Patterns of space use and habitat preferences of grey seals (*Halichoerus grypus*) within the Parc Naturel Marin d’Iroise

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A Introduction

The life cycles of animals are defined by several life stages such as growth, survival and the exploitation of environmental resources. The distribution of an animal’s habitat can influence its life cycle because the distribution of resources and environmental conditions varying with the habitats. Habitats can be defined as contiguous in environmental space (Aarts et al., 2008; Hirzel and Le Lay, 2008) that are composed of multiple dimensions, each representing an biotic or abiotic environmental variable. Because habitats are heterogeneously distributed (Beyer et al., 2010), animals tend not to use them equally. Therefore, habitat use can be defined as the proportion of time animals spend in particular habitats. Selection of habitat is the process by which an animal actually chooses habitat (Johnson, 1980). If the habitat is not used proportionately compared with its availability, use can be considered as selective (Beyer et al., 2010). This availability depends of the habitat accessibility to an animal. When the access to habitat in geographical space is limited by a complex function of many social interspecific and environmental factors that can be defined as the habitat accessibility (Garshelis, 2000; Matthiopoulos, 2003; Aarts et al., 2008). The preference as the likelihood of an animal selecting a given item when offered alternative choices on an equal basis (Johnson, 1980). Furthermore, this habitat preference is defined as the use of habitat relative to the availability in the environment and conditional on the availability of all habitat to the animal (Aarts et al., 2008).

The spatial use of top marine predators such as grey seals (*Halichoerus grypus*) has been shown to be influenced by a wide range of environmental variables, such as depth (Aarts, 2007; Sjöberg and Ball, 2000), sediment type (Aarts, 2007) and distance from haul out (Thompson et al., 1996). This distance from the land is important. Seals always need to go back to the land and so are central place foragers (McConnell et al., 1999). However, the foraging areas are more driven by the availability of prey than the environmental variables (Hoelzel, 2002).

Seals use land to rest (Schneider et al., 1980), to moult, to maintain thermoregulation (Feltz and Fay, 1966), and to breed, these can be defined as haul out sites. Grey seals spend a portion of their time hauled out on land probably to rest and interact socially. Grey seals also aggregate in high numbers and densities at breeding colonies. They breed
at different time in clockwise cline around the United Kingdom, Ireland and France (from August to December). These specific sites are located above the intertidal area.

The distribution of the northeast Atlantic grey seal ranges from the Kola Peninsula in Russia to France, with the majority of the population located around the United Kingdom (Gerondeau et al., 2007). About 111,300 were estimated in the UK in 2010 (SCOS, 2011), where around 75% of the population of this stock breed (SCOS, 2011). This UK portion represents 40% of the global population, the largest in the west Atlantic. Grey seals in France are at the southern most limit of the species range, with two breeding colonies: in the Sept Iles and the Molene archipelago, both in Brittany. The Molene archipelago is located in the Iroise sea, at the western tip of Brittany, and is the largest colony with 100 individuals (Vincent C., personal comments).

The Parc Naturel Marin d’Iroise (PNMI) was created in the Iroise sea in 2007, to preserve the equilibrium between protecting natural resources and the anthropogenic activities that take place within the park such as fishing. The marine park provides 10 management directives, aiming to maintain the population size and habitat of protected species. The management and conservation of the grey seal population is included in this directive. Management directives also take into account the requirements of fisheries within the park. Seal-fisheries interactions need to be quantified to inform future management plans.

Several activities take place in the marine park. There are different fisheries distributed in the Iroise sea. For example, sea bass (*Dicentrarchus labrax*), pollock (*Polliachus pollia-chus*) and sardine (*Sardina pilchardus*) fisheries are located in the south of the marine park. A dragnet fishery is located in the east part (Le Niliot, P, personal comments). Trawl fishery is forbidden along the coastal and islands areas. There are also different recreational activities such as diving, kayak, sailing and recreational fishing.

The PNMI is characterized by two areas, one containing Molene archipelago and the Isle of Ouessant, and the other containing the Isle of Sein and the Ar Men Lighthouse.

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The Molene archipelago also contains six shallow islands, only one of which is inhabited and numerous tidal reefs, surrounded by an extended plateau at depths shallower than 20m (Ridoux et al., 2007). This archipelago contains an important kelp forest (Laminaria sp). In the marine park, the principal prey of grey seals is wrasse (Labrus bergylta, (Ridoux et al., 2007), representing 50.6% of the diet by mass. This fish is mainly found in the kelp forest (LeNiliot P., personal comments).

