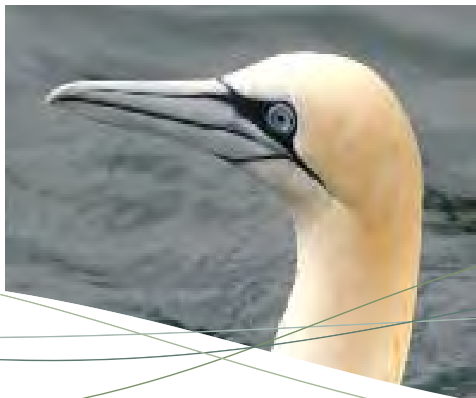
Marine Research Sub-Programme (NDP 2007–'13) Series

SeaChange
Casadh na Taoide

Marine Mammals and Megafauna in Irish Waters - Behaviour, Distribution and Habitat Use. *Research into Ecosystem Links and Habitat Use between Ceteceans and Fisheries in the Celtic Sea*

Project-based Award



Lead Partner: Galway Mayo Institute of Technology

NDP National Development Plan Transforming Ireland

An Roinn Ealaíon, Oidhreachta agus Gaeltachta
Department of Arts, Heritage and the Gaeltacht

Marine Institute Foras na Mara

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Marine Research Sub-Programme 2007–2013

Project-based Award

Marine Mammals and Megafauna in Irish Waters - Behaviour, Distribution and Habitat Use *(Project Reference: PBA/ME/07/005(02))*

WP4 Research into Ecosystem Links and Habitat Use between Cetaceans and Fisheries in the Celtic Sea

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Project Duration:	01 February 2008 to 31 August 2011

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We would like to thank the scientists and crew on board the annual Marine Institute Celtic Sea Herring Cruises for providing the project partners with the opportunity to gather the data used in this project.

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Disclaimer

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PREFACE

Introduction

Irish waters are internationally important for cetaceans (whales, dolphins and porpoises), with 24 species recorded to date (Berrow, 2001). These range from the harbour porpoise, the smallest species in European waters, to the blue whale, the largest animal to ever have lived on Earth. Some species are relatively abundant and widespread while others are extremely rare and have never been sighted in Irish waters, only known from carcasses stranded on the Irish coast. At least 12 cetacean species are thought to calve within the Irish Exclusive Economic Zone (EEZ)[1] (Berrow, 2001). Marine mammals, including cetaceans and seals, represent almost 50% of the Irish native mammal fauna, and thus Ireland has a significant conservation obligation towards them and their habitats. In 1991 the Irish government recognised the importance of Ireland for cetaceans by declaring all Irish waters within the EEZ a whale and dolphin sanctuary (Rogan and Berrow, 1995).

This diversity of cetacean species in Ireland reflects the range of marine habitats, which extend to 200 nautical miles (nmls) (370km) offshore and comprise an area of 453,000km^2. This is a little over six times the area of the land of Ireland. These habitats range from shallow continental shelf waters to shelf slopes, deep-water canyons, offshore banks, carbonate mounds and associated deep water reef systems and abyssal waters.

Legal framework

All cetaceans and their habitats are protected under Irish and international law. The Wildlife Act[2] and Wildlife (Amendment) Act[3] entitle all cetaceans and their habitats up to 12nmls from the coast to full protection, including from disturbance and willful interference. All cetacean species occur on Annex IV of the EU Habitats Directive[4], and are thus entitled to strict protection, including prevention of deliberate capture or killing, prevention of deliberate disturbance, prevention of deterioration of breeding or resting sites and prevention of capture for sale. There is also a requirement to monitor the incidental capture or killing of these species. Two species, the harbour porpoise and bottlenose dolphin, are on Annex II, which requires the designation of Special Areas of Conservation (SACs) to protect a representative

[1] EEZ: a seazone in which a state has special rights over the exploration and use of marine resources.
[2] Wildlife Act (1976)
[3] Wildlife (Amendment) Act (2000)
[4] Council Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora

range of their habitats. To date, two candidate SACs have been designated for the harbour porpoise, Roaringwater Bay, Co Cork and the Blasket Islands, Co Kerry, and one for the bottlenose dolphin, the Lower River Shannon. The European Court of Justice (ECJ) ruled in February 2009 that the Irish government had failed to 'put in place a comprehensive, adequate, ongoing monitoring programme for cetaceans that could enable a system of strict protection for those species to be devised'.

Under Article 17 of the Habitats Directive, each member state must report on the status of all species and habitats listed under the Habitats Directive which occur within the state. The first reporting round was completed in 2007 and covered the period 2000-2007. A conservation assessment requires information on range, habitat, population, and future prospects. The conservation assessments for cetacean species were considered very inadequate due to a significant lack of data on range, habitat, and population estimates for nearly all cetacean species in Irish waters. The next reporting round will be completed in 2013, and the National Parks and Wildlife Service (NPWS) must ensure that available data are adequate to make a proper conservation assessment, at least for the most abundant and widespread species.

In December 2009, the National Parks and Wildlife Service (NPWS) published its Conservation Plan for Cetaceans in Irish Waters[5]. This plan lists 41 actions. These include conducting further research to determine the distribution, relative abundance, and habitat preferences of cetaceans (Action 1); identifying breeding ecology, movements, and migration routes (Action 2); devising a programme to effectively monitor cetaceans inside and outside designated areas (Action 3); encouraging the development of passive acoustic monitoring (Action 4); exploring the possibility of using static acoustic monitoring to provide data for monitoring cetaceans (Action 9); including cetacean surveys on fisheries cruises to collect information on the possible relationships between fish and cetacean abundance (Action 18); and carrying out spatial monitoring using GIS to explore the relationship between cetacean distribution and fisheries (Action 19).

The Irish government also has legal obligations to protect cetaceans and other marine megafauna, and their habitats, under a range of other legislation. These include the Convention on the Conservation of Migratory Species[6] (Bern Convention) and the Convention on the Conservation of European Wildlife and Natural Habitats[7] (Bonn Convention). Under the

[5] Conservation Plan for Cetaceans in Irish Waters (2009). Department of Environment, Heritage and Local Government.
[6] Convention on the Conservation of Migratory Species of Wild Animals (1979)
[7] Convention on the Conservation of European Wildlife and Natural Habitats (1979)

OSPAR Convention[8], Ireland is obliged to address recommendations on the protection and conservation of species, habitats, and ecosystems that make it not only relevant to marine mammals and turtles but also to basking sharks.

The National Biodiversity Data Centre recently established a marine mammal database. The data collected during this project will be used for this database in order to make the data available for a range of assessments, including Environmental Impact Assessments, Strategic Environmental Assessments and Appropriate Assessments. Amendments to the EU Common Fisheries Policy require an Ecosystem Approach to Fisheries Management (EAFM). This requires data on the predators as well as the fish prey, and the drivers linking the different ecological systems. This presents a great challenge and member states are exploring how such an approach can be implemented.

The development of a sustainable marine tourism industry has been identified as a national priority by both the Marine Institute and Fáilte Ireland. While marine wildlife tourism has great potential as a high spend product for peripheral coastal regions, the species targeted are usually protected and populations often depleted through over-exploitation. Information on the distribution, abundance, and status of these species is essential for responsible development of this resource.

Marine Mammals and Megafauna in Irish Waters - behaviour, distribution and habitat use

The research termed *Marine Mammals and Megafauna in Irish Waters – behaviour, distribution and habitat use* attempted to address some of these issues. The project was delivered under six Work Packages. Work Package 1 attempted to increase coverage of offshore waters using platforms of opportunity (both ship and aircraft) to map the distribution and relative abundance of marine megafauna within the EEZ and to provide recommendations on how best to meet monitoring obligations for these species. Work Package 2 attempts to develop static and passive acoustic monitoring techniques in order to use these techniques to monitor Annex II species within SACs. Under Work Package 3, we intended to develop experience and capacity in the biotelemetry of marine megafauna through satellite tracking of fin whales (*Balaenoptera physalus*). In Work Package 4, results from eight years of cetacean and other

[8] Convention for the Protection of the Marine Environment of the North-East Atlantic (1992)

marine megafauna surveys concurrent with the Celtic Sea Herring Survey organised by the Marine Institute were used to create a GIS in order to explore ecosystem links.

Thus, the deliverables under this project will provide data which could be used to address a wide range of issues, and will contribute to developing policy advice on meeting Ireland's statutory obligations.

Executive Summary

Visual line transect survey data for cetaceans were simultaneously collected during synoptic acoustic sampling surveys of small schooling pelagic fish, i.e. herring (*Clupea harengus*) and sprat (*Sprattus sprattus*) in the Celtic Sea, off the south coast of Ireland, from 2004 to 2009. These data were used to investigate the interactions of cetaceans with biological and environmental variables in the survey area. Geographic information systems and generalized linear and generalized additive models were used in this study.

Sightings of minke (*Balaenoptera acutorostrata*), fin (*Balaenoptera physalus*) and humpback whales (*Megaptera novaeangliae*) and common dolphins (*Delphinus delphis*) were used in the analysis. An initial geospatial analysis of the combined logged Nautical Area Scattering Coefficient (NASC) values for herring and sprat indicated a significant positive relationship to the presence of large whales and common dolphins. Modelling of baleen whale count data indicated a positive correlation with the logged NASC values. The count data of common dolphins showed no such relationship with the logged NASC value.

Further analysis involving the modelling of presence/absence data and count data of cetaceans against a number of explanatory variables was conducted. Logged NASC value, distance from shore and remotely sensed autumn chlorophyll *a* values were shown to have a significant relationship with cetacean presence data and cetacean count data of baleen whales in the study area. Relative fish biomass and spring and autumn sea surface temperature were shown to be important variables when predicting the presence of common dolphins. However, geospatial analysis of the cetacean count data highlighted a lack of a significant relationship between common dolphins and the explanatory variables.

A second analysis – yearly comparisons of the overlap between interpolated NASC scores and cetacean distribution – was conducted. In all bar one instance, the tests failed to reject the null hypothesis of independence, indicating that there was no significant direct overlap. This was consistent across a variety of tests. Similar results were obtained when the fish explanatory variables were combined into a single variable and re-analysed.

This dichotomy of results probably represents an inability to deal with the highly mobile nature of both predators and prey in question. In an attempt to rectify this situation, analysis of the data is continuing under the auspices of an Erasmus Mundus Joint Doctorate Scholarship between GMIT/IWDG and collaborators in the University of Paris and IFREMER

1. Introduction

The seasonal occurrence of cetaceans, including fin, humpback and minke whales as well as common dolphins off the south coast of Ireland, has been recorded in some detail since 1999 (Berrow *et al,* 2002; 2010, Whooley *et al,* 2003). Research into the presence of fin and humpback whales in the region strongly suggests that whales utilise this habitat predominantly for feeding (Berrow *et al,* 2003; 2005; O'Donnell et al, 2004-2009). Fin whales and common dolphins also show a strong seasonal aspect to their use of this foraging habitat (Wall and Murray, 2009).

