

Ana Rita Correia

**Home range analysis of the semi-  
resident Bottlenose dolphin (*Tursiops  
truncatus*) population of Cardigan Bay  
(Wales)**



UNIVERSIDADE DO ALGARVE

Faculdade de Ciências e Tecnologia

2017

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Bottlenose dolphin (*Tursiops truncatus*)  
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**MESTRADO EM BIOLOGIA MARINHA**

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UNIVERSIDADE DO ALGARVE

Faculdade de Ciências e Tecnologia

2017



## Declaração de autoria de trabalho

Declaro ser a autora deste trabalho, que é original e inédito. Autores e trabalhos consultados estão devidamente citados no texto e constam da listagem de referências incluída.

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(Ana Rita Correia)

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## ACKNOWLEDGEMENTS

There are many people I'd like to thank. This work, as all scientific studies, didn't come from just one person, it's the result of the work and dedication of many, many people.

Firstly, the one person to actually give me the idea to do this project, Dr Mark Fernandez. You said I'd feel like hitting you for giving me this idea and I'd feel frustrated and desperate at some point and I just laughed, but I want to tell you that you were so, so right. It really was a good idea though, so thanks anyway.

I owe a special thanks Dr Colin MacLeod for all the help you gave me, the advice and replies to all those emails I sent, thank you so much for your patience and kindness. Without your help these maps would have never seen the light of day.

I would also like to thank the Sea Watch Foundation staff and volunteers for gathering all the data throughout the years, specially the 2017 volunteers for period 1. Those many days at sea and on landwatch were very important for keeping my sanity when computer work started. A very special thanks to Rhodri and Steph for the help with the Arc GIS program, without you I don't know how I would have done those damned maps.

To Professor Peter Evans and Katrin Lohrengel from the SWF for supervising and providing all the data necessary for this study to happen. A big thanks for professor Ester Serrão from UAlg for looking at my draft.

To everyone at the MBM in UAlg, particularly Monica, Maya, Inês and Teo for all the help with the exams and presentations we did and for all the fun we had.

To my favourite cousin, Olivier for the help with my computer issues.

A very very heartfelt thanks to whoever wrote the website <http://abacus.bates.edu/~ganderso/biology/resources/writing/HTWsections.html>, thank you so much, you are awesome!!

A great thanks for all the dolphins who let themselves be photographed by the SWF, believe it or not some of them were not very good dolphins and wouldn't let us photograph them, so those who did deserve all the affection I have for them, especially the ones bow ridding and staying close to the boat for a long time, they are really nice good dolphins.

Lastly, to those people that lost hours and days, if not weeks, trying to give all the help they could, for putting up with me all those years, my parents and my brother. It

was never easy, I know, but they say the hardest things in life are the best. If we all had to choose a family, I'd never hesitate to choose you three. Thank you for all the support, all the worries you had for me, for letting me scuba dive and drive my motorbike and all that crazy stuff I wanted to do. Most importantly for the support when I was eight and told you I wanted to be a marine biologist. You didn't laugh or said I shouldn't do it, you just supported and encouraged me and I thank the ocean every day for the gift I was given to be part of your family.

To all this people and maybe some that I'm forgetting, thank you for all the help.

*"What is a scientist after all? It is a curious man looking through a keyhole, the keyhole of nature, trying to know what's going on."*

Jacques-Yves Cousteau



## ABSTRACT

The common bottlenose dolphin (*Tursiops truncatus*, Montagu, 1821) belongs to the sub-order Odontoceti and is one of the most widely distributed species of cetaceans. Within this species it is possible to find strict resident populations, semi-resident populations or transient communities. The Cardigan Bay bottlenose dolphin population is one of the two semi-resident populations in the United Kingdom.

With the increasing anthropogenic disturbance, particularly significant for cetacean communities whose geographic ranges are limited or decreasing, the survival of a certain population depends a great deal on its habitat. As a result, understanding the home range of a population is crucial in order to attempt any protection and monitoring measures. Also known as pattern of residency, the home range is the area where the individual spends its time feeding, breeding and nursing the young.

The purpose of this work is to estimate the home range of the bottlenose dolphin population by comparing different group sets in order to infer if there are any dissimilarities between the distributions of the selected groups.

Using photo-identification data from 2007 to 2016 obtained from surveys, combined with other information regarding the individuals, Minimum Convex Polygons and Kernel Density Estimators were calculated and mapped for each group and then compared. Both mean home range (95% KDE) and core areas (50% KDE) were inferred. Mean water depths were also determined for each group.

No significant differences were obtained for gender, markings in the dorsal fin and presence or absence of calf. There were, however differences in distribution for the summer and winter sightings.

Additional important areas for this bottlenose dolphin populations were determined, as well as seasonal differences in distribution. Further surveys are required, mainly at the areas outside the Special Areas of Conservation in Cardigan Bay.

**KEY WORDS:** Bottlenose dolphin, Home range, Core Area, Kernel density estimators (KDE), Minimum Convex Polygon (MCP), Cardigan Bay.

## RESUMO

O Golfinho-Roaz comum (*Tursiops truncatus*, Montagu, 1821) pertence à subordem Odontoceti e é uma das espécies de cetáceos mais amplamente distribuídos. Pode ser encontrado em águas costeiras e oceânicas nas regiões tropicais e temperadas dos oceanos e mares. Dentro desta espécie, é possível encontrar populações residentes, cuja faixa residencial é limitada a um local específico, residentes sazonais, que só podem gastar parte do tempo na área e comunidades transitórias. A população de golfinhos roazes de Cardigan Bay (CB), utilizada para este estudo, é uma das duas populações semi-residentes no Reino Unido, sendo a outra em Moray Firth, na Escócia. Atualmente existem duas Áreas Especiais de Conservação (SACs) implementadas em Cardigan Bay: o Cardigan Bay SAC e o Pen Llŷn a'r Sarnau SAC. Apesar das constantes medidas de monitorização e proteção aplicadas, essa população tem sofrido um forte declínio desde 2007.

Com o aumento do impacto antropogénico, particularmente significativo para as comunidades de cetáceos cujas amplitudes geográficas são limitadas ou decrescentes, a sobrevivência de uma determinada população depende muito do seu habitat. Como resultado, a compreensão dos padrões de residência de uma população é crucial para tentar qualquer proteção e medidas de monitorização. Também conhecido como padrão de residência, o home range é a área onde o indivíduo gasta o seu tempo a alimentar-se, a reproduzir-se e a criar as crias.

O objetivo deste trabalho é identificar o home range da população de golfinhos roazes de CB. Ao comparar diferentes grupos, de acordo com certas características (género, data de avistamento, grau de marcações de barbatanas dorsais e presença de crias), é possível inferir as áreas que são mais importadas para cada grupo ou para toda a população, avaliando as desigualdades entre as distribuições dos grupos selecionados, a fim de verificar quais as medidas que podem ser aplicadas para diminuir o impacto exercido sobre estes animais. O uso de dados de foto identificação de 2007 a 2016 obtidos a partir de pesquisas, combinadas com outras informações sobre os indivíduos, os Minimum Convex Polygons (MCP) e os Kernel Density Estimators (KDE) foram calculados e mapeados para cada grupo, sendo depois comparados. O MCP é usado para delinear a área total onde os animais são encontrados, enquanto o KDE determina quais as áreas que são mais utilizadas pela população. O intervalo médio dos padrões de residência, que representa as áreas sem os locais pouco comuns e distantes

relativamente à área de ocupação normal do indivíduo, corresponde a 95% de KDE, enquanto a core area, que representa as áreas mais ocupadas pela população, onde ocorreram 50% dos avistamentos, é representada por 50% do KDE. Ambos os home range médio (95% KDE) e core area (50% KDE) foram inferidos. As profundidades médias da água também foram determinadas para cada grupo. Quanto à comparação entre fêmeas e machos, a área total, a média dos padrões de residência obtidos e a core area foram ligeiramente maiores para os machos e as áreas de sobreposição também foram semelhantes. Como as diferenças não foram significativas, a distribuição espacial é semelhante para ambos os sexos. A maior limitação foi o maior número de fêmeas em relação ao número de machos estudados.

O home range relativo aos encontros ocorridos durante os meses mais quentes (1 de Abril até 31 de Outubro - Verão) está localizada principalmente em ambos os SAC e em menor grau no norte de Anglesey. Pelo contrário, o home range dos meses de Inverno (1 de Novembro até 31 de Março) foi mais dispersa, com menor presença na área de Cardigan Bay e maiores concentrações de golfinhos desta população em torno de Anglesey, perto de Liverpool Bay e da Isle of Man. Estes resultados implicam que a maioria dos animais passa o ano em locais completamente diferentes, durante o Inverno encontram-se no norte e passam o Verão no sul, em Cardigan Bay.

Os golfinhos com barbatanas dorsais bem marcadas foram contrastados com golfinhos sem uma barbatana dorsal marcada. As áreas ocupadas pelos golfinhos sem marcas nas barbatanas dorsais sobrepuseram-se com as áreas ocupadas por indivíduos bem marcados. O facto dos animais bem marcados terem uma área estimada maior não significa que eles são mais ou que se expandam em áreas maiores. Os animais bem marcados são muito mais fáceis de identificar, enquanto que uma barbatana dorsal não marcada é muito mais difícil de usar como característica identificável. Deste modo, a área determinada pelos golfinhos sem marcas visíveis nas barbatanas dorsais é menor devido ao menor número de identificações ocorridas quando os encontros ocorreram.

As fêmeas com crias foram avistadas em locais muito mais próximos da costa e mais concentrados nos dois SAC de Cardigan Bay, com algumas fêmeas sendo avistadas na costa norte de Anglesey, enquanto que durante os anos sem crias, as fêmeas não eram apenas vistas nesses locais mas também em Liverpool Bay e na Isle of Man. A sobreposição indicou que as fêmeas com crias não procuram áreas diferentes das ocupadas por outros golfinhos fêmeas sem crias. Em vez disso, as fêmeas sem crias tendem a dispersar-se mais para fora, ocupando toda a área da baía, enquanto as fêmeas

com crias tendem a ficar mais perto da costa em locais mais protegidos. Esta comparação foi limitada pelo, por vezes, reduzido número de avistamentos de mães com crias, dado que, em alguns anos, os encontros não eram suficientes para determinar se a fêmea tinha crias ou não.

Em relação às profundidades, a maioria dos grupos apresentou faixas de profundidade semelhantes com desvios padrão semelhantes. A única diferença notável foi a profundidade média dos avistamentos realizados no Inverno, porém a variação não foi significativa, pois o valor do desvio padrão também foi maior para este grupo. Isso pode ser devido ao facto da maioria dos golfinhos estarem localizados fora da área de Cardigan Bay durante o estes meses. Como algumas áreas em torno de Anglesey são ligeiramente mais profundas do que a área de CB, a profundidade seria ligeiramente maior do que nos locais de verão.

Neste estudo foram determinadas áreas importantes para esta população de golfinhos roazes, bem como diferenças sazonais na distribuição. Pesquisas adicionais serão necessárias, principalmente fora das Áreas Especiais de Conservação em Cardigan Bay.

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## LIST OF ABBREVIATIONS

<i>Abbreviation</i>	<i>Meaning</i>
CB	Cardigan Bay
KDE	Kernel Density Estimator
MCP	Minimum Convex Polygon
PVC	Percentage Volume Contours
SAC	Special Area of Conservation
SWF	Sea Watch Foundation

## 1. INTRODUCTION

Despite being an emblematic and widespread group, small cetaceans are heavily impacted by anthropogenic activities (Cheney *et al.*, 2013). The life history characteristics of these animals, since they are K-selected species, as well as the impacts caused by human activities on the marine habitats, particularly in near-shore environments, are reasons for their vulnerability (Ross *et al.*, 2011).

Human disturbance causes a particularly significant impact on cetacean communities whose geographic ranges are limited or decreasing. It is important to understand that the survival of a certain population depends a great deal on its habitat (Ross *et al.*, 2011). Consequently, understanding the home range of a population is crucial in order to attempt any protection and monitoring measures (Ingram and Rogan, 2002; Ross *et al.*, 2011; Dwyer *et al.*, 2016; Sprogis *et al.*, 2016).

As the population is presently declining (Feingold and Evans, 2014a; Lohrengel and Evans, 2015), more conservation measures are necessary in order to reverse this trend, as these animals are being increasingly affected by anthropogenic activities.

This study aims to estimate the home range of the bottlenose dolphin population by comparing different group sets in order to infer if there are any dissimilarities between the distributions of the selected groups. By analysing the core areas it is possible to determine the most important areas to protect, assessing if there are different areas for opposite groups and how best to manage them, decreasing the pressure exerted on the population.

### 1.1. *Cetaceans*

The order Cetacea, comprised of 87 species of whales, dolphins and porpoises (Hoyt, 2011) is divided into two sub-orders, the Mysticeti (baleen whales) and the Odontoceti (toothed whales), which include dolphins and porpoises (Evans and Raga, 2012). The two suborders have radiated during the Oligocene from the archaeocetes, primitive toothed cetaceans that emerged from terrestrial mammals (Fordyce, 1980).

Cetaceans vary in length, from 1.5m to 33m and inhabit marine ecosystems, although some species can be found in lakes and river systems. Having descended from mammals, cetaceans share certain traits with their terrestrial relatives, such as being air-breathing homeotherms (Alves, 2013).

These aquatic mammals are well adapted to living in aquatic ecosystems, with a streamline shaped body, flat paddle-shaped forelimbs and no external hindlimbs, having a horizontal tail - the fluke. In some species it is possible to find a dorsal fin. The nasal opening is located on top of the head in addition to reduced appendages (internal reproductive organs as well as internal ears) in order to decrease the water resistance (Fordyce, 1980; Evans and Raga, 2012; Jefferson *et al.*, 1993). Furthermore, insulation is provided through a thick layer of sub-dermal fat named blubber, allowing these animals to occupy a wide variety of temperatures, from 2°C to over 30°C (Evans and Raga, 2012; Alves, 2013).

Despite all this similarities, there are quite a few differences between the two sub-orders. The mysticetes are often larger than the toothed whales and possess baleen plates, a feeding apparatus that allows the animal to filter prey organisms present in the water column. On the other hand, odontocetes feed on individual large food items, such as fish, cephalopods and crustaceans, using their teeth. Exceptions can be found, as these do not erupt through the gums of the females of the family Ziphiidae (Fordyce, 1980; Evans and Raga, 2012).

The other main distinction regards the nasal cavity, known as blowhole. Mysticetes have two blowholes, whereas odontocetes only possess one (Jefferson *et al.*, 1993; Evans and Raga, 2012).

Diverse studies have been conducted in order to gather knowledge on these animals, however, in opposition to terrestrial animals, aquatic mammals are not frequently visible, since they spend most of their time underwater (Gowans *et al.*, 2007).

Their aquatic lifestyle presents a challenge for scientific studies, as it is often complicated to observe or detect the animals. Moreover, these species are highly mobile

and may occupy a wide geographical area, including sometimes great depths. Most research studies are concentrated in small areas, which can hinder the possibility to gather information if the animals occur in a greater range or even in neighbouring countries (Evans and Hammond, 2004; Alves, 2013; Nuuttila *et al.*, 2013).

In addition, the large body size, fragility, endangered status and the high levels of public attention towards these aquatic mammals can lead to a more demanding way to acquire knowledge from cetaceans (Alves, 2013).

### 1.2. The bottlenose dolphin

The common bottlenose dolphin (*Tursiops truncatus*, Montagu, 1821) belongs to the sub-order Odontoceti and is one of the most widely distributed species of cetaceans (Fig. 1). It can be found in both coastal and oceanic waters in the tropical and temperate regions of oceans and seas. Some populations reside in rivers and estuaries (Gregory and Rowden, 2001; Santos *et al.*, 2007).