There are several techniques to assess grey seal abundance, site fidelity (Pomeroy et al., 2005), individuals movement and haulout site use such as surveys, photo-identification (Vincent et al., 2005) or telemetry tracks (McConnell et al., 1999). Telemetry studies allow monitoring of individual movements over several months. Satellite tracking tags deployed by the Sea Mammal Research Unit have aided in following the movements of marine mammals over a much larger range and allowed spatial analysis of these predators (Aarts et al., 2008; Matthiopoulos et al., 2004; McConnell et al., 1999).

The objective of this study was to characterize the habitat preference of grey seals in the areas along the Breton mainland coasts, including the PNMI. Presence only data from telemetry tracks were used to predict the spatial usage and preference of grey seal in the Iroise sea.

B Methods

B.1 Overview of methods

An overview of methods is presented (Fig. 1). Telemetry data were cleansed through a set of protocols to remove null, missing and anomalous data points. Only return trips that were within the marine park were selected. These represented the presence points. Because telemetry tracks only give presence points, pseudo-absence points were created randomly. For the second step, the presence/absence points were used as the response data and environmental data were used as a covariates in a generalized linear model (GLM). Finally, this response was used to predict the spatial usage and preference of grey seals in the marine park. R software version 2.14.1 and Manifold GIS software version 8.0 were used.
B.2 Study area

The PNMI covers an area of 3550 km$^2$ between the isle of Ouessant in the North (48°31’N) and the isle of Sein in the south (47°59’N), (Fig. 2). This area contains the Molene archipelago, which is composed of some islands and multiple rocky haul out sites for seals at low tide. The study area includes this marine park and is extended to the Abers (on the north of Finistere), because this area is close to the marine park.

B.3 GPS/GSM tags

Twelve seals were caught and tagged with GPS/GSM tags (Fig. 3) in the marine park, close to Beniguet island during 2010 and 2011. Tags were glued to the fur of the neck, and therefore fall off during the moult period. That is the reason why all the data were collected outside the moult period. Telemetry monitoring was carried out from the beginning of the summer (June) until the period of reproduction (October-December).

The GPS/GSM tags (Series 900 GPS Fastloc) are produced by the Sea Mammal Research Unit (SMRU) at the University of St Andrews (McConnell et al., 2004). This tag uses depth and wet/dry sensor data to determine whether the seal is hauled out on land or diving at the surface. The tags are able to record a seal’s behavior and location over several months. The GPS tags need to be in range of satellite receivers for the
transmission activation (McConnell et al., 2004).

Data are recorded and transmitted in GMT time zone. The positional accuracy of the GSM tags is high (Bryant, 2007).

Figure 3: Grey seal (a) and GPS/GSM tag (b), photographs by Cécile Vincent
B.4 Data

B.4-a Return-trip selection

Seals can perform transition trips, from a haul out site to an other one in a different geographical area, so not all are return trips (Hoelzel, 2002). In the United Kingdom (UK), 88% of trips to sea terminated at the same haulout site from where they started (McConnell et al., 1999). These trips are called return-trips. Grey seals are able to travel over long distances. For example, some grey seals of this study travelled from Brittany to Ireland or England. Analysis were focused on an area containing the marine park and the Abers zone (situated in the north of Iroise sea) to take into account the fine scale of environmental covariates. Furthermore, the accessibility is available in this model. Return trip accessibility is the same on the outwards and return journeys of the trips. These concepts explain the reason why only the return trips in the Iroise sea were selected (Fig. 4), representing 80% of the telemetry locations, where all seals kept in the analysis.

![Figure 4: Telemetry points considered as return-trip points from all seals tracks](image)

B.4-b Environmental data

To model the habitat preference of grey seals in Brittany, four principal covariates were used: bathymetry, sea surface current (SSC), sea surface temperature (SST) and sediment types. These data came from different sources and covered different areas. Sea surface current data had the least spatial extent and therefore the study area was limited by the
spatial extent of SSC. These covariates were chosen because of previous work realized on UK populations (Aarts et al., 2008; McDowall, 2011).

**Bathymetry**

Bathymetry data were available from the GEBCO website\(^3\) (General Bathymetric Chart of the Oceans). The data base corresponded to the GEBCO_08 GRID model (global 30 arc-second grid) with a grid resolution of 100m (Fig. 5a).

Slope was derived from the bathymetry data using the Manifold GIS software. The fine scale resolution of the data made all slope angles between 1 and 3 degrees. It was determined that seals would not biologically be able to preference slopes on this scale and so the covariate was not used in the analysis.