The use of photo-identification techniques has yielded several inter-annual re-sightings of individual fin and humpback whales (Whooley *et al,* 2010), suggesting that these species exhibit a degree of site fidelity off the south coast of Ireland. Although it has been noted that the increase in the abundance of large whales in the study area during autumn and winter coincides with coastal spawning aggregations of herring and sprat, the relationship between availability of pelagic fish as prey and cetaceans as predators has not been defined for the Celtic Sea. The distribution and abundance of baleen whales and common dolphins across the study area is also different. Common dolphins are more numerous and more widespread than baleen whales (Wall *pers. comm*.) and also appear to utilise the study area as an important seasonal feeding habitat, with their distribution moving southward from the Irish Sea and northward from the Bay of Biscay into the Celtic Sea in the autumn and winter (Wall and Murray 2009, Brereton. *pers. comm*.).

It is of considerable importance in working towards an ecosystemic approach to the conservation and management of this foraging area and its fisheries that the factors which affect the seasonal presence of cetaceans off the south coast of Ireland are investigated. A large biomass of schooling fish (i.e. herring and sprat) is thought to drive the seasonal foraging behaviour of baleen whales (fin and humpback) in the region. However, the mechanisms and ecosystem links behind the presence of both cetaceans and fish are not fully understood and questions exist as to why similar aggregations of small pelagic schooling fish biomass elsewhere (e.g. spawning herring off the northwest coast of Ireland) do not appear to generate the same foraging activity by cetaceans (Wall *pers. comm*.).

Numerical modelling provides a method to investigate the relationships between variables (in this case, cetacean abundance and distribution) and covariates, biological or environmental variables. The dynamic nature of marine environments requires a flexible analysis to allow for a complex range of variables and model structures (Redfern *et al,* 2006). Ingram *et al* (2007) reported on the role of environmental variables on minke and fin whales by using generalized linear models (GLM) and generalized additive models (GAM). Mapping of data on geographical information systems (GIS) can help to indicate patterns in distribution and habitat preference, as was reported by Firestone *et al* (2008) in a study of North Atlantic right whale migration. The current study examined the aggregations of cetaceans, especially baleen whales (fin, humpback and minke) and common dolphins, off the south coast of Ireland by using GIS and GLM to explore the ecosystem links that may be driving this activity.

2. Methods

The study area (Figure.1) is located off the south coast of Ireland in the Celtic Sea and extends from inshore (one nautical mile) to 78 nautical miles offshore between latitudes 52.1°N and 50.5°N and longitudes 10.6°W and 6.4°W. For the purposes of data analysis, the study area was divided into 9x9 km^2 grid cells, as this was the resolution available for remotely sampled Level 3 seasonal sea surface temperature and chlorophyll *a* data.

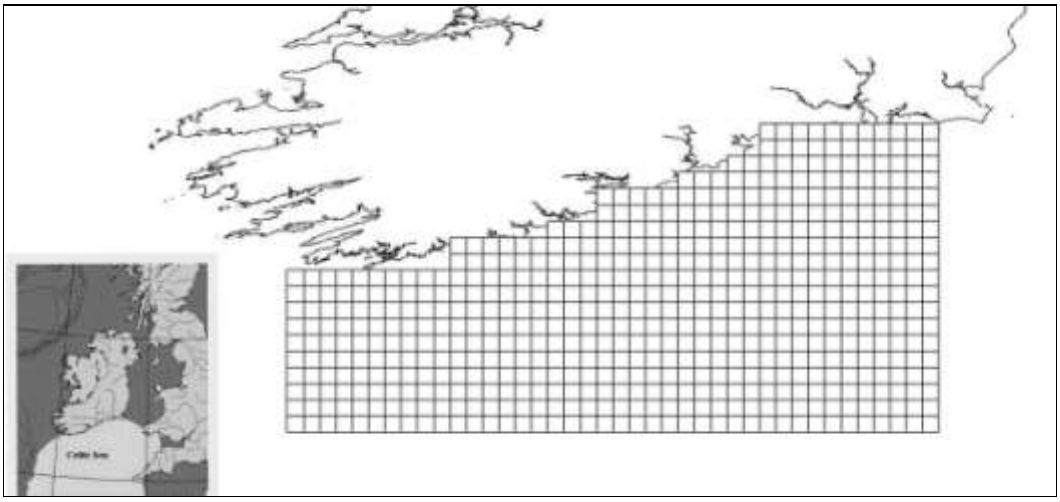


Figure 1: Study area the Celtic Sea is shown divided up with 9x9km grid cells

Cetacean visual line transect data were collected during the Celtic Sea Herring Acoustic Survey on board the research vessel *R.V. Celtic Explorer*, operated by the Marine Institute. These surveys were conducted annually between 2004 and 2009 during October (with the exception of 2004, when the survey took place from mid-November to mid-December) over a 21-day period, targeting spawning and pre-spawning herring. A single cetacean observer conducted survey effort from the 'crow's nest' located 18m above sea level. The same observer conducted survey effort in all years. Observer effort focused on a 90-degree arc ahead of the ship. However, sightings located up to 90 degrees to port and starboard were also included. The surveyor scanned the area by eye and used 10X50 binoculars. Bearings to sightings were measured using an angle board and distances were estimated with the aid of a range finding stick (Heinemann, 1981). Environmental data were recorded every 15 minutes, using Logger 2000 software (IFAW 2000). Sightings were also recorded using Logger 2000. Automated position data were obtained through a laptop computer linked to a GPS Receiver. Surveying was conducted up to Beaufort sea-state 6 and in moderate to good visibility. Surveys were conducted in 'passing mode' and cetaceans sighted were not approached. Sightings were identified to species level where possible, with species identifications being graded as definite, probable or possible.

For the purposes of this study, cetacean sightings for the six years were broken up into two categories, baleen whales and common dolphins. Sightings were not stratified by sea state nor was any truncation distance used. Using ArcGIS sightings were layered over the 9x9km grid. Presence/absence values and total counts of individuals of each category were assigned to each cell. Distance from the shore was determined using the ArcGIS measuring tool from the centre point of the grid cell. The average depth of each grid cell was determined by overlaying chart data.

Acoustic data used to calculate the relative abundance of shoaling fish species were continuously collected by a calibrated split beam Simrad scientific echo sounder. The Simrad ES-38B (38 KHz) split-beam transducer is mounted within the vessel's drop keel and lowered to the working depth of 3.3m below the vessel's hull or 8.8m below the sea surface. Nautical Area Scattering Coefficient (NASC) values, which are a relative measure of biomass, were assigned to specific fish schools or scattering layers, based on visual recognition and trawl composition. The main schooling fish species encountered over the six years were herring (*Clupea harengus*), sprat (*Sprattus sprattus*), pilchard (*Sardina pilchardus*) and mackerel (*Scomber scombrus*). Herring and sprat were consistently encountered each year and, therefore, were chosen to be used in the analysis of this study. NASC values were log transformed to down-weigh large numbers, layered over the grid cells using ArcGIS, and a maximum logged NASC value for herring and sprat was assigned to each cell. Remotely sensed sea surface chlorophyll *a* data were obtained from the SeaWIFS archive at the Goddard Space Flight Centre (GSFC). Their processed data were used for chlorophyll *a,* and concentrations are presented as $mg.m^{-3}$. Due to gaps in coverage from daily, weekly or monthly data from spring 2004 to winter 2009, seasonal (spring, summer, autumn, winter) level 3 data was used. GSFC have defined these seasons as follows:

Winter – 21st December to 20th March of the following year
Spring – 21st March to 20th June of the same year
Summer – 21st June to 20th September of the same year
Autumn – 21st September to 20th December of the same year.

For the purposes of the model, this data was then pooled to produce a six-year (2004–2009) mean seasonal sea surface chlorophyll *a* value at the midpoint of each of the study area cells. Sea surface temperature data was obtained from MODIS aqua dataset at GSFC. Level 3 mapped data was selected and pooled for the same reasons as the chlorophyll *a* data treatment described above.

ArcGIS was used to display all data, and maps were produced to help identify possible patterns in the data. Once the data had been layered onto ArcGIS, they were then joined to the grid cells. These cells, together with an identifier (0 to n), were exported from ArcGIS and formatted for input into the open-source statistical package R (R Development Core Team 2009). This involved renaming the co-variables, removing 'false' values and reducing the spatial extent of the grid to account for cells that were not covered by the track line of the survey. The analysis of the distribution of baleen whales and common dolphins in the Celtic Sea, therefore, used the covariates listed in Table 1.

Table 1: Response and explanatory variables available for modelling

Response Variable	Explanatory Variable
Presence/absence of baleen whales (0/1)	Mean Spring SST 04-09 (°C)
Presence/absence of common dolphins(0/1)	Mean Summer SST 04-09(°C)
Total number of baleen whales (0 to n)	Mean Autumn SST 04-09(°C)
Total number of common dolphins (0 to n)	Mean Winter SST 04-09(°C)
	Mean Spring Chlorophyll a 04-09 (mg/m^3)
	Mean Summer Chlorophyll a 04-09(mg/m^3)
	Mean Autumn Chlorophyll a 04-09(mg/m^3)
	Mean Winter Chlorophyll a 04-09(mg/m^3)
	Logged NASC value Herring (0 to n)
	Logged NASC value Sprat (0 to n)
	Logged Herring and Sprat NASC (0 to n)
	Distance from the shore (km)
	Depth (m)

Data exploration, in preparation for modelling, included checking for outliers using two graphical tools, box plots and Cleveland dot plots. No outliers were found in the response variables. Outliers identified in the explanatory variables were investigated by returning to the raw data and checking for errors. One outlier was identified in the mean winter chlorophyll *a* data. This was removed as the data point was possibly influenced by proximity to the coast, which can lead to poor readings by the satellite. It was, therefore, replaced by NA (not available). NA data points were allowed for in the modelling syntax. To check for high co-linearity between the explanatory variables, a multi-panel matrix was generated, displaying pairwise scatterplots and correlation coefficients between each variable. Variables displaying a correlation coefficient greater than 0.5 were checked and one or the other variable was rejected. Modelling of both presence/absence and count data of the cetaceans were analysed to ensure information available in count data was not lost. A first analysis of the data focused on the relationship between the response variables and combined logged NASC values. GLM and quadratic GLM were conducted to test both linear and non-linear relationships respectively. Binomial GLM and quadratic binomial GLM were used, with a logit function, for the presence/absence baleen whale and common dolphin data, with the combined logged NASC values of herring and sprat as an explanatory variable. Negative binomial GLM and quadratic negative binomial GLM were used with a log function to model the count data of baleen whales and common dolphins with the combined logged NASC values. Due to concern over the number of zeros in the cetacean count data, zero-inflated Poisson (zip) and zero-inflated negative binomial (zinb) models were also analysed and were compared using Akaike's Information Criterion (AIC) values to identify which model best fitted the data. A second analysis was then performed, using multiple explanatory variables that remained following the removal of seasonal Chlorophyll *a* collinear variables. Again binomial GLM and negative binomial GLM were used on the presence/absence data and count data respectively. A stepwise algorithm was then preformed to select the best fitting model, using the AIC value.

Given the primary interest in the current study of the relationship between cetaceans and their prey in the Celtic Sea, a second set of analyses was conducted. NASC scores for each year were interpolated to form a surface for comparison with the cetacean distribution. The simplest possible analysis of the overlap between cetacean (baleen whale or common dolphin) observations and NASC scores (herring or sprat) involved categorizing both variables as binary 'yes' for positive counts and 'no' for zero counts. The variables were then tabulated as a two-way contingency table consisting of the number of observations per category. If positive cetacean sightings were associated with positive NASC scores and no cetacean observations were associated with any NASC scores, an independence test of the two-way contingency table should reject the null hypothesis of no association between the two variables. Pearson's chi-squared test is a commonly applied independence test but it can suffer inaccuracies under small sample sizes and unequal distribution of counts amongst the cells. Fisher's exact test circumvents these issues but assumes that the marginal counts are fixed (experimentally).

