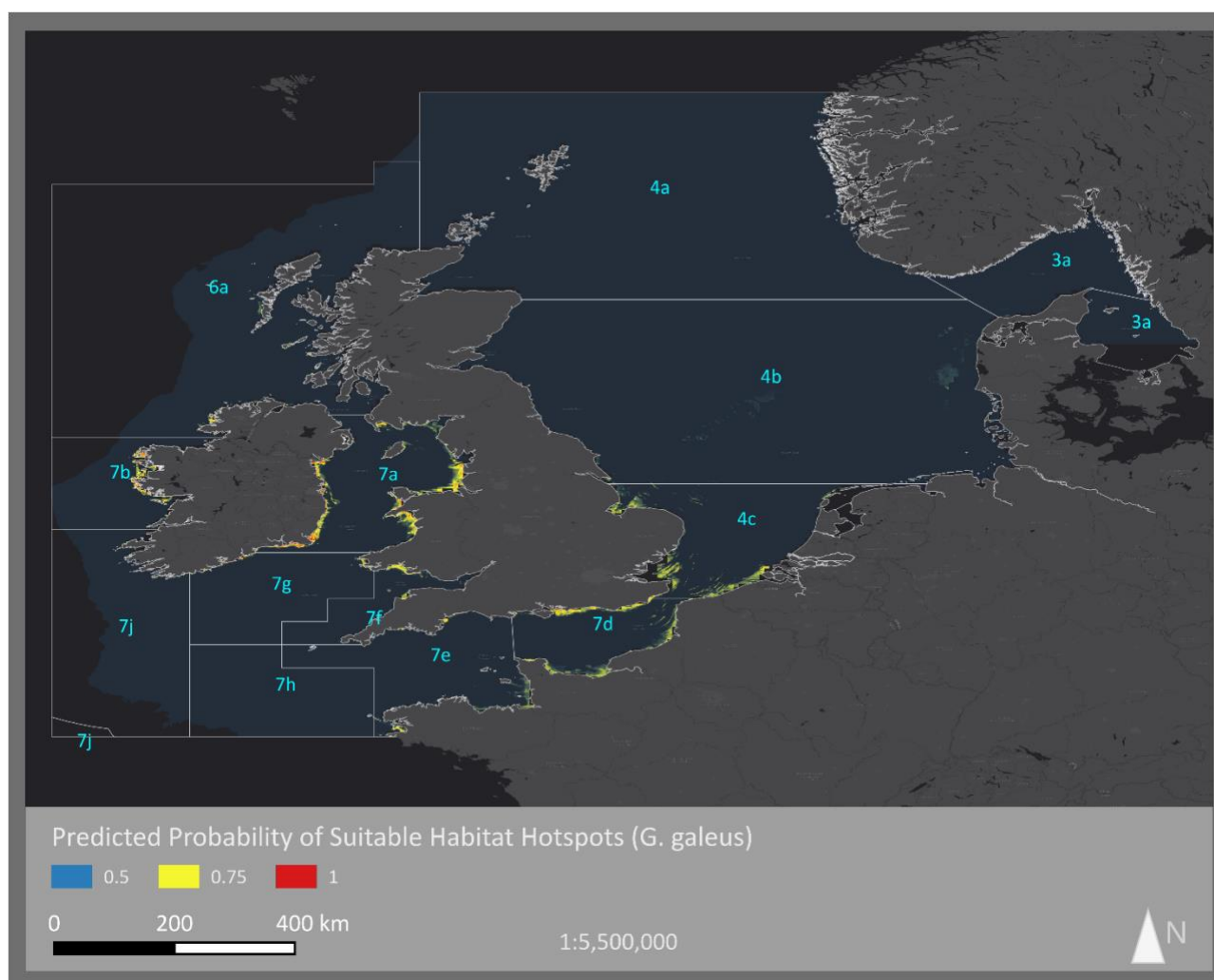

Figure 11: Average annual probability of presence for juvenile G. galeus. Basemap by ESRI et al., 2018.

For *M. asterias,* advised protected areas and MPAs include mapped coastal habitat with high probability of presence (>0.75 or 75%) in EEZ waters of IE and UK as well as BE and partially FR. It is to be noted that through large indifference from assumed juvenile and mature habitat both population groups are included in the determination of the hotspot regions for *M. asterias*. Hotspots for the mixed population of M. asterias include the ICES subareas: The Southern North Sea (4c), the Eastern English Channel (7d) and the Irish Sea (7a).
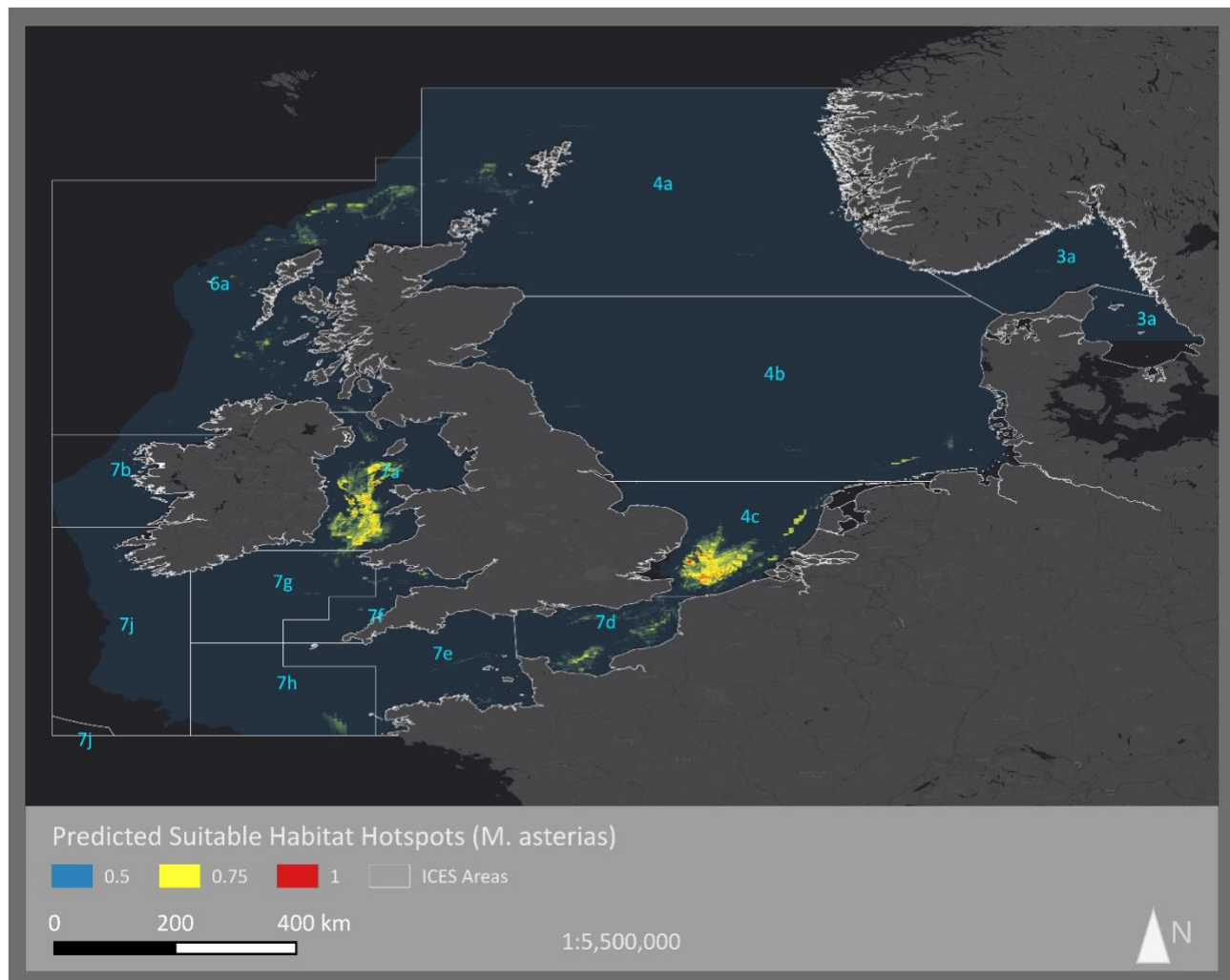
Figure 12: Average annual probability of presence for juvenile and mature M. asterias. Basemap by ESRI et al., 2018.

Protected areas and MPAs for hotspots should be designed following suggestions of the recent report of the European Environmental Agency (EEA, 2015). Delineated areas should be well enforced, possibly no-take zones, at least cover 100km^2 in size and be well monitored through time.

The hotspots provided by this study could be implemented by instruments with aim for species and habitat protection such as the Habitats Directive, which is mentioned to facilitate the environmental goals of the MSFD. The objectives of the Habitats Directive, including the reduction of mortality and protection of habitat and temporary habitats such as areas with regard to breeding, rearing or migration (EC, 1992, Article 12), can alongside the declining conservation status of *M. asterias* (to 'Near threatened' in 2015) provide justification for the inclusion of a first shark species such as the target species in the Annex II or IV of the Directive.

Ideally, already threatened species such as *G. galeus* (IUCN status *Vulnerable* is within the overarching category for threatened species) would be included in the OSPAR list of threatened and/or declining species. This could initiate the protection of the species under stricter EU law, and promote their accommodation in the OSPAR MPA network in the NEA in order to prevent further degradation of the species and its habitat under a precautionary approach and/or to protect and even restore the species and its habitat (OSPAR, 2017). Already in 2012, OSPAR, which lists several shark species, attempted to increase ecological coherence in its MPA network. However, due to a lack of species distribution- and habitat data no comprehensive conclusions could be drawn (EC, 2015). For the improvement of the situation, OSPAR deemed comprehensive species records necessary, for which the data provided of contracting parties was prior to that insufficient. OSPAR specifically required polygon data on the distribution of its listed species (OSPAR, 2013), which can be derived from here illustrated distribution data and thus pioneer the implementation of management for this threatened shark species. All of this adds to the actions for protecting sharks, as required by the OSPAR Quality Status Report (OSPAR, 2010) (Appendix G, Box 3).

Advice for fisheries regulation in protected areas:
Verifying the here identified juvenile habitat, which can possibly contribute to population stability of important marine biological resources, could provide an incentive for the fishing industry to accommodate considerations for the adaptation of industrial and recreational fisheries regulation in those areas.

Protected area or MPA regulations should put emphasis on trawl- and gill net fisheries as those pose the most serious threat to juvenile *G. galeus* and *M. asterias*. While no-take zones for fisheries would be ideal, the use of physically disturbing fishing practices by trawling should further be reduced, as pursued e.g. for ecological sensitive areas by The Netherlands (Dupont *et al.*, 2018b). Also, passive fishing methods such as gillnets should be strictly regulated in delineated hotspots. For gill nets a general ban in *M. asterias* hotspots is advised as including a mixed population of juveniles and mature specimen. Gill nets in exclusively *G. galeus* hotspots should only allow the use of mesh sizes of 152 to 165mm to protect possible neonates from increased early mortality through by-catch in passive gear is advised.

For both species, juvenile retainment on board should be prohibited for individuals measuring 450mm or less. Handling advice should include an exception from the landing obligation for incidental by-catch in non-target fisheries for alive- and all fins attached individuals, under consideration of high survival rates of sharks. This suggestion however should follow a study with aim to ascertain discard survival of juvenile and mature individuals of *G. galeus* and *M. asterias*.

The fishing industry under the CFP has expressed the need for sustainability in fisheries repeatedly, also stating to reduce mechanical impact of fishing gear in- and outside protected areas and to implement additional measures to protect sensitive habitats, "when awareness about such habitats emerges" (EC, 2008b). The here proposed advice contributes to the awareness of sensitive habitats in the EU and provides an opportunity for fisheries regulation to comply with its ambitions for spatial environmental protection.

Additional advice:
On another note, many states also refer to OSPAR which could be an opportunity to create actual awareness for threatened species through its range in the NEA when included in the list of threatened and declining species. For *G. galeus,* currently included in a 'threatened' category under the IUCN Red List assessment, this could be applicable by preference for OSPAR region II.

It is additionally advised for the implementation of measures to tackle the frequent misidentification of species in order to enable accurate stock assessments and monitoring,

especially of *M. asterias.* This is because the species is still commonly mistaken as its Mediterranean sister genus *M. mustelus (and vice versa),* when not simply recorded as hound shark or dogfish, which is also problematic for caught and recorded *G. galeus*. This could include lecturing and/or educational workshops and programs aiming at fisheries of the designated hotspot regions and would benefit the generation of fisheries data and derived fisheries management.

4. Discussion

This study was conducted in order improve management of sharks in the Greater North Sea and adjacent Celtic Seas, by predicting essential habitats of *G. galeus* and *M. asterias.*

Patterns in the Prediction of Suitable Habitat for G. galeus
The assumption that *G. galeus* uses dedicated nursery areas is supported by the prediction that juveniles generally find suitable habitat in other areas than matures. While juveniles are expected to find habitat in relatively shallow (< 85m), low-energy (< 500 N m^2/s) areas in proximity to the coastline, matures are predicted to find it within wider depth-ranges, under low- as well as high-energy conditions, and further offshore. The limitation of suitable habitat to low-energy areas for juveniles supports the thesis that *G. galeus* uses sheltered marine areas such as bays and estuaries as nurseries.