Aspect was also derived from the bathymetry data using the Manifold GIS software. This covariate represented the slope orientation, and was a circular statistic. To provide relevant biological interpretation, it was transformed in two vectors, one for the north-south orientation of the slope and an other one for east-west orientation by using the cosine and sine of the orientation.

**Sea surface Current**

Sea surface current data was available from the database Previmer\(^4\). This database corresponds to one of the North East Atlantic models, the MARS2D Iroise model. The resolution of this model is 0.003\(^*\)0.003 decimal degree grid cell size (Fig. 5b).

**Sea Surface Temperature**

Sea Surface Temperature data (Fig. 5c) comes from two different databases to cover all track durations.

The first one was provided by the NOAA database using the Optimum Interpolation 1/4 degree Daily Sea Surface Temperature Analysis (OISST) model\(^5\). The resolution was 1/4 degree of grid cell size. Because the data was daily, a monthly average was calculated. This data covers the period from 06/2010 to 08/2010.

The second comes from the MyOcean Database and corresponded to the SST-NWS-SST-L4-NRT-OBSERVATIONS-010-003 model and to Atlantic European North West

\(^3\)http://www.gebco.net/data_and_products/gridded_bathymetry_data/
\(^4\)http://www.previmer.org/
\(^5\)http://www.ncdc.noaa.gov/thredds/catalog/oisst/NetCDF/AVHRR/catalog.html
Shelf Ocean satellite observations. The grid cell size was 0.02*0.02 degree horizontal resolution. Data were downloaded per month but only covered the 09/2010-12/2010 and 06/2011-01/2012 periods. That is the reason why the first data base was used to cover all the track duration even if the resolution of grid size of the second data base is better.

**Sediment**

Sediment data was provided by the MESH website (Mapping European Seabed Habitat) and corresponded to the MESH_EUNI model. The MESH project predicts of seabed habitat types. The resolution of the grid cell size is 300m (Fig. 5d). Seabed habitats are divided up into seabed substrate distribution with different sublittoral sections and energy levels.

In order to use this sediment data, each seabed habitat was translated into a percentage of rock, gravel, mud and sand according to the FOLK sediment classification (Davies et al. 2004).

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6 http://www.myocean.eu
7 http://www.searchmesh.net/default.aspx
8 http://www.searchmesh.net/default.aspx
Figure 5: From left to right and from top to down: bathymetry data (meters) (a), current data (m/s) (b), sea surface temperature data (°C) (c), sediment data (d).
B.4-c Biological distance

The distance to haul-out was used in the model as covariate in the model to describe the accessibility of points to a central place foragers (Aarts et al., 2008). The biological distance is the at-sea distance (in Km) between any points in space and the haul out (Aarts et al., 2008). The biological distance explains how accessible sea is spatially to the seals from their haul-outs. A 500m resolution raster was created to calculate the distance from each unique haul out site. This 500m resolution was chosen because it was a balance between fine scale resolution and computer processing time. The obstacles such as landmasses, considered as physical barriers to seals moving in the Iroise sea, were taken into account.

B.5 Control-points

Telemetry points give an indication on a seal’s presence in some areas, but in contrast this kind of point does not give information on the absence of seals. Both provide information on spatial preference.

Pseudo-absence points were generated from a uniform random distribution (Pearce and Boyce, 2006; Aarts et al., 2008) within the study area (Fig. 6). This area was created from a buffer, covering the surface area. To avoid creating random point on the land, land was deleted from the buffer. One track point was associated with two pseudo-absence points because of the restricted size of the area.

Figure 6: Pseudo-absence points used in model fitting and validation. Points are drawn from a uniform random distribution within the study area.
B.6 Model

The data frame containing the response variable with all covariates was divided in two parts. One part for the model fitting (representing 75% of the data) and the other part (25%) for the model validation. There was not a second data set to validate the model, so that is the reason why 25% of the each track in the fitting data frame were selected randomly for the validation of the model.

The model used presence-absence as the response variable, taking values ’1’ for the telemetry observations, and ’0’ for the pseudo-absence points.

The habitat preference of grey seals was modeled using a generalized linear model (GLM) from the Stats package in R. The GLMs is a statistical linear model based on the equation:

\[ Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \ldots + \beta_p X_{ip} + \varepsilon_i \]

Where \( Y_i \) is the \( i \)th observation of the dependent variable, \( X_{ij} \) is \( i \)th observation of the \( j \)th independent variable with \( j=1,2,...,p \), \( \beta_0 \) is the intercept, \( \beta_j \) represent the values to be estimated and the coefficients for each variable.

Because of the presence-absence response variable, the binomial family, based on the 0-1 data, was used with a logit link function.