Finally, Barnard's test does not assume fixed marginals. All three tests were applied for completeness. In addition to analyzing individual associations with herring or sprat, additional analyses were conducted using the presence/absence of herring or sprat combined. Note that no attempt was made to adjust for spatial autocorrelation or multiple test corrections, but the direction of doing so would be to further decrease the significance.

3. Results

A total of 126 days of survey effort were conducted over the study period (2004-2009). Approximately 8,399km of survey transects were covered from close in-shore to a maximum distance of 145km offshore. Eight species of cetaceans (common dolphin, fin whale, humpback whale and minke whale) and four schooling fish species were identified in the study area (O'Donnell *et al,* 2004-2009).

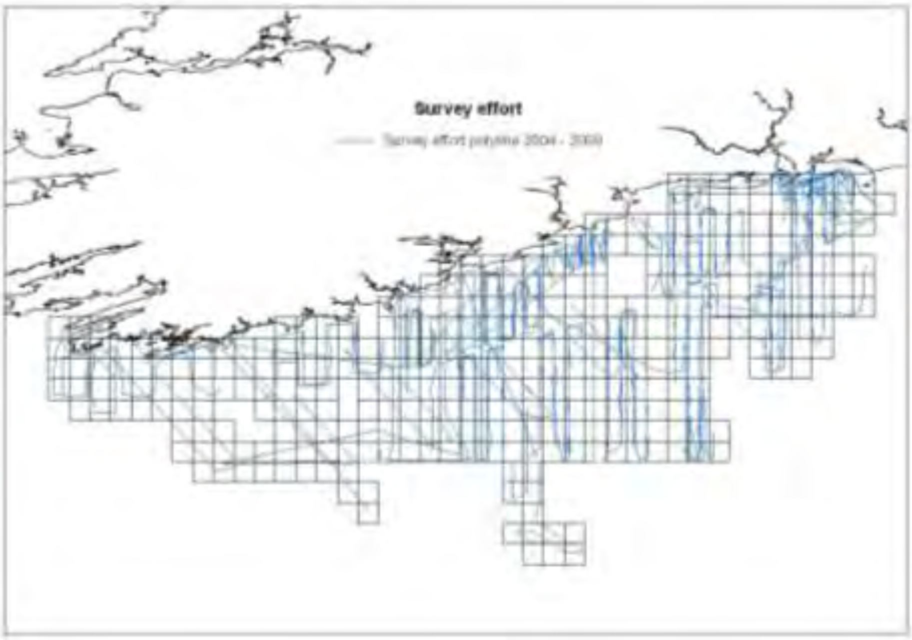


Figure 2: Combined track line of the Celtic Sea herring acoustic surveys from 2004 to 2009

Common dolphins were the most abundant and commonly observed cetacean species throughout the survey period, with a total of 142 sightings comprising 5,401 individuals (Table 2). GIS mapping of common dolphin distribution shows a wide dispersal throughout the study area (Fig. 3). Baleen whale on-effort sightings were less common, with a total of 42 sightings comprising 99 individuals (Fig. 4). Fin whales were the most abundant of the baleen whales recorded over the six-year period (72 individuals), followed by minke whales (24 individuals) and humpback whales (2 individuals). Plotting of baleen whale sightings using ArcGIS showed a clumped, inshore distribution (Fig. 4).

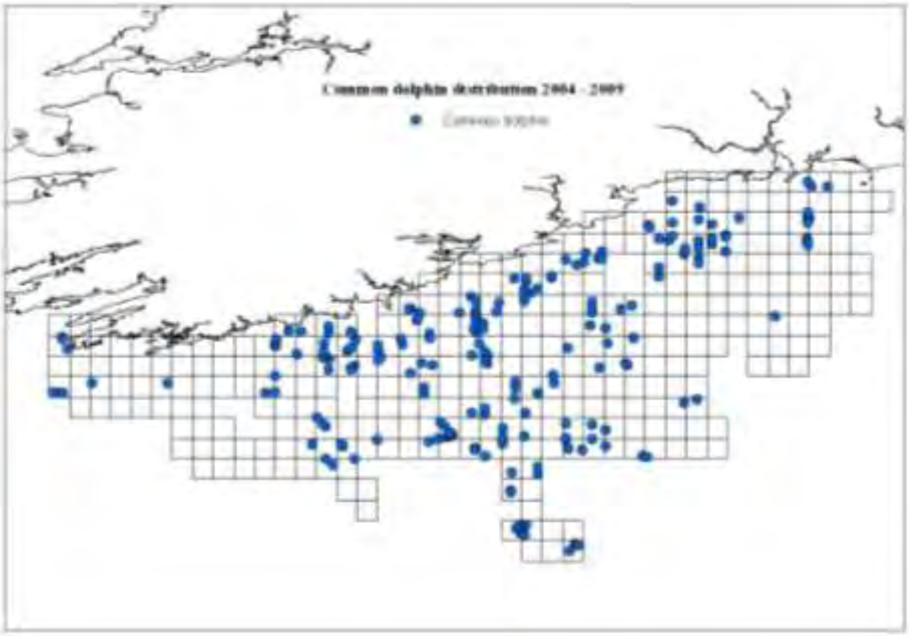


Figure 3: Distribution of common dolphins throughout the study area from 2004 to 2009

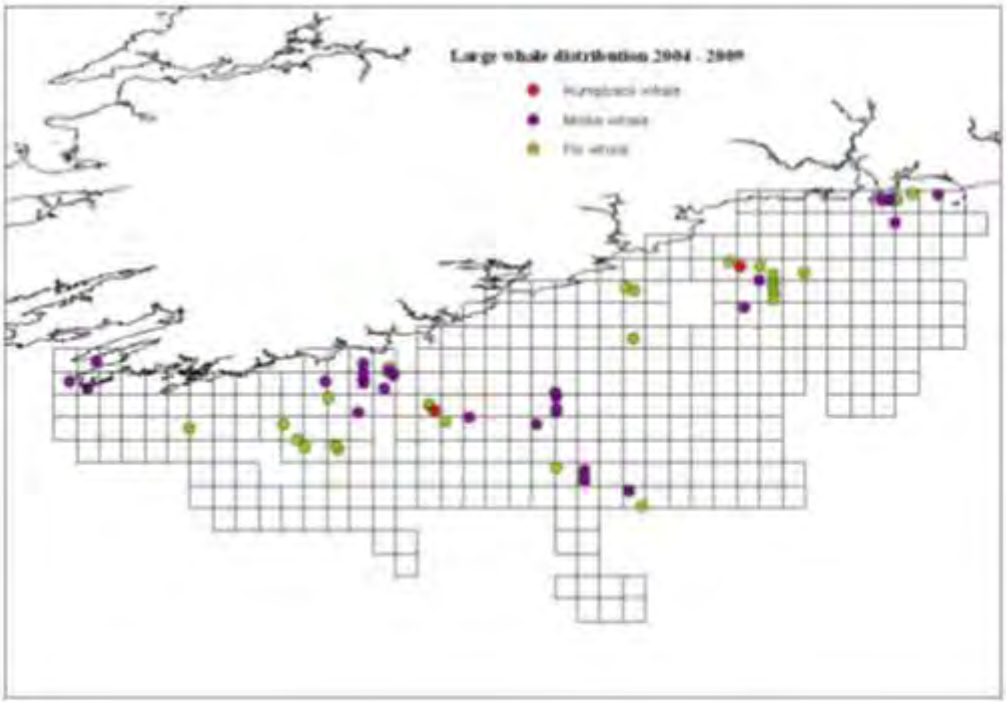


Figure 4: Distribution of baleen whales throughout the study area from 2004 to 2009

Table 2: Cetacean species sighted number of sightings and number of individuals observed in the study area during the Celtic Sea herring acoustic surveys 2004 to 2009

Cetacean species	Number of sightings	Number of individuals
Fin whales	23	72
Humpback whales	2	3
Common Dolphins	142	5401
Minke whales	27	24

An initial analysis of the data was carried out using GLM with the four possible response factors with respect to the explanatory variable of combined logged NASC value for herring and sprat. For the presence/absence data of baleen whales and common dolphins, the binomial GLM in both cases showed a significant relationship with the combined logged NASC value ($p = 0.0222$ & $p = 0.0252$ respectively). To investigate if there was a possible non-linear relationship with the data, a quadratic binomial GLM was also run. This indicated a marginal interaction between the presence/absence of common dolphins and the fish data ($p = 0.0494$), while no relationship was present for the baleen whales and the fish data. The AIC value of each model indicated that the binomial GLM both for baleen whales and common dolphins was a slightly better fit for the data than the quadratic binomial GLM.

Count data for the baleen whales and common dolphins were then modelled using negative binomial GLM and, again, quadratic binomial GLM for the same reasons as stated above. The possible influence of zero inflation in the count data was investigated using zero-inflated poisson and zero-inflated binomial models. The negative binomial GLM indicated a significant relationship with the baleen whale count data and the fish data ($p = 0.0472$). No significant relationship was seen in any of the models for common dolphin count data and fish other than with the zero inflation poisson (zip) model. However, a comparison of the AIC values between the models indicated an extremely high AIC for the zip (AIC = 6584.775), which is roughly six times bigger than the resultant AIC of the other models run on the common dolphin count data. Therefore, it was not accepted as a good fit model. Further to initial data exploration described above in the methods section, the four response factors were run in individual models with the following explanatory variables: distance from the shore, autumn chlorophyll *a*, spring sea surface temperature, autumn sea surface temperature and the combined logged NASC value of herring and sprat. The resultant models which best fit the data are outlined in Tables 3 to 5.

Table 3: Parameter estimates for a Binomial Generalised Linear Model (GLM) of large whale presence/absence with respect to the listed variables. Significant p values (<0.05) are in bold

Parameter	Estimate	SE	Z-statistic	p-value
Intercept	1.2778	1.08091	1.182	0.2371
Distance off shore	-0.04687	0.0118	-3.973	**<0.00001**
Autumn Chlorophyll *a*	-1.45625	0.5188	-2.807	**0.005**
Logged NASC herring and sprat	0.31008	0.1452	2.136	**0.0327**

Table 4: Parameter estimates for a binomial Generalised Linear Model (GLM) of common dolphin presence/absence with respect to the listed variables. Significant p values (<0.05) are in bold

Parameter	Estimate	SE	Z-statistic	p-value
Intercept	13.551885	6.450191	2.101	**0.0356**
Distance from the shore	0.010158	0.006156	1.65	0.099
Autumn sea surface temperature	-1.196426	0.527949	-2.266	**0.0234**
Logged NASC herring and sprat	0.202673	0.089854	2.256	**0.0241**

Table 5: Parameter estimates for negative binomial Generalised Linear Model (GLM) of large whale abundance for the listed variables. Significant p values (<0.05) are in bold

Parameter	Estimate	SE	Z-statistic	p-value
Intercept	2.86391	1.31858	2.172	**0.029858**
Distance from the shore	-0.04992	0.01286	-3.881	**0.000104**
Autumn Chlorophyll a	-1.92184	0.63088	-3.046	**0.002317**
Logged NASC herring and sprat	0.3948	0.17962	2.198	**0.027948**

The presence of baleen whales was strongly and negatively correlated with distance from the shore and autumn chlorophyll *a* but was strongly and positively correlated with the combined logged NASC values of herring and sprat. This result was reflected in the negative binomial GLM with the baleen whale count data. Presence of common dolphins was positively correlated with the combined logged NASC value of herring and sprat and negatively correlated to autumn sea surface temperature. The negative binomial GLM of the common dolphin count data showed no significant relationship with any of the explanatory variables.