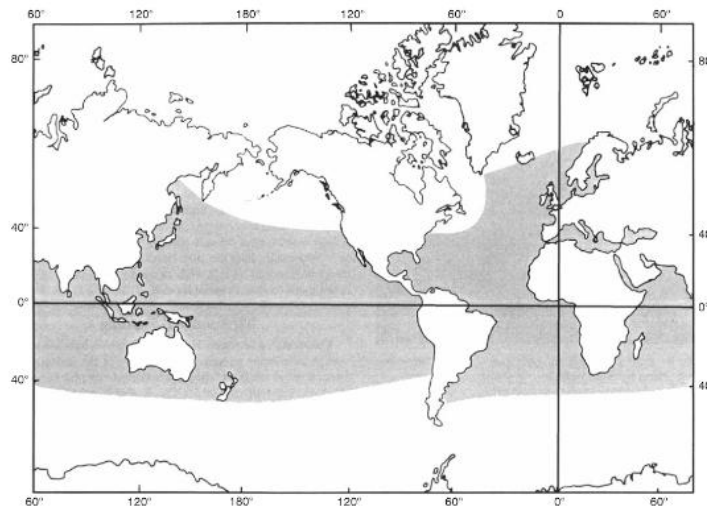


Figure 1 - Map with the distribution of the common bottlenose dolphin (*Tursiops truncatus*) in grey.  
Source: Perrin *et al.*, 2009, p.251

It is probably the most recognised species of cetaceans, featuring in several movies and due to its captivity in zoos and dolphinariums. Despite this, there has been a debate in the scientific community regarding the systematics of this genus. Presently, the genus *Tursiops* consists of three distinct species: *Tursiops truncatus*, *T. aduncus* and *T. australis* (Connor *et al.*, 2000; Charlton-Robb *et al.*, 2011).

Members of this species display great variation in size and coloration. Adults can measure between 1.9 to 4.1 meters and weigh between 150 to 650kg, with the males typically slightly larger than the females. Coloration can range between dark gray to light grey with a white belly (Fig.2). Individuals are usually found in groups (Shirihai, 2006).



Figure 2 - Common bottlenose dolphin (*Tursiops truncatus*). Source: Ana Rita Correia/CRRU.

In this species, two disparate strategies have been considered: the coastal resident populations and the wide ranging oceanic populations. In resident populations, since the amount of prey and resources available is relatively small, large groups would be disadvantageous. For that reason, group size in these communities is reduced, leading to lower competition for food. Since these populations inhabit locations with lower risk of predation, safety in numbers is not a necessity. On the other hand, oceanic groups have a tendency to expand over large areas, as prey availability is often irregular and in low concentration. Frequently, these communities must rely on a big group, as refuge from predators is scarce and prey schools tend to concentrate in small regions, with large areas without any food available. In both these cases, a large community provides protection and increases foraging and ability to catch prey (Gregory and Rowden, 2001; Gowans *et al.*, 2007).

It is, however, quite complicated to conclude with certainty the strategies and patterns of movement of the oceanic groups, as the act of studying them is complex, particularly considering its large area of distribution. Furthermore, offshore bottlenose communities have a tendency to present a dissimilar social structure, exhibiting

relatively lower low-term associations and greater ranges (Gregory and Rowden, 2001; Gowans *et al.*, 2007).

Gowans *et al* (2007) have also referred that, based on genetic studies, inshore and offshore ecotypes display marked genetic differences. For that reason, both are isolated from each other on a reproductive level.

### 1.3. *Group living in bottlenose dolphins*

When encountering members of the species *Tursiops truncatus*, it is possible to observe several individuals. Like most delphinids, these animals form groups or pods. A group is a set of individuals that display stronger associations amongst each other than with the other members of the population over large periods of time (Connor *et al.*, 1998).

There are several advantages in forming groups such as the decrease in mortality due to predation, increase in detection and acquisition of prey and other resources and a bigger amount of individuals for reproduction. Moreover, the probability of acquiring knowledge through learning and social interactions increases when an individual is inserted in a group (Gowans *et al.*, 2007).

However, group living may increase competition for food and other resources as well as probability of spreading certain illnesses or parasites (Gowans *et al.*, 2007).

Despite the existence of a few disadvantages, grouping is quite common in cetaceans. In fact, Connor *et al* (2000) refers that all populations of bottlenose dolphins appear to form what was called fission-fusion groups. In this grouping strategy, associations formed between different animals often change in composition for small periods of time.

Depending on the activity in progress at the time, different groups may be defined, nevertheless each individual can be considered to be in more than one simultaneously (Gowans *et al.*, 2007). One example could be of a nursery group, where several females have grouped to take care of calves, that join a feeding group.

The decrease or absence of competition is quite beneficial for the success of the group or groups and cooperation can exist even when the animals are not related to each other (Gowans *et al.*, 2007).

#### 1.4. Photo-identification

Photo identification is a method based on the analysis of photographs whose goal is to identify and recognise different individuals (Fig.3).



Figure 3 - Common bottlenose dolphin (*Tursiops truncatus*) dorsal fins for photo-identification purposes. a and b are photos of dolphin 014-94W (Gandalf); c and d correspond to dolphin 152-05W. Photo a was taken on July 15<sup>th</sup>, 2003. Photo b was taken on May 24<sup>th</sup>, 2017. Photo c was taken on August 14<sup>th</sup>, 2016. Photo d was taken on August 6<sup>th</sup>, 2009. Source: Katrin Lohrengel, SWF.

According to Würsig and Jefferson (1990) studies comparing natural marks in cetaceans have started in the early 1970's.

One main advantage to using this particular method is that it does not harm the animals sampled. It also provides an array of information with a relatively low cost (Evans and Hammond, 2004).

Photo-identification can be useful in assessing movement and population parameters, namely life history information, such as age of sexual maturity, reproductive and total life span, calving intervals, length of nursing, and, in some cases, mortality and disease rates. Group composition and behaviour of the population is possible to be inferred when all the individuals are accounted for. Area distribution as well as short term movement patterns and migrations are also possible to be determined,

when the photo-identification occurs in different locations (Würsig and Jefferson, 1990; Evans and Hammond, 2004; Connor and Krutzen, 2015).

Reliable data must be attained for these studies, in order to avoid getting biased information. The natural marks used for the recognition of the animal must be discernible over time as well as be unique to that specific individual. In most cases this condition is easily met, since most marks will seldom change beyond recognition even when other marks appear in the dorsal fin/fluke. In addition, most marks will be present throughout the individual's lifetime (Würsig and Jefferson, 1990; Evans and Hammond, 2004).

Another consideration when photographing the individuals is that most dolphins or whales acquire marks or nicks as they get older, hence the probability to recognise a calf or a juvenile is much lower. Fortunately, marks tend to appear as the individual gets older, improving the possibilities of identification (Würsig and Jefferson, 1990).

Despite most photo-identification work only accounting for the marks, nicks and amputations present in flukes or dorsal fins as well as its shape, some studies (Katona and Whitehead, 1981; Würsig and Jefferson, 1990; Hartman *et al.*, 2014) have pointed out other ways to positively identify cetaceans, such as using pectoral fins in order to identify Humpback Whales (*Megaptera novaeangliae*), as well as pigment patterns in different species of whales. In addition, shading of the fin and upper body, wounds and foreign objects present in the animal can be useful when recognising a specific individual. One trait more commonly found in the Risso's dolphins (*Grampus griseus*) is the scarification pattern present on the animal's dorsal fins and bodies.

Despite all the different characteristics, all these must be identifiable and including poor quality photographs may lead to animals not being recognized or correctly named. Even when the photographs have a good quality, not all animals in the population may bear distinguishable markings along with the fact that in some species most individuals do not hold natural lasting marks or scars. (Evans and Hammond, 2004).

Moreover, other approaches have been used in order to collect the same type of information as the one gathered through photo-identification. Some whale species have been identified from airplanes, however delphinids are not possible to identify using this method. Another method used is underwater acoustics, which does not require visualisation of the animals. However, the animals must be vocalising for this method to be successfully employed and some species only do so throughout specific times of the

year. Underwater photography is also a potentially important method, as the animals are more frequently under water (Würsig and Jefferson, 1990; Evans and Hammond, 2004).

Despite having some disadvantages, photo-identification can be applied to several studies, such as habitat preference (MacLeod *et al.*, 2007). By understanding the species' habitat preference, it may be possible to predict its response to changes of the environment, mitigating the impact of human interactions with cetaceans. Another use of employing photo-identification is to ascertain home range as well as determining resident and non-resident cetacean populations (Hartman *et al.*, 2014; Hartman *et al.*, 2015). Additionally, mark-recapture methods applied to photo-identification are frequently used in monitoring programs, often improving conservation efforts (Evans and Hammond, 2004).

### 1.5. *Home range*

Burt (1943) has defined home range, also known as pattern of residency, as the area where the individual spends its time feeding, breeding and nursing the young (Defran *et al.*, 1999; Ingram and Rogan, 2002).

In the past this concept has been used in studies of terrestrial mammals (Ingram and Rogan, 2002), however residence patterns have increasingly been used to determine important habitats for populations of aquatic mammals (Dinis *et al.*, 2016).

Nevertheless, not all species and even populations of the same species will occupy the same exact locations: some populations can use the same home range for decades and other populations may display temporary or seasonal migrations away from the area. Sometimes it is even possible to find different home ranges for different individuals in the same geographical area (Defran *et al.*, 1999).

In bottlenose dolphins, it is possible to find strict resident populations, whose home range is limited to a specific location, seasonal residents, which may only spend a portion of time in the area and transient communities (Papale *et al.*, 2016).

Using location data, the home range can be estimated through two simple widely applied methods: MCP (Minimum Convex Polygon) and KDE (Kernel Density). MCP is used to outline the total area where the animals are found. However, this approach tends to overestimate the home range, as it builds a convex polygon of the area used, assuming that the animals use this area equally. Odd locations, far away from the normal area used will induce a biased home range, as MCP does not take into account

that most animals tend to spend more time in some areas than other (Anderson, 1982; MacLeod, 2013; Sprogis *et al.*, 2016).

In order to determine which areas are more frequently used by the population a different method must be applied. The KDE assumes the areas with a greater number of sightings are more important for the individuals than the areas with low density of records. In this approach, 50% and 95% KDE polygons are created. Mean home range, that represents the areas without the odd locations far away from the individual's normal range, corresponds to 95% KDE whereas the core area, which stands for the most occupied areas by the population, where 50% of the total number of sightings occurred, is represented by 50% KDE (Anderson, 1982; Hauser *et al.*, 2007; MacLeod, 2013).

The original KDE was used for populations within study areas that did not contain any barriers to movement. For offshore cetacean species, whose habitat allows them to move freely, this method can be used. However, for coastal cetacean population, such as the Cardigan Bay bottlenose dolphins, this implies an overestimation of the home range, as the coastline acts as a barrier to the movement. In order to avoid a biased home range estimation the method used must take into account the presence of barriers in the study area (MacLeod, 2013; Sprogis *et al.*, 2016).

Other than the presence of barriers to the movements of the animals, home range may be affected by physical habitat features, such as depth, variability in climate, temperature, salinity, tidal cycles and other ocean processes (Ingram and Rogan, 2002; Hauser *et al.*, 2007).

Individuals use their home range to gather food and other resources, to avoid predators and attain conditions for their survival. Therefore, home range is not a fixed location in time. Ecological conditions may alter, causing modifications on the distribution patterns with the goal to increase the group's chances of survival and reproductive success (Lusseau, 2005; Hauser *et al.*, 2007; Powell and Mitchell, 2012).

These changes in distribution may also include areas known by the animal, yet were not visited before (Powell and Mitchell, 2012). By studying home range, particularly in cetaceans, the researcher must take into account not only the areas where the animals can be found, but also the social organisation and behaviour of the populations (Hauser *et al.*, 2007).

In an innovative study, Powell and Mitchell (2012) have attempted to determine how an individual would perceive its home range and have presumed that a residence pattern originates from a combination of resource availability (the environment) and the

animal's understanding of that environment, its cognitive map. By determining how the individual's decision-making process works in regards to changes in the environmental conditions, home range would be more accurately estimated.

It is, however, still not possible to determine a home range based on this method. Consequently, quantitative statistical approaches are presently used. One other disadvantage is the dynamism of residency patterns, often altering in a timescale that would not allow an effective data collection for its estimation (Powell and Mitchell, 2012).

There are several methods that can be used to obtain information to estimate a population's home range. Previously, visual data was the main method used (Sveegard *et al.*, 2011). Nevertheless, other techniques started being employed in order to attain the same information. These include use of telemetry (Powell and Mitchell, 2012) and multiple acoustic methods (Sveegard *et al.*, 2011; Nuutila *et al.*, 2013).

Although a decrease in resource availability can play an important role in shifting a population's home range (Defran *et al.*, 1999; Gowans *et al.*, 2007; Sveegard *et al.*, 2011), anthropogenic disturbance caused by fishery activities as well as overall boat traffic and noise are cause for concern regarding the dolphin's welfare. For dolphins, boat presence could lead to physical injuries from collisions, hearing problems from the excessive noise, more time spent foraging due to avoidance of areas with large amounts of boats (Lusseau, 2005; Pierpoint *et al.*, 2009; Papale *et al.*, 2016).

Information regarding residency patterns can be applied in conservation and management efforts of resident populations. By determining the most frequently used areas for a certain population or group, considered to be the locations where food and other resources are more abundant, it would be possible to more effectively protect it, creating Marine Protected Areas or decreasing anthropogenic impact close to that area (Sveegard *et al.*, 2011; Hartman *et al.*, 2015). One example was the creation of the Gully Marine Protected Area, in Nova Scotia due to the presence of a resident population of the northern bottlenose whale (*Hyperoodon ampullatus*) (Hartman *et al.*, 2015).

### 1.6. *The study population*

The Cardigan Bay bottlenose dolphin population is one of the two semi-resident populations in the United Kingdom, the other being the Moray Firth, in Scotland (Feingold and Evans, 2014a).

Estimates of the size of the population vary between 121 and 230 individuals, with a greater presence during the summer season. On the other hand, some individuals keep being sighted in the bay during the winter months (Feingold and Evans, 2014a).

Previous studies have determined that several individuals have been moving towards the north, mostly at the north coast of Anglesey, with sightings recorded as far as Liverpool Bay and the Isle of Man during the summer months, which leads to the conclusion that these dolphins no longer inhabit the Cardigan Bay area during the summer (Gregory and Rowden, 2001; Pierpoint *et al.*, 2009; Feingold and Evans, 2014a; Lohrengel and Evans, 2015).

Until recently the dolphin population was growing in numbers. However, with the increase in boat disturbance, the decrease in prey and overall anthropogenic impact the population has suffered a decline (Feingold and Evans, 2014a; Lohrengel and Evans, 2015).

### 1.7. *Objectives*

The present study aims to assess the home range of the bottlenose dolphin population of Cardigan Bay using long-term photo-identification data in order to improve the knowledge of this population and contribute for its conservation.

The objectives of this study are as follows:

- Compare the Minimum Convex Polygon (MCP) as well as 50% and 95% Kernel Density Estimators (KDE) of males vs females.
- Compare the MCP as well as 50% and 95% KDE of the individuals sighted in the summer vs individuals sighted in the winter.
- Compare the MCP as well as 50% and 95% KDE of the dolphins without marks in the dorsal fin vs heavily marked dolphins.
- Compare the MCP as well as 50% and 95% KDE of females with calves vs females without calves.
- Determine the mean depths for each group.

These objectives are designed to answer the following questions:

(1) Do females and males occupy the same areas and where do they stay?

(2) Does the population remain at the same location during the summer and the winter? If not, where do they go?

(3) Is there a difference in identification between dolphins with a well-marked dorsal fin and dolphins without marks in their dorsal fins?

(4) Do bottlenose dolphin mothers stay in different locations with their calves than when they don't have a calf? Is there a place in Cardigan Bay where mothers do not go with their calves or a place only mothers and calves go to?

