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MARK RECAPTURE ABUNDANCE ESTIMATES AND DISTRIBUTION OF BOTTLENOSE DOLPHINS (TURSIOPS TRUNCATUS) USING THE SOUTHERN COASTLINE OF THE OUTER SOUTHERN MORAY FIRTH

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"Society is defined not only by what it creates, but what it refuses to destroy."

-John Sawhill

Table of Contents

List of Figures

List of Tables

1.0 Acknowledgments

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2.0 Abstract

Within the inshore, coastal waters of the Moray Firth in northeast Scotland, bottlenose dolphins (*Tursiops truncatus)* occur in high numbers during the summer and autumnal months. The southern coastline of the outer firth supports a large percentage of the approximate 200 individuals estimated in northeast Scottish waters at this time and is thought to provide an important nursery/calving area for the population. Using individual sightings data collected systematically between May and October 2006 to 2014 inclusive, the fine-scale inter-annual and seasonal changes in the abundance of bottlenose dolphins inhabiting this region were investigated. Dedicated photo-identification data was examined to identify the inter-annual changes in abundance, occurrence, and site fidelity. The Program MARK and embedded analytical tool, CAPTURE, was used for capture-recapture analysis, providing annual population estimates for the animals utilizing the outer southern Moray Firth. Closed population individual sightings history datatype inputs were ran through a Chao time-dependent heterogeneity model (M_{th}) producing annual population estimates of two separate dataset groups, namely, 'well-marked individuals' and 'all marked individuals'. Inter-seasonal and inter-annual temporal and spatial distribution patterns were mapped and analysed. Results estimated a peak of 165 (95% *CI*: 121-177) recaptureable individuals, and 91 well-marked individuals using the southern

firth study area, accounting for over 70 percent of the estimated coastal North Sea bottlenose dolphin population. Distribution patterns indicated that individuals occupied all extents of the study area throughout the study period with trends in seasonal movement. Animal group size raged from 1 to 70 individuals with an average of approximately 22 individuals. The present results support the notion that the outer southern Moray Firth provides an important breeding and foraging habitat for this northeast Scottish bottlenose community. Results satisfied the overall aim of this project by providing a numerical estimate of the bottlenose dolphins utilizing the outer southern Moray Firth and what proportion of the entire Moray Firth/North Sea population is occupying this area.

3.0 Introduction

Marine habitats are spatially and temporally heterogeneous resulting in non-random distribution of their inhabitants. Such fluctuations may be particularly important for marine mammal predators such as cetaceans (whales, dolphins, and porpoises), in terms of their spatio-temporal occurrence, movements, social associations, and foraging strategies. The success of efforts to conserve coastally-occurring cetacean populations therefore depends upon a robust understanding of the factors influencing their respective distribution and habitat use over spatial and temporal scales, along with a solid foundation of individual life history patterns, population structure and dynamics.

3.1 The Bottlenose Dolphin

The bottlenose dolphin (*Tursiops truncatus,* Montagu 1821) is a culturally and environmentally iconic species occupying oceanic and coastal habitats worldwide (Wells & Scott, 1999). These habitats come into direct contact with anthropogenic activities, which can lead to potential disturbances of viable wildlife populations. As a common coastal-based marine mammal, the bottlenose dolphin is accordingly subject to human pressures that can adversely affect their distribution and abundance (Louis, 2015). As such, effective environmental protection and ongoing, quality management of critical areas used by the species is essential for their conservation. In order to minimize

disturbances to coastal bottlenose dolphin populations, it is intrinsically important to identify and quantify current and historical patterns of abundance, movement and distribution parameters (Cheney *et al.*, 2014).

As one of the most well-known marine animals, the bottlenose dolphin has a worldwide cosmopolitan distribution ranging from high to low latitudes. The Bottlenose dolphin is a member of the oceanic dolphin family, Delphinidae. With a light grey to black colouration, a countershaded belly, robust body and a short, thick beak, individual weights range from 135 to 635 kilograms with lengths ranging from 1.8 to 4 metres. The lifespan is anywhere from 40 to 50 years. Females are slightly smaller than males and may also live longer. The gestation period is 12 months long. Weaning takes place around 18 to 20 months. Sexual maturity differs between sexes at 5 to 13 years of age for females and 9 to 14 years for males. Calving occurs every 3 to 6 years on average. Bottlenose dolphins are highly social animals commonly found in groups ranging from 2 to 15 individuals (NOAA, 2015). Abundance varies from very small communities to very large communities of thousands of individuals (Read *et al.*, 2003). Communities of individuals are most commonly distributed in relation to foraging resources.