Yearly comparisons of the overlap between interpolated NASC scores and cetacean distribution are presented in Figure 5 (common dolphin/herring), Figure 6 (common dolphin/sprat), Figure 7 (baleen whale/herring) and Figure 8 (baleen whale/sprat). An interpolated surface for NASC scores was chosen as it provided a more realistic representation of the spatial distribution of the selected pelagic fish species. Positive NASC scores, close to but not exactly at the same location of cetaceans, were missed using the previous discrete NASC point analyses. In addition, the authors disaggregated the data from the previous pooled dataset into discrete years as it was felt that if the data was available as such, it should also be analysed as such if possible. This was done to provide a greater insight into the distribution of prey species within the study area on a temporal basis. In all bar one instance (baleen whales/sprat, 2007), the tests failed to reject the null hypothesis of independence, indicating that there was no significant direct overlap. This is consistent across all three tests. Similar results were obtained for combined herring or sprat presence/absence (see Appendix I for comparison tables).

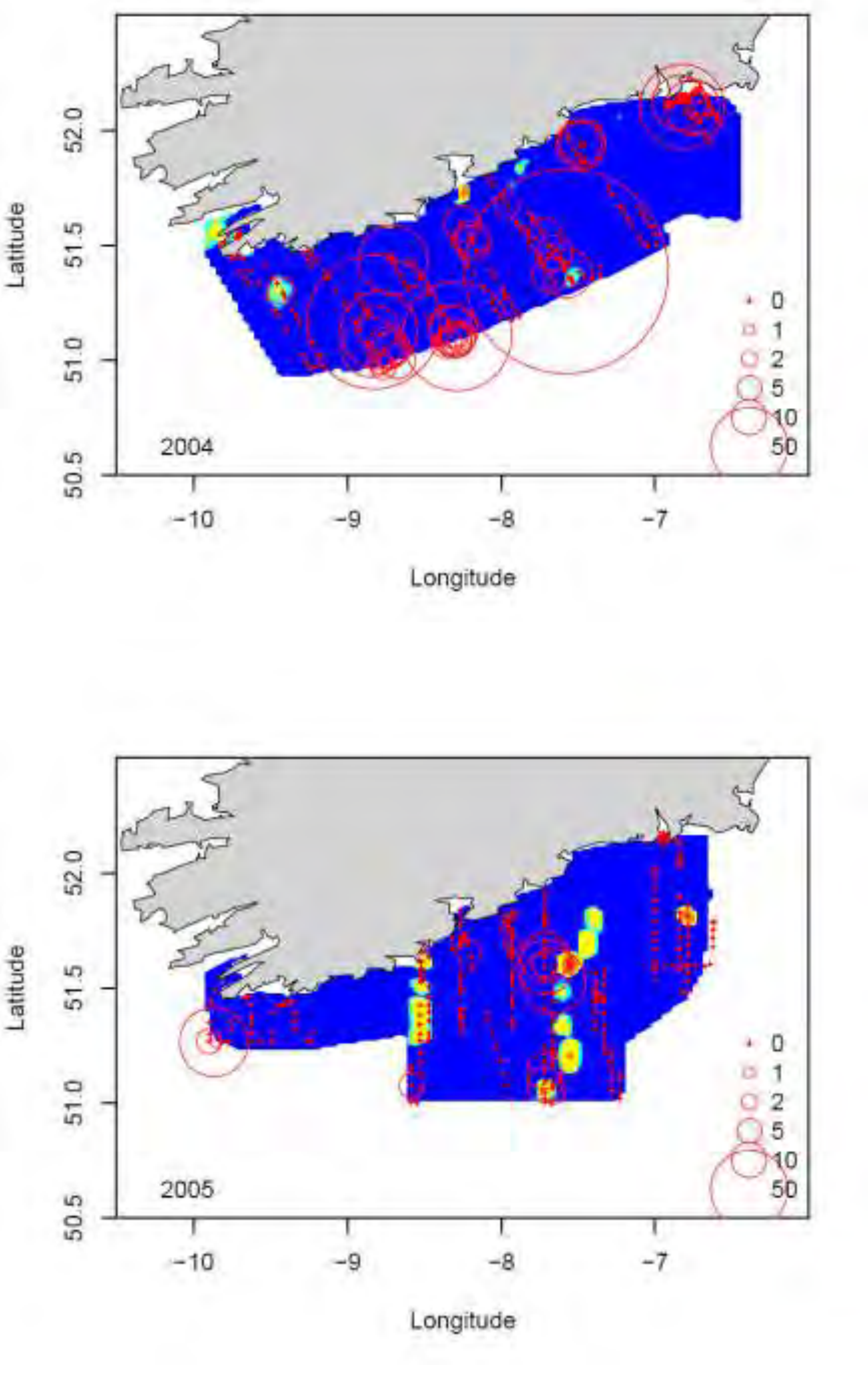
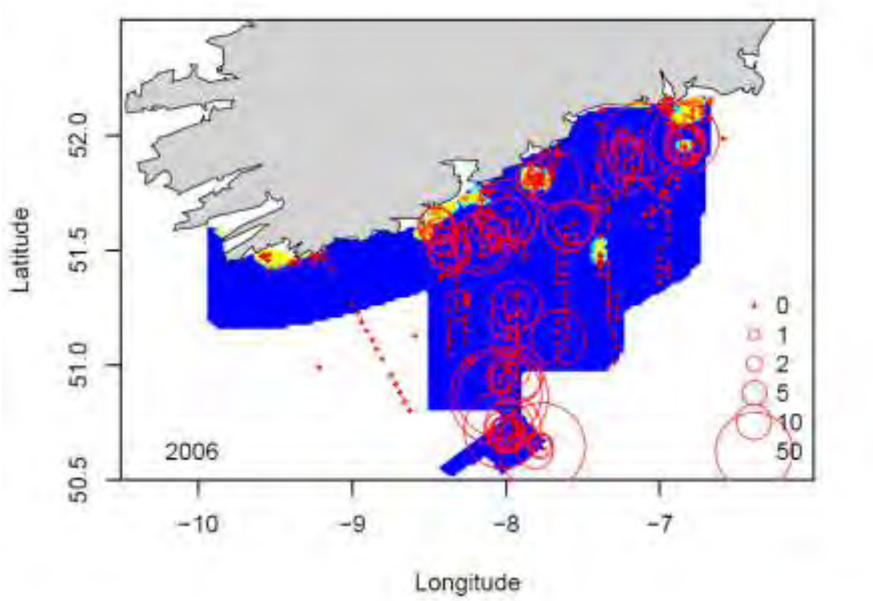


Figure 5 (a, b): The overlap between common dolphin and herring by year between 2004 and 2009. The circle dimensions reflect the number of dolphins; the coloured surface is an interpolated NASC score for herring



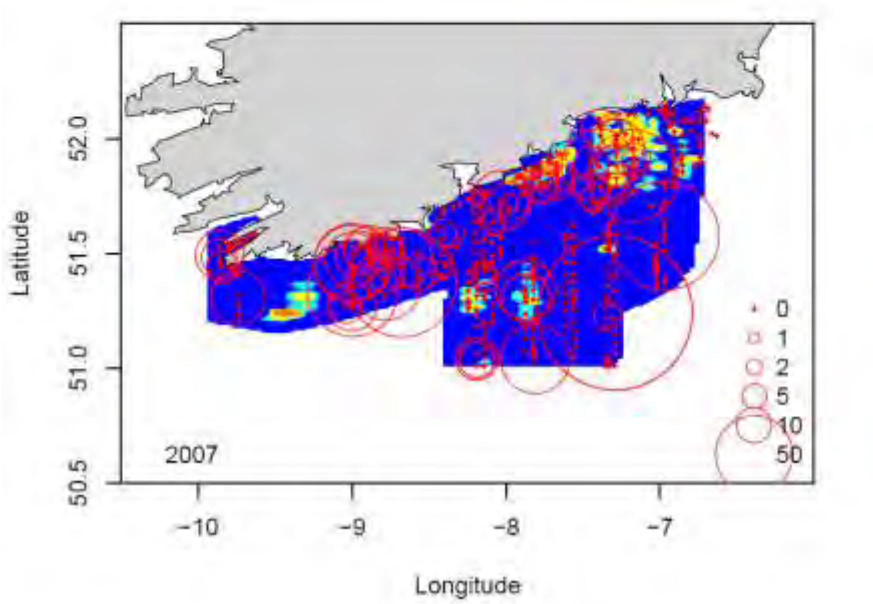
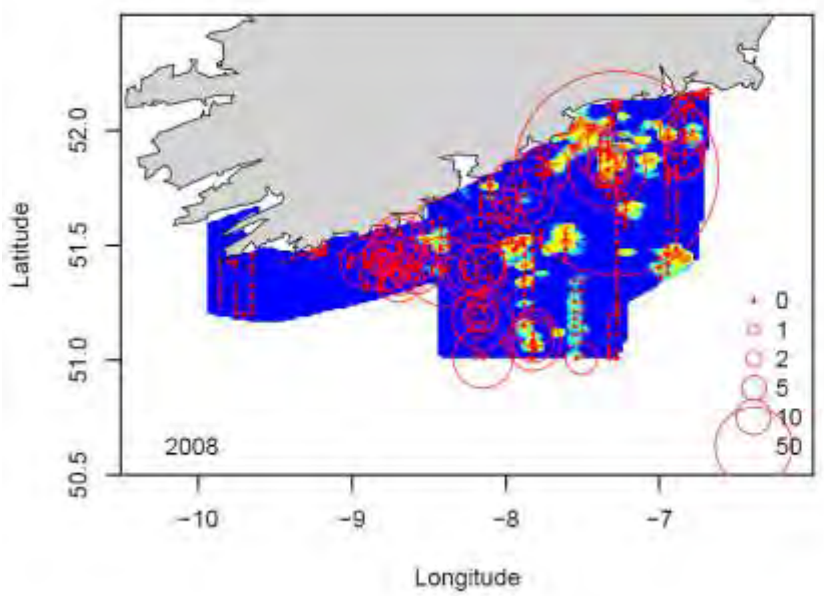


Figure 5 (c, d): The overlap between common dolphin and herring, by year between 2004 and 2009. The circle dimensions reflect the number of dolphins; the coloured surface is an interpolated NASC score for herring