However, the SBT and salinity, which were of high importance in the majority of the models, do not explain the large differences in suitable habitat between juveniles and matures, as they were predicted to be similar for both life-stages in each season. Also, seasonal migrations cannot be readily explained by these variables, as habitats with varying SBTs and salinities are inhabited in the different seasons. This gives reason to believe, that the environmental parameters used in this study cannot determine all mechanisms driving the behavior of the species. Presumably, other environmental variables, which are not readily accessible in the form of GIS data, might play an important role in the determination of suitable habitat. For example: The abundance of prey and the presence/absence of predators are variables which are often considered to have a strong influence on the distribution of juveniles (e.g. Heithaus *et al.*, 2009), but could not be assessed during this study. Considering that abiotic factors often act as proxies for biotic variables and movement (Schlaff *et al.*, 2014), this study might provide a valid indication of suitable habitat, while not being able to determine the direct mechanisms that drive the distribution of *G. galeus.*

Considering the habitat suitability maps of *G. galeus*, another prominent abnormality can be observed in the winter model of juveniles, and the spring and winter models of matures. Due to the strong contribution of the substrate type predictor to these models, the predicted habitat suitability depicts the "mud to muddy sand" and "sand" sediment classes in the juvenile winter model, and the "mixed sediment" and "sand" classes in the spring and winter model of mature *G. galeus.* Given the broad-scale, categorical sediment data, and the low number of presence records (n<25) for these models, it can be expected, that this pattern might solely be due to chance. Therefore, these models are expected to deliver a poor predictive performance, even though the AUC indicated a moderate model performance in the winter model of juveniles (0.793) and a good model fit for the spring model of matures (0.897). To assess whether a true sediment preference is present, or if these findings are an artifact of modelling, further research is necessary.

When disregarding the unsatisfying winter model of juvenile *G. galeus*, "hotspot areas", which were predicted to be suitable throughout the year, could be identified for juveniles.
These areas can be found along the coasts of the Irish Sea, the eastern English Channel, and the southern North Sea, as well as at the north-west-coast of Ireland. Furthermore, some areas near the Wadden Islands seem to play a role. Unfortunately, the habitat suitability of the Wadden Sea could not be fully assessed due to the unavailability of remote-sensing data (CMEMS) for dry-falling areas, and the under-sampling of species presence the area. However, the here modelled indication that *G. galeus* finds suitable habitat near, and in parts of, the Wadden Sea area, especially in spring and summer, is supported by a recent increase in catches in the area (Walker (NEV), personal communication, n.d., 2018). Furthermore, this study supports the thesis by

Leopold & Baptist (2016) that juvenile *G. galeus* may inhabit the areas in between the Wadden Islands, as suitable habitat is predicted near the Dutch Wadden Islands throughout the year.

A point of discussion for determining hotspots is that the predicted suitable habitat for juveniles often extended vastly beyond these areas in the different seasons, and that the low quality of the winter model introduced a margin of uncertainty for determining these permanent hotspot areas. Further research is necessary to resolve the high uncertainty in the unsatisfying models, and to validate the findings of this study, especially in regard to the Wadden Sea.

Patterns in the Prediction of Suitable Habitat for *M. asterias*

For *M. asterias*, the predictions of suitable habitat for juvenile and mature individuals do not differ significantly. Similar areas – varying by their extent – are inhabited by both life-stages in each season. However, a north-south migration pattern for the presumably mixed stock can be observed for *M. asterias* when comparing suitable habitat among seasons. The suitability maps indicate, that the species migrates from its winter habitats in the northern North Sea down south along the east- and west-coast of the UK in spring, until it reaches its summer habitats in the eastern English Channel and southern North Sea. In fall, the pattern is reversed, with suitable habitat being predicted in the western English Channel, and further North in the Irish and Celtic Seas, as well as alongside the British east-coast.

This study supports the in ICES (2017b) described utilization of the Southern North Sea as summer habitat, and parts the English Channel as winter habitat by predicting the areas as suitable in spring and summer, or fall and winter, respectively.

The response curves show that in winter higher SBTs (17°–19°C) are predicted to offer suitable habitat than in fall (12°–17.5°C). This suggests a temperature-induced south-north migration which is initiated when a certain low-temperature threshold is reached during the cooling of the seas after summer. Depth, salinity and sea bottom energy ranges remain similar between seasons, indicating that *M. asterias* inhabits ecologically similar habitats while migrating with changing SBTs. While this study might provide an indication of such a migration pattern, research is necessary to provide further scientific evidence.

Given that the predicted suitable habitats of juveniles and matures generally coincide, a nursery concept cannot be applied for *M. asterias*. However, although the predicted suitable habitats differ substantially between seasons, they partially overlie each other. Hotspots areas, such as the southern North Sea, the eastern English Channel, and the Irish Sea are (on average) predicted to be suitable throughout the year. This result suggests that the area is of particular importance for the species, and that the reason being should be further investigated.

The suitable habitat which is predicted in this study agrees with the presence of *M. asterias* at the south-coast of England, the Bristol Channel (in fall) and partly for the outer Thames estuary throughout the year, as described by research of Ellis *et al.* (2005). Assumptions by Farrell *et al.* (2015) for pupping areas of *M. asterias* offside Holyhead, Wales are reflected in the general importance of the Irish Sea for the species. Similarly, the assumption that the area of the Westerschelde estuary is an important habitat for juvenile *M. asterias* (Brevé *et al.,* 2016) is reflected in the general importance of the southern North Sea for the species, as predicted in this study. Assumed parturition of *M. asterias* in the western English Channel during February can hardly be confirmed by this study, however there is some indication for the presence of juvenile *G. galeus* during summer in the eastern English Channel (ICES, 2017b). Recommendations for amending research are given in Chapter 6.

Suitable habitat for *M. asterias* in the Dutch Wadden Sea could hardly be confirmed by the results of this study, although the area in front of the Wadden Islands was predicted to be highly suitable

in summer and fall. However, individuals of the species have been observed in the Wadden Sea, and in between the Wadden Islands. This suggests that the under-sampling of the Wadden Sea might have led to an underestimation of the areas' suitability for the species.

Also, parts of the German Wadden Sea have been predicted to offer suitable habitat for *M. asterias* in summer, suggesting the importance of the Wadden Sea area for the species.

Possibly, the species uses tidal currents to move in out the Wadden Sea area as a foraging or predator-avoidance strategy, as observed in several other elasmobranch species (Carlisle & Starr, 2009; Schlaff *et al.,* 2014). However, to determine the role of the Wadden Sea area for *M. asterias,* and to gain scientific insights of their lifestyle further research is necessary.

Life-strategies of G. galeus and M. asterias in comparison
This study suggests that *G. galeus* and *M. asterias* pursue different life-strategies.

As mature and juvenile *G. galeus* primarily find suitable habitat in different areas, juveniles might use certain areas as nurseries. One reason for this behavior could be varying prey preferences as linked to the adoption of an alternative, pelagic lifestyle with maturation. As mentioned above, further research is necessary to investigate the underlying mechanism to this behavior.

M. asterias, on the other hand, generally shows no significant distinction between the mature and juvenile life-stage, indicating that the species might not use dedicated nurseries. Compared to *G. galeus* the species is not known to adapt a pelagic lifestyle with maturation, which might explain that matures and juveniles are predicted to find suitable habitat in similar areas.

M. asterias is generally smaller in size and might therefore have other prey-predator interactions than *G. galeus,* explaining the utilization of different habitat by the two species.

However, it is necessary to note that both species might use dedicated pupping areas, and that neonates might show a different behavior than all juveniles. The hotspot areas, which are predicted to be suitable for *M. asterias* throughout the year support this assumption. However, due to the unavailability of sufficient data, this could not be further investigated in this study.

Limitations to Species Distribution Modelling in this Study
The main pitfall in this study was the unavailability of data appropriate for modelling suitable habitat of *G. galeus* and *M. asterias.*

For example, biotic variables indicating the prey availability and the presence of predators were not available for the research area. While the abiotic variables used in this study might have been suitable to model the fundamental niche of the two species, the identification of the realized niche requires more input in the form of biotic factors which directly influence the distribution of the shark species. Consequently, the results of this study might over-estimate suitable habitat and not depict the true distribution of the species. However, it is probable that the realized niche lies within the fundamental niche, meaning that the here modelled suitable habitat contains the distribution of the species. Further scientific investigation is necessary to assess the validity of the modeled suitable habitats.

Another consequence of the unavailability of such biotic data is that not all mechanisms driving the behavior of *G. galeus* and *M. asterias* can be understood. As shark nursery areas are often characterized by prey availability and predator absence, the mechanisms driving nursery usage by *G. galeus* remain unknown. Therefore, further research is necessary to investigate the underlying parameters driving the distribution and lifestyle choices of both shark species.

Another pitfall was the unavailability of environmental data, and the under-sampling of presence data in many coastal areas, including bays, estuaries, and great parts of the Wadden Sea. Considering that individuals of *G. galeus* and *M. asterias* may be present in these areas, this might

have resulted in the under-estimation of suitable habitat in these regions. Therefore, further investigation of the species' presence in coastal areas is required in order to fully access the role of these habitats for their distribution.

Furthermore, the use of environmental data of higher resolution could improve the predictions of suitable habitat, and restrict the predictions of suitable habitat to smaller areas – especially in coastal habitats where the environment is often highly variable.

However, many other SDM studies run into similar problems with data availability and quality, and use datasets with very few presence points (Merckx *et al.*, 2011). Comparatively, this study utilized datasets with numerous presence points of long-term surveys, reliable environmental data of the highest available quality, corrected for sampling bias, and yielded models of high predictive power. Therefore, the results of this study can be considered as a reliable indication of suitable habitat for *G. galeus* and *M. asterias* in the Greater North- and Celtic Seas area, despite the given limitations.

Management

Sharks, such as *G. galeus* and *M. asterias*, which inhabit the shelf- and coastal regions are threatened by fisheries and affected by coastal habitat degradation. Still, only few coastal and/or demersal sharks are addressed in species specific management and are possibly underrepresented when considering joint ambitions for a GES of the marine environment in the EU. When comparing seasonal habitat of high probability with hotspot regions, the marine regions with important EU Member States suddenly exclude Germany. However, as this Member State has not formulated any measures concerning sharks as part of their marine strategy this can be a bearable loss. Also, in all Member States, but Germany sharks play a role (to a varying extent) in the development of Marine Strategies for the MSFD. Nevertheless, individual targets concerning sharks in National Marine Strategies are still far from congruent, although all express the need for the development of marine spatial protection. While overall hotpots in this study depict essential habitats, the importance of seasonal habitat should also not be neglected, especially considering which influence the Dutch Marine Strategy on the protection of sharks in the light of such novel information could have. Unfortunately, hotspot areas are scarcely included in the Dutch EEZ.

The alignment of Member State targets and indicators under common shark management goals, e.g. orientated on the Dutch Marine Strategy, would benefit the coherency of among Marine Strategies and also cross-national habitats of the target species. Additionally, it has to be acknowledged that most Member States already communicated to the Commission that a GES will not be fully achieved by 2020, but to a later moment. Therefore, current targets are but intermediate, which on the other hand might leave room for adaption throughout review of national PoMs in 2021.

5. Conclusion

In this study, MaxEnt species distribution models were fit to identify nursery areas of the two shark species *G. galeus* and *M. asterias* in the Celtic- and North Sea area. Models were produced for each season, and split up by the juvenile and mature life-stage. In terms of the AUC, all models, except the ones for *G. galeus* in winter, yielded good to excellent results. However, when the discussed data limitations are considered, it can be concluded that all models, except the winter model of juvenile *G. galeus,* and the spring and winter models of mature *G. galeus,* can provide a valuable indication of the potential distribution of both target species, even though they cannot provide results of full confidence. Considering the encountered limitations, follow-up research is necessary to validate the findings of this study, and to gain deeper insights into the distribution and life-strategies of *G. galeus* and *M. asterias*.

Throughout the year, juvenile *G. galeus* find suitable habitat along the coastlines of four ICES subareas: The southern North Sea (4c), the eastern English Channel (7d), the Irish Sea (7a) and the West of Ireland (7b). Considering that matures of the species are usually found in deeper habitats further offshore, the consistent use of similar coastal areas by juvenile *G. galeus* implies that they use them as nursery habitat. The use of different habitat by juveniles and matures might be due to varying prey-predator interactions and the adaptation of a pelagic lifestyle with maturation, but further research is necessary to assess the validity of these assumptions.

For *M. asterias* the concept of nursery areas could not be supported, as juveniles and matures were predicted to use similar habitat in each season. However, the suitability maps suggest a migration from habitats in the northern North Sea in winter, down around the coasts of the UK and Ireland in spring into the southern North Sea and the English Channel in summer. In fall, the pattern reverses and *M. asterias* migrates north again. Response curves indicate that the migration is triggered by changing water temperatures. However, further research should be conducted to provide more scientific evidence for these assumptions.
Interestingly, some areas were predicted to be suitable for *M. asterias* throughout the year. These hotspots can be found in three ICES subareas: The southern North Sea (4c), the eastern English Channel (7d) and the Irish Sea (7a). In contrast to *G. galeus*, *M. asterias* is predicted to primarily inhabit off-shore habitats within these ICES areas.

The sea bottom temperature (SBT) and the salinity were the two parameters which proved to be essential in every model of this study, often contributing considerably to them. Furthermore, the depth (bathymetry), the energy at sea bottom, the distance to coast, and the substrate type were important predictors in the majority, but not all, of the models. The sea surface temperature, the Chlorophyll-a, and the Dissolved Oxygen concentration, on the other hand, could be omitted without great reductions in model performance.

Given the results of the SDM, recommendations on how to improve the spatial management of migratory and demersal sharks such as *G. galeus* and *M. asterias* in the Greater North- and Celtic Seas could be drawn from the predicted seasonal models and habitat hotspots. Spatial management of hotspots in the form of protected areas or MPAs can provide a measure, that benefits both target species and possibly stabilize the reproductive capacity of the NEA stocks.
Emphasis in spatial management for those regions is put on trawl- and gill net fisheries with consideration for blanket closures, including recreational fisheries. This protection of juvenile habitat can prove beneficial not only for neonates and juveniles but also for breeding populations, birthing females and other species. Spillover from MPAs to adjacent waters is also a confirmed

phenomenon and could bring passive benefits beyond the assigned areas. Here produced spatial information certainly adds to tackle the general data deficiency regarding sharks as addressed alike by the EUPOA sharks, OSPAR and the NEV. Above all, if hotspots were to be put down as protected areas or MPAs they would therewith contribute to EU MPA coverage goals under ambitions expressed by the MSFD, the environmental pillar of EU IMP. Ultimately, illustrated hotspots for *G. galeus* and *M. asterias* might at least be able to provide a comprehensive instrument of communication for stakeholders and decision-makers across sectors of EU maritime policy and an incentive for the more sustainable use of the marine environment of Community waters.