The bottlenose dolphin has a specialized behaviour unique to only a few mammals known as echolocation. This behaviour is used to locate and capture prey as 'clicks' are produced/processed from a specialized brain structure known as the melon. Other feeding strategies include 'bubble netting' and 'fish whacking'. As generalists, they feed on prey items that are endemic to their habitat. Hunting strategies are employed both individually and cooperatively. Their diet primarily consists of invertebrates, cephalopods, and fish. A highly mobile lifestyle allows these animals to maximize foraging success (NOAA, 2015). Prey species are abundant along the United Kingdom coastlines providing a thriving habitat for cetacean species, such as bottlenose dolphins.

Historical literature suggests that bottlenose dolphin presence in the United Kingdom was relatively rare until the late 20th century and were seen far less than other species in this area such as the harbour porpoise (*Phocoena phocoena*) (Cheney *et al.,* 2013).

Contemporarily, bottlenose dolphins are observed regularly throughout the coastal waters of the British Isles and are perhaps the best known and most studied of all the cetacean species found in UK coastal waters. The population that inhabits the Moray Firth in north-east Scotland (57º400N 3º300W), with a current estimate of 195 animals (Cheney *et al.,* 2013), is one of only two well-studied resident populations of this species in the UK (Wilson *et al.*, 1997), the other being in Cardigan Bay, Wales (Bristow *et al.*, 2001; Bristow & Rees, 2001), and is the only population in the North Sea.

3.2 The Moray Firth, Scotland

The Moray Firth is a 5,230 square kilometre sea embayment on the north-east coast of Scotland, made up of four smaller firths with several freshwater river inputs (Figure 1) (Harding-Hill, 1993). The Moray Firth is Scotland's largest firth with more than 800 kilometres of coastline. The economy of this area thrives on marine environment tourism, fishing, and the oil and gas industries.

Wildlife is abundant, as the Moray Firth has a diverse array of coastal landscapes affording protection in a number of ways. For over 200 years the Moray Firth has been exploited as an important fishing area where demersal fish species such as haddock (*Melanogrammus aeglefinus*), cod (*Gadus morhua*), plaice (*Pleuronectes platessa*), and salmon (*Salmo salar*) and are present (Santos *et al.,* 2001*)*. Local fish species found in the stomach contents study by Santos *et al.* in 2001 included cod (*Gadus morhua),* saithe (*Pollachius virens*), whiting (*Merlangius merlangus*) at 77 % of prey weight, haddock (*Melanogrammus aeglefinus*) and salmon (*Salmo salar*). Prey weight of salmonids may be underestimated due to the friable structure of the bones. Evidence of salmon consumption is likely only to be seen in animals that have recently fed on salmon. Bottlenose dolphins have been observed using low frequency bray calls when feeding on salmonids. Specialized salmonid feeding behaviours indicate that salmonids

7

are an important prey species of bottlenose dolphins. As a productive salmon (*Salmo salar*) spawning area the Moray Firth provides an abundance of food for the dolphins utilising these waters (Butler *et al.,* 2008; Santos *et al.*, 2001)*.*

The Moray Firth is divided into two sections. The area to the west of a line drawn from Helmsdale on the northern coast to Lossiemouth on the southern coast is generally referred to as the 'inner' Moray Firth, whilst the area to the North and East of these designations is known as the 'outer' Moray Firth (Harding-Hill, 1993). Bottlenose dolphins are abundant in both the inner and outer sections of the Moray Firth.

Integrated datasets from multiple research sites provide a best current estimate of 195 animals for this east coast population (Cheney *et al.,* 2013), of which at least 65 sexually-mature females are presently recognised/alive (Robinson *et al.*, 2015). Cheney *et al.* (2014) results indicate that the wider population is stable or even increasing at this time, with a decline in numbers in the inner firth Special Area of Conservation (SAC) revealing evidence of habitat shifts in long-term trends in the overall population status. Female bottlenose dolphins are seen to range widely along the northeast coastline in earlier stages of young rearing (Quick *et al.*, 2014), but evidently favour the inner firth Special Area of Conservation (SAC) and adjoining outer southern Moray Firth study area where the highest number of individual exchanges occur (Culloch & Robinson, 2008; Cheney *et al.,* 2014). The outer southern Moray Firth is thought to provide important calving / nursery areas for this population (Robinson *et al.*, 2007; Culloch & Robinson, 2008) and long-term, mark-recapture studies in this region by the Cetacean Research & Rescue Unit (CRRU) from 1997 to 2014 have documented no less than 171 calves by 77 identified females recorded using this area to date (Robinson *et al.,* 2015).