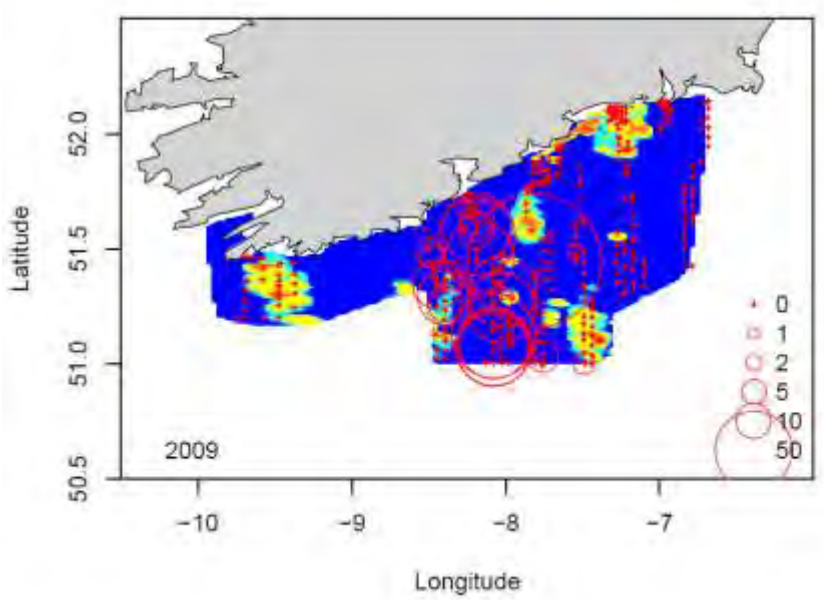
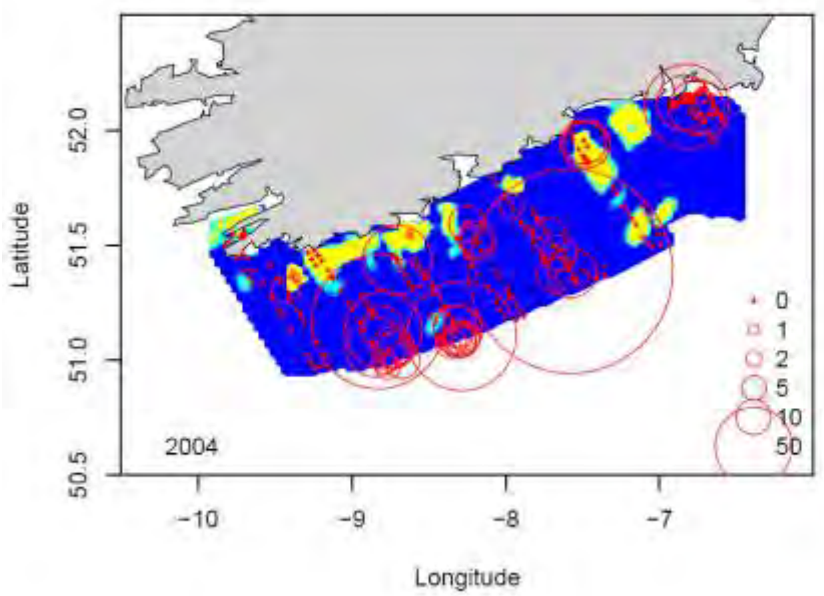


Figure 5 (e, f): The overlap between common dolphin and herring by year between 2004 and 2009. The circle dimensions reflect number of dolphins; the coloured surface is an interpolated NASC score for herring



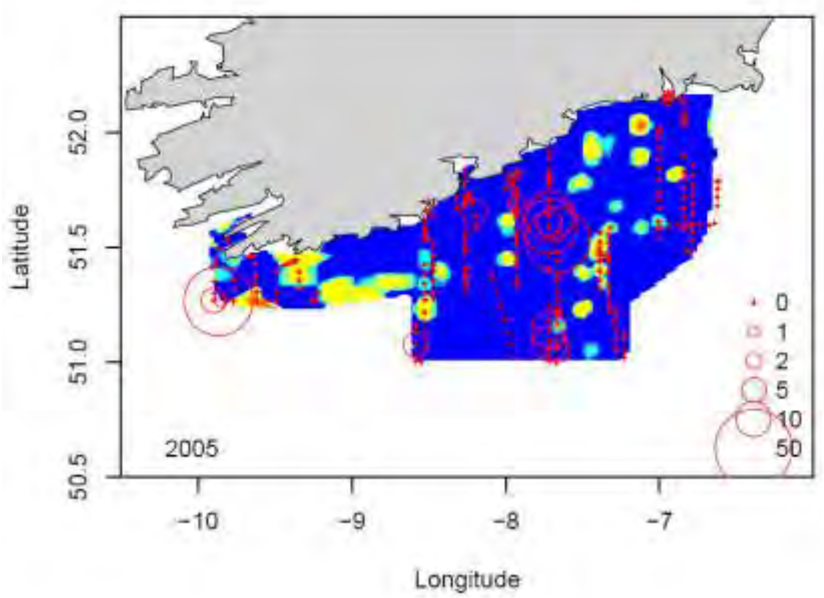
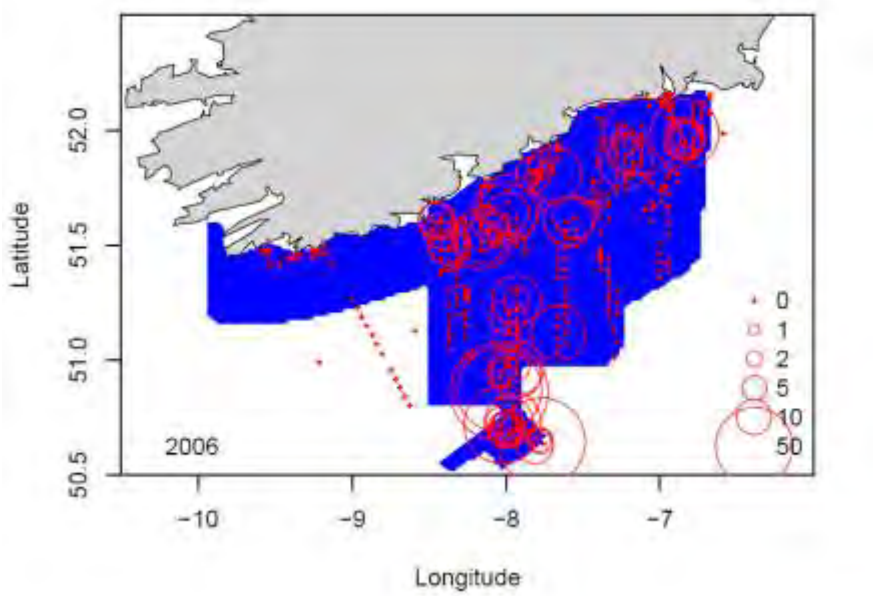


Figure 6 (a, b): The overlap between common dolphin and sprat by year between 2004 and 2009. The circle dimensions reflect the number of dolphins; the coloured surface is an interpolated NASC score for sprat



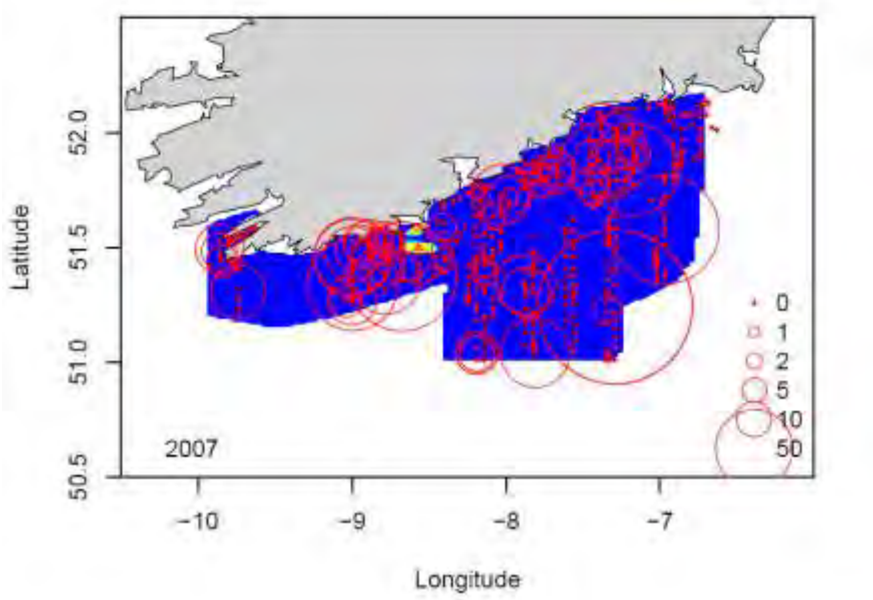
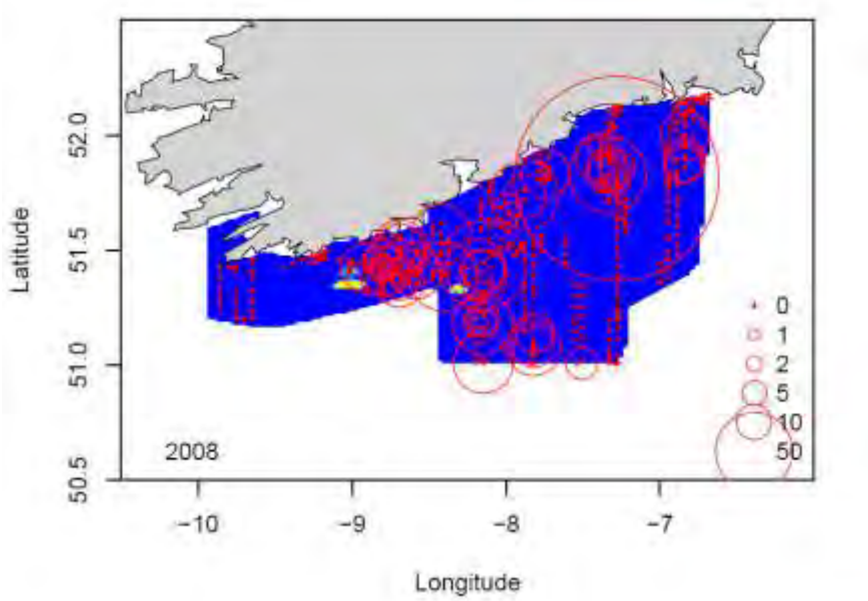


Figure 6 (c, d): The overlap between common dolphin and sprat by year between 2004 and 2009. The circle dimensions reflect the number of dolphins; the coloured surface is an interpolated NASC score for sprat