6. Recommendations

Handling Data Limitations

A major limitation to modelling suitable habitat of *G. galeus* and *M. asterias* was the scarcity or unavailability of data.

Presence records, especially of *G. galeus*, were few in some seasons, and many coastal areas such as bays, estuaries and the Wadden Sea were not sufficiently sampled. Therefore, it is recommended to expand large-scale surveying, especially in spring and winter, and to conduct surveys in under-sampled coastal areas to better assess the importance of these habitats.

Furthermore, remote-sensing data of environmental variables from the CMEMS were not available for some coastal areas, including large parts of the Wadden Sea. To assess the suitability of these areas for *G. galeus* and *M. asterias*, *in-situ* surveying of environmental conditions (together with species presence) might be a more suitable approach to analyzing habitat preferences and modelling suitable habitat in these areas.

Another limitation was the unavailability of biotic environmental variables (e.g. prey availability and predator presence), which are possibly important for determining the realized nice of the two species, and for assessing the mechanisms driving their behavior and distribution. To solve these limitations, further research into prey preferences and predator relations, as well as the subsequent inclusion of important biotic variables in SDMs is recommended (if available).

Management

Established protected areas and MPAs should be enforced, and progress should be monitored over time, as the success of such areas often becomes visible only with age of the area. To assess the success of protected habitats monitoring should include stock status assessments in the identified hotspots, whereas the difficulty to accurately lay down species abundance in a marine region is acknowledged. It is further recommended to establish a subsequent monitoring program for delineated hotspots, as although both target species are not fished commercially, economic impact of proposed shark management on affected fisheries has to be identified.

To acknowledge sharks and their ecological as well as economic importance it is strongly recommended to amend the EU Member States National Marine Strategies to adopt shark specific indicators such as population status as part of a GES in the EU, as devised by the current Dutch PoMs and Shark Action Plan for the next revision of implemented PoMs in 2021.

Follow-Up Research

As modelling results of this study cannot provide full certainty, the validation of the models by *in-situ* research in the identified hotspot regions, is recommended in order to support the assumptions and management recommendations made by this study. While juvenile presence could be indicated for both target species with high probability, derived shark management would benefit further from successive research which can be facilitated through the here provided spatial information.

Successive research to this study should contribute to management objectives by determining specific migration patterns as well as reproduction cycles. Migration pattern of e.g. large gravid females might provide confirmation of assumed nursery grounds and could support suggestions for parturition months if explored temporal. On its basis a similar SDM approach as laid down in this study could be used if sufficient data on such species individuals is found within the dataset. Additionally, the access to recapture data from tagging programs could explore migration of the species further and could give indication for movement as well as confirm assumed nursery areas by factors such as over time repeated use of assumed nursery areas.

7.   References

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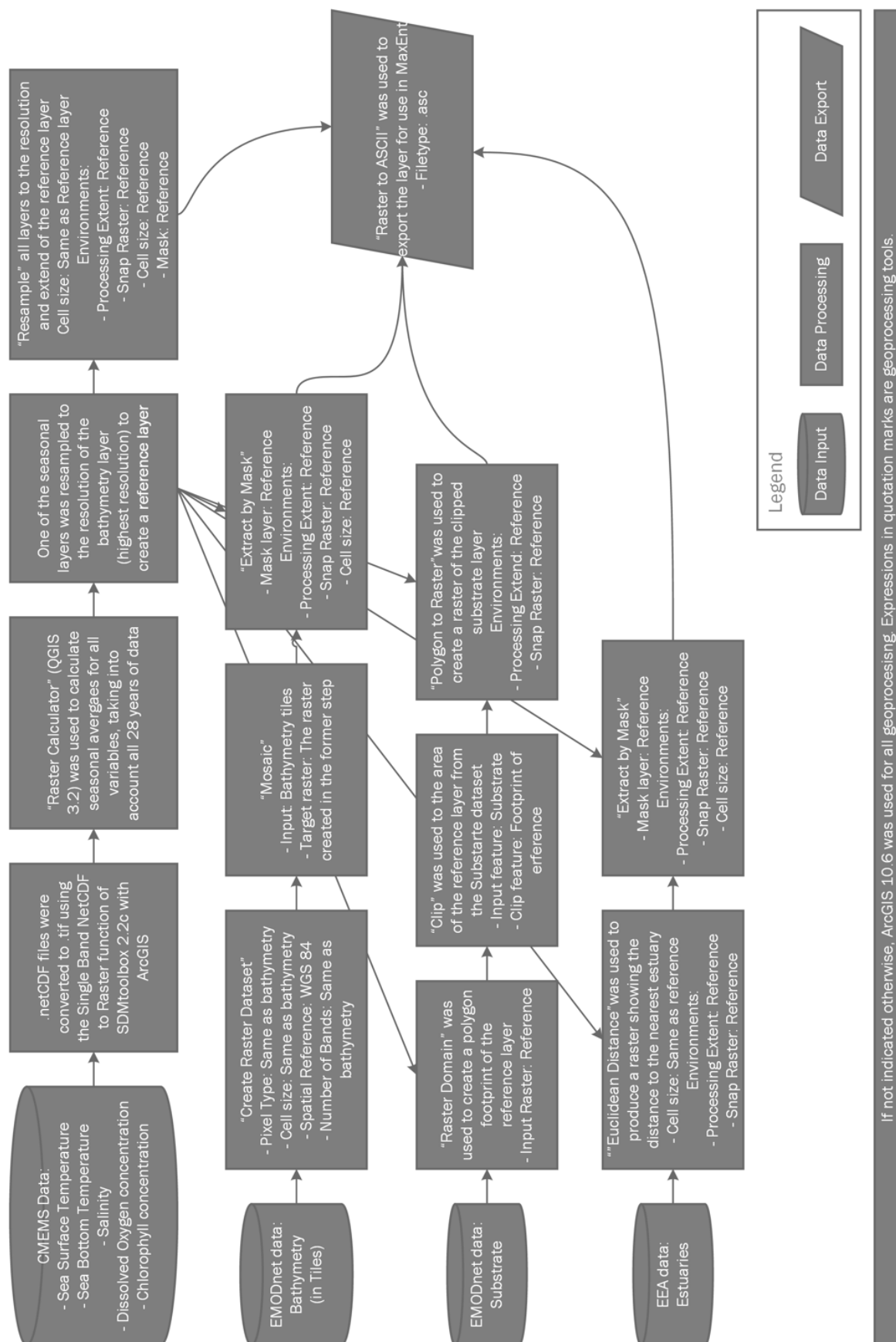
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8. Appendices

8.1 Appendix A: Flowchart and Description of the Data Processing

CMEMS Data:
- Sea Surface Temperature
- Sea Bottom Temperature
- Salinity
- Dissolved Oxygen concentration
- Chlorophyll concentration

.netCDF files were converted to .tif using the Single Band NetCDF to Raster function of SDMtoolbox 2.2c with ArcGIS

"Raster Calculator" (QGIS 3.2) was used to calculate seasonal avergaes for all variables, taking into account all 28 years of data

One of the seasonal layers was resampled to the resolution of the bathymetry layer (highest resolution) to create a reference layer

"Resample" all layers to the resolution and extend of the reference layer
Cell size: Same as Reference layer
Environments:
 - Processing Extent: Reference
 - Snap Raster: Reference
 - Cell size: Reference
 - Mask: Reference

EMODnet data: Bathymetry (in Tiles)

"Create Raster Dataset"
- Pixel Type: Same as bathymetry
- Cell size: Same as bathymetry
- Spatial Reference: WGS 84
- Number of Bands: Same as bathymetry

"Mosaic"
- Input: Bathymetry tiles
- Target raster: The raster created in the former step

"Extract by Mask"
- Mask layer: Reference
Environments:
 - Processing Extent: Reference
 - Snap Raster: Reference
 - Cell size: Reference

"Raster to ASCII" was used to export the layer for use in MaxEnt
 - Filetype: .asc

EMODnet data: Substrate

"Raster Domain" was used to create a polygon footprint of the reference layer
- Input Raster: Reference

"Clip" was used to the area of the reference layer from the Substarte dataset
- Input feature: Substrate
- Clip feature: Footprint of erference

"Polygon to Raster" was used to create a raster of the clipped substrate layer
Environments:
 - Processing Extend: Reference
 - Snap Raster: Reference

EEA data: Estuaries

"Euclidean Distance" was used to produce a raster showing the distance to the nearest estuary
- Cell size: Same as reference
Environments:
 - Processing Extent Reference
 - Snap Raster: Reference

"Extract by Mask"
- Mask layer: Reference
Environments:
 - Processing Extent Reference
 - Snap Raster: Reference
 - Cell size: Reference

Legend
- Data Input
- Data Processing
- Data Export

If not indicated otherwise, ArcGIS 10.6 was used for all geoprocesisng. Expressions in quotation marks are geoprocessing tools.

i

Pre-Processing of CMEMS Data

All CMEMS variables were processed in the same fashion. After downloading the monthly averages of SST, SBT, Salinity, DO concentration, and CHL concentration, the data were converted from ".netCDF" format to ".tif" format for further processing using the "Single Band NetCDF to Raster" tool of SDMtoolbox 2.2c (Brown, 2014) and ESRI ArcGIS Desktop 10.6 (ESRI, 2018; hereafter referred to as ArcGIS).

Using the raster calculator function in QGIS 3.2 (QGIS Development Team, 2018) seasonal averages of the variables were calculated, considering all 28 years of data. Seasons were defined in the same way as for the species presence points.

Pre-Processing of Bathymetry Data

Since the data come in the form of large mosaic tiles, all tiles necessary to cover the research area were downloaded and merged into one raster layer using the "Create Raster Dataset" and "Mosaic" tool in ArcGIS.

Pre-Processing of EUSeaMap Data

The data come in the form of a polygon shapefile and were converted to a raster layer with the same resolution as the bathymetry layer and the same extend as the research area using the "Polygon to Raster" tool in ArcGIS.

Pre-Processing of the Distance to Coast layer

Using the "Clip" tool in ArcMap, the coastline layer was clipped to the extent of the research area. Then, a raster layer containing the distance to the coast from any point in the research area was produced, using the "Euclidean Distance" tool in ArcGIS. The cell size was chosen to be the same as the bathymetric layer, and the extend of the produced raster was chosen to fit the research area.
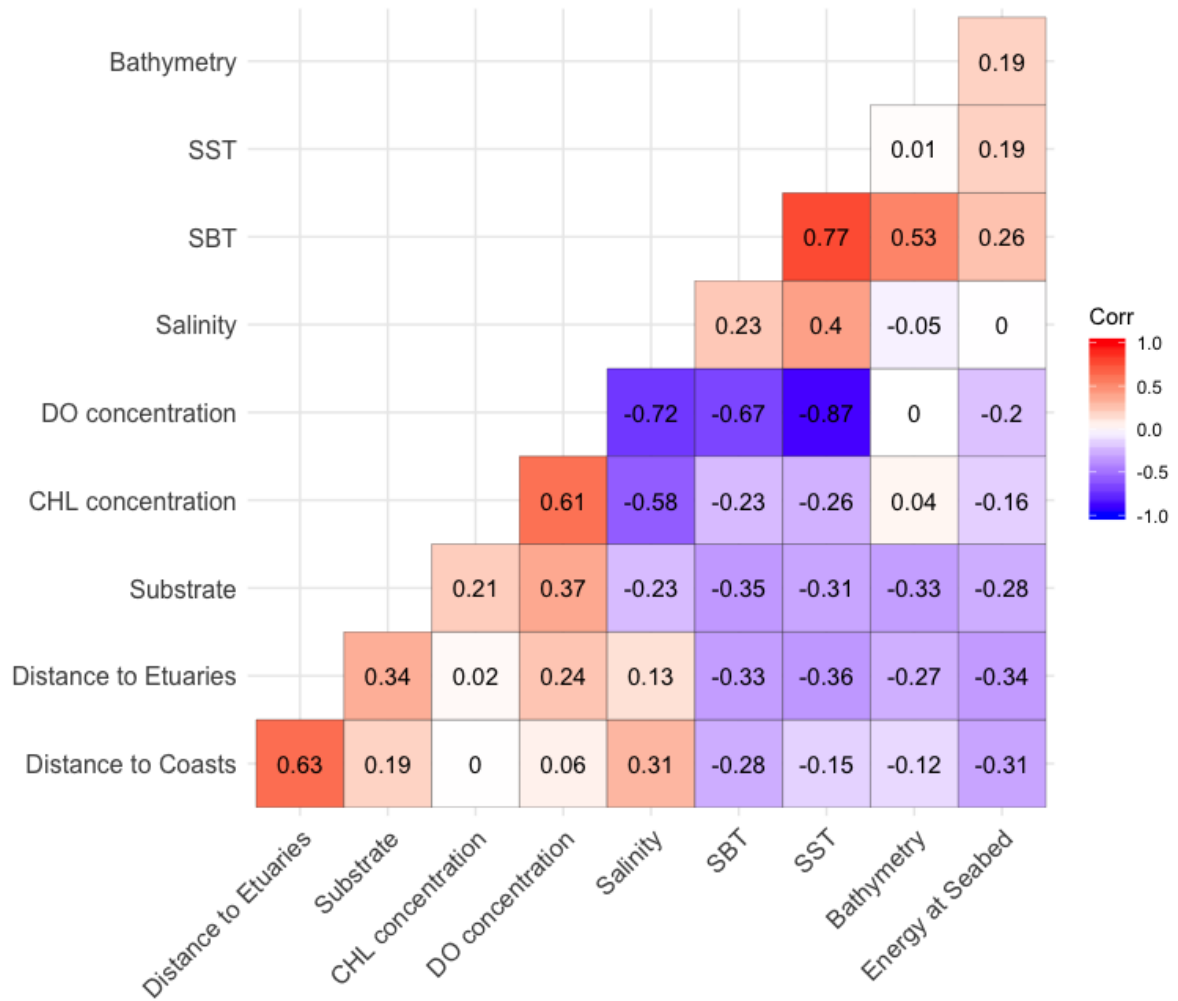
Processing of all Data Layers for the Use in MaxEnt