B.6-a Multicollinearity

Multicollinearity is a statistical phenomenon in which two or more covariates are highly related. This phenomenon is a problem because the coefficient estimates may change erratically in response to small changes in model or data. Multicollinearity affects calculation regarding individual predictions.

Varaince inflation factors

To assess the multicollinearity between the different covariates, variance inflation factors (VIFs) of the variables was used. The VIF is an ordinary least squares regression analysis. It provides an index measuring how much the variance of an estimated regression coefficient is increased because of the collinearity. Multicollinearity can be considered as important when the VIF value is higher to 10 (Kutner et al., 2004).

\(^9\)http://cran.r-project.org/
During the step of data exploration, multicollinearity was detected between sediment variables. To avoid this multicollinearity, a Principal Component Analysis was used on these variables.

**Principal component analysis**

The principal component analysis (PCA) uses an orthogonal transformation to convert some collinear variables into a set of linearly uncorrelated variables called principal components (Matthiopoulos, 2011). The number of principal component is less than or equal to the number of variables (Matthiopoulos, 2011). The first principal component explains the highest variance and each succeeding component has the largest variance possible under the constraint that it be orthogonal to the preceding component. In this study, PCA was used to avoid multicollinearity between sediment covariates (rock, mud, sand and gravel). Four principal components were obtained, but the first three components explained almost all of the variance in the data (100%, Fig. 7). The first two components were used for the model. These principal components were explained 85% of the variance, which was enough to not include the third in the model. The composition for each principal component is:

\[
PC1 = -0.6400041 \times rock + 0.3780933 \times sand + 0.4684239 \times gravel + 0.4775136 \times mud
\]

\[
PC2 = 0.1151003 \times rock - 0.8133242 \times sand + 0.3826400 \times gravel + 0.4228976 \times mud
\]

Each principal component represents mainly the variables with the highest coefficients (with the absolute value). Here, PC1 mainly represents rock and PC2 sand.

**B.6-b Quadratic terms**

When a non linear response was expected to an environmental variable, indeed an optimal value of the covariate, higher-order for the covariates were added. Three covariates were added as quadratic terms. These covariates are:

- Bathymetry, because seals usually forage on the bottom but generally do not dive down more than 150m.

- Sea Surface Temperature, because the wrasse habitat is located in the kelp forest on the rocky areas. Kelp forest needs an optimum temperature for its growth.
Figure 7: Percentage of variance explained by each principal component

- Sea Surface Current, because, seals usually use the current to travel but do not use really strong current, because of the energetic costs. Furthermore, areas with strong current correspond to areas with a good oxygenation, indeed, with a good primary production.

At the opposite, two other covariates were not used as quadratic terms:

- Sediment, because of the usage of principal components, instead the real components do not permit to use quadratic terms for this covariate

- Biodistance, because it is considerate as a resource, and the response to a resource is asymptotic and is unlimited.

B.6-c Model selection and model validation

A stepwise procedure was applied to select the model that fitted the data, in conjunction with AIC values (Akaike’s Information Criteria; (Akaike, 1973)). AIC is a trade-off between bias and variance in the model, i.e. it penalizes for the number of covariates in the model. The best model is the model having the lowest AIC.
The model was validated using the remaining 25% of the data. Different processes can be used to validate the model. A confusion matrix and ROC curves were used in this study.

A confusion matrix (Kohavi and Provost, 1998) contains information about actual and predicted classifications done by a classification system. Performance of such systems is commonly evaluated using the data in the matrix. The matrix table shows the confusion matrix for a two class classifier. It was constructed containing observed values (0 or 1) and predicted values for the validation dataset. The prediction values range from 0 to 1 and are considered as the probability of presence. The confusion matrix, provides the model accuracy by tabulating the false negative, false positive, true negative and true positive values.

The Receiver Operator Curves (ROC) are generated from the confusion matrix. This system analyses the predictive performance of the model by comparing rates of correct and incorrect prediction. Different metrics can be obtained with ROCs:

- Sensitivity is the probability that the model correctly predicts a high value for true presence points within the confusion matrix (Boyce et al., 2002)
- Specificity is the probability that the model correctly predicts a low value for true absence points (within the confusion matrix (Boyce et al., 2002))
- Area Under Curve (AUC) is defined as ROC space, when specificity and sensitivity are plotted for each threshold value. The area under the plotted curve is defined as the AUC value which measures the predictive model performance of the model. A AUC value equal to 0.5 indicates no predictive power, and a value of 1 indicates a perfect prediction (Boyce et al., 2002; Pearce and Ferrier, 2000).