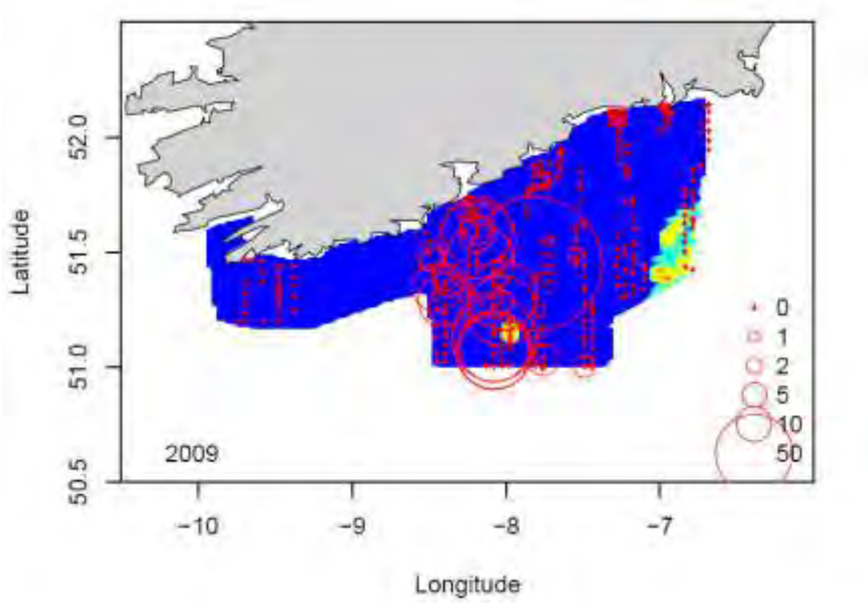
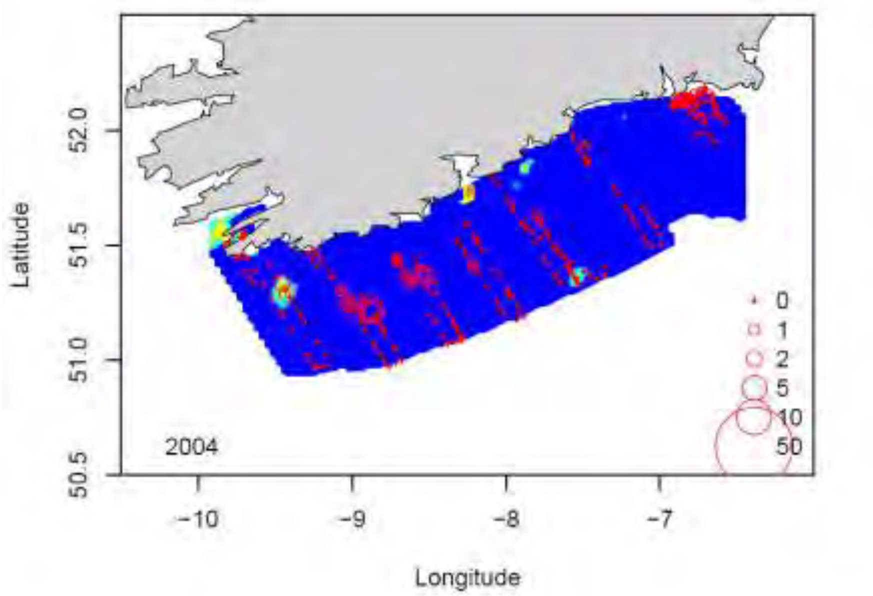


Figure 6 (e, f): The overlap between common dolphin and sprat by year between 2004 and 2009. The circle dimensions reflect the number of dolphins; the coloured surface is an interpolated NASC score for sprat



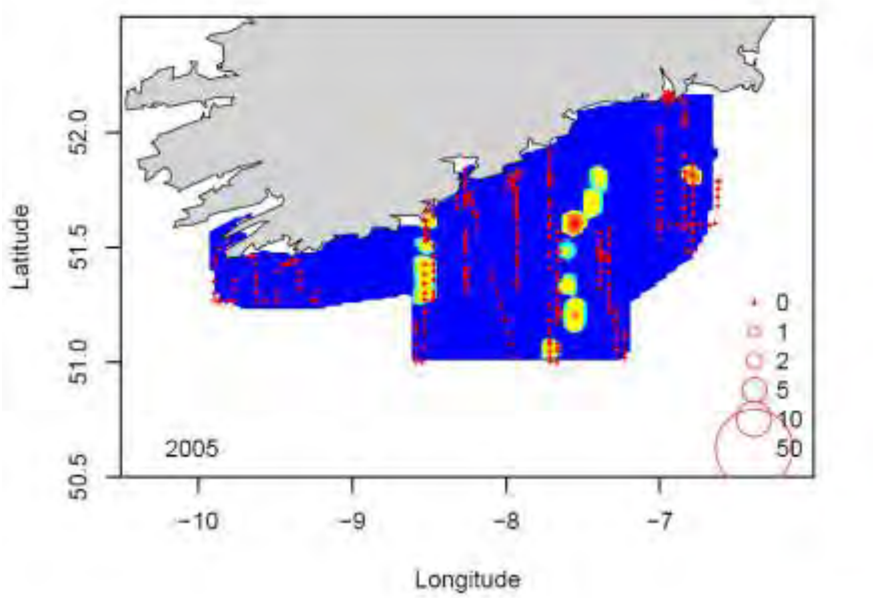
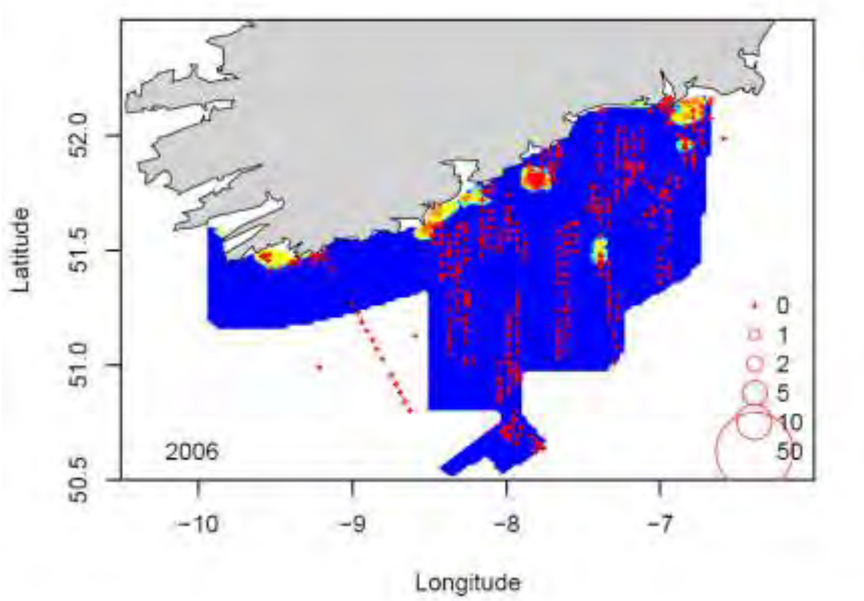


Figure 7 (a, b): The overlap between baleen whale and herring by year between 2004 and 2009. The circle dimensions reflect the number of whales; the coloured surface is an interpolated NASC score for herring



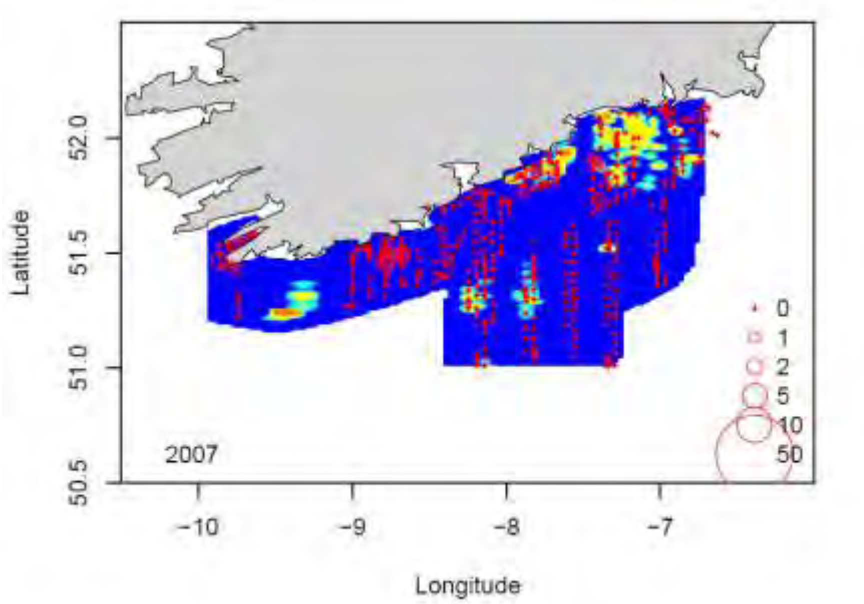
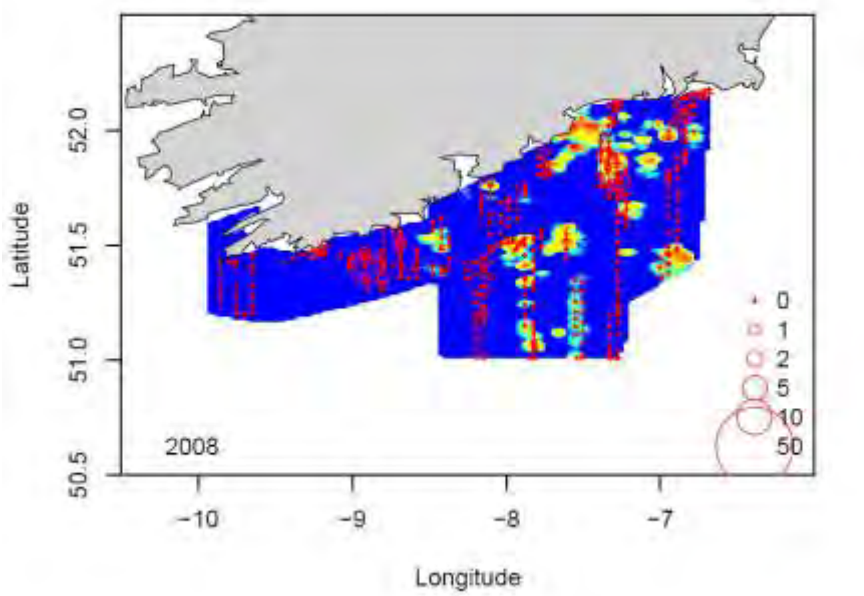


Figure 7 (c, d): The overlap between baleen whale and herring by year between 2004 and 2009. The circle dimensions reflect the number of whales; the coloured surface is an interpolated NASC score for herring



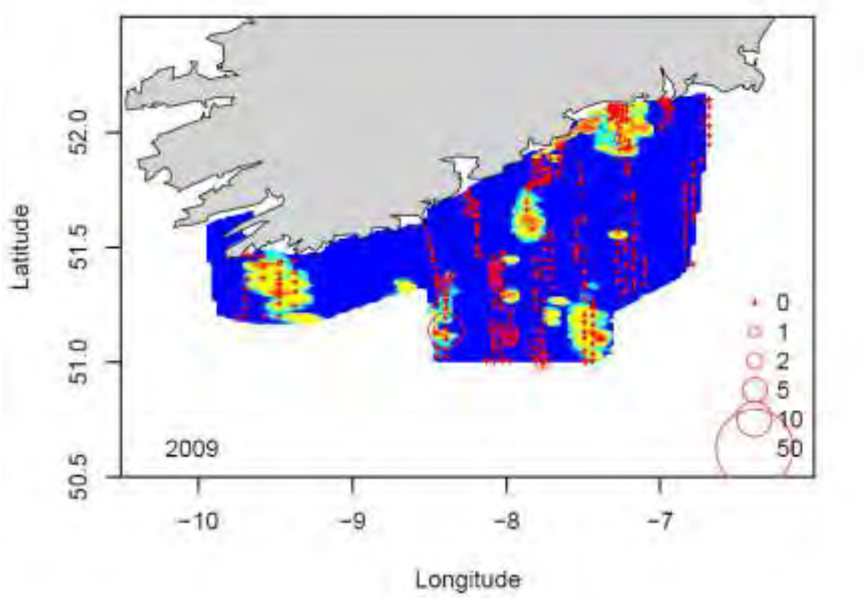
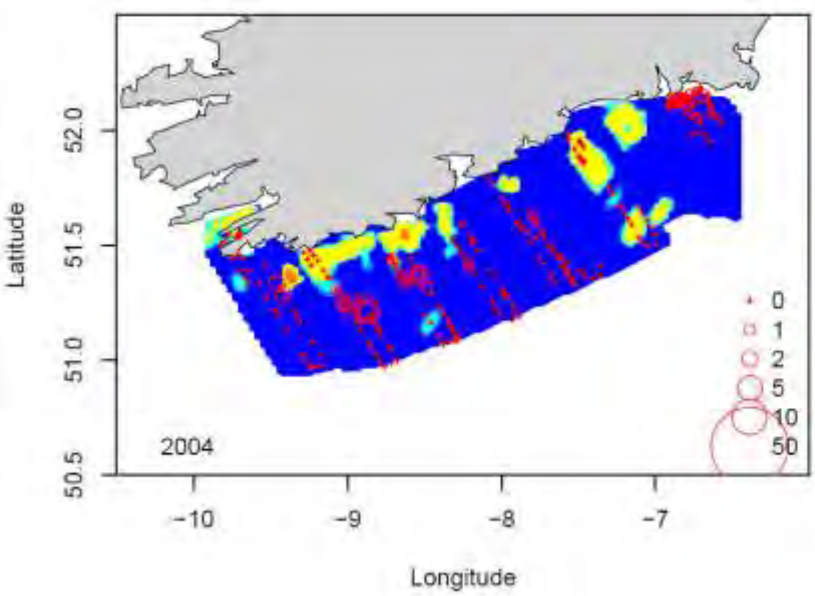