(5) Is there a different depth range for any of the groups previously mentioned?

## 2. MATERIALS AND METHODS

### 2.1. Study Area

Located in West Wales, Cardigan Bay is the largest bay of the British Isles with an estimated area of 5000 km<sup>2</sup> measuring over 100km between its northern (the Llŷn Peninsula) and southern boundaries (St David's Head). It is surrounded by the coastline of Wales on three sides and opens to the Irish Sea on its western border (Fig.4). Its greatest depth reaches about 50 m, however the average depth is approximately 40 meters. Its depth increases from east to west with very gentle slopes (Gregory and Rowden, 2001; Anon, 2007; Lohrengel and Evans, 2015).



Figure 4 - Map of the study area: Cardigan Bay, Wales.

Cardigan Bay is relatively sheltered, having calm waters, particularly at small embayments within the bay. Salinity is greater in the south and lower near the coast due to freshwater input from rivers and rainfall (Anon, 2007).

The seabed of the bay is diverse in its nature, being comprised of sand and broken shells, gravel, shingle and mud (Gregory and Rowden, 2001; Anon, 2007).

Boat traffic is frequent, mainly in the summer months, with tourist activities such as water sports and recreational boat trips, with wildlife boat trips actively chasing the semi-resident population of bottlenose dolphins present in the bay (Gregory and Rowden, 2001).

Under the European Community's Habitats Directive, two Special Areas of Conservation (SACs) were implemented in Cardigan Bay: the Cardigan Bay SAC in the south and the Pen Llŷn a'r Sarnau SAC in the north (Fig.5).

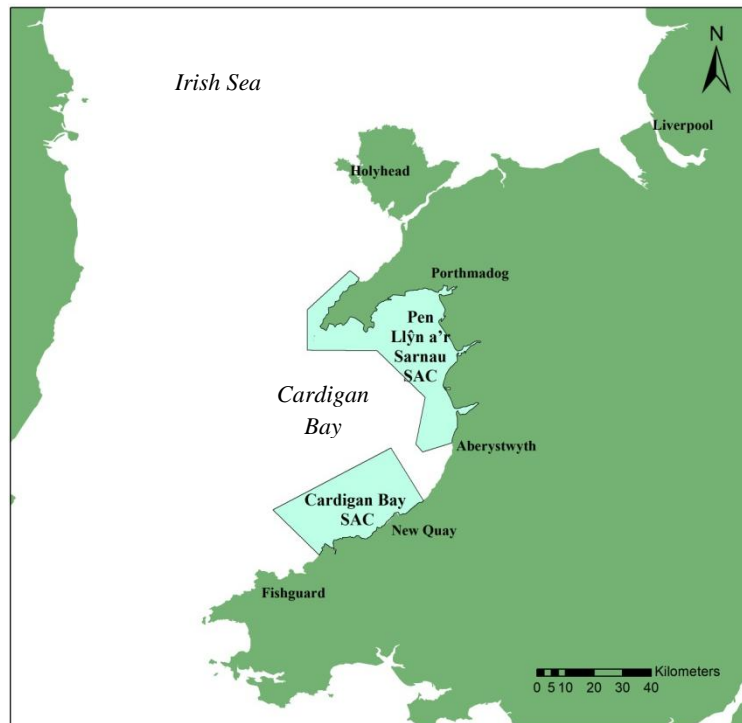


Figure 5 - Map of the two Special Areas of Conservation in Cardigan Bay, Wales (Cardigan Bay SAC and Pen Llŷn a'r Sarnau SAC).

Proposed in 1996, both officially started in 2004, with the main purpose of protecting the marine wildlife present in both areas (Anon, 2007; Evans and Pesante, 2008; Pierpoint *et al.*, 2009)

The Cardigan Bay Special Area of Conservation is located from the Teifi Estuary to Aberaeron. It has approximately 960km<sup>2</sup> and its primary objective is to protect the semi-resident bottlenose dolphin population as well as other species and habitat features, such as the Atlantic Grey Seal (*Halichoerus grypus*), the River Lamprey (*Lamptera fluviatilis*), the Sea Lamprey (*Petromyzon marinus*), reefs, submerged sea banks and submerged or partially submerged sea caves (Anon, 2007; Evans and Pesante, 2008; Pierpoint *et al.*, 2009; Lohrengel and Evans, 2015).

The Pen Llŷn a'r Sarnau Special Area of Conservation, between the Dovey Estuary and around the Lleyn Peninsula, has an estimated area of 1460km<sup>2</sup>. Originally designed to protect mostly habitat features, such as estuaries, reefs, shallow bays and inlets, mudflats and subtidal sand banks, as well as the European Otter (*Lutra lutra*) it

later encompassed the Bottlenose Dolphin (Pen Llŷn cSAC Plan, 2001; Evans and Pesante, 2008; Lohrengel and Evans, 2015).

## 2.2. Data collection, treatment and analysis

The dataset used in this study was collected by the Sea Watch Foundation (SWF) between 2007 and 2016. Land-based and boat-based surveys were conducted throughout the year in Cardigan Bay, around the coast of Anglesey, in Liverpool Bay and at the Isle of Man.

Surveys occurred mainly between April and October, however there have been sightings in other months, particularly in the north of Anglesey.

While collecting data, environmental conditions need to be favourable, with sea state 3 or less, the visibility must be over 1.5km and absence of precipitation (Lohrengel and Evans, 2015).

Boat-based data was collected from dedicated line transect surveys aboard motorised vessels with members of the SWF as well as trained volunteers. The line transects had been previously defined (Figures 6 and 7) and are chosen at random at the beginning of each survey.

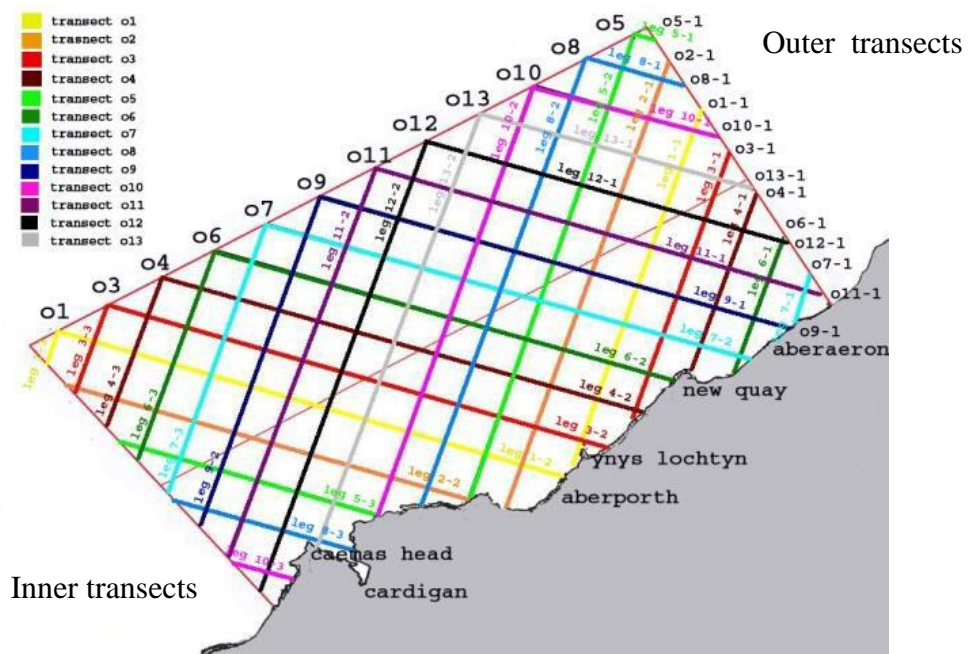


Figure 6 - Map of the inner and outer transects to be selected at random at the beginning of each line transect survey conducted in the Cardigan Bay SAC. Source: Lohrengel and Evans (2015).

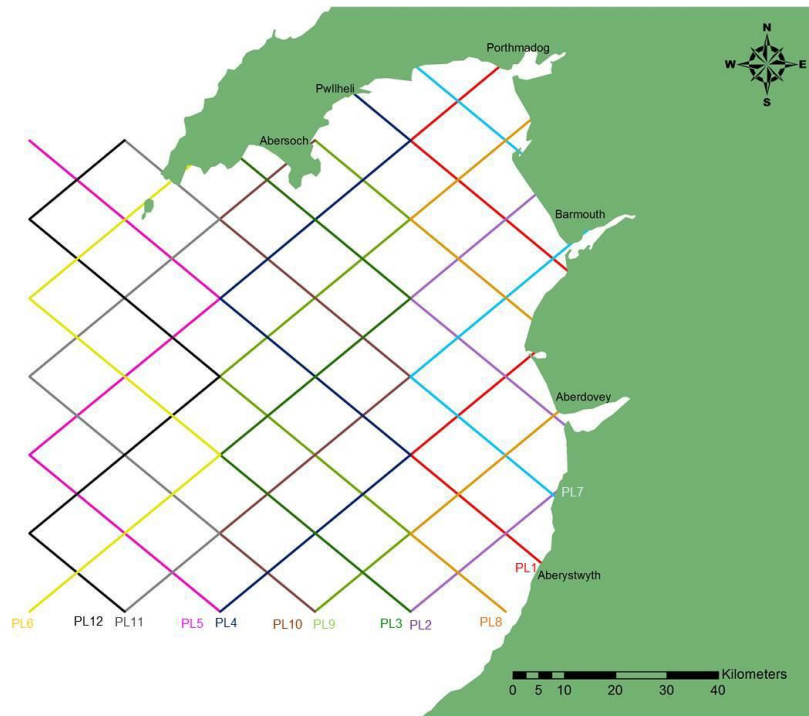


Figure 7- Map of the transects to be selected at random at the beginning of each line transect survey conducted in the Pen Llŷn a'r Sarnau SAC. Souce: Lohrengel and Evans (2015).

As seen in Lohrengel and Evans (2015), there are four observers (two primary and two independent) actively searching for the animals as well as a researcher recording effort data at all times throughout the survey. Environmental data such as visibility, precipitation, glare, sea state and swell are recorded on the effort forms every 15 minutes. Other information such as boat speed and course, location coordinates and presence or absence of other vessels in the area is also registered (Fig. 3.1 - Appendix III). When bottlenose dolphins are present, effort must be done every three minutes. Data recorded includes location (geographical coordinates), behaviour, group size and composition, video and underwater video recordings. Occasionally, underwater acoustic data and drone footage can also be attained. Information such as the distance from the boat, first cue the observer spotted (dorsal fin, fluke, back, head, blow,...), reaction to the boat and the angle where the animal was first spotted is also part of the data collected.

Photo-identification is also carried out, when possible, both in the line transect and the *ad libitum* surveys. The latter are conducted when weather conditions are not ideal or aboard wildlife watching vessels. Photographs were taken using a Canon EOS 40D or a Canon EOS 7D camera body with 18-200mm, 18-300mm or 75-300mm

telephoto zoom lens (Lohrengel and Evans, 2015). The trips aboard the whale watching vessels are only carried out at the near-shore area of the Cardigan Bay SAC.

On land-based surveys it is necessary to document the number of animals (adults and calves) that can be seen along with the location they were first spotted. Additionally, all boat encounters must be registered as well as the distance of the animals to the boats. The number of vessels present in the water is another feature that must be written down.

All research was carried out under licence from Natural Resources Wales and following all the rules regarding interactions with cetaceans.

After the encounters, all data is treated. Each dorsal fin photograph must have enough quality so that it can be used to confidently identify the individual. If this is not possible, the photo must be deleted. After the photographs are determined to have sufficient quality, each one is given a code. An example of the code is 160124\_001\_dunbar\_RCO\_001, where 160124 is the date (year 2016, on January 24<sup>th</sup>), 001 represents the encounter number, dunbar is the name of the boat (when the survey is land-based, this should be replaced with "land"), RCO corresponds the initials of the photographer (Rita Correia) and the last three numbers stand for the consecutive order of the photograph.

After the photographs are batch renamed, they must be cropped in order to obtain a photograph that shows the fin and any scars present on the body that could be used to more easily identify the individual. All pictures of the same individual must be given the same code at the beginning of the name.

The dorsal fin is then compared with the photographs catalogued. There are three different catalogues: two containing all the unmarked dorsal fins, divided into the left and right catalogues, corresponding to the side represented in the photograph. The third catalogue is divided into two sub-catalogues, the well-marked and the slightly marked.

After a match is found or the animal is not on the catalogue, it must be validated. The validation process will be completed by someone else, in order to have certainty that the identification is correct. Afterwards, the sighting information is stored to be used for future studies.

In this study the dataset had the following information: name, sex, date of sighting and geographic coordinates. All sightings from the marked catalogue were used, however, in order to prevent using the same animal more than once, only data from the left catalogue was analysed.

All dolphins not sighted a minimum of 4 years between 2007 and 2016 were excluded from the dataset. The individuals had to have been sighted in at least four different years in order to insure that these were not transients or occasional visitors.

All the dolphins present in the dataset were divided into several different datasheets, according to the characteristics analysed. A minimum of 30 sightings were used for determining home ranges, as done in other studies (Hartman *et al.*, 2014; Hartman *et al.*, 2015), in order to obtain an accurate analysis.

In order to compare females and males, the dataset was divided into only females and only males. Possible females and possible males were excluded from this study, as sexing is often difficult and no confirmation of these animals' gender could lead to a biased home range estimation.

When comparing summer and winter, all the sightings were ordered by their date of occurrence. Sightings between April 1<sup>st</sup> and October 31<sup>st</sup> were classified as summer sightings. Between November 1<sup>st</sup> and March 31<sup>st</sup> occurred the winter sightings. All dolphins that did not have both winter and summer sightings were excluded.

In the well-marked against not-marked study, only the well-marked and the non-marked left catalogued individuals in the dataset were included.

As for the females with calves and females without calves, every female that had been seen next to calf at least 3 times in the same year was considered a mother in that year. Only females who had previously been mothers were used in the comparison. Furthermore, information regarding females and calves from the year 2016 was not available for this study, as a result the sightings used occurred between 2007 and 2015.

All data was analysed using the ArcGIS Desktop 10.1 software. The geographic coordinate system used was WGS 1984 whereas the projected coordinate system was a custom Transverse Mercator (Latitude of Origin: 51; Central Meridian: -1).

In order to calculate the total area used by each group of individuals an MCP (Minimum Convex Polygon) was estimated (Hartman *et al.*, 2015). Considering the fact that cetaceans are exclusively aquatic mammals, all areas of the MCP that fall on land were removed. For each group to be compared a map was created and the total area was calculated.

The residency patterns are calculated using kernel density estimators (KDE) in order to determine the distributions and space use of each group (Hauser *et al.*, 2007; Dwyer *et al.*, 2016). Once again, all areas that fall on land must be excluded, making this a kernel analysis with barriers. To remove the land from the study a polygon data layer, whose coordinate values are as follows: Top: 300000; Right: 90000; Bottom: -60000; Left: -170000.

Subsequent to attaining the map with the KDE values with barriers, two PVCs (Percentage Volume Contours) were created for each group of dolphins, the 95%PVC that represents the mean home range and the 50%PVC, which corresponds to the core area (Hauser *et al.*, 2007). Using the 50% and 95% polygons previously created, the whole area was then calculated for each different group.

The areas for each set of individuals to be compared were combined into a single polygon in order to determine the overlap between each set of dolphins. Percentage of overlap was also determine for both methods.

After all the comparisons, a water depth raster was added in order to determine the mean depth for each group, using the 95% PVCs previously attained, with the determination of the mean water depth and standard variation of each group.

The standard error for each group was calculated as follows:

$$\text{Standard error} = \frac{\sigma x}{\sqrt{n}}$$

where  $\sigma x$  corresponds to the standard deviation obtained and  $n$  is the total number of sightings for the group.