C Results

C.1 Model

The model retained by the model selection had the lowest AIC. The model explains 78% of the presence variation (obtained by the deviance explained). Outputs of the model are presented Table 1. All covariates retained in the model with the lowest AIC. Even if all $p$-value are not significant, the model selection was made with the estimated values.
Estimated values represent the weight of the variable in the model. The results show that the model is mainly driven by the current (estimate= 2.907), its quadratic term (estimate= -1.096) and SST (3.565) variables, with the highest estimated values. These three variables are the most important variables affecting seal habitat preference.

Table 1: Output model

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimate</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biodistance</td>
<td>-2.00*10⁻¹</td>
<td>&lt;2*10⁻¹⁶</td>
</tr>
<tr>
<td>Bathymetry</td>
<td>-5.597*10⁻²</td>
<td>&lt;2*10⁻¹⁶</td>
</tr>
<tr>
<td>Bathymetry²</td>
<td>2.810*10⁻⁴</td>
<td>3.46*10⁻⁷</td>
</tr>
<tr>
<td>Cosine-aspect</td>
<td>-3.382*10⁻¹</td>
<td>1.11*10⁻⁶</td>
</tr>
<tr>
<td>Sine-aspect</td>
<td>-5.781*10⁻¹</td>
<td>1.99*10⁻¹³</td>
</tr>
<tr>
<td>Current</td>
<td>2.907</td>
<td>0.008289</td>
</tr>
<tr>
<td>Current²</td>
<td>-1.096</td>
<td>0.118542</td>
</tr>
<tr>
<td>SST</td>
<td>3.565</td>
<td>0.000428</td>
</tr>
<tr>
<td>SST²</td>
<td>-1.152*10⁻¹</td>
<td>0.00437</td>
</tr>
<tr>
<td>PC2</td>
<td>5.631*10⁻³</td>
<td>0.000291</td>
</tr>
</tbody>
</table>

**Biological distance**

Biological distance was included as a linear term in the model. The variable was retained as significant (p-value < 2*10⁻¹⁶). The probability of seal presence reduced with increasing the distance.

**Bathymetry**

Bathymetry was included as a quadratic term. Bathymetry was retained as a significant variable (p-value < 2*10⁻¹⁶ for the linear term and p-value = 3.46*10⁻⁷ for the quadratic term). Figure 8a shows the variation in the probability of presence against the bathymetry. Usage declines with an increase of bathymetry to reach a plateau around 30 meters of depth. This output shows a preference for positive values of depth, indeed for the land. It is likely to be an artifact of the control-points’s buffer extent.

The two vectors of bathymetry aspect were included as linear terms. Both were significant (p-value = 1.99*10⁻¹³ for sine aspect, and p-value = 1.11*10⁻⁶ for cosine aspect). The cosines vector, representing a north-south orientation, shows decreasing usage with an increase in value. This means that usage is supported by a south orientation, and decreases with a north orientation. The south orientation reaches a direction from the Abers area to the archipelago, and from the archipelago to the isle of Sein and the Ar-Men lighthouse. A similar observation was made for the sine vector (representing the east-west
orientation). A preference of usage was shown for low value of sine, which is the east slope orientation. The east orientation shows an orientation to shallow waters, towards to the land (island and mainland).

![Graphs showing prediction responses against environmental covariates]

**Figure 8:** From left to right: Prediction response against environmental covariates: bathymetry (m) (a) current (m/s) (b) SST (°C) (c)

**Sea Surface Current**

The SSC covariate was included as a quadratic term. The linear term ($pvalue = 0.008289$) and the quadratic term ($pvalue = 0.118542$) were retained as significant in the model, even if the $pvalue$ of the quadratic term was not significant. Usage increases with strong currents to reach a peak at a 1.3 m/s speed (Fig 8 b). This means this speed value is the optimal value of usage. The linear and quadratic terms for current have the second and the third largest parameter estimates in the model and therefore a large effect on preference.

**Sea Surface Temperature**

Sea surface temperature was included as a quadratic term in the model. This variable was kept by the model as significant ($pvalue = 0.000428$ for the linear term and $pvalue = 0.00437$ for the quadratic term). The usage increases then decreases after a certain value of temperature. This response shows a optimal value of SST for the presence of seal around 15.5 degrees celcius (Fig 8c).

**Sediment**
The principal components PC1 and PC2 were included in the model as linear terms. PC1 was dropped and PC2 was retained as a significant variable ($p\text{value} = 0.000291$). The estimate of PC2 shows a positive relationship with the usage. PC2 is principally explained by sand, with a high negative coefficient. This shows a negative relationship between usage and sand. The usage decreases with a sea floor containing sand.