Figure 7 (e, f): The overlap between baleen whale and herring by year between 2004 and 2009. The circle dimensions reflect the number of whales; the coloured surface is an interpolated NASC score for herring



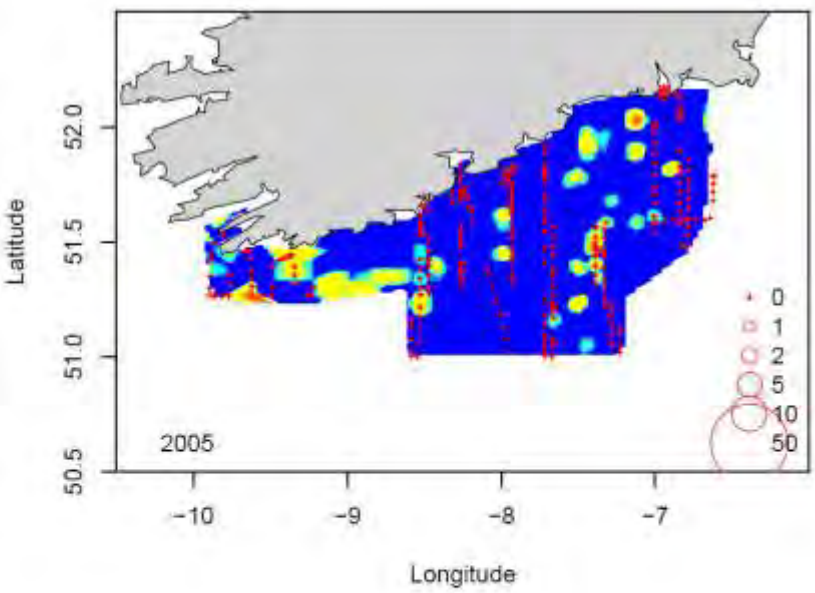
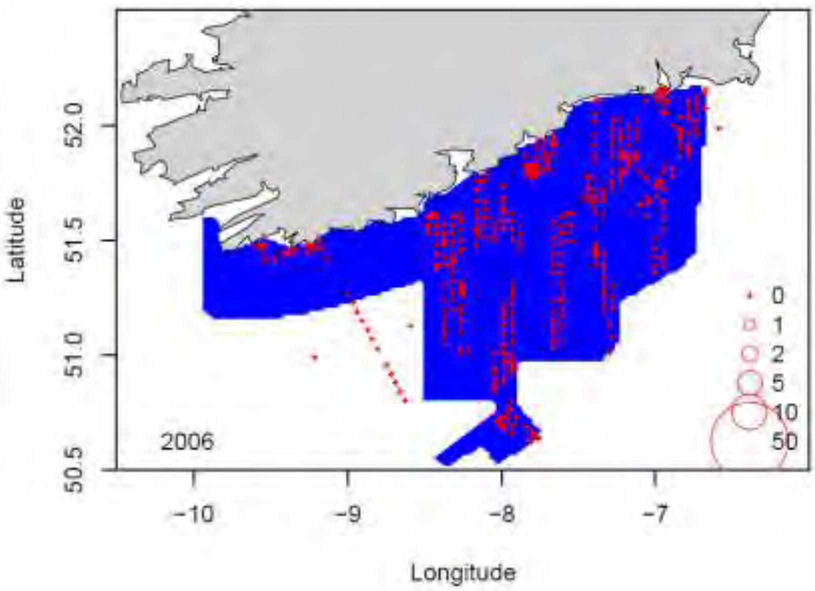


Figure 8 (a, b): The overlap between baleen whale and sprat by year between 2004 and 2009. The circle dimensions reflect the number of whales; the coloured surface is an interpolated NASC score for sprat



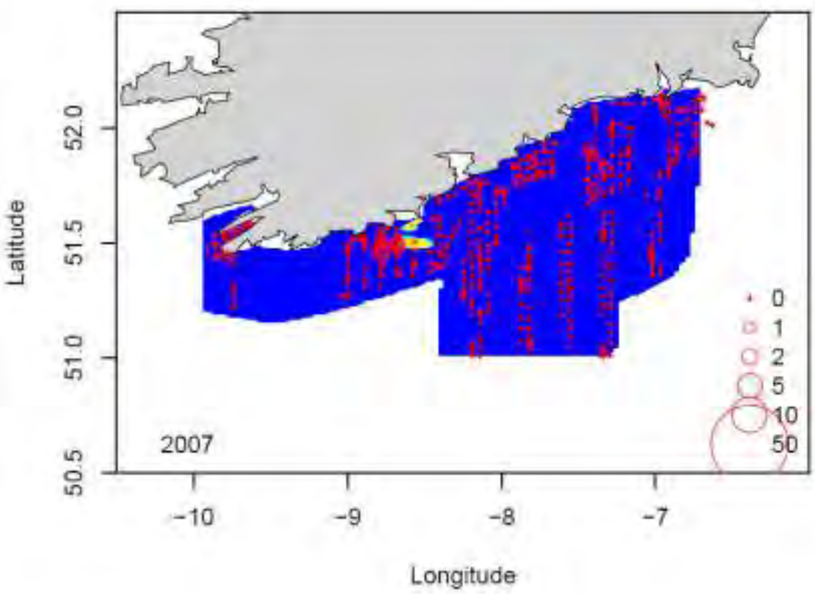
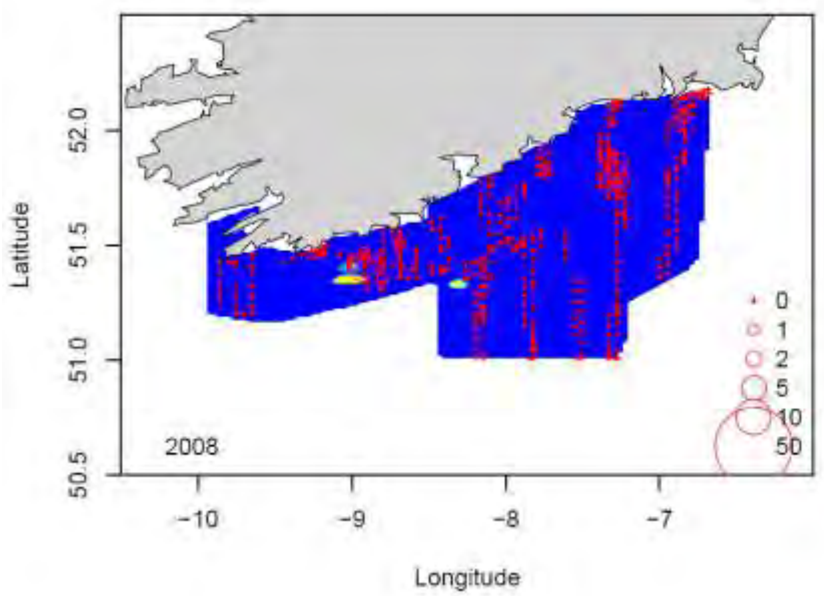


Figure 8 (c, d): The overlap between baleen whale and sprat by year between 2004 and 2009. The circle dimensions reflect the number of whales; the coloured surface is an interpolated NASC score for sprat



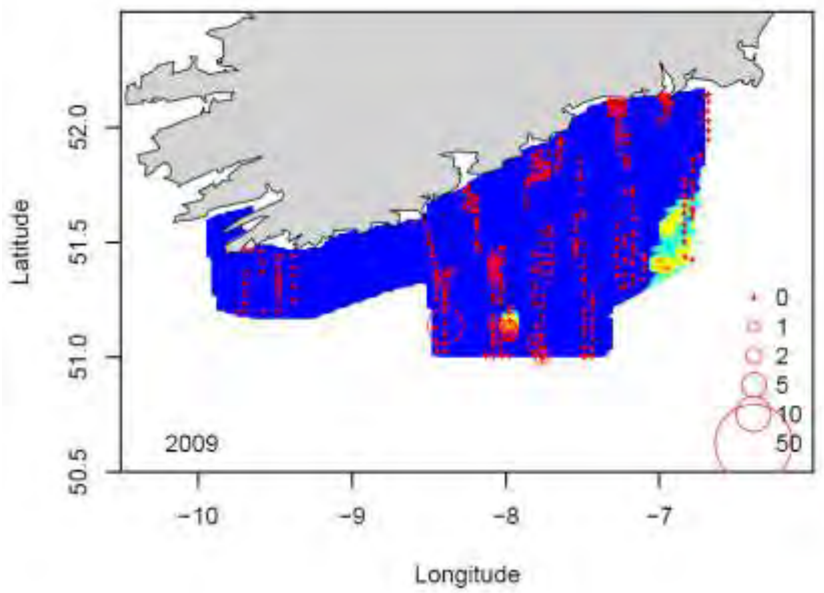


Figure 8 (e, f): The overlap between baleen whale and sprat by year between 2004 and 2009. The circle dimensions reflect the number of whales; the coloured surface is an interpolated NASC score for sprat

4. Discussion

Initial analysis of the data indicated a highly significant relationship between the presence of baleen whales and common dolphins with the combined logged NASC value of herring and sprat. This supports field observations that foraging is a primary activity of baleen whales and common dolphins, present in the study area during the autumn and winter months (Wall *pers. Comm)*. The four cetacean species in the study appear to have similar prey preferences for small pelagic schooling fish. Berrow and Rogan (1995) found that herring, sprat and whiting were the most prevalent fish species in the stomach contents of 16 stranded and 10 by-caught common dolphins. Dietary analysis of minke whale stomachs in Scotland by Pierce *et al* (2004) and Norway by Skaug *et al* (1997) showed a preference for small schooling fish such as sandeel, sprat and herring. Humpback whales and fin whales have a diet that consists of predominantly of krill, but also of small schooling fish, such as sandeel, sprat and herring (Winn and Reichley, 1985). Initial analysis of count data of baleen whales also indicated a significant positive relationship with the combined logged NASC value of herring and sprat in the negative binomial GLM, which indicates that larger biomasses of fish attract greater numbers of baleen whales and may help explain the clumped nature of baleen whale distribution observed in the data. However, the common dolphin count data only showed a significant relationship with the combined logged NASC value of herring and sprat in the zero-inflated poisson model, which had an extremely high AIC value, and, therefore, was not an appropriate fit for the data. The lack of significant relationship with the common dolphins count data may mean that the biomass of fish is not as important a factor in affecting the number of individuals present.