3.3 Special Area of Conservation

3.3.1 European Union's Habitats Directive

Currently, bottlenose dolphins are listed under Annex II of the European Union's Habitats Directive, which requires the designation of Special Areas of Conservation (SACs) for their protection (Figure 1). Specific ranges of actions of the directive include:

1. Conservation of landscape features important for wildlife populations.
2. Protection of species listed under the annexes from damage, destruction or over-exploitation.
3. The surveillance of natural habitats and species.
4. Oversight and monitoring of non-native species introduction impacts on naturally occurring habitat and species.
5. Obligation to the most effective selection, designation and protection of a network of sites - special areas of conservation (SACs).

3.3.2 Site Selection

The rationale for site selection is guided by a specific process supported by principles used to guide the selection of the network of SACs in the UK.

The conservation status of a natural habitat is considered 'favourable' when the natural range is stable or increasing with a necessary long-term maintenance structure and function continuing to exist in the foreseeable future. A typical species conservation status is considered favourable when the species population dynamics data shows that the population is able to maintain itself on a long-term basis as a viable component of the natural habitat.

Article 3 of the Habitats Directive requires the establishment of a network sites across Europe will make a significant contribution to conserving the 189 identified habitat types and 788 species types listed under the first and second annexes of the directive.

Each SAC has a set of unique measures of implementation aiming to deliver the Habitats Directive conservation objectives in which satisfy the most favourable outcome.

Conservation measures must correspond to ecological requirements of Annex listed species of the site while avoiding deterioration or disturbance of the natural habitats and species. Generally, SAC boundaries drawn closely around the qualifying habitat type or habitats of listed species. Buffer zones have not been included as part of the SAC boundaries (JNCC, 2009).

3.3.3 Species Protection Management

By establishing a network of sites across the European Community, these designations are intended to protect rare, endangered or vulnerable habitats and species. In 1994, an area of the inner Moray Firth (Figure 1) was put forward as a candidate SAC (cSAC) (Council Directive 92/43/EEC). It was not until 2005 that the cSAC was officially designated as a SAC. However, additional research conducted before this time had clearly shown that the home range of the bottlenose dolphin population of interest extends much further than originally thought (Wilson *et al.*, 2004), throughout the larger, outer southern firth (Robinson *et al.*, 2007; Culloch and Robinson, 2008), along the Aberdeenshire coastline (Stockin *et al.*, 2006; Weir *et al.*, 2008) to Fife (Quick & Cheney, 2011) and even further south to Northumberland in northern England and beyond (Thompson *et al.*, 2011; Robinson *et al.*, 2012). Consequently, understanding the distribution and movements of this North Sea population in areas outside the SAC boundaries requires directed monitoring studies in these adjacent coastal waters.

The framework for the co-operative management of activities affecting the Moray Firth is provided by 'The Management Scheme for the Moray Firth Special Area of Conservation (SAC)'. Conservation Objectives have been outlined to achieve the establishment and maintenance of a viable population of bottlenose dolphins, while conserving the condition of subtidal sandbanks within the Moray Firth. In terms of marine ecosystem biodiversity contribution and socio-economic benefits, the bottlenose dolphin population is considered to be a valuable asset to the area. The presence of this top marine predator is considered to be a positive indicator of the status of the marine environment. Management objectives

that aim to improve the environment for this species will also benefit many other wildlife species. While boosting tourism, it is widely recognised that the presence of this species is also to be enjoyed by visitors as well as the local people (92/43/EEC).

The following conservation objectives of the European Community Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora (92/43/EEC), namely bottlenose dolphins, have been established, and will be maintained in the long term:

1. Population of the species (including range of genetic types where relevant) as a viable component of the site.
2. Distribution of the species within site.
3. Distribution and extent of habitats supporting the species.
4. Structure, function and supporting processes of habitats supporting the species.
5. No significant disturbance of the species.

Recently categorized as meeting required objectives as a 'favourable' habitat, the Moray Firth and other protected area designations may subsequently afford less protection than originally envisioned and recommended. Therefore, the potential for long-term mobility should be actively incorporated into such management schemes from the outset (Wilson *et al.*, 2004). It is recognised that site protection alone is largely inadequate for highly-mobile, wide-ranging animals (Parsons *et al.*, 2002), such as bottlenose dolphins, and hence the Directive affords further protection to individuals from core populations when outside current SAC boundaries.

Anthropogenic activities