Model validation

The confusion matrix and ROC were used as validation procedures to test the model. The confusion matrix calculated the accuracy of the model as 0.94. The Receiver Operator Curves from the model is presented in figure 9. The ROC of the model is closed to the ROC of the perfect model. The ROC provided different outputs of AUC, sensitivity and specificity. The values were respectively 0.951, 0.972 and 0.930.

![ROC curve from model validation](image)

**Figure 9:** ROC curve from model validation

<table>
<thead>
<tr>
<th></th>
<th>AUC</th>
<th>Sensitivity</th>
<th>Specificity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>0.951</td>
<td>0.972</td>
<td>0.930</td>
</tr>
</tbody>
</table>

**Table 2:** Model validation coefficients
C.2 Model output

C.2-a Probability of expected usage

The predictions were plotted with Manifold GIS software and presented figure 10, representing the probability of expected usage. The results show strong spatial usage around Isle of Sein and ArMen lighthouse (situated in the west of Sein), in Molene archipelago, and around the coast in the north Finistere with strong predictive values (between 0.8 and 1). Conversely, poor usage is observed in the north and south of the Iroise Sea, and in the Abers offshore. Medium usage is observed around the land, and between Molene archipelago and Isle of Sein.

![Map of predicted spatial expected distribution by grey seals in the study area](image)

Figure 10: Map of predicted spatial expected distribution by grey seals in the study area

C.2-b Predicted preference of habitats

Predicted preference habitat was obtained with the exponential of the predictive values and plotted with Manifold GIS software. The results are presented figure 11. These results show a predicted preference in some areas. Grey seals have a predicted preference for the Molene archipelago, in the Abers, at the entrance of the *Rade of Brest* (Goulet area) and around the Armen lighthouse.
C.2-c Preferred habitats

The preferred habitat is presented figure 12. The values were obtained with the exponential of predicted value, but with the assumption that each point in the space has the same accessibility. The biological distance was set to 0. Manifold GIS software was used to plot the preferred habitat values. The preferred habitat values are located around all the coastline and island. Furthermore, there is a strong preference for the Molene archipelago area, Roscanvel (located at the entrance of the Rade of Brest) and Crozon tip (at the entrance of bay of Douarnenez).

D Discussion

The objective of this study was to characterize the habitat preference and usage of grey seals in the areas along the Breton mainland coasts, particularly in the Parc natural Marin d’Iroise. The results obtained can be used to provide some management directive for the PNMI. Similar studies have been undertaken, particularly for the Scottish populations of grey seals (Aarts et al., 2008; McDowall, 2011).
D.1 Model output

GLMs were used for the habitat preference and usage modelling. Different covariates have been used as biological distance to haulout, current, sea surface temperature, sediment and bathymetry.

Biological distance was retained as significant by the model. The probability of seal presence declines with an increase in distance. These results agree with other studies (Aarts et al., 2008; McDowall, 2011), showing that the distance to the haulout had a negative relationship to the response. This shows that usage far away from the haulout was over-predicted by the accessibility model (Aarts et al., 2008). A study on North Sea populations (McConnell et al., 1999) has shown that an average of 43% of all seals’s time was spent within 10 km haulout site, and the main activities of seals are around 50 km of haul out site. This is partly due to the fact that seals are central placed foragers and by definition they will spend the majority of their time close to the haul out. In this study, this can be explain, firstly because return-trips location were selected, and secondly because the breton seal preferred habitats is really close to land, i.e. because the kelp forest (and therefore wrasse) are coastal, so is the habitat preference. In the Molene archipelago
haul out site are located within the kelp forest, and it provides a good resource of food with preys distribution, for example wrasse. Biodistance could be use as quadratic term. The seal presence decrease with an increase of biodistance, to reach minimum and should increase after. This decrease can correspond to the time that a seal uses to travel from one haulout site to a feeding area. At the opposite, the increase of the presence can correspond to the time spend by the seal in this area, increasing the presence of seal.

For the bathymetry, the artefact of the control points’s buffer extent can be explain. The land was removed from the buffer so that there were no control points on land. However, some islands were too small to be take into account by the software and so were not removed. Only the mainland and the Isle of Ouessant were removed. Grey seals are benthic feeders (Thompson et al., 1999) and shallow divers (Sjöberg and Ball, 2000). Different depth preferences have been shown: between 10 and 50m (Tollit et al., 1998), 80m (Aarts et al., 2008). These findings correspond with the results of this study, because grey seals show a preference for shallow water. This preference can be linked to the prey distribution of grey seal. In the North Sea, sandeels seem to be its principal prey (Prime and Hammond, 1990; Hammond et al., 1994b), representing 84% of its diet. Nevertheless, the principal prey of grey seals in the Iroise sea is the wrasse. This prey should be accessible in shallow waters, hence explaining the current result.