For the use in MaxEnt, all environmental raster layers must have the same geographical extend and grid size. Furthermore, all layers must be converted to ESRI ASCII raster format (.asc) (Phillips, 2017b). A reference layer with the extent of the research area and the cell-size of the layer with the highest resolution (Bathymetry; Grid size: 0,00208333*0,00208333) was produced using the "Resample" and "Extract by Mask" function in ArcGIS. The reference layer was then used to achieve that all environmental layers have the same extend and grid size, again using the "Resample" and "Extract by Mask" tool in ArcGIS. To assure that all grid cells are aligned the "Snap Raster" function in the environments was set to the reference layer. Afterwards, the datasets were converted to .asc files and exported using the "Raster to ASCII" tool in ArcGIS. With the exception of substrate type all the environmental layers used in this study were of continuous nature.
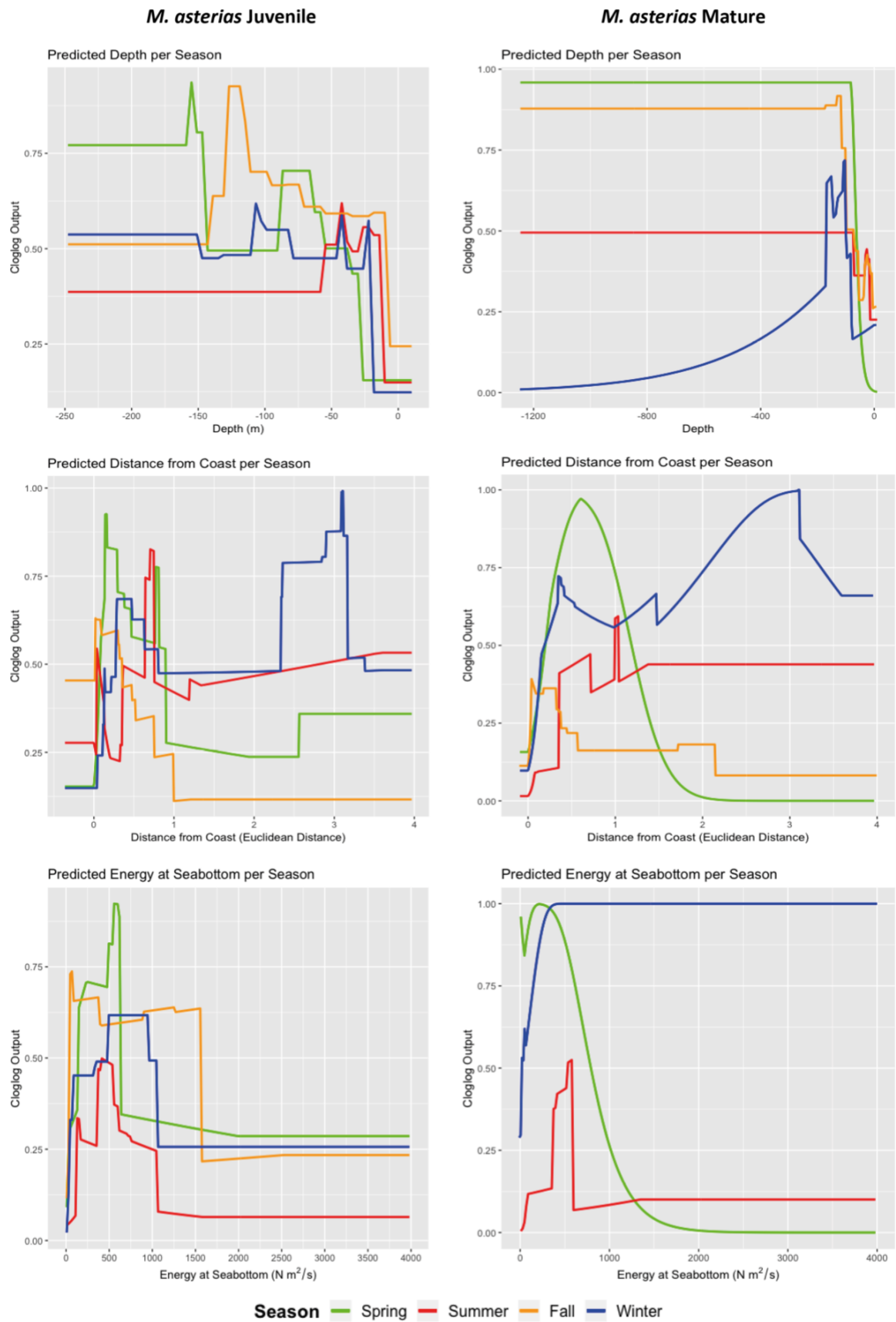
Gaussian Kernel Density (Juvenile G. galeus Presence Records)
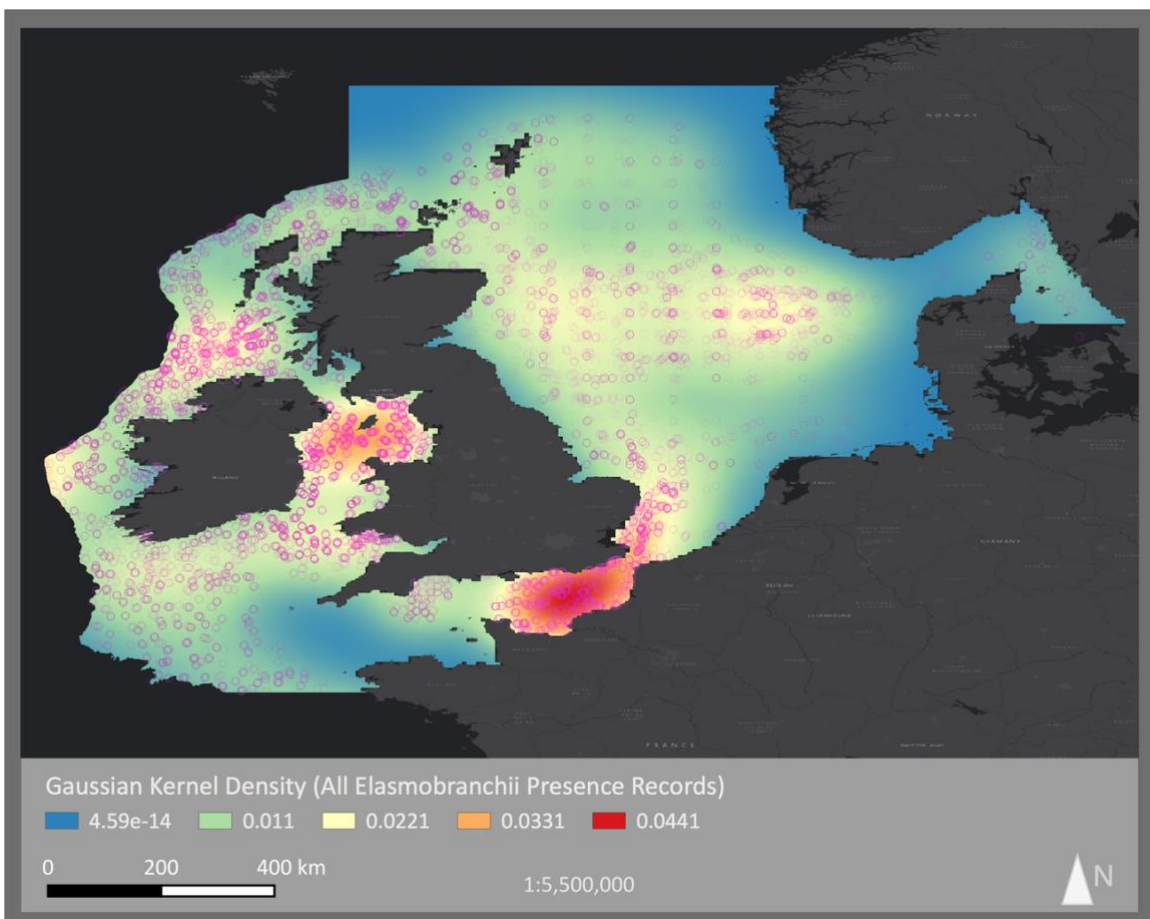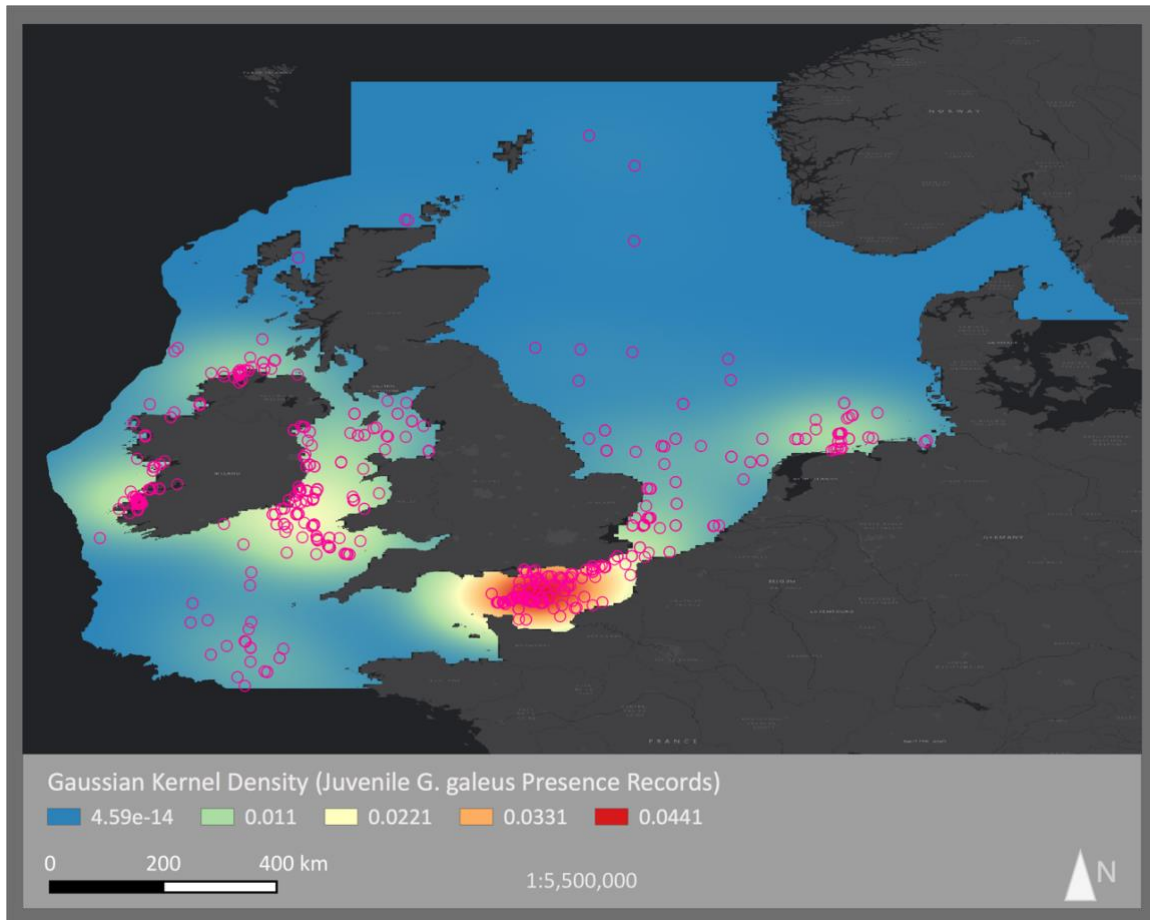
Gaussian Kernel Density (All Elasmobranchii Presence Records)