Both MCP and KDE were determined following MacLeod (2013).

### 3. RESULTS

The main dataset contained a total of 4232 sightings from 189 dolphins. As previously stated, the dataset was divided into several groups. The number of sightings and dolphins analysed in each groups is depicted in Table 1.

Table 1 – Number of sightings and dolphins in each groups used for estimating the respective home ranges.

<i>Groups</i>	<i>Number of sightings</i>	<i>Number of dolphins</i>
Females	1441	55
Males	510	16
Summer	3026	172
Winter	1040	169
Well marked	2015	73
Non-marked	481	24
Females with calves	565	41
Females without calves	564	40

#### 3.1. Females vs Males

Though the number of females was greater than the number of males in the dataset, the Minimum Convex Polygon (MCP) was higher for the males (9715,30 km<sup>2</sup>) than the females (8812,05 km<sup>2</sup>). However, the area of overlap represents a big portion of both MCP areas (7512,54 km<sup>2</sup>), with a similar percentage of overlap for both groups (77.3% for males and 85.3% for females). Both maps with the females and males' MCPs are represented by figures 8 and 9.

The Kernel Density Estimate areas calculated for both females and males can be found on Table 2, while the maps are located in figures 1.1 and 1.2 (Appendix I), respectively.

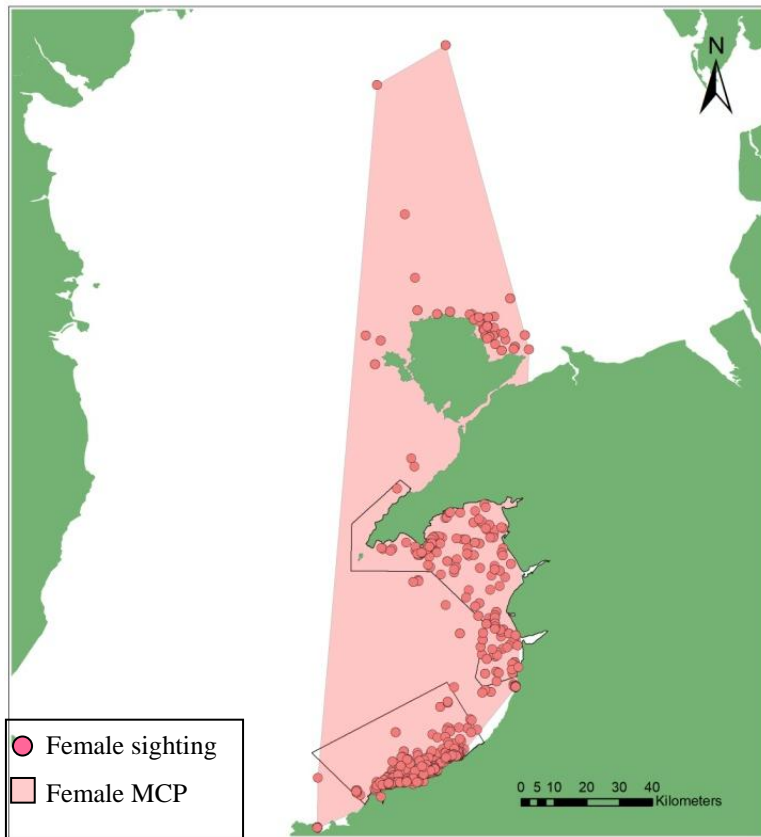


Figure 8 – MCP of all the females. Each dot corresponds to a single sighting of a female individual.

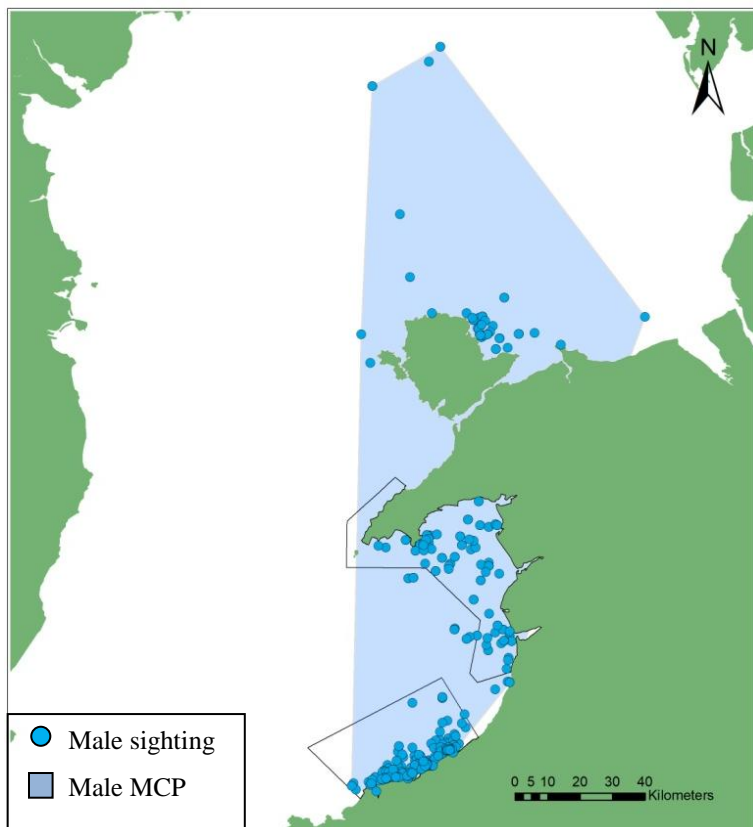


Figure 9 – MCP of all the males. Each dot corresponds to a single sighting of a male individual.

Table 2 – 95% and 50% KDE areas for females and males as well as the overlap between the two groups.

<i>Method</i>	<i>Females</i>	<i>Males</i>	<i>Overlap</i>
<i>KDE 95% (km<sup>2</sup>)</i>	883,70	932,25	647,50
<i>KDE 50% (km<sup>2</sup>)</i>	58,63	65,75	53,21

The percentage of overlap for the females was 73.3% (95% KDE) and 90.8% (50% KDE). For males was 69.5% (95% KDE) and 80.9% (50% KDE).

### 3.2. Summer vs Winter

When comparing sightings that occurred in the cold and hot months, the winter MCP was higher (8139,72 km<sup>2</sup>) than the summer MCP (6373,77 km<sup>2</sup>). The overlap consisted of 5052,90 km<sup>2</sup>(figures 10 and 11). The percentage of overlap was 79.3% for the summer and 62.1% for the winter.

In table 3 can be found the KDE areas for each groups. The maps generated are located in figures 1.3 (summer) and 1.4 (winter) (Appendix I).

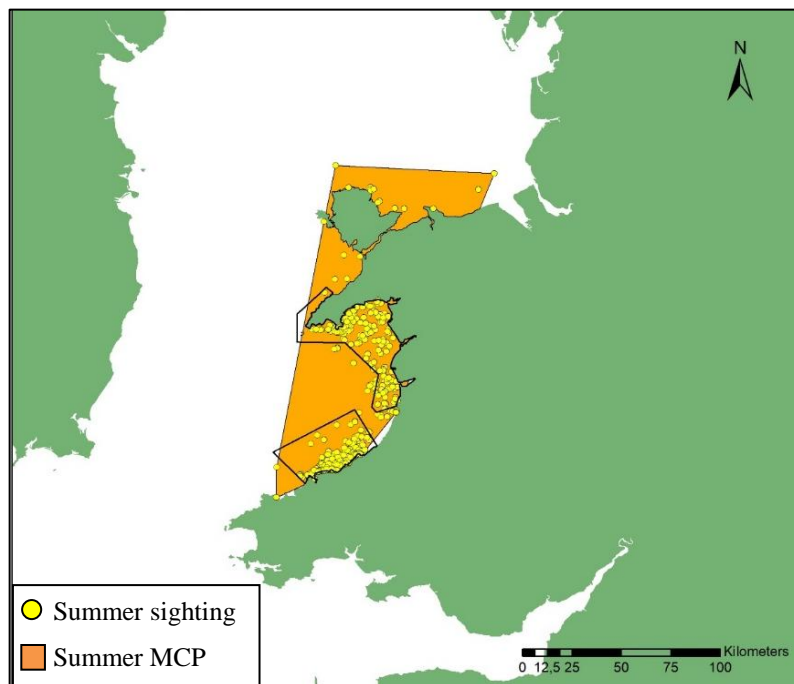


Figure 10 – MCP of the summer sightings. Each dot corresponds to a single dolphin sighting that has occurred between April 1<sup>st</sup> and October 31<sup>st</sup>.

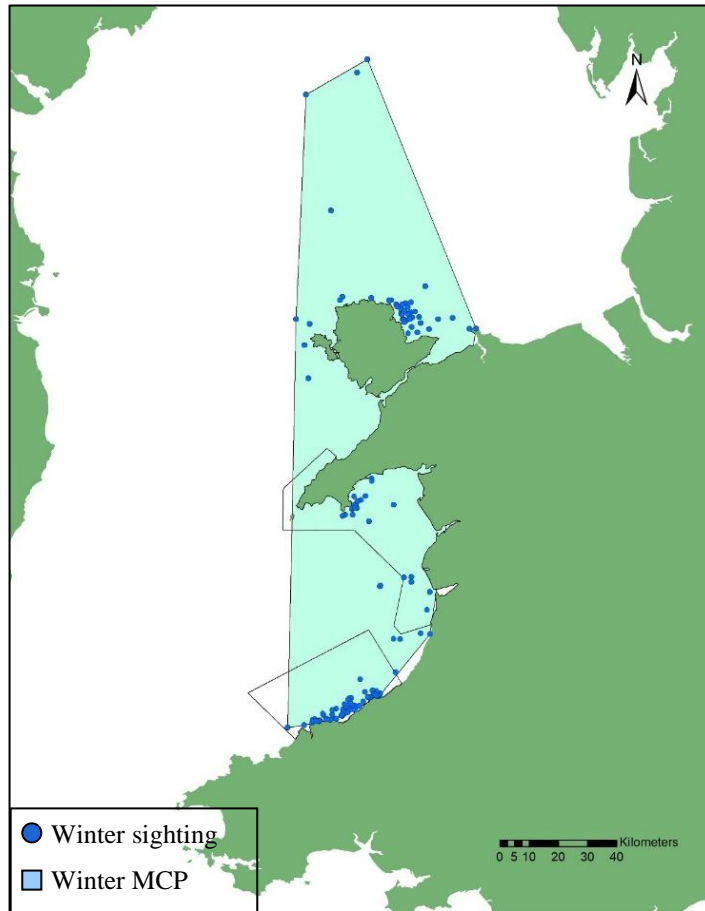


Figure 11 – MCP of the winter sightings. Each dot corresponds to a single dolphin sighting that has occurred between November 1<sup>st</sup> and March 31<sup>st</sup>.

Table 3 –95% and 50% KDE areas for winter and summer sightings as well as the overlap between the two groups

<i>Method</i>	<i>Summer</i>	<i>Winter</i>	<i>Overlap</i>
<i>KDE 95% (km<sup>2</sup>)</i>	1805,92	1444,13	723,85
<i>KDE 50% (km<sup>2</sup>)</i>	137,57	143,49	38,75

The percentage of overlap for summer was 40.1% (95% KDE) and 28.2% (50% KDE). For winter was 50.1% (95% KDE) and 27.0% (50% KDE).

### 3.3. Well marked vs Non-marked

In relation to the comparison between the well marked and the non-marked dolphins, the MCP regarding the well marked individuals was 2,14 times higher (11666,74 km<sup>2</sup>) than the MCP of the non-marked dolphins (5454,76 km<sup>2</sup>). The overlap consisted of 5454,76 km<sup>2</sup> (figures 12 and 13), while the percentage of overlap was 100% for the unmarked individuals and 46.8% for well marked individuals.

In table 4 are represented the mean home range and core area for each groups. The maps generated are located in figures 1.5 (well-marked) and 1.6 (non-marked) (Appendix I).

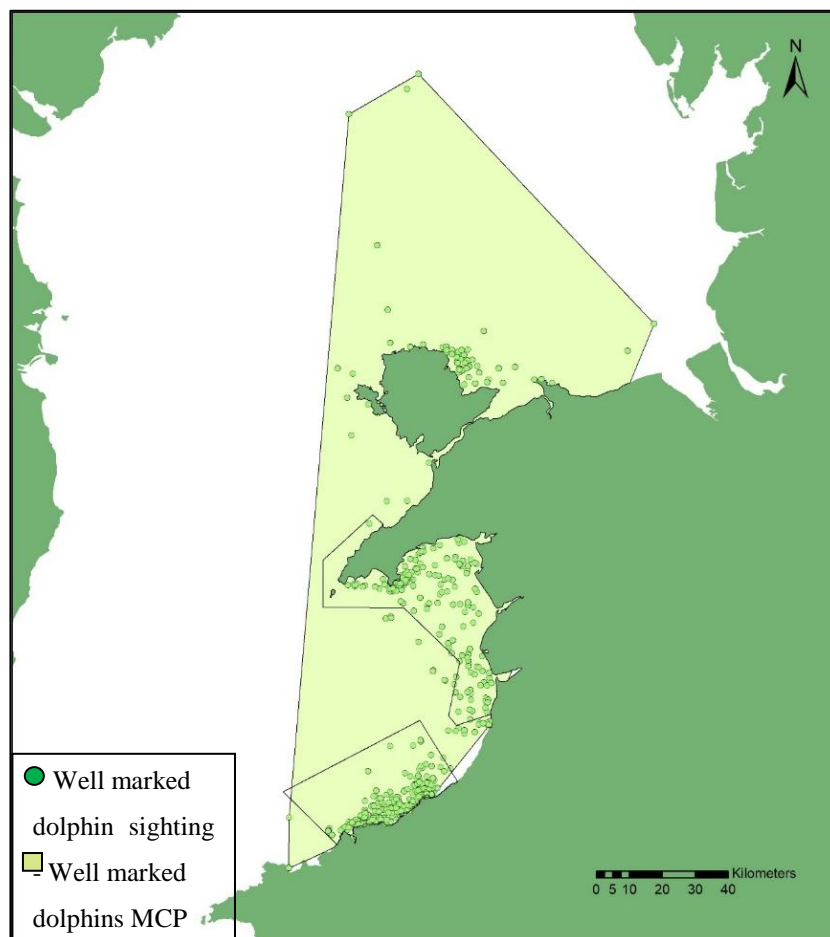


Figure 12 – MCP of the well marked dolphins sightings. Each dot corresponds to a single well marked dolphin sighting.

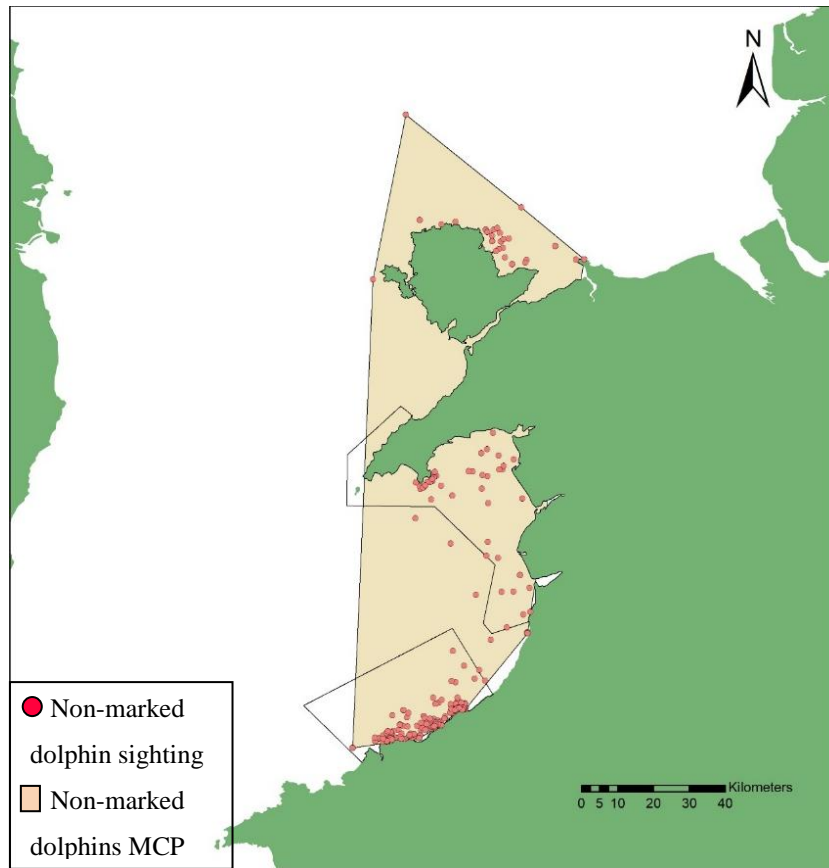


Figure 13 - MCP of the non-marked dolphins sightings. Each dot corresponds to a single non-marked dolphin sighting.