The south orientation seems to have an influence on the behavior of the bottlenose dolphin’s population of Isle of Sein (Liret, 2001). In the isle of Sein, the current has a North South orientation. In this channel, dolphins are moving in the downstream of the rock (with a south orientation slope). The food resources seem to be increased in this part (Liret, 2001), because the water here is more biologically productive. This process can explain the south orientation preference and we can make the same hypothesis for the Molene archipelago area.

In some cases, grey seals show an avoidance for mud (Boulcott et al., 2007; Aarts et al., 2008; McDowall, 2011). This avoidance in the North Sea, seems to be linked with the distribution of their prey, the sandeel. The distribution of the sandeels are more located in sand sediments (on sandy seafloor off the east Scotland coast for example). As for the sandeels, the sediment, here, can be used as a proxy of prey distribution, which is
wrasse. Wrasse is distributed in kelp forest, situated on the rocky area, and not on the sand sediment. That explains the avoidance for sand in this study.

Seals seem to have a preference for strong current. This result can be interpreted in two ways: on the one hand, seals can use the current, and move with it to save energy; on the other hand, seals can use the current for foraging. The link between seal predation on salmon and tidal current has been shown (Zamon, 2001). There is a strong current influence in nearshore predator-prey interactions, because of the strong interaction between current, plankton and planktivorous fish (Zamon, 2003), increasing the primary production. In the area with strong current, preys are not more numerous but more dispersed and more available to predators (Zamon, 2003). Fishes aggregate themselves in concentrated schools to avoid predation. Juveniles and weak individuals are protected by the school, because they are located in the middle of the shoal and surrounded by stronger and healthier individuals. But if the school is dispersed, weak and young preys become isolated and more vulnerable for the predation. Fishes which are feeding are more visible than fishes who are not feeding (sillvery flash concept (Zamon, 2003)). The strong currents are around the islands in the rocky areas (Figure 5b). That is why, with this concept, we can suspect the seals to use the current to forage on their principal prey, the wrasse.

Grey seals do not seem to have a preference for temperature in the west coast of the North Sea (MacLeod et al., 2007). However, it was one of the two main variables to drive the model (see Estimate value, Table 1). The SST seems to have an important role in the distribution of grey seals in the Iroise sea. Seals are preferring shallow waters, the SST could be higher in this area. Optimum temperature are moving between seasons. The optimum temperature in the summer is not located in the same area than during the winter. Furthermore, the temperature interval is not the same during the seasons. The winter SST interval has lower temperatures than the summer. If seals are located in the same areas during the summer and the winter, the SST influence is not the same than if the seals are not located in the same areas during the different seasons. In this case, seals can follow changing temperature. To take into account this influence, SST can be normalized around a same interval. The real impact of SST on the grey seals distribution should be shown with this normalization.
The influence of all these covariates can be linked. We have seen that grey seals prefer shallow waters, a south-east slope orientation, strong sea surface current, low biodistance, temperature of 15.5°C, and areas with low sand level. Figure 5b shows that strong SSC were around the islands and these are located in the south east part. There are some channels with strong current, the Fromveur channel (between Molene and Ouessant), Four channel (north of Abers area) located more for a north-west orientation, with a high bathymetry and with a sandy seafloor. Currents in the south east part of islands, are located in shallow waters and in rocky areas. This hydrodynamic system creates turbulence areas with a mix of water mass and with a strong biological productivity. The prey, more abundant, can be more accessible in the hydrodynamic shadow of the rock (Liret, 2001), because prey cannot hide in the rock. Some studies have shown this slope orientation influence in other areas (Zamon, 2001; Zamon, 2003; Baumgartner, 1997). In the Iroise sea, the kelp forest is located all around haul-out sites, indeed in the rocky area. This kelp forest affects the current, by slowing down it and needs an optimum of temperature for it growth. Furthermore, the wrasse is distributed in this area. This place should be a good foraging area for grey seals and can explain all covariates preference. Indeed, seals prefer: habitat close to the land because of the repartition of the kelp forest; a SST of 15.5°C, because it should be the optimum temperature for the kelp growth; avoid sand floor, this is not the floor for kelp forest; strong current, located in the kelp forest. Seals are central place forager prefer (McConnell et al., 1999). Central places to forage are located in the kelp forest, that explains the preference for shallow waters.