M. asterias Juvenile

M. asterias Mature
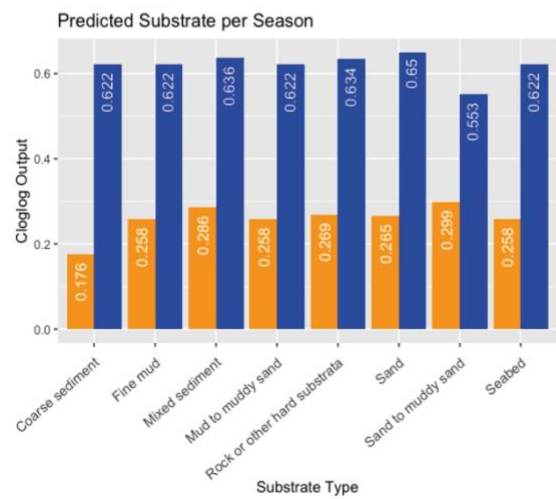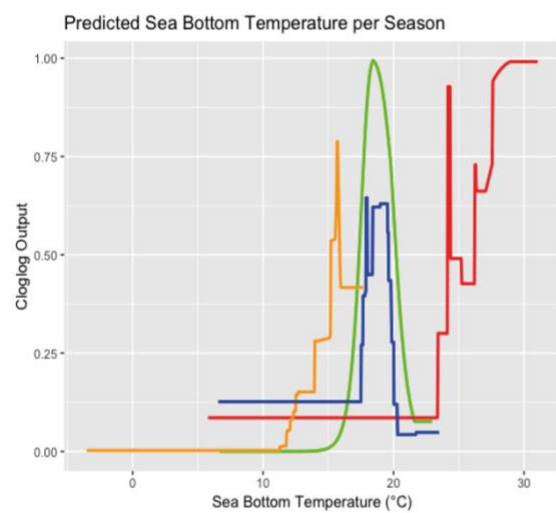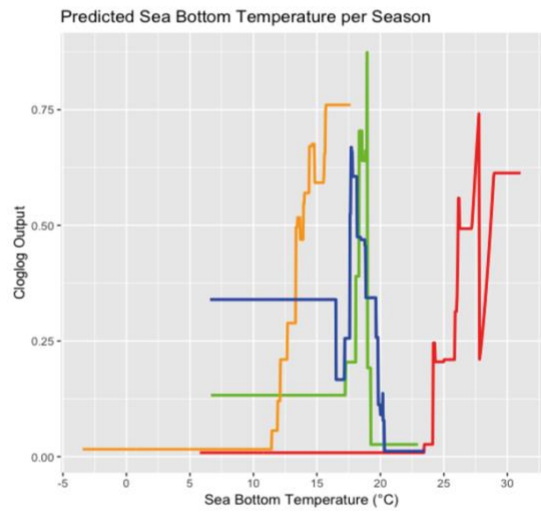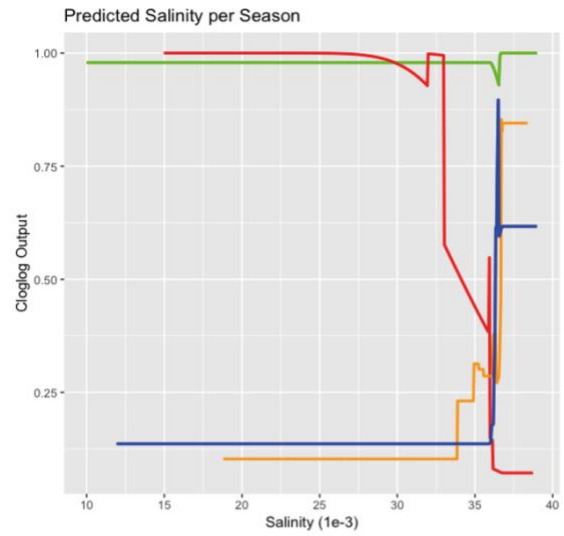
Predicted Salinity per Season

Predicted Salinity per Season

Predicted Sea Bottom Temperature per Season

Predicted Sea Bottom Temperature per Season

Predicted Substrate per Season
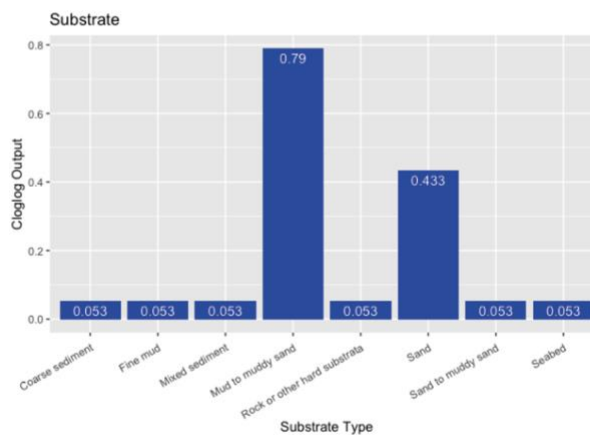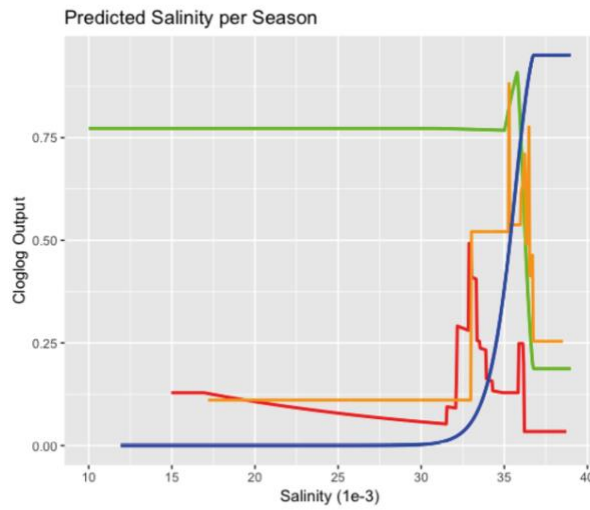
Season — Spring — Summer — Fall — Winter
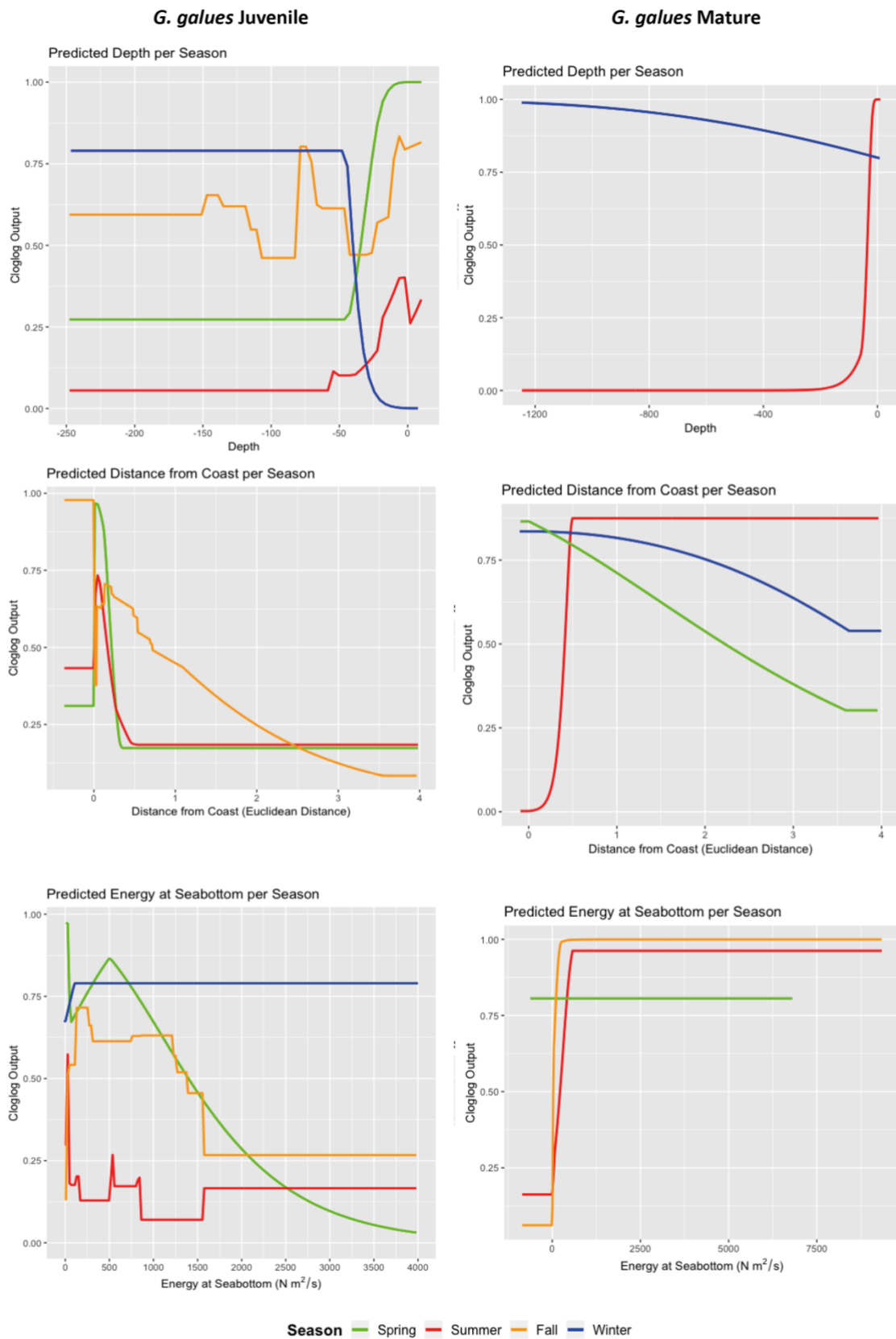
G. galues Juvenile

G. galues Mature

Predicted Depth per Season

Predicted Depth per Season

Predicted Distance from Coast per Season

Predicted Distance from Coast per Season

Predicted Energy at Seabottom per Season

Predicted Energy at Seabottom per Season

Season — Spring — Summer — Fall — Winter

G. galues Juvenile

Predicted Sea Bottom Temperature per Season

Predicted Salinity per Season

Substrate

G. galues Mature

Predicted Sea Bottom Temperature per Season

Predicted Salinity per Season

Predicted Substrate per Season

Season — Spring — Summer — Fall — Winter

Model Contributions *G. galeus*

Model Contributions *M. asterias*
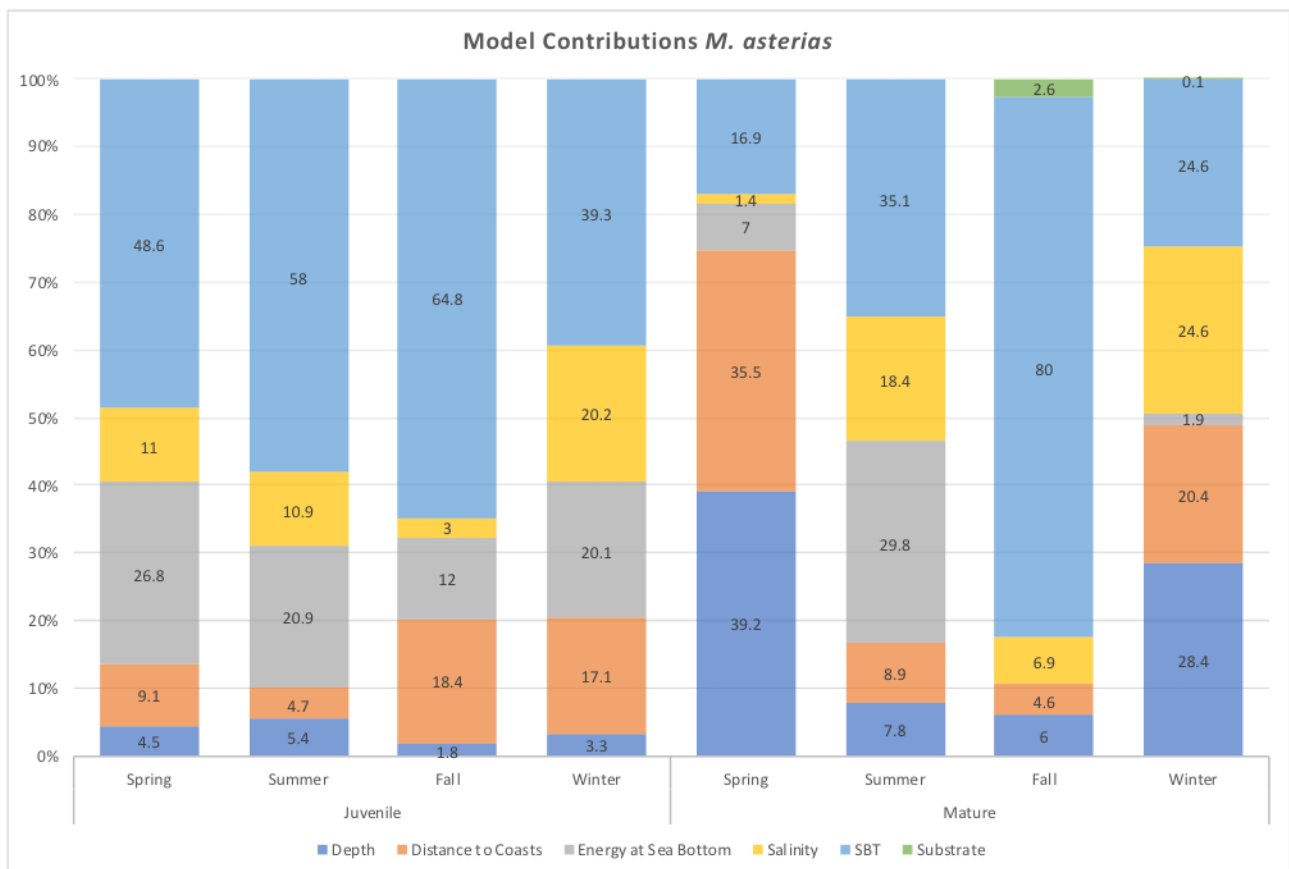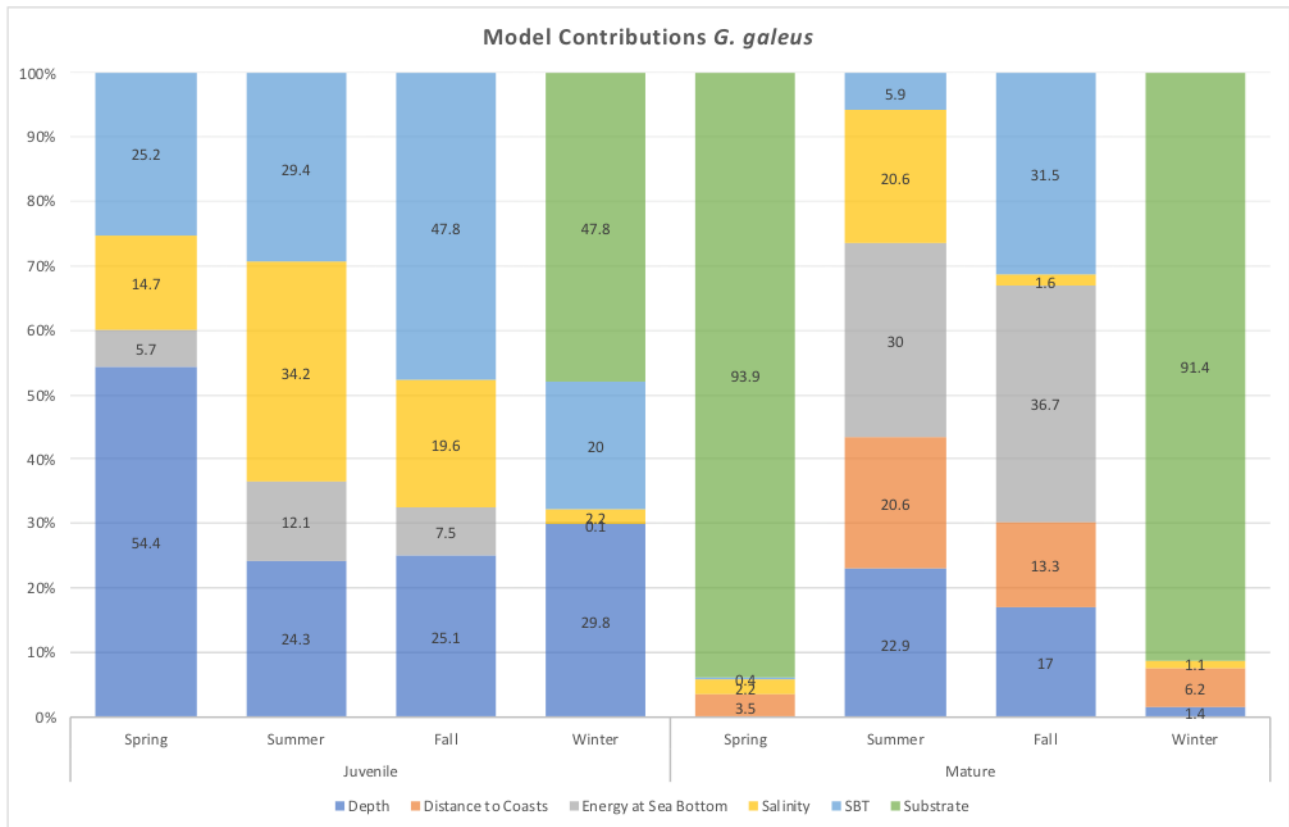
The Common Fisheries Policy (1983)