Table 4 –95% and 50% KDE areas for well marked and non-marked dolphins' sightings as well as the overlap between the two groups

<i>Method</i>	<i>Well marked</i>	<i>Non-marked</i>	<i>Overlap</i>
<i>KDE 95% (km<sup>2</sup>)</i>	2464,15	1275,44	1164,14
<i>KDE 50% (km<sup>2</sup>)</i>	181,82	58,05	57,31

The percentage of overlap for well-marked dolphins was 47.2% (95% KDE) and 31.5% (50% KDE). For non-marked individuals was 91.3% (95% KDE) and 98.7% (50% KDE).

### 3.4. Females with calves vs Females without calves

When comparing the females with and without calves, the females without calves had an MCP of 9788,94 km<sup>2</sup>, 1.75 times greater than the females with calves, with an MCP of 5590,31 km<sup>2</sup>. The areas overlapped 5561,23 km<sup>2</sup> (figures 14 and 15). Percentage overlap was much greater for females with calves (99.5%) than for females without calves (56.8%).

Table 5 contains the mean home range and core area for each groups. The maps representing the 95% and 50% KDE are located in figures 1.7 (females with calves) and 1.8 (females without calves) (Appendix I).

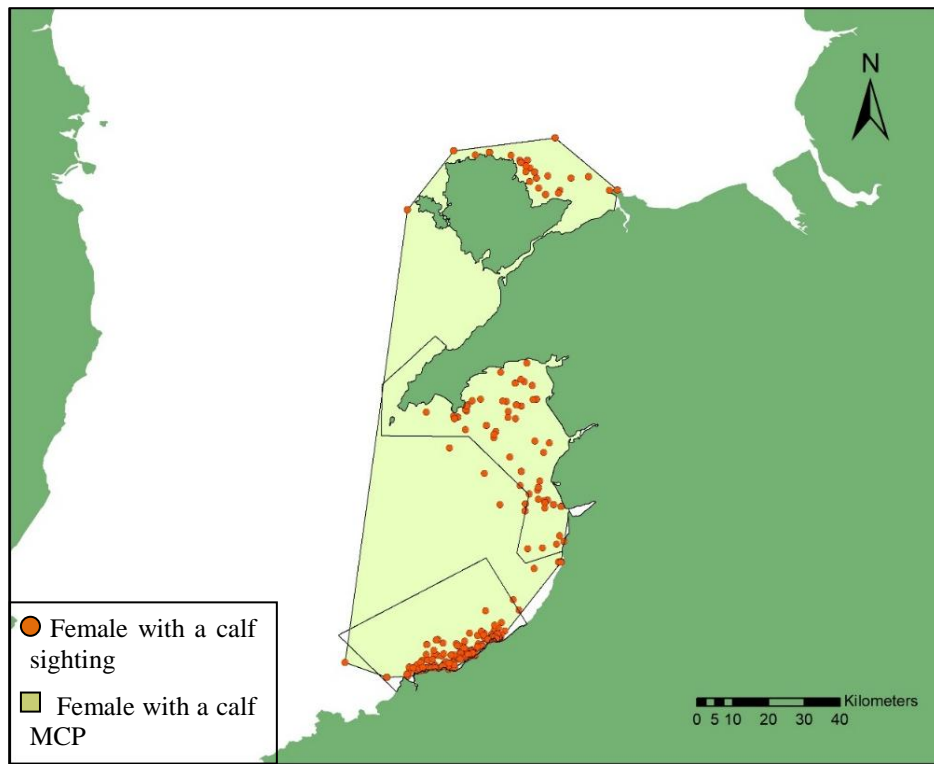


Figure 14 - MCP of females with calves sightings. Each dot corresponds to a single sighting of a female dolphin in the company of her calf.

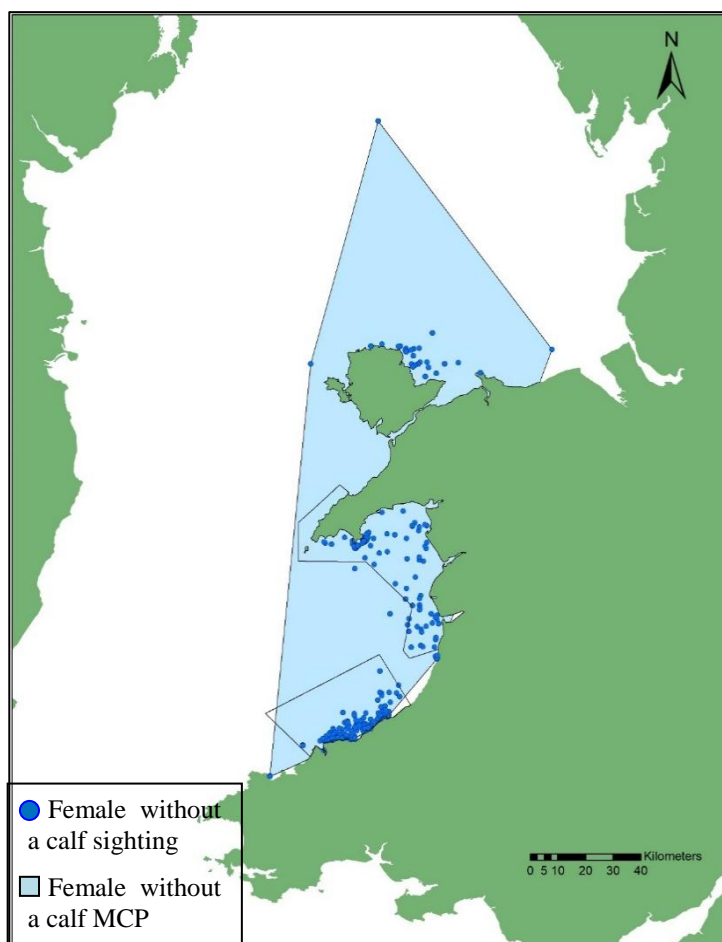


Figure 15 - MCP of females without calves sightings. Each dot corresponds to a single sighting of a female dolphin when she does not have a calf.

Table 5 –95% and 50% KDE areas for sightings of female dolphins with and without calves as well as the overlap between the two groups

<i>Method</i>	<i>With calves</i>	<i>Without calves</i>	<i>Overlap</i>
<i>KDE 95% (km<sup>2</sup>)</i>	1250,90	1987,60	1162,24
<i>KDE 50% (km<sup>2</sup>)</i>	62,56	137,68	61,60

The percentage of overlap for females with calves was 92.9% (95% KDE) and 98.5% (50% KDE). For females without calves it was 58.5% (95% KDE) and 44.7% (50% KDE).

### 3.5. Water depth

The average water depth where each group occurs is depicted in table 6 as well as the standard deviations obtained and the standard errors calculated for each group.

The map obtained illustrating the depth of the study area is located in Appendix II (Fig. 2.1).

Table 6 –Average depths where each group of dolphins occurs, with the respective standard deviations and calculated standard errors.

<i>Groups</i>	<i>Average Depth (m)</i>	<i>Standard deviation</i>	<i>Standard Error</i>
<i>Females</i>	-19,56	9,10	0,24
<i>Males</i>	-19,09	8,56	0,38
<i>Summer</i>	-18,42	9,36	0,17
<i>Winter</i>	-26,61	15,88	0,49
<i>Well marked</i>	-20,55	10,90	0,24
<i>Non-marked</i>	-20,80	10,09	0,46
<i>With calves</i>	-20,24	9,42	0,40
<i>Without calves</i>	-20,72	10,20	0,43

## 4. DISCUSSION

The present study has determined the home range of the semi-resident population of bottlenose dolphins in Cardigan Bay. As previously stated, some of these animals spend the entirety of their time in the Cardigan Bay (CB) area. However, many individuals have been seen outside the bay at some point around the years (Feingold and Evans, 2014a; Lohrengel and Evans, 2015). Taking this into account, I have decided to include the sightings from the north coast of Anglesey, Liverpool Bay and the Isle of Man, in order to determine the real extent of these dolphin's home range, including locations outside the study area. These animals inhabit a specially changeable habitat due to the increasing anthropogenic disturbance, hence all data available must be used in the efforts to improve the conservation measures for this population.

### 4.1. *Females vs Males*

Regarding the Minimum Convex Polygon comparison between females and males of the population, the greater area of MCP for the males was mostly caused by a few sightings of male dolphins between north Anglesey and the Liverpool Bay, as visible in figure 9. Further information is required in order to determine if only males are present in the area or if these sightings correspond to an uncommon occurrence.

In respect to the core area and home range estimation, despite males having larger areas, these differences were not high enough to be significant, as the percentage of overlap is similar for both groups. A percentage of overlap of 69.5% means that the area of overlap constitutes 69.5% of the male's total home range while the females' area of overlap corresponded to 73% of their total mean home range area.

Thus, despite the slight difference in home range areas, males and females do not seem to use different areas, both inside and outside the bay. These results are in accordance with a previous masters thesis study on the relationship between reproductive success and home range (Baylis, 2013).

The number of females and males was not proportionate in this study, as fewer males were used (16 males and 55 females). As previously stated, possible males and females were excluded from this comparison. This marked difference in number of

individuals used was a result, as stated in Feingold and Evans (2014a) of the difficulty in gender determination of male dolphins. The genital area is not often seen and females are easier to identify when they are seen with their calves.

In order to attain better data, gender determination must be improved. As suggested by Feingold and Evans (2014a), genetic sampling would contribute to the increase in information regarding the population studied.

#### *4.2. Summer vs Winter*

The greater MCP area for the winter sightings suggest that the population is much more dispersed between November 1<sup>st</sup> and March 31<sup>st</sup>. As seen in figure 10, the summer sightings were mostly concentrated in Cardigan Bay, with a few dolphins spotted around Anglesey and two sightings in the Liverpool Bay area. The absence of sightings at the Isle of Man also contributes to the lower MCP area determined.

Moreover, the overlap between the winter and summer MCPs was much greater for the summer locations than the winter (79.3% for summer and 62.1% for winter), meaning the area of overlap makes up 79% of the summer area and only 62% of the winter area.

Concerning the home range estimations, as seen in figure 1.3 (Appendix I), the summer mean home range is located mostly in both SACs and in north Anglesey. The core area is located in the coastal area of Cardigan Bay SAC. On the contrary, the winter home range is more disperse, with a lower presence in the Cardigan bay area and greater dolphin concentrations around Anglesey, near Liverpool Bay and at the Isle of Man. The winter core areas were mostly at the northern coast of Anglesey and, on a lower level, at the Cardigan Bay SAC. The presence of bottlenose dolphins in these areas is in line with previous works. Feingold and Evans (2014a) and Lohrengel and Evans (2015) have mentioned the presence of individuals from the CB area at the previously mentioned areas during the winter time, as shown in this study, as well as during the summer. The data used for this study, however did not contain summer sightings at such locations. This may be due to the fact that only dolphins sighted both during the winter and the summer were selected or due to the low coverage of the northern areas.

The mean home range is greater for the summer sightings, as there are more individuals that occupy the whole bay, in opposition to the winter home ranges, where the animals are mostly concentrated around the northern coast of Anglesey and a few animals are scattered between the two Special Areas of Conservation and the Isle of Man. The greater concentration of dolphins around Anglesey, however, leads to a slightly greater core area, as the summer core area is only found at the coastal area of the Cardigan Bay SAC. The overlap in core areas was extremely low but similar for both groups, meaning the majority of the animals spend the year in completely different locations: winter in the north and summer in the south.

Despite demonstrating a clear difference between summer and winter sightings, additional data is necessary, especially in the winter time and at the northern areas outside Cardigan Bay, as surveys were mostly conducted in the summer and at the CB SAC area.

#### *4.3. Well marked vs Non-marked*

As the percentage overlap for the non-marked MCP corresponds to the entirety of the area we can determine that there is no difference in distribution of non-marked and well marked animals, as both well-marked and non-marked animals were sighted in the exact same places where the areas overlap. However, as the overlap only corresponds to less than half of the well marked MCP area (46,8%), these dolphins can be found across a much greater area.

The home range and core area are in line with the MCPs obtained, with slight insignificant variations, with similar percentage overlaps and similar areas for both, only smaller for the non-marked animals.

The fact that well-marked animals have a greater estimated area does not mean they are greater in numbers or expand in greater areas. Well-marked dolphins are much easier to identify and most photographs taken will lead to a correct identification, even if the photograph does not have excellent quality, whereas a non-marked dorsal fin is much harder to use as an identifiable feature. Using non-marked unidentifiable dorsal fins is even discouraged for population size estimations (Würsig and Jefferson, 1990).

All non-marked dolphins used in this study were positively identified, through other distinct features, such as dorsal fin shape, distinctive markings in their body or even particular pigmentations patterns unique to the individuals.

The lower number of non-marked animals with lower home ranges derives from the low level of certainty from the identification of these dolphins. At the SWF, a greater number of marked individuals were positively identified than un-marked individuals during a portion of the years used at this study (Lohrengel and Evans, 2015).

Though there has been an improvement in technology in relation to photographic equipment, in order to obtain better identification features for non-marked dolphins, greater improvements must be attained in order to get better quality photographs. Other equipment, as drone footage and better quality underwater video cameras, would be useful for spotting more defining features in the body of unmarked individuals.

#### *4.4. Females with calves vs Females without calves*

As seen previously, the MCP percentage overlap for females with calves was approximately 99.5% whereas the females without calves overlap was 56.8%. As represented in figures 14 and 15, the females with calves were sighted in locations much closer to shore and more concentrated at the two Cardigan Bay SACs, with a few females being spotted at the northern coast of Anglesey, whereas during the years without a calf, females were also seen at Liverpool Bay and the Isle of Man.

When observing the home range and core area estimations, the females with calves had an almost total overlap while the overlap for females without calves was around 50% for both 95% and 50% KDE, which indicates that the females with calves do not seek different areas than the ones occupied by other females dolphins without calves. Instead, females without calves tend to spread further away offshore, occupying the whole bay area, while females with calves tend to stay closer to shore at more sheltered locations. These locations may be more attractive to mothers, providing the opportunity to forage more quickly, leaving the calves alone for less time as well as allowing the calves to start learning how to catch prey (Feingold and Evans, 2014a).

The northern areas (Liverpool Bay and Isle of Man) were not represented, as the number of encounters was not sufficient for establishing this area as important for these animals.

The females with calves had a much smaller home range and core areas than the females without calves, which corresponds to the results obtained by Baylis (2013) that has stated that females with greater reproductive success tend to have smaller home ranges and core areas.

The Cardigan Bay area is an important nursery area for the bottlenose dolphins (Lohrengel and Evans, 2015). The presence of mothers and calves at the Pen Llŷn a'r Sarnau SAC suggests this area is also used as a nursery in opposition to being exclusively used for socialization and mating, which further strengthens the hypothesis mentioned at Feingold and Evans (2014a).