All locations in a "trip" were used to characterize the habitat preference and usage of grey seals. This includes animal’s departure to and from an haulout site, traveling between areas, and foraging. Data from traveling and foraging can be used for future analyses to characterize foraging areas. Telemetry tags provide data on diving activities and foraging behaviour, with the Time Allocation at Depth (Fedak et al., 2001). These informations can be used to identify the foraging areas using Stat Space Model analysis for example, and can be compared to the habitat preference to see if this preference is really driven by the wrasse distribution. These future analyses could implement the future directives managements. This study is a first step of ecology modelling of grey seals in Brittany. Because the Breton population is increasing, grey seals in this area continue to be tagged. The new data can be used to study the dynamic of habitat preference of
grey seals. Sixteen grey seals were tagged with Argos tags, before the marine park was set up. These data cannot be used to see the influence of implementation of the marine park. Due to Argos error, the scale accuracy of Argos data is not appropriate to the space scale of the marine park. The accuracy of locations with GPS/GSM tag is more relevant than with other kind of tag. Furthermore, there is new colony in the Bay of Somme, in the north of France. In contrast to Brittany, this bay is a sandy area. Nine seals were tagged this year. Activities and habitat preference of grey seals should be compared between these two areas.

D.2 Model validation

The AUC value of the model was 0.95. This value is close to 1, and shows that the model is close to the perfect prediction. This can be explained by removing the multicollinearity of sedimental covariates by PCA. The accuracy of the model is high but can be improved. Conversely, the collinearity between bathymetry and biodistance was not deleted because it made biological sense to keep them in the model, i.e. by definition seals will haul out next to shallow waters, which will be at 0 biological distance, so we already now they are correlated. But it is more detrimental to the model to leave them out than it is to include them both. Finally, the prediction and the coefficient validation values of the model are relevant.

D.3 Marine park management directives

One objective of this study was to help the marine park to make management directives. The marine park is a fishery area so there is a potential for interactions with grey seals. Some negative interactions such as accidental bycatch, have been reported, particularly with subadults (Vincent, C. personal comments). There are different types of fisheries, but all are regulated by the park management directives. Maps of seal usage and preference can be used to inform these directives. The maps to predict usage and preference can be used for the current population level. These maps have shown usage and preference around the Molene archipelago, the south of marine park (including the isle of Sein and the Ar-men lighthouse), the Abers area, the entrance of the Rade de Brest, and between the Molene archipelago and Le Conquet. The distribution of the bottom line fishery is located in the Molene archipelago. Furthermore two types of fishery are found in the
around the isle of Sein and the Ar-men lighthouse, the bolinche and lingers fisheries. The
dragnet fishery is found around the entrance of the Rade de Brest and the south of Le
Conquet. Even if the principal prey of grey seals is not a commercial species, we can
expect indirect interactions between these fisheries and grey seals, because they forage in
similar areas. This can be particularly the case of subadults, because they have a larger
prey species range than adults. The grey seal population increase with a rate of 7% per
year (Gerondeau et al., 2007). In the future, the number of seals could be too large for the
same number of haulout sites. With the increase of grey seal population, we can expect
an increase of number of haulout sites. In this case, the preferred habitat map can be used
to inform new management directives. Delimitation of fishery activities can be reviewed
and they can be updated to the incorporate updated habitat preference to limit indirect
interaction and accidental by catch.

E Conclusion

The objective of this study was to characterize the habitat preference and usage of grey
seals in the Iroise sea, particularly in the Parc Naturel Marin d’Iroise. GLMs were used
to model these habitat preference and usage. Different environmental covariates were
used and almost all were retained during the model selection. The habitat preference
of grey seal seems to be influenced by biological distance, depth and slope aspect, sea
surface current, sea surface temperature and sediment type. The probability of presence
of grey seals increase with a strong current, shallow waters, a poor sandy seafloor, and
a South-East slope orientation. The areas, joining all good environmental characteristics
together, seem to be a good area for wrasse feeding. But for SST influence interpretation,
SST data need to be normalized by season. The output of the model have show high
probabilities of preference and usage around the Molene archipelago, Isle of Sein and Ar-
men lighthouse, and Abers area. When accessibility is equal over all areas of the marine
park, the distribution of preferred habitat should be along all the coast line and islands of
the area of study with hotspot close to Molene archipelago and the entrance of the Rade
de Brest.

These results can provide management directives for the marine park. Some fisheries
areas correspond to the habitat preference and usage of grey seals\textsuperscript{10}. These areas, in the
\textsuperscript{10}http://iroise-parcnational.gouv.fr/medias/documents/www/contenu//cartographie/regl_peche_88.pdf
future should take into account to draw new directives for the fisheries management.