Previous studies have shown that depth, slope and distance from the shore may have an influence on the distribution of some marine mammals in specific habitats (Panigada *et al,* 2008; Macleod *et al,* 2007). Results from the models using multiple variables with the response factor of baleen whale presence/absence and count data of baleen whales indicate that the occurrence of baleen whales is negatively correlated with distance from the shore. The question arises: why do baleen whales such as fin and humpback whales show an inshore distribution, whereas common dolphins do not? The distribution of baleen whales is clumped when compared to the scattered distribution of the common dolphins (see Fig. 3 and Fig. 4). The data suggest that baleen whales tended to be located around the spawning grounds, which are close to shore. These spawning grounds are where the highest concentrations of herring and sprat biomass are located (O'Donnell *et al,* 2004-2009). Therefore the differences in the distribution of baleen whales and common dolphins may reflect their differing feeding techniques and requirements. Fin, humpback and minke whales, which rely on mass intake of fish through gulp or lunge feeding, require a large and concentrated biomass of fish in order to obtain enough food to satisfy their energy requirements (Piatt and Methven, 1992). Common dolphins, which are of smaller size and rely on agility and group cooperation to feed, could find sufficient prey in much smaller fish schools and areas of lower biomass concentration. Both the correlation with the combined logged NASC and their inshore distribution in areas of highest fish biomass concentration are an indication that baleen whale distribution in the study area is influenced primarily by prey density. This explanation of baleen whale distribution is in agreement with that found by Laidre *et al* (2010a) in relation to baleen whales and krill biomass off the coast of Greenland.

Large whales were negatively correlated with autumn chlorophyll-*a* in situ and satellite-derived chlorophyll-a has been shown to have poor correlation (Laidre *et al,* 2010b). Chlorophyll-*a* variables also were highly correlated with each other. Variables that were dropped due to high collinearity could just as easily be driving the system as those that remain (Zuur *et al,* 2010). Remotely sensed sea surface temperature (SST) has predictive ability that can be as good as and in some cases better then analogous *in situ* data (Becker *et al,* 2010). The binomial GLM of the presence/absence of common dolphins is negatively correlated with autumn SST, indicating a preference for colder water. Preference for colder water could also be indicative of a preference of the herring and sprat for colder water and that the common dolphins are simply following their prey (Littaye et al, 2004). Therefore, common dolphin distribution is influenced primarily by their prey habitat preference (MacLeod *et al,* 2004). During data exploration, mean seasonal autumn SST was found to be highly collinear with mean spring, summer and winter SST. The removal of the other variables in favour of autumn SST creates the possibility that it is the other variables that are, in fact, driving the system.

Given the primary interest in this study of examining the relationship between the distribution of cetaceans and pelagic fish in the Celtic Sea – and the results from the initial analyses as discussed above – further analyses comparing the cetacean and pelagic fish distribution were warranted. Results from the analyses of interpolated NASC scores and cetacean distribution in Figures 5 to 8 show significant inter-annual variation in the distribution of herring and sprat as determined by the acoustic surveys.

The predators and prey being examined in this study are highly mobile. The dynamic nature of their distribution varies not only on an inter-annual basis within the study area but also within the year, and indeed within timescales impossible to account for in a study such as this. The question remains as to why a significant relationship between cetacean distribution and logged

NASC scores for herring and sprat, using the pooled data, was not reproduced using the more resolved yearly data and an interpolated surface to represent the NASC values. If one considers the pooled (by year) data, perhaps locations with a high average NASC score are repeatedly visited by whales. Another question of interest is whether the distribution of cetaceans, as determined by the snapshot taken during the surveys, is representative of their overall distribution throughout the study area during the time period fish are also present in abundance? What may be more likely, given the contradictory results obtained by the analyses of the pooled and yearly data, is that their distribution is a by-product of the dynamic nature of the predators and prey in question. What statistically may be, on the one hand, a significant result and, on the other hand, a random appearance merely reflects our inability to account for their mobility in space and time.

The Celtic Sea herring acoustic survey (source of fisheries and cetacean data used) is fixed spatially and temporally. Peak spawning (i.e. peak abundance of herring) varies from year to year due to a range of factors, yet it remains to be fully understood (O'Donnell *pers comm*.). These surveys can only deliver a snapshot of the ecosystem dynamic over a few short weeks in autumn. Since 2004, the observed peak spawning period has changed within a relatively small time scale. In April 2010, fishermen in the study area reported that they were landing large numbers of spawning herring. What caused this is not known, but it may possibly be linked to climate change or to the recovery of a late spawning population. It is important that we build a solid understanding of the factors influencing the origins, distribution and abundance of cetaceans and their prey in the Celtic Sea so that changes in their ecology and conservation status may be monitored for the future.

5. Conclusions

This Work Package represents the first attempt to integrate the Marine Institute's fisheries data with simultaneously collected cetacean distribution data in the Celtic Sea. Furthermore, the biological data was augmented with remotely sensed environmental data, sea surface temperature and Chlorophyll *a* concentration. As a result, this Work Package has added considerable value to data collected to date.

The scale of variation in the distribution of pelagic schooling fish and the difficulty in obtaining simultaneous cetacean distribution data represented significant challenges in the mathematical exploration of the relationships between the distributions of this predator-prey combination. Nevertheless, the data used in these analyses is the most comprehensive of its type in Ireland.

This Work Package resulted in continued collaboration between fisheries biologists in the Marine Institute, marine mammal ecologists and quantitative ecologists in GMIT and the IWDG. This collaboration is continuing through ongoing collection of coincident fisheries and cetacean distribution data.

Based on a year-by-year analysis of the distribution of cetaceans and pelagic schooling fish in the Celtic Sea, no statistically significant link between the variables was detected. The results of this Work Package have raised questions concerning how best to represent the distribution of the predators and prey within the study area based on the data available, and also led to the development of further research cruises looking at small-scale patterns of distribution of pelagic schooling fish and cetaceans in the Celtic Sea.

Notwithstanding the lack of statistically significant links between the variables, field observations and the data used in this work suggest that the study area appears to be an important seasonal foraging habitat for both baleen whales and common dolphins.

Research into this predator-prey combination is continuing at GMIT in collaboration with scientists at the University of Paris VI and IFREMER through an EU funded PhD. A PhD thesis on the ecology of baleen whales in Irish waters, nearing completion in GMIT, will also add further to our understanding of the ecology of these species in the Celtic Sea. Both of these PhD projects had their origins in this Work Package.

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APPENDIX I – CONTINGENCY TABLES FOR INTERPOLATED PELAGIC FISH NASC SCORES AND CETACEAN DISTRIBUTION 2004–2009.

Two-way contingency table tests of counts of cetacean and pelagic fish (by species) presence and absence. Counts in columns 4 to 7 represent the number of times a cetacean/fish category was observed with 'yes', indicating a positive count, and 'no', indicating a zero count. For example, for a given cetacean and fish 'no/no' indicates no cetacean and no fish observed, whereas 'yes/no' indicates cetacean observed but no fish observed. pχ2, pFisher and pBarnard are p-values obtained using a Pearson's chi-squared, Fisher's exact and Barnard's exact tests for independence respectively. Missing p-values for the chi-squared and Barnard's exact test occur where marginals sum to zero. Significant results are in bold.

Cetacean	Pelagic fish	Year	no/ no	no/ yes	yes/ no	Yes/ yes	$P\chi^2$	P_{Fisher}	$P_{Barnard}$
Baleen whale	Herring	2004	244	21	24	2	0.735	1.000	1.000
Baleen whale	Herring	2005	254	24	0	0	-	1.000	-
Baleen whale	Herring	2006	387	41	2	2	0.065	0.051	0.053
Baleen whale	Herring	2007	371	109	20	3	0.406	0.440	0.287
Baleen whale	Herring	2008	308	134	8	5	0.747	0.548	0.624
Baleen whale	Herring	2009	250	94	13	2	0.368	0.371	0.270
Baleen whale	Sprat	2004	212	53	23	3	0.433	0.435	0.383
Baleen whale	Sprat	2005	225	53	0	0	-	1.000	-
Baleen whale	Sprat	2006	428	0	4	0	-	1.000	-
Baleen whale	Sprat	2007	479	1	23	0	**0.029**	1.000	1.000
Baleen whale	Sprat	2008	428	14	12	1	0.910	0.357	0.632
Baleen whale	Sprat	2009	332	12	13	2	0.212	0.111	0.150
Common dolphin	Herring	2004	235	20	33	3	0.820	1.000	1.000
Common dolphin	Herring	2005	245	21	9	3	0.124	0.074	0.147
Common dolphin	Herring	2006	346	39	44	4	0.887	1.000	1.000
Common dolphin	Herring	2007	346	99	45	13	0.889	1.000	1.000
Common dolphin	Herring	2008	285	124	31	15	0.880	0.738	0.814
Common dolphin	Herring	2009	245	91	18	5	0.751	0.808	0.796
Common dolphin	Sprat	2004	204	51	31	5	0.519	0.500	0.463
Common dolphin	Sprat	2005	213	53	12	0	0.179	0.131	0.147
Common dolphin	Sprat	2006	385	0	48	0	-	1.000	-
Common dolphin	Sprat	2007	444	1	58	0	0.228	1.000	1.000
Common dolphin	Sprat	2008	395	14	45	1	0.989	1.000	1.000
Common dolphin	Sprat	2009	322	14	23	0	0.658	1.000	0.527

Two-way contingency table tests of counts of cetacean and combined pelagic fish presence and absence. Details as per previous table.

Cetacean	Pelagic fish	Year	no/no	no/yes	yes/no	Yes/yes	$P\chi^2$	P_{Fisher}	$P_{Barnard}$
Baleen whale	Herring or sprat	2004	201	64	21	2	0.748	0.809	0.672
Baleen whale	Herring or sprat	2005	207	71	0	0	-	1.000	-
Baleen whale	Herring or sprat	2006	387	41	2	2	0.065	0.051	0.053
Baleen whale	Herring or sprat	2007	370	110	20	3	0.394	0.441	0.289
Baleen whale	Herring or sprat	2008	294	148	7	6	0.513	0.378	0.396
Baleen whale	Herring or sprat	2009	238	106	11	4	0.956	1.000	0.808
Common dolphin	Herring or sprat	2004	201	64	21	5	0.748	0.809	0.672
Common dolphin	Herring or sprat	2005	207	71	0	0	-	1.000	-
Common dolphin	Herring or sprat	2006	387	41	2	2	0.065	0.051	0.053
Common dolphin	Herring or sprat	2007	370	110	20	3	0.394	0.441	0.289
Common dolphin	Herring or sprat	2008	294	148	7	6	0.513	0.378	0.396
Common dolphin	Herring or sprat	2009	238	106	11	4	0.956	1.000	0.808

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