Further studies must be conducted at the northern coast of Anglesey, as several females with calves encounters have occurred at this location. Possible conservation measures may be applied in order to protect the areas if they are in fact important for this species. Also, surveys must be also done at the northern locations (Liverpool Bay and Isle of Man), in order to determine if this is in fact an area with a regular presence of individuals from this population.

#### *4.5. Water depth*

Most groups had similar depth ranges with similar standard deviations. The only noticeable difference was the winter depth, of -26.6m. The variation was not significant, however, as the standard deviation value was also greater for this group (Table 6).

The greater depth is in line with the fact that most dolphins are located outside the Cardigan Bay Area during the winter time. As some areas surrounding Anglesey are slightly deeper than the CB area, the depth would be slightly higher than at the summer home range locations.

Studies conducted on other resident populations show a variable array of depths for this species. The resident population of bottlenose dolphins in Sarasota Bay (Florida) prefer sites with a depth lower than 3 meters whereas the populations of the

Moray Firth (Scotland) and Shannon estuary (Ireland) prefer deep waters with steep slopes (Wilson *et al.*, 1997; Ingram and Rogan, 2002).

Ingram and Rogan (2002) have determined that the depth preferred by the Shannon Estuary resident bottlenose dolphin population was of 30m to 50m, slightly greater than the depths determined in this study. However, this preference was correlated to the greater prey availability. Further studies must be conducted in order to determine if prey availability in the Cardigan Bay area corresponds to the depths attained in this study or if there are other factors that contribute for the lower depth preference.

#### *4.6. Data gathering*

The processing of acquiring data is extremely complex in cetacean research as, unlike terrestrial animals, cetaceans are hidden beneath the surface most of the time, only becoming visible for a few moments each time. Consequently, some errors and restrictions are bound to occur.

Firstly, boat traffic has been known to have an impact on behaviour and distribution of bottlenose dolphins, especially with a great number of vessels (Feingold and Evans, 2014a; Lohrengel and Evans, 2015). When aboard the whale watching vessels, this influence is greater, namely at the New Quay bay, where boat density is high mainly in the summer months. This disturbance, though in a smaller scale, also extends to the presence of the research vessels. It is, however, not possible to study these animals without some degree of disturbance. Nevertheless, researchers always seek to keep the impact to a minimum.

Some errors in the dataset were deleted, such as a dolphin encounter near Birmingham (central England). The volunteer's lack of experience may lead to errors committed during data collection or at the data treatment. The most detectable errors can be excluded, yet other less perceptible errors are often included in research data. On the other hand, these errors are rare and volunteers gain experience doing consecutive surveys.

Additionally, sampling during the years analysed was not even for all locations, as coverage of the Cardigan Bay SAC was higher than for all other locations, since surveys outside this Special Area of Conservation only started in 2011 (Feingold and Evans, 2014a; Lohrengel and Evans, 2015). The offshore area was also under-surveyed when

in comparison with the coastal area sampled. Time and money constraints as well as the poor weather conditions typical of this area contributed to the lower offshore coverage (Lohrengel and Evans, 2015).

Using opportunistic platforms, namely the land-watches and the whale watching trips, the effort was most frequently concentrated in the New Quay bay and the coastal area of the Cardigan Bay SAC. However, these data gathering methods were the most frequently employed as they are a highly cost effective way to record dolphin sightings. One consequence of using these means frequently to acquire data is the overestimation of the core areas in almost all groups. In order to more accurately assess unbiased core areas, it is necessary to conduct more surveys at the other areas and less at the New Quay bay and the near shore area of the Cardigan Bay SAC.

With the population's decrease in numbers in Cardigan Bay and the apparent shift in the individual's locations (Lohrengel and Evans, 2015), it is imperative to increase survey coverage in other areas of Cardigan Bay as well as the other areas where encounters occurred (north Anglesey, Liverpool Bay, Isle of Man).

Prey availability also seems to be decreasing (Feingold and Evans, 2014a) and, as a result, measures that prevent overfishing should be implemented. Vessel speed and driver's behaviour should also be monitored by the authorities, in order to insure a lower level of disturbance towards the animals, as sometimes excesses may be committed, often out of ignorance for the established rules.

## 5. CONCLUSION

The present study aimed to determine the home range of the bottlenose dolphins population of Cardigan Bay, in Wales. By comparing different groups, according to certain characteristics (gender, time of sighting, degree of dorsal fin markings and presence of offspring), it is possible to assess the areas that are more important to each group or to the entire population and ascertain which measures can be applied in order to decrease the impact exerted in these animals.

MCP (Minimum Convex Polygon), the total area where the animals were sighted and KDE (Kernel Density Estimators), the locations the animals use more, were determined for each group and the pairs were compared.

Regarding the comparison between females and males, the total area, mean home range and core area were slightly higher for males. The overlap areas were also similar. As a result there were no significant differences in spatial distribution in both sexes. The greater limitation was the greater number of females relatively to the number of males studied. Gender determination is hard to achieve for males when the genital area is not visible during the observation. The presence of calves near an individual several times ensures an easier identification of female dolphins, but there is no such way to determine when a dolphin is male.

When comparing sightings between April 1st to October 31st (summer) and November 1st to March 31st (winter), the locations obtained were quite different. The summer mean home range is located mostly in both SACs and in north Anglesey. The core area is located in the coastal area of Cardigan Bay SAC. On the contrary, the winter home range is more dispersed, with a lower presence in the Cardigan Bay area and greater dolphin concentrations around Anglesey, near Liverpool Bay and at the Isle of Man. The winter core areas were located mostly at the northern coast of Anglesey and, on a lower level, at the Cardigan Bay SAC. The lack of constant survey coverage of the locations outside the Cardigan Bay area and, to an extent, outside the Cardigan Bay SAC limit the number of sightings used for this study. More surveys would probably lead to a much more reliable conclusion regarding these two groups.

Animals with well marked dorsal fins were contrasted with dolphins without a marked dorsal fin. The areas overlapped, with further areas occupied by well marked individuals. However, this does not mean they are greater in numbers or expand in

greater areas. Well-marked animals are much easier to identify, whereas a non-marked dorsal fin is much harder to use as an identifiable feature. The areas estimated were the same but the well marked dolphins had a greater area since these animals are more easily identifiable.

Concerning the females with calves vs females without calves, the females with calves do not seek different areas than the ones occupied by other females dolphins without calves. Instead, females without calves tend to spread further away offshore, occupying the whole bay area, while females with calves tend to stay closer to shore at more sheltered locations. This comparison was limited by the sometimes low number of sightings of mothers and calves as, in some years, encounters were not enough to determine if the female had a calf or not.

When determining the mean depth for each group, most groups had similar depth ranges with similar standard deviations. The only noticeable difference was the winter depth, however the variation was not significant. The greater depth is in line with the fact that most dolphins are located outside the Cardigan Bay Area during the winter time. As some areas surrounding Anglesey are slightly deeper than the CB area, the depth would be slightly higher than at the summer home range locations.

The core areas were mostly located at the coastal area of the Cardigan Bay SAC, as both land-based surveys and whale watching trips were conducted exclusively at this location. The effort regarding all the surveys conducted throughout the years was, as a result, much more concentrated around this area than all the remaining locations. In addition, due to several constraints, surveys were mostly conducted both during the summer time as well as inshore.

Despite all the limitations, conclusions were drawn regarding the population studied.

Regarding the similarity between females and males' home range, these results are similar to a previous masters thesis study on the relationship between reproductive success and home range (Baylis, 2013), conducted in the Cardigan Bay dolphins.

The presence of individuals around Anglesey, near Liverpool Bay and at the Isle of Man is in line with previous works. Feingold and Evans (2014a) and Lohrengel and Evans (2015) have mentioned the presence of the Cardigan Bay dolphins in these areas as well as the conclusion that most animals spend the winter in the north and summer in the south.

The home range estimation regarding the presence of females and calves at the Pen Llyn a'r Sarnau SAC is in line with a hypothesis from a previous work (Feingold and Evans, 2014a) that stated that this Special Area of Conservation was not only used for socialization and mating, but also as a nursery.

The results obtained in this comparison correspond to the results found by Baylis (2013) that has stated that females with greater reproductive success tend to have smaller home ranges and core areas.

The average depths determined were in opposition with results found in Sarasota Bay (Florida), where preferred depths were lower than 3 meters, however were closer to the average 30-50meters found at the Shannon Estuary (Ireland) (Ingram and Rogan, 2002).

As suggested by Feingold and Evans (2014a), genetic sampling would contribute to the increase in information regarding the population studied, mainly for gender determination. The use of underwater cameras would also be an important tool to both determine gender and, when close enough, determine other ways to identify an individual, particularly when the dorsal fin does not present visible marks or nicks.

In addition, further surveys outside the Cardigan Bay SAC are required, mainly around Anglesey, as this location seems an important place for dolphin population. If this is the case, further protection measures are required for this region and possibly establishing a Special Area of Conservation, particularly for the north coast of this island. Other areas would also require further coverage, as Liverpool Bay, the Isle of Man and the Pen Llyn SAC, both during the winter and summer and specially the offshore areas of the two SACs. Furthermore, since dolphins were encountered outside both Special Areas of Conservation, other transects outside these areas could prove beneficial to estimating the real range of these individuals.

Furthermore, further studies must be conducted on prey availability in the Cardigan Bay area, since prey seems to be decreasing (Lohrengel and Evans, 2015).

This study is intended to be continued so other discoveries regarding this population can lead to its increase in numbers and habitat quality improvement.

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## 7. APPENDICES

### 7.1. Appendix I - Home range maps of all the groups.

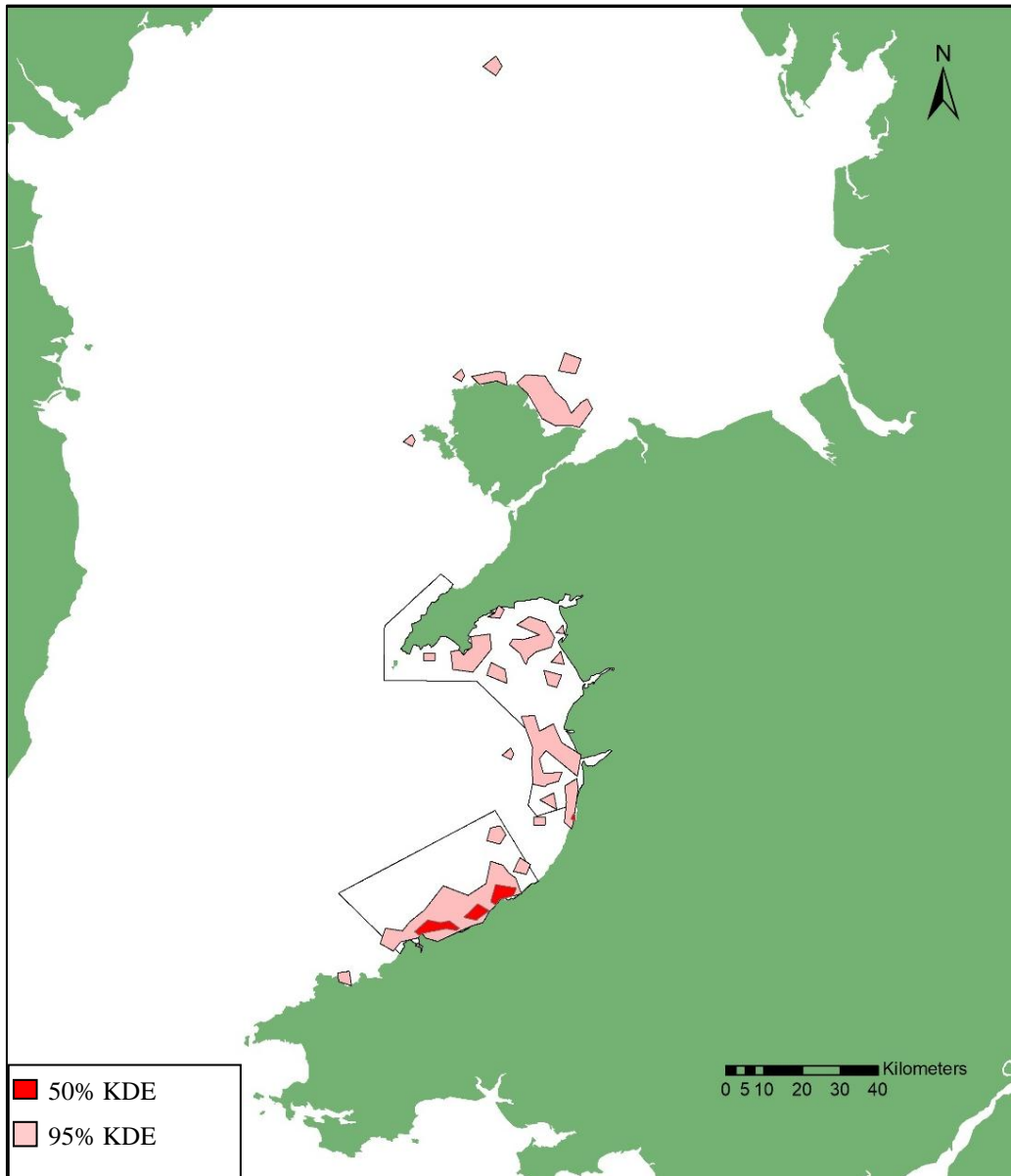


Figure 1.1 – Home range of all the females. The 95% KDE (mean home range) is represented in pink whereas the 50% KDE (core area) is represented in red.

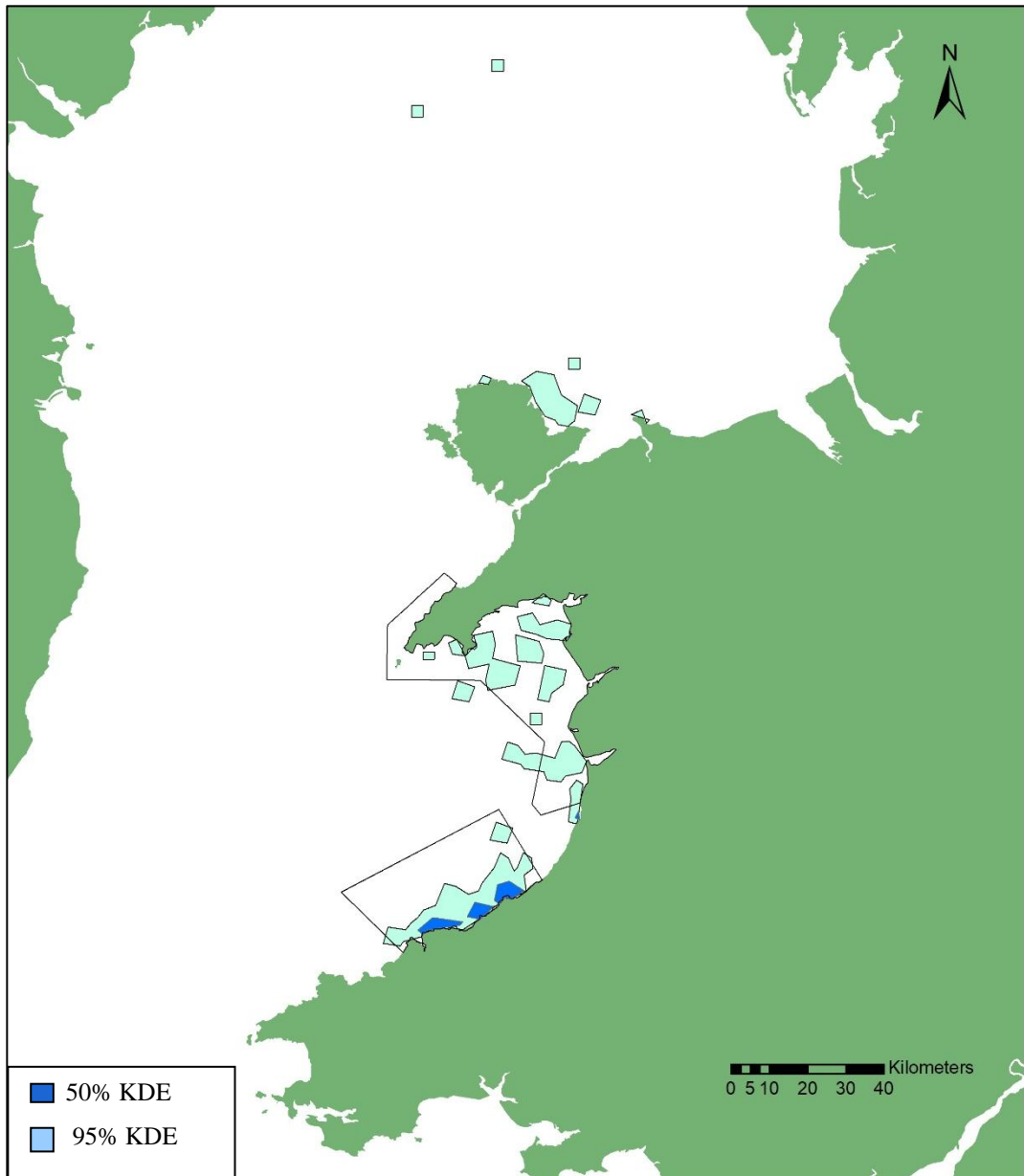


Figure 1.2 – Home range of all the males. The 95% KDE (mean home range) is represented in light blue whereas the 50% KDE (core area) is represented in dark blue.