General Provision – Article 1, para. 1 (a): *"The Common Fisheries Policy shall cover: The conservation of marine biological resources and the management of fisheries and fleets exploiting such resources"* (EC, 2013, L 354/28)

Formally introduced in 1983, the Common Fisheries Policy (CFP) once aimed to prevent fisheries conflicts in times prior to UNCLOS and the consequently established EEZs. Today the CFP is the key instrument for the management of European fisheries, with goal to conserve and ensure long-term exploitation of commercial fish stocks, today largely enforced by Council Regulation (EC) No 1224/2009[1].

Throughout its development, a reform of the CFP in 2002[3], was deemed necessary considering the growing EU fishing fleet and the lack of coherent long-term strategy as well as the application of the precautionary approach and the implementation of a progressive ecosystem-based approach to fisheries management (EC, 2002, Article 2, para. 1). With the reform, annual decisions concerning TACs and quotas were more frequently replaced by the establishment of multiannual plans that cover longer periods of time and could include conservation objectives based on the eco-system approach.

As a consequence, many important fish stocks are now under long-term management. Also, EU fisheries experienced an improvement in control and enforcement while several Member states effectively resized their fishing fleets to comply with the new regulations. Additionally, the reform sought to address the difficulties that still persisted in the communication

> Box 5: EC-On the role of the CFP:
> The European Commission has early addressed the role of the CFP in managing marine environments and resources under an ecosystem approach by Commission Communication COM(2008) 187 final[2]. Within the document, instruments like the Habitats Directive and derived Natura2000 as well as eventually by the MSFD protected areas and sites are mentioned as representing important key elements for facilitating an ecosystem based approach.

between stakeholders and regulators which seemed to have been affecting the success of the CFP so far. Still, the Regulation established an early system for marine resource conservation and sustainable fishery exploitation.

A proposal to reform the CFP addressed the pending fleet overcapacity and decline of caught volumes in EU fisheries, as in fault to the current policy. Subsequently, it notices the fact, that the fisheries sector in quote: *"…can no longer be seen in isolation from its broader marine environment and from other policies dealing with marine activities"* (EC, 2009b). The Green Paper, which identifies the current structural issues of the CFP, further mentions the role of Marine

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[1] Council Regulation (EC) No 1224/2009 of 20 November 2009 establishing a Community control system for ensuring compliance with the rules of the common fisheries policy

[2] Communication from the Commission to the Council and the European Parliament COM(2008) 197 final The role of the CFP in implementing an ecosystem approach to marine management

[3] Council Regulation (EC) No 2371/2002 on the conservation and sustainable exploitation of fisheries resources under the Common Fisheries Policy

Spatial planning as well as the need for policy to be coherent within the EU context. The resulting reform package and current regulation[4] sets the basis for current legislation in EU fisheries.

Next to emphasis on management based on an ecosystem approach as well as the precautionary principle to assure sustainable exploitation of marine resources, the CFP acknowledges its role in contributing to the protection of the marine environment and to the achievement of GES under the MSFD.

The CFP and its recently discovered need for sustainability raises potential for indirect and direct shark management measures, foremost considering fisheries regulations in spatial/habitat and technical/species terms. By definition, sharks as living aquatic resource fall within the scope of the Common Fishery Policy (CFP) and therefore fall under the afore mentioned ambitions of sustainable development.

Instruments to facilitate sustainability in fishing effort are in a first instance pursued by exploiting target stocks under the principle of the Maximum Sustainable Yield (MSY).

These limits which include several shark species are commonly laid down by annual amendments on fixing the quotas for fish stocks and biennial amendments on fixing certain deep-sea stocks. Currently total allowable catch (TAC) formulated under Council Regulation (EU) 2018/120[5] and Council Regulation (EU) 2016/2285[6] respectively.

Within, the amendment acknowledges the harmful effect, even of limited fishing activity, for many shark species and proposes general prohibitions. Several 0-TACs are provisioned with obligation to release accidental catches even by neglecting the landing

> **Box 6: CFP -Ecosystem approach to fisheries:**
>
> *"Ecosystem-based approach to fisheries management' means an integrated approach to managing fisheries within ecologically meaningful boundaries which seeks to manage the use of natural resources, taking account of fishing and other human activities, while preserving both the biological wealth and the biological processes necessary to safeguard the composition, structure and functioning of the habitats of the ecosystem affected, by taking into account the knowledge and uncertainties regarding biotic, abiotic and human components of ecosystems"* (EC, 2013,– Definitions, pt. 9)

obligation, which is applicable for prohibited species but not deemed detrimental considering the high discard survival of elasmobranchs (EC, 2013, Article 15, pt. 4 a.; EC, 2018b, p.2, pt. 10).

Next to the establishment of rules about the quantity and quality of sustainable catches, the CFP also lays down rules for the technical measures applied in EU fisheries. Basic measures include the minimum mesh sizes for nets, closed areas and seasons, minimum landing sizes, limits on by-catch as well as nurturing incentives for specific fishing gear to increase fishery selectivity (EC, 2008b). The aim of the most recent CFP (EC, 2013) includes the gradual elimination of unwanted catches and discards by accounting to the best available scientific advice. Both ambitions can affect sharks, especially juveniles that are still caught as by-catch in several EU fisheries.

In spatial regard, the current CFP also expresses ambition for the protection of biologically sensitive areas, emphasizing also spawning grounds while urging the Union to designate marine protected areas to achieve that objective. In that regard, the CFP provides the potential to

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[4] Regulation (EU) No 1380/2013 of the European Parliament and of the Council of 11 December 2013 on the Common Fisheries Policy

[5] Council Regulation (EU) 2018/120 of 23 January 2018 fixing for 2018 the fishing opportunities for certain fish stocks and groups of fish stocks, applicable in Union waters and, for Union fishing vessels, in certain non-Union waters, and amending Regulation (EU) 2017/127

[6] Council Regulation (EU) 2016/2285 of 12 December 2016 fixing for 2017 and 2018 the fishing opportunities for Union fishing vessels for certain deep-sea fish stocks and amending Council Regulation (EU) 2016/72

regulate fisheries in a way to benefit habitat protection objectives as e.g. proposed under the Habitats Directive. Moreover, with ensuring that instruments are applied congruent in a cross-sectoral manner, goals relevant for MSFD and Habitats Directive could be enforced.

European Community Action Plan for the Conservation and Management of Sharks (2009)

> *".... given its commitment to sustainable fisheries and its weight at international level, the Community (EU) should assume a leading role in the development of policies aiming at the rational exploitation of chondrichthyans. It is therefore timely and appropriate to develop and implement at EC level a comprehensive, effective and integrated policy and regulatory framework for sharks fisheries."* (EC, 2009a, p. 3)

The in 2009 agreed upon, European Action Plan for the Conservation and Management of Sharks (EC, 2009a) (EUPOA) orientates itself widely on the provisions given by the FAO International Plan of Action for the Conservation and Management of Sharks (FAO, 1999). The FAO Action Plan Sharks (IPOA) used to address the concern for the lack of knowledge regarding sharks as well as the issues fisheries caused in the effort to conserve and manage shark stocks and was developed in framework with the FAO Conduct for Responsible Fisheries (FAO, 1995). The voluntary code, that was however formed based on legal documents such as UNCLOS, provided principles to develop and manage global fisheries in a sustainable manner, also by embracing a precautionary approach.

The derived EU Action Plan Sharks communicates the acknowledgement, that sharks are through their life history vulnerable species, especially to unregulated exploitation, that populations in EU waters are declining and in cases threatened with extinction. The Plan outlined the once current situation regarding shark management, while proposing what was still needed to establish coherent legislative shark management for the EU and beyond. The pending ambitions, that the Plan addressed were to improve knowledge about shark fisheries and the role of sharks in the ecosystem, sustainability in target and non-target fisheries by-catch reduction, and additionally to encourage a coherent approach between in- and external Community policy of sharks. In this framework the Action Plan further highlights the critical role, inherited by fisheries, within a stable framework for management of sharks including their sustainable exploitation. The Plan also refers to the ICES Working Group on Sharks (WGEF) 2007-2009 stock assessment as a basis for any future actions. Also, the international cooperation with conventions like CMS and CITES are highlighted to ensure the control of shark fishing and finning.

In facilitation of those principles, the Plan puts emphasis on scientific evidence as basis for shark related issues and presumes, that all fisheries should be managed under sound scientific advice based on the precautionary

> **Box 7: EUPOA Annex**
> The, to the EUPOA enclosed Annex specifies and provides a framework for objectives of derived shark management, whose two focal points are described as *to:*
> 1)*"deepen knowledge both of shark fisheries and of shark species and their role in the ecosystem"* so as to address a gap in knowledge and further to:
> 2)*"ensure that directed fisheries for sharks are sustainable and that by-catches of shark resulting from other fisheries are properly regulated"* so as to acknowledge the role of fisheries in shark management.
>
> The framework is proposed with potential to not only benefit sharks, but also related species and for the overall commitment to sustainable fisheries on international level, the European community was addressed as having a leading role in the development of such measures.

principle (EC, 2000). And further, that scientific support should include internationally operating RFMOs to strengthen regional cooperation in shark related issues.

Under the Dutch Marine Strategy principles of the EUPOA sharks are referred to in the Shark Action Plan 2015-2021.

EC Habitats Directive

> Article 2, Paragraph 1.: *"The aim of this Directive shall be to contribute towards ensuring bio-diversity through the conservation of natural habitats and of wild fauna and flora in the European territory …"* (EC, 1992, p.9-10)

With the adoption of Council Directive 92/43/EEC[7], on the Conservation of Natural Habitats and of Wild Fauna and Flora (EC Habitats Directive) in 1992, the European Union established a key instrument to protect threatened habitats and species. The Directive is largely based on provisions established with the Bern Convention and finds also relation to the CBD and CITES. Closely related to the Habitats Directive are the Birds Directive[8] and the Water Framework Directive[9]. Both are frequently found as framework for subsequent marine conservation ambitions. The overarching objective of the Habitats Directive is to reach 'favorable conservation status' (Article 1, Paragraph (e) and (i)) for habitats and species. For habitats this status is determined as covering its natural range while that range is stable or increasing, the specific structure and functions within that habitat are existing and will do so in the near future and the conservation status of with the habitat associated species is favorable as well. This species status is achieved when a population is able to maintain its dynamics on a long-term basis as a viable component of its natural habitats, while the natural range of that species is neither being reduced, nor likely to be reduced in the foreseeable future and finally that there is and will be a sufficiently large habitat to maintain its population on a long-term basis.

The Directive becomes specific as it outlines the species and habitats that need protection in three different Annexes. Annex II thereby describes species whose habitats must be protected by signatory states. Annex IV describes "Species of community interest", which require strict protection. And finally Annex V lists "Species of Community interest", which may require further management under the aspect of commercialization. For which in total the Directive lists 447 animal and 695 plant species.

Next to general obligations of ensuring biodiversity through the conservation of natural biological resources, the Directive further includes two obligations, the conservation of natural habitats also as habitats of specific species under the established Natura2000 network (*Article 3 -10*) and further the protection of species (*Article 12 - 16*) through the reduction of mortality, commercializing, and protection of habitat and temporary habitats such as areas with regard to breeding, rearing or migration.

Box 8 and 8.1 include the from the Directive derived Natura2000 network as part of measures taken to conserve the EU natural environment as well as a short introduction to one of those environments, the Wadden Sea.

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[7] Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora

[8] Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds

[9] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy

The 1992 Habitats Directive features the ambition of establishing a European ecological network (*Article 3*) which was set up under the name "Natura2000". By definition the supposedly coherent ecological network consists of the habitat types listed in Annex I and habitats of the species mentioned in Annex II, and maintains those habitats or restores them to 'favorable conservation status'. Today, the network features around 25,000 sites, is maintained by 27 Member States, and is deemed the current standard for nature conservation in Europe. However, gaps in off-shore protection through Natura2000 still exist (EEA, 2015).