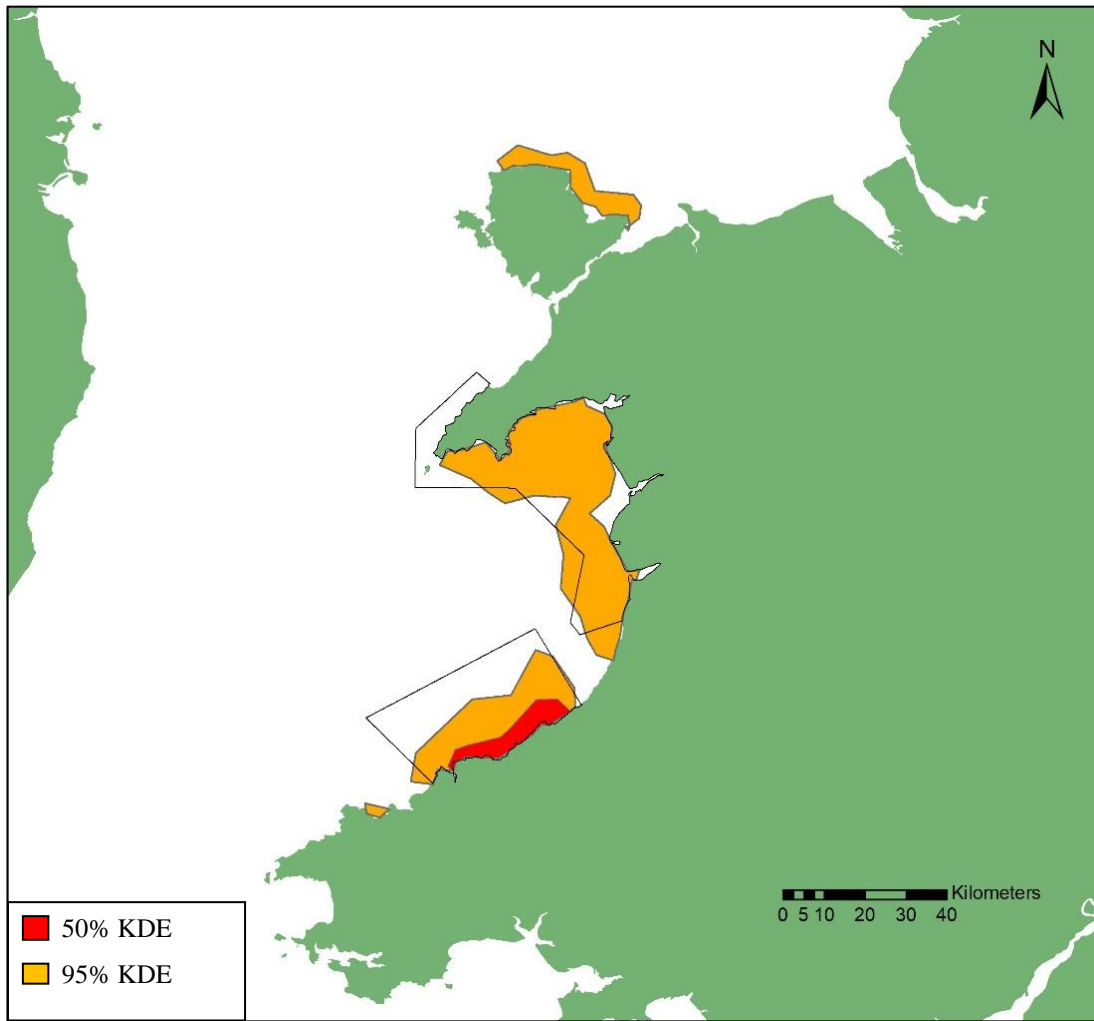


Figure 1.3 – Home range of the dolphins sighted in the summer (between April 1st and October 31st). The 95% KDE (mean home range) is represented in orange whereas the 50% KDE (core area) is represented in red.

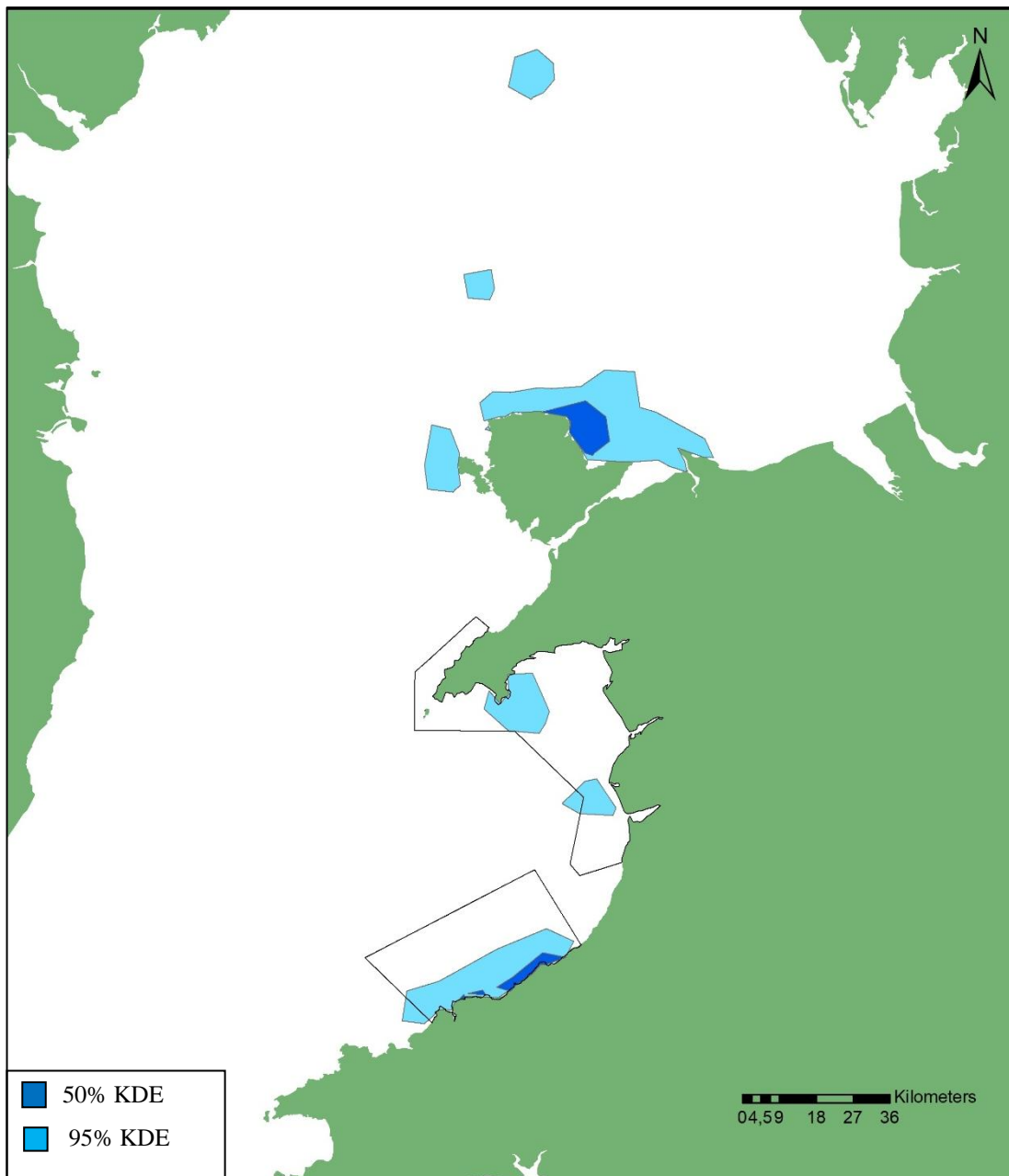


Figure 1.4 – Home range of the dolphins sighted in the winter (between November 1st and March 31st). The 95% KDE (mean home range) is represented in light blue whereas the 50% KDE (core area) is represented in dark blue.

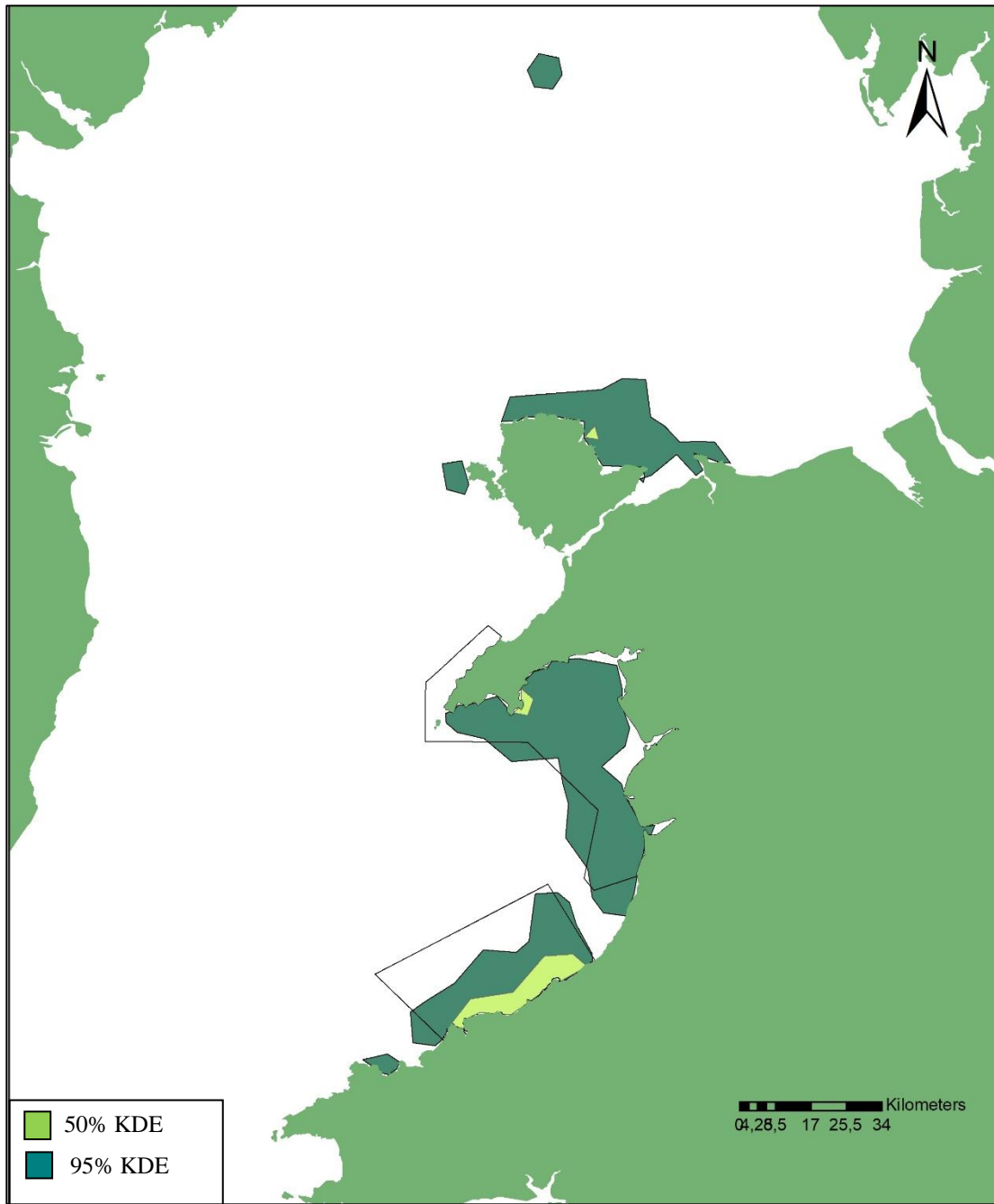


Figure 1.5 – Home range of the well-marked dolphins. The 95% KDE (mean home range) is represented in dark green whereas the 50% KDE (core area) is represented in light green.

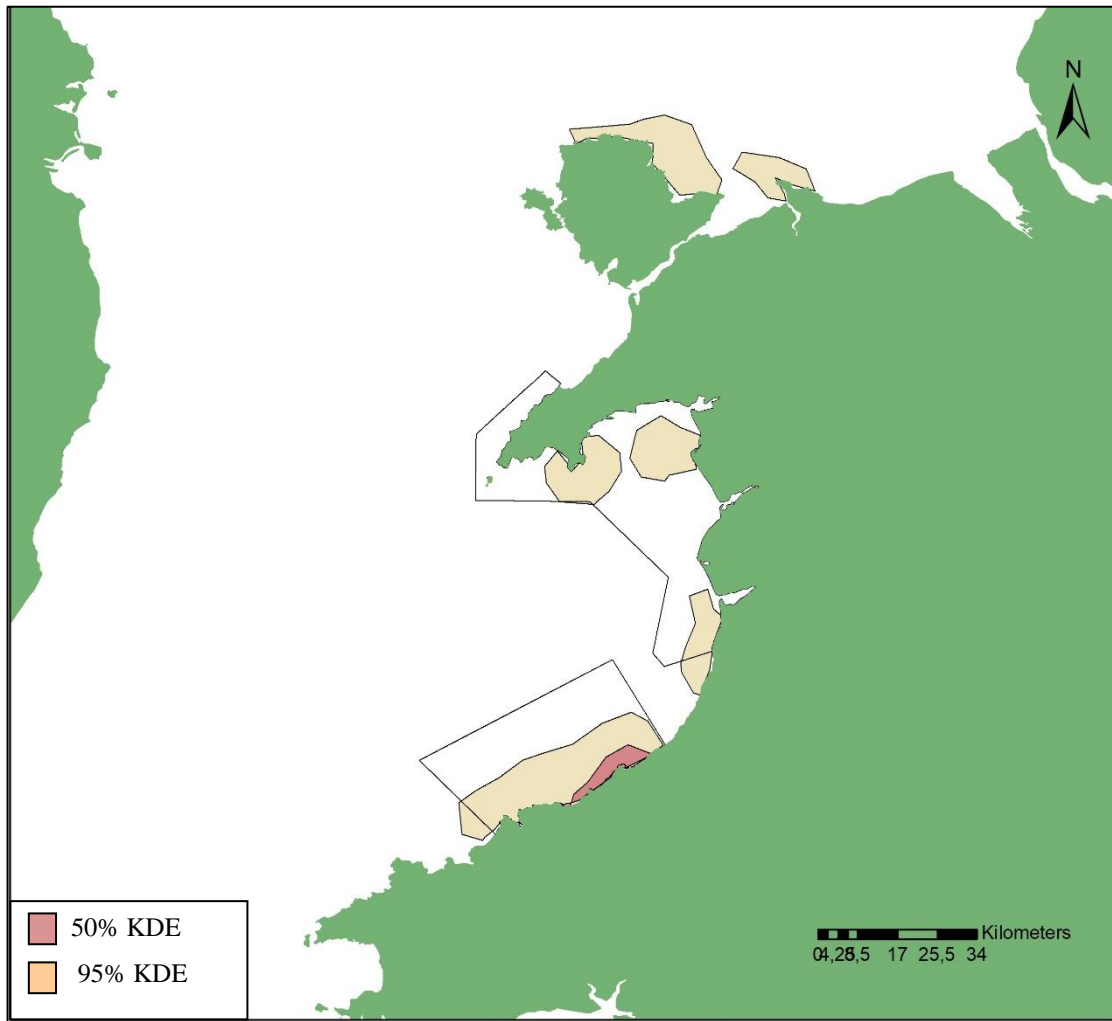


Figure 1.6 – Home range of the non-marked dolphins. The 95% KDE (mean home range) is represented in tan whereas the 50% KDE (core area) is represented in burgundy.