Box 8.1: Wadden Sea, as region of special environmental interest

The Wadden Sea, on which is put special interest in this report as assumed nursery/pupping area for migrating shark.

The coastal region and World Heritage Site of the Wadden Sea stretches alongside the Danish, German and Dutch coastline and is of pronounced ecological importance as providing an unique ecosystem/habitat and nursery ground for many species, while also being subject of substantial human pressures.

In order to achieve consistent EU legislation for the region, the Trilateral Wadden Sea Cooperation (TWSC) was established with aim to implement ecosystem-based management in the Wadden Sea, while orientating itself on EU Directives and set provisions as e.g. under the Habitats Directive, for instance under *Article 6* of the Directive mentioning the obligation to establish special areas of conservation. (Common Wadden Sea Secretariat, 2010)

The Oslo-Paris Convention for the Protection of the Marine Environment of the NEA (1992)

Article 2 – General Obligations, Paragraph 1. (a)*: "The Contracting Parties shall, …. take the necessary measures to protect the maritime area …. to conserve marine ecosystems and, when practicable, restore marine areas which have been adversely affected" (*OSPAR, 1992, p. 8)

The Oslo-Paris Convention for the Protection of the Marine Environment of the NEA (OSPAR) was established in 1992, mainly around the issue of marine pollution. Today the Convention provides guidance for the protection of the marine environment in the NEA with focus on international cooperation and harmonization of policies. Including the European Community, the Convention has 16 contracting parties that are urged to implement and enforce the provisions of the Convention. Although, the Convention itself is not legally binding, provisions have been translated into EU law. OSPAR advice is based on a list of threatened and/or declining species and habitats, which are to be prioritized in applied conservation efforts through the contracting parties.

In terms of coherency OSPAR refers to other agreements to be considered in cases Member States are already committed to, as e.g. the Habitats- and Birds Directive, in order to avoid duplication of work. Also mentioned is the Bern Convention of 1979, which as well features protected shark species, as listed in Appendix H. The Convention itself recognizes sharks as being threatened and/or declining in all OSPAR regions and further that sharks as top predators play an important role in maintaining the fish community structure in their habitats (OSPAR Commission, 2010). By OSPAR listed shark species are found in Appendix H. Recently sharks found mention as part of the EU marine environment under the OSPAR quality assessment for the North Sea (Box 9).

Box 9: OSPAR Ecological Quality Objectives for the North Sea

For the North Sea Together with the International Council for the Exploration of the Sea (ICES), OSPAR has been developing a system of Ecological Quality Objectives (EcoQOs). Objectives were designed to represent indicators for the entire ecosystem in the NEA including the pressures upon it and not meeting these objectives for an ecosystem approach calls for an appropriate

party response to regulate human activity and to identify reasons why goals are not met.

Those indicators have been assessed for a first time in the period of 2002–2009 (OSPAR Region II) and results were compiled in a Quality Status Report (QRS) of 2010 (OSPAR, 2010).

Based on the assessment of the EcoQOs, OSPAR devised advice in the Report of the OSPAR workshop on defining actions and measures for the OSPAR list of threatened and/or declining species and habitats (OSPAR, 2009), including advice for elasmobranch sharks.

Suggestions encompass to encourage contracting parties to share relevant sampling data especially for species with data deficiencies in their life history. Also, to promote collaboration between parties to identify critical habitats, sites of aggregation as well the integration of such measures in the development of MPAs. Finally, for OSPAR to remain catalyst for future legislative policy for the conservation of sharks by encouraging contracting parties.

The QRS (OSPAR, 2010) identified the following necessary actions to protect sharks:
1) *"Support improved identification of threatened species especially sharks, skates and rays among key users"*
2) *"Improved monitoring and coordination of species habitats and pressures and data sharing to reduce by-catch"*
3) *"Establish MPAs to protect important functional areas, including key life stages for elasmobranchs"*

In reaching EcoQOs, fisheries have been identified as having a major impact on the North Sea ecosystem, not only with direct impact on targeted species but further also on food web dynamics. OSPAR further mentions that the work put into the development of EcoQO indicators needs to be linked with the requirements made under MSFD and the respective GES descriptors.

The Marine Strategy Framework Directive

To address the lack for marine protection in EU waters the European Commission issued the Directive 2008/56/EC[10] which then should become the Marine Strategy Framework Directive (MSFD) and is deemed the environmental pillar in the EU's IMP (EC, 2012). The Directive acknowledges, that pressures on the marine environment are in many cases too high and that the impact needs to be reduced by the Community.

To apply an ecosystem-based approach to the management of human activities while at the same time exploit marine resources in a sustainable manner, a legislative framework was required that also should bring coherency between different national environmental policies.

As a framework for an improved status of the marine environment the EU provided eleven 'descriptors' which, if addressed in National Marine Strategies should lead to the overarching goal of achieving GES throughout EU waters in 2020.

At its basis the Directive mentions already existing and enforced provisions by MPAs, established through the Habitats Directive, Birds Directive as well as coherency with measures of the CFP and international agreements such as the CBD, as instrumental to achieve GES within the set scope (EC, 2008a).

The Directive affects 24 individual Member States, to give an understanding of the pursued Marine Strategy, but not all might be directly relevant for the implementation of shark management in the Greater North- and Celtic Seas.

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[10] Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy

As the MSFD follows an adaptive approach its progress gets reviewed and adapted cyclical. Over the first cycle (2008, 2012 - 2018) participating states were urged to develop National Marine Strategies until latest July, 2012 of which all where received by 2013.

The results of a Commission Assessment (Article 12) on the development of National Marine Strategies (Article 8, 9, 11), as devised in the Technical Report for the NEA is presented here as compiled by Dupont *et al.* (2014). The review includes the initial assessments (including status and pressure assessment), the definition of national GES and those of environmental targets and indicators for the NEA ocean region and should serve as assessment and to further provide guidance for Member States. The development included the formulation of the 'initial assessment' (Article 8).

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Box 10: Initial Assessment (Article 8)

Chapter 2 – Article 8, para. 1 a, b: "*Member States shall make an initial assessment of their marine waters …. comprising an analysis of the essential features and characteristics and current environmental status …. an analysis of the predominant pressures and impacts, including human activity ….*" (EC, 2008a, p.27)

All Member States reported on habitats, but therein a majority did not include pelagic (water column) habitats, instead in focus were different kinds of seabed habitats. Almost all states refer to the Habitats Directive and to OSPAR.

Pressure assessment among Member States was concluded as being of relatively high coherence, resulting in most Nations acknowledging offshore structures as main cause for physical loss in the EU marine environment and trawling as well as the extraction of materials as playing a major role in exerting physical damage to the marine environment. Pressures most frequently impacting habitats were concluded to include physical damage through abrasion and physical loss through smothering.

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Further, Member States were required to determine the strived for GES, which is an essential step within the Directive considering that every other actions acts upon it. Generally determined, the Directive provides qualitative descriptors for GES on the basis of its Annex I (Article 9) (most recently amended by Commission Decision (EU) 2017/848[11]).

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Box 11: Good Environmental Status (Article 9)

Chapter 2 – Article 9, para. 1: "*By reference to the initial assessment …. Member States shall, in respect of each marine region or sub-region concerned, determine, for the marine waters, a set of characteristics for good environmental status …*" (EC, 2008a, p.28)

Descriptors provided in the MSFD, with direct relevance for the protection of species and habitat are represented by Descriptor 1 (D1: Biodiversity). Whereas D1 is achieved when: "*Biological diversity is maintained. The quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climatic conditions.*" (EC, 2008a, p.34, pt. 1)

And next, indirectly through D4 (Food Web Integrity), attention for the protection of species and habitat could also be given to D3 (Fisheries) and D6 (Seabed Integrity).

The determination of national GES concerning Descriptor 1: Biodiversity during the first cycle, came out to be different for all Member States and most states have tried to define GES more specifically than the framework provided under Annex I of the Directive.

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[11] Commission Decision (EU) 2017/848 of 17 May 2017 laying down criteria and methodological standards on good environmental status of marine waters and specifications and standardized methods for monitoring and assessment

In regard to species and functional groups, GES for half of the Member States (BE, DK, NL, SE, UK) include the three main highly-mobile species groups: birds, fish and mammals (Dupont *et al.*, 2014). Species are mentioned in very different ways, though only three Member States (BE, FR, UK) include individual species as indicators for the Species GES definition, in other cases all species are included by default or in case of German GES only listed and protected ones. On a different note, some Member States e.g. including Belgium and Denmark have made mention to species types of the sort with long-live spans and slow reproduction such as top predators.

Also, only part of the Member States included a specific statement towards already by the Habitats Directive, OSPAR or IUCN listed or protected species within their GES (BE, DE, ES and limited also IE, UK).

Concerning habitats as criteria within the Biodiversity descriptor, most Member States did not refer to specific habitats. The Netherlands made only reference to seabed habitats, Denmark distinguishes between hard- and soft-bottom habitats and Germany again includes exclusively regions which are covered under protection, mention to those specific habitats is made by half of the Member States (BE, DE, ES, IE, UK), whereas mostly OSPAR habitats or such included in the Habitats Directive were referred to.

The overall ecosystem is mentioned by most States (DK, ES, FR, IE, PT, SE, UK) as including the whole structure, with no further distinctions.

Moreover, Marine Strategies required the establishment of 'environmental targets' (Article 10) to guide the progress to achieve GES.

Box 12: Environmental Targets (Article 10)

Chapter 2 – Article 10, para. 1: "*On the basis of the initial assessment …. Member States shall …. establish a comprehensive set of environmental targets and associated indicators for their marine waters so as to guide progress towards achieving good environmental status ….*" (EC, 2008a, p.29)

Except for two Member States all have defined their environmental targets according to the biodiversity descriptors (which can include D1: Biodiversity, D4: Marine food webs and D6: Sea-floor integrity). Amongst others Denmark, Germany, The Netherlands and the UK all have addressed all those descriptors with a recapitulatory set of targets.

All Member States of that region, who also party in OSPAR, express an effort for regional coordination and refer especially to cooperation through the OSPAR Convention and some further mention the OSPAR Convention Quality Status Report of 2010. More so, half of the Member States appear to have put direct or indirect reference to definitions for 'favorable conservation status' as mentioned under the Habitats Directive as well as considered Good Ecological Status as defined under the Water Framework Directive.

The MSFD also stipulates the implementation of coordinated Monitoring Programs (Article 11) based on the Initial Assessment. Together, those measures are to be translated into Programs of Measures (PoMs) (Article 13), representing the final instrument to move towards the GES by 2020. The Directive hereby urges the integration of spatial protection measures within National PoMs to contribute to a network of MPAs as well as special areas of conservation already determined on international level or such as under the Habitats Directive.

Sharks, are mentioned specifically or as part of elasmobranchs, only by The Netherlands and Spain within the 'environmental targets and indicators' as "*fish species with a long-term negative trend in population size and fish species with a low reproductive capacity (i.e. skates, rays and sharks)*"

and by the UK as being a functional group and acknowledged representative for the lack of higher trophic level organisms within the national strategy.

Amongst, for the research area relevant, Member States unique emphasis was put on sharks only by The Netherlands. In a letter from 2016, addressed directly to the Second Chamber of the Dutch parliament, reasoning for improved shark management and an overview about the most pressing issues are provided by the attached KRM Shark Action Plan 2015-2021 (Box 13) in reference to the Dutch National Marine Strategy.

Box 13: KRM Shark Action Plan 2015-2021

The Dutch Action Plan orientates itself on the EUPOA sharks and highlights as well as specifies three important areas of improvement adapted on existing Dutch measures:

1) *Education and communication*

Addressing issues in identification and records of elasmobranch species with effect on data and derived advice. Measures planned include workshops for training in identification and handling of sharks and rays.

2) *The reduction of by-catch*

Measures include the development of 'best practices' amongst fishers and fisheries to reduce shark by-catch. Also, to increase survival of sharks on-board and the adaption of gear in that regard. The amendment of prohibited species TACs also applicable for vulnerable sharks such as spurdog (*Squalus acanthias*) and starry smooth-hound (*Mustelus asterias*). Species included in general/mixed TACs should only remain under positive ICES advice. Additional regulation for commercialized by-catch species.

3) *The increase of survival*

Acknowledging that sharks have general good chances for survival when caught and released depending on fishing method and on-board handling. Measures include an adapted landing obligations with more room for direct release species and the consideration of recreational fisheries as being not immediate detrimental but still harmful even when directly released as proposed.

The ambitions provided stand also in application on EU or international level and should be integrated into strategies pursued by RFMOs, CMS, OSPAR and CITES.

The first evaluation (Article 20) of the implemented Marine Strategies is to be held for to be concluded latest in 2019. The second cycle (2018 - 2024) starts in 2018 with a review/adaption of the originally established initial assessment, GES and environmental targets and indicators. Followed by the review of part 2, the monitoring program set for 2020, and review of the PoMs in 2021. At the end of the second cycle the second Commission evaluation of the adapted strategies is planned for the year 2023, initiating the third cycle. Achieved GES in the marine environment by 2020 is either maintained or further pursued.

	Convention	Species
UNCLOS (UN**,** 1982)	**Annex I**. Highly migratory species; pt. 16. Oceanic sharks Article 64 – *Highly migratory species* "*ensuring conservation and promoting the objective of optimum utilization of such species throughout the region, both within and beyond the exclusive economic zone*"	▪ Family Hammerhead sharks (*Sphyrnidae*) ▪ Family Thresher sharks (*Alopiidae*) ▪ Basking sharks (*Cetorhinus maximus*) ▪ Whale sharks (*Rhincodon typus*) ▪ Family Requiem sharks (*Carcharhinidae*) ▪ Family Mackerel sharks (formerly *Isurida*, accepted as *Lamnidae*) ▪ Bluntnose six-gill shark (*Hexanchus griseus*)
CITES (CITES, 2017)	**Appendix I.** Species threatened with extinction, which are or may be affected by trade International (commercial) trade of wild specimen prohibited	
	Appendix II. Species not necessarily currently threatened with extinction International (commercial) trade permitted but regulated	▪ Great hammerhead shark (*Sphyrna mokarran*) ▪ Scalloped hammerhead shark (*Sphyrna lewini*) ▪ Smooth hammerhead shark (*Sphyrna zygaena*) ▪ Family Thresher sharks (*Alopiidae*) ▪ Basking shark (*Cetorhinus maximus*) ▪ Whale shark (*Rhincodon typus*) ▪ Great white shark (*Carcharodon carcharias*) ▪ Oceanic whitetip shark (*Carcharhinus longimanus*) ▪ Silky shark (*Carcharhinus falicformis*) Porbeagle (*Lamna nasus*)
	Appendix III. Species for which a country is asking Parties to help with its protection International trade permitted but regulated	
CMS (CMS, 2015)	**Appendix I. and II.** (Obligatory protection)	▪ Great white shark (*Carcharodon carcharias*) ▪ Basking shark (*Cetorhinus maximus*)
	Appendix II. (Encouraging management)	▪ Great hammerhead shark (*Sphyrna mokarran*) ▪ Scalloped hammerhead shark (*Sphyrna lewini*) ▪ Thresher sharks (*Alopiidae*) ▪ Whale shark (*Rhincodon typus*) ▪ Shortfin mako shark (*Isurus oxyrinchus*) ▪ Longfin mako shark (*Isurus paucus*) ▪ Silky shark (*Carcharhinus falicformis*) ▪ Porbeagle (*Lamna nasus*) [Northern] Spurdog (*Squalus acanthias*)
OSPAR (OSPAR, 2008)	**List of Threatened and/or Declining Species and Habitats** Pt. 3: " *The purpose of the*	▪ Basking shark (*Cetorhinus maximus*) ▪ Porbeagle (*Lamna nasus*) ▪ Angel shark (*Squatina squatina*) ▪ [Northern] Spurdog (*Squalus acanthias*)

	list is to guide the OSPAR Commission in setting priorities for its further work on the conservation and protection of marine biodiversity. The inclusion of a species or of a type of habitat on this list has no other significance."	- Gulper shark (*Centrophorus granulosus*) - Leafscale gulper shark (*Centrophorus squamosus*) - Portuguese dogfish (*Centroscymnus coelolepis*)
BERN (BERN, 1979a, b)	**Appendix II.** Strictly protected Fauna Species	- Basking shark (*Cetorhinus maximus*) - Great white shark (*Carcharodon carcharias*)
	Appendix III. Protected Fauna Species	- Shortfin mako shark (*Isurus oxyrinchus*) - Porbeagle (*Lamna nasus*) - Blue shark (*Prionace glauca*) - Angel shark (*Squatina squatina*)
ICCAT (Bonfil & Hazin, n.d.)	**Prohibited catch and trade species**	- Family Hammerhead sharks (*Sphyrnidae* except *S. tiburo*) - Family Thresher sharks (*Alopiidae*) - Oceanic whitetip shark (*Carcharhinus longimanus*)

COUNCIL REGULATION (EU) 2018/120 of 23 January 2018 fixing for 2018 the fishing opportunities for certain fish stocks and groups of fish stocks, applicable in Union waters and, for Union fishing vessels, in certain non-Union waters, and amending Regulation (EU) 2017/127 Note: That prohibition can be conditioned in spatial and technical regard.	Prohibited species (conditioned): - Great white shark (*Carcharodon carcharias*) - Basking shark (*Cetorhinus maximus*) - Kitefin shark (*Dalatias licha*) - Leafscale gulper shark - Portuguese dogfish (*Centroscymnus coelolepis*) - Birdbeak dogfish (*Deania calcea*) - Great lanternshark - Smooth lanternshark - Tope shark (*Galeorhinus galeus*) - Porbeagle (Lamna nasus) - Picked dogfish/Spurdog (*Squalus acanthias*) - Angel shark (Squatina squatina) General prohibitions: - Bigeye thresher sharks (*Alopias superciliosus*) - Target fisheries for *Alopiidae* - Hammerhead sharks (*Sphyrnidae*) (except for *Sphyrna tiburo*) - Oceanic whitetip shark (*Carcharhinus longimanus*) (partly conditioned) - Silky shark (*Carcharhinus falicformis*) Prohibited third-country species (conditioned): - Great white shark (*Carcharodon carcharias*) - Basking shark (*Cetorhinus maximus*) - Kitefin shark (*Dalatias licha*) - Smooth lanternshark - Tope shark (*Galeorhinus galeus*) - Porbeagle (Lamna nasus) - Picked dogfish/Spurdog (*Squalus acanthias*) - Ange shark (Squatina squatina)

COUNCIL REGULATION (EU) 2016/2285 of 12 December 2016 fixing for 2017 and 2018 the fishing opportunities for Union fishing vessels for certain **deep-sea** fish stocks and amending Council Regulation (EU) 2016/72	In effect of this regulation as deep-sea sharks listed species: ▪ Deep-water catsharks (*Apristurus* spp.) ▪ Frilled shark (*Chlamydoselachus anguineus*) ▪ Gulper shark (*Centrophorus* spp.) ▪ Portuguese dogfish (*Centroscymnus coelolepis)* Longnose velvet dogfish (*Centroscymnus crepidater*) ▪ Black dogfish (*Centroscyllium fabricii*) ▪ Birdbeak dogfish (*Deania calcea*) ▪ Kitefin shark (*Dalatias licha*) ▪ Great lanternshark (*Etmopterus princeps*) ▪ Velvet belly (*Etmopterus spinax*) ▪ Mouse catshark (*Galeus murinus*) ▪ Bluntnose sixgill shark (*Hexanchus griseus*) ▪ Sailfin roughshark (Sharpback shark) (*Oxynotus paradoxus* ▪ Knifetooth dogfish (*Scymnodon ringens*) ▪ Greenland shark (*Somniosus microcephalus*)

	Statement or Objective	Level	Source
MSFD	*"The strategy, aimed at conservation and protection of marine ecosystem should include protected areas and should address human impacts. The establishment hereby should include already designated areas including international agreements.* *Such protected areas under the Directive* *Will be an important step fulfilling commitments under the World Summit on Sustainable Development and in the CBD."* *"This Directive should also support the strong position taken by the Community, in the context of the CBD, on halting biodiversity loss, ensuring the conservation and sustainable use of marine biodiversity, and on the creation of a global network of marine protected areas by 2012."* *"It is crucial for the achievement of the objectives of this Directive to ensure the integration of conservation objectives, management measures and monitoring and assessment activities set up for spatial protection measures such as special areas of conservation, special protection areas or marine protected areas."* *"Article 13, pt. 4: 4. Programmes of measures established pursuant to this Article shall include spatial protection measures, contributing to coherent and representative networks of marine protected areas, adequately covering the diversity of the constituent ecosystems, such as special areas of conservation pursuant to the Habitats Directive, special protection areas pursuant to the Birds Directive, and marine protected areas as agreed by the* *Community or Member States concerned in the framework of international or regional agreements to which they are parties."*	Community	EC, 2008a

Commission	*The Community acknowledges MPA as conservation measure and provides benefits for society and the addition of MPAs to the convergence between EU blue- and green economy.* *"To date the MSFD and Habitats Directive as well as the reformed CFP contain provisions that can add to the expansion of EU MPAs in the near future.* *Whereas MPAs should be an integral part of maritime spatial plans supporting the Green and Blue Infrastructure approach to ensure and improve the delivery of multiple ecosystem services from the same area. This integrated approach is also essential to ensure that pressures across the seas are reduced and ecosystem resilience is therefore strengthened."* *"The Commission will continue supporting national and international efforts in relation to the designation and effective management of marine protected areas, as well as the implementation of other spatial protection measures for marine biodiversity."*	Community	EC, 2015
Commission	*"In 2017, the EU hosted the fourth edition of the Our Ocean Conference with great success, as it resulted in 433 tangible commitments amounting to EUR 7.2 billion in financial pledges and 2.5 million km2 of additional Marine Protected Areas"*	Community	EC, 2018c

Commission	*"In compliance with what is required by the MSFD all Member States report, in their programmes of measures, on the use of spatial protection measures. These are measures meant to create coherent and representative networks of marine protected areas, such as special areas of. Such spatial measures were often reported in connection with fisheries, or the protection of certain habitats. While 2 Member States clearly list new marine protected areas, another 8 reported they were planning or designating new marine protected areas as measures. The overall coverage has increased significantly through the Birds and Habitats legislation and international conventions."* *"Most Member States have also introduced new measures to reduce the pressure on over-exploited stocks, e.g. by requiring the use of specific fishing gear or by introducing targeted temporal/spatial restrictions or bans. Most Member States have put in place spatial protection measures, either within the Natura 2000 network or by strengthening the management plans for existing marine protected areas."* *"Most Member States report using spatial protection measures based on the Habitats Directive's Natura 2000 network to protect some fish species and to a lesser extent, the Water Framework Directive to protect migratory pathways for fish. Spatial measures have also been used to protect certain seabed habitats which act as fish breeding and nursery grounds."*	Community/ Member State	EC, 2018b
CFP	*"The CFP acknowledges itself as instrument to regulate fisheries through e.g. closures and no-take zones so that objectives of protected areas, such as the Habitats Directive and Natura 2000 and areas under the MSFD can be fulfilled."* *"Also measures should include the reduction of mechanical impact of fishing gear also outside of such protected areas and additional measures to protect sensitive habitats, when awareness about such habitats emerge."*	Community	EC, 2008b

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	"In order to contribute to the conservation of living aquatic resources and marine ecosystems, the Union should endeavor to protect areas that are biologically sensitive, by designating them as protected areas." *"Spatial measures under the Habitats Directive might require the adoption of measures under the CFP to fulfill obligations* *In regard to areas of special protection, conservation and MPAs."*	Community	EC, 2013
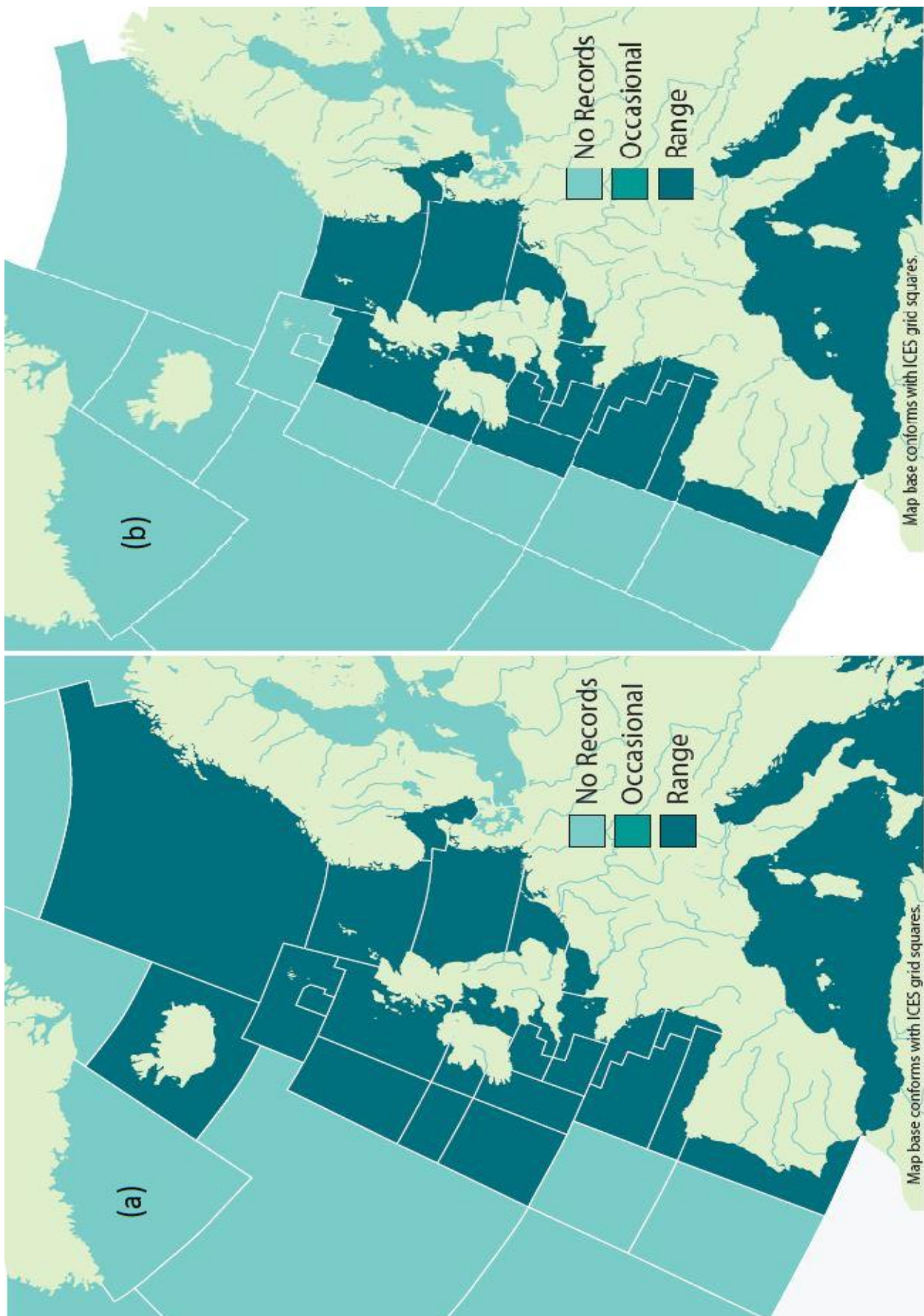
Figure 13: G. galeus (a) and M. asterias (b) range in the NEA by ICES subareas. (Shark Trust, 2010)