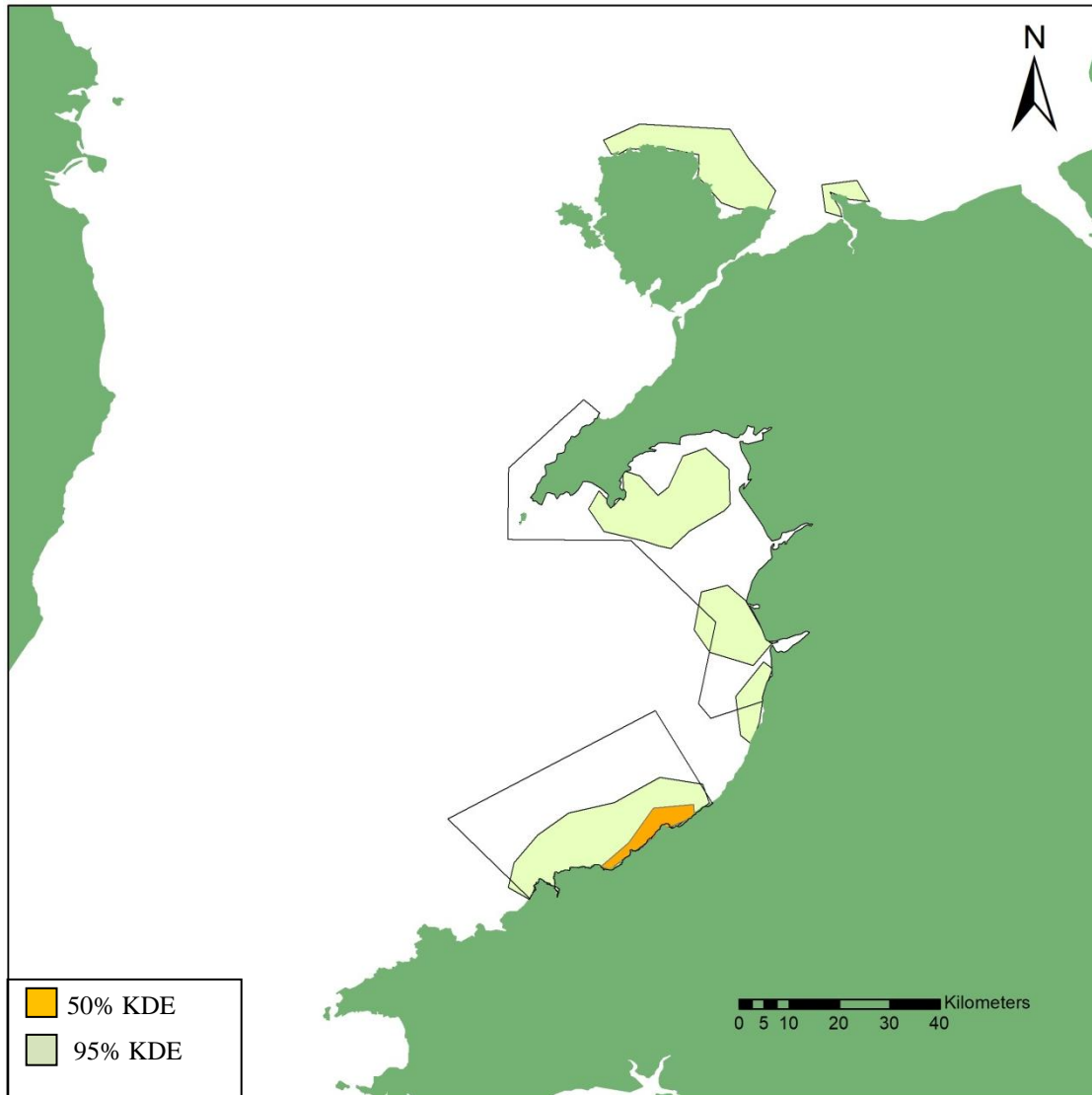


Figure 1.7 – Home range of the female dolphins sighted in the years they were nursing their calves. The 95% KDE (mean home range) is represented in light green whereas the 50% KDE (core area) is represented in orange.

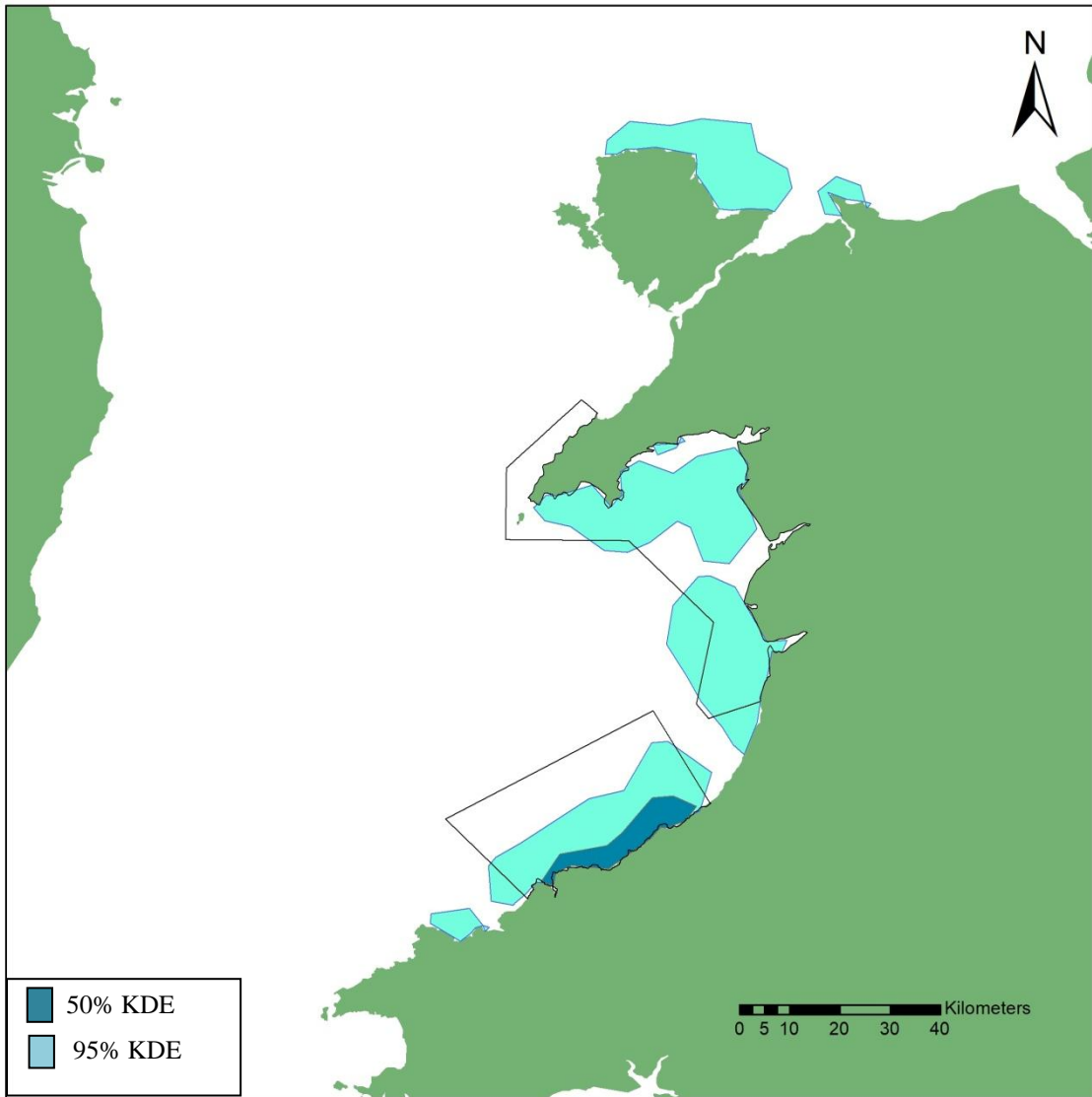


Figure 1.8 – Home range of the female dolphins sighted in the years they did not have calves. The 95% KDE (mean home range) is represented in light blue whereas the 50% KDE (core area) is represented in dark blue.

7.2. Appendix II - Map of the water depth in the study area.

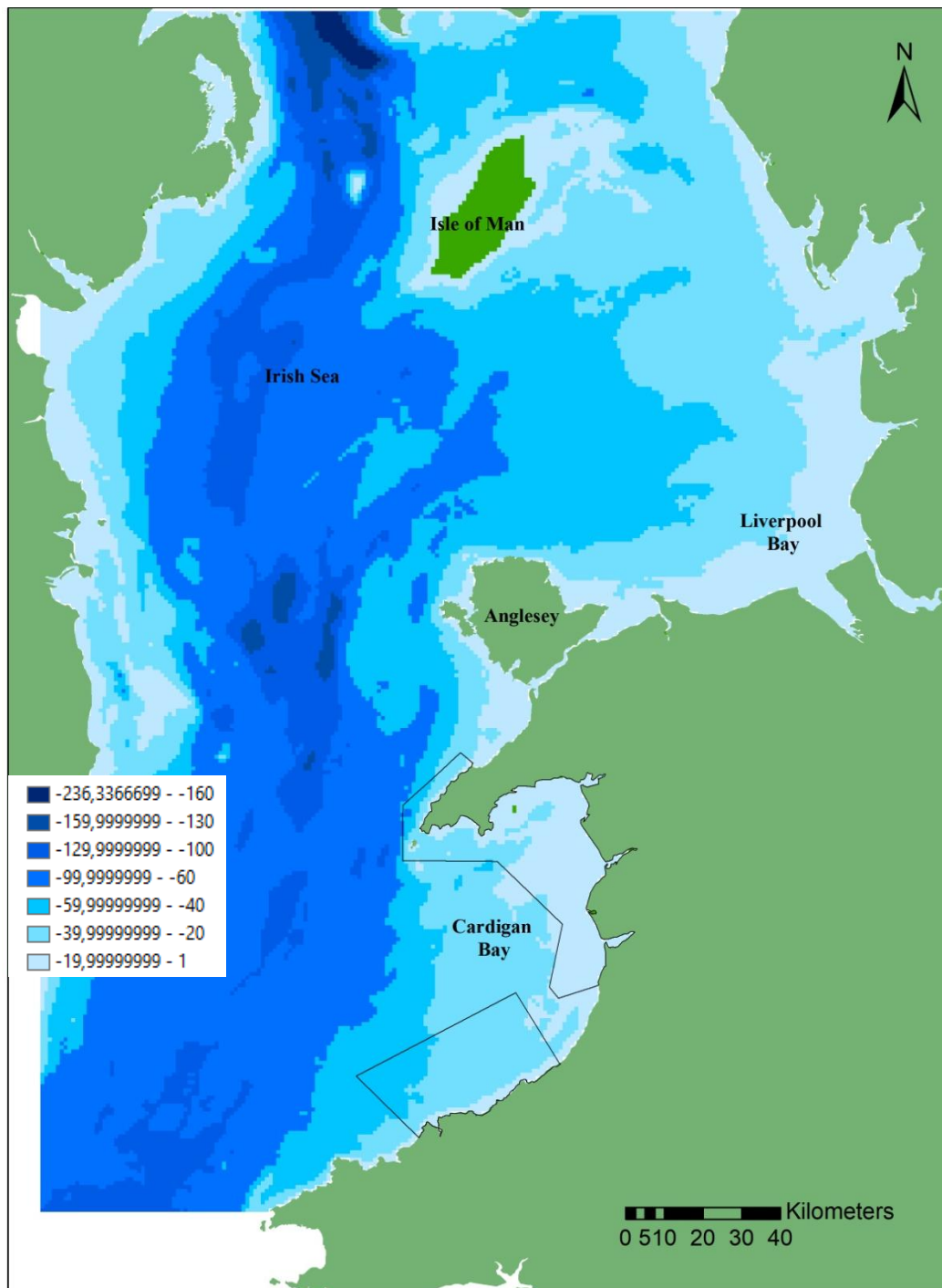


Figure 2.1 – Map of the study area depicting the water depth, in meters.

7.3. Appendix III - Effort form for line transect surveys

Boat: \_\_\_\_\_ Person responsible for data \_\_\_\_\_ Crew: \_\_\_\_\_ Page \_\_\_ of \_\_\_

Date: \_\_\_\_\_ Time start \_\_\_\_\_ Time end \_\_\_\_\_ GMT or BST \_\_\_\_\_ Type of trip: LT  NLT

Time hh:mm	Lat. (min.sec)	Long. (min.sec)	Transect	Leg num.	Tran. point	Boat act.	Speed knots	Course Deg.	Glare degrees	Effort type		Precipitation				Visibility (km)	Sea state		Sigh. ref.	Comments
										Type	Int.	N	R	I	L		B	S		
	N52°	W004°		S C E					0 1 2 3	CW LT	DS ID	N F	R C	I C	L H	<1 6-10 >10				
	N52°	W004°		S C E					0 1 2 3	CW LT	DS ID	N F	R C	I C	L H	<1 6-10 >10				
	N52°	W004°		S C E					0 1 2 3	CW LT	DS ID	N F	R C	I C	L H	<1 6-10 >10				
	N52°	W004°		S C E					0 1 2 3	CW LT	DS ID	N F	R C	I C	L H	<1 6-10 >10				
	N52°	W004°		S C E					0 1 2 3	CW LT	DS ID	N F	R C	I C	L H	<1 6-10 >10				
	N52°	W004°		S C E					0 1 2 3	CW LT	DS ID	N F	R C	I C	L H	<1 6-10 >10				

**Type of trip** LT = line-transect surveys, NLT = other than line-transect surveys; **Leg** S=start, C=continuation, E=end; **Boat activity** NB=none, YA=yatch or sailing, RB=kayak, JS=jet ski, SB=speed boat, MB=motorboat, FI=fishing boat, Fe=ferry, LS=>30m; **Glare** 0=no glare, 1=mild, minimal impact on sightability, 2=moderate, 3=severe **Effort type** CW=casual watch, DS=dedicated search, LT=line-transect, ID=photoid; **Precipitation type** N=none, R=rain, F=fog, I=intermittent, C=continuous, L=light, M=moderate, H=heavy; **Sea state** B=sea state in Beaufort scale, S=swell presence and height (L= <1m, M= ≥1 and <2, H ≥ 2m) Entered into PC  by \_\_\_\_\_  
Checked by \_\_\_\_\_

Figure 3.1 – Effort form to fill in when on line transect surveys. Every line must be recorded every 15 minutes in the absence of bottlenose dolphins and every 3 minutes when an encounter is happening. Source: Lohrengel and Evans, 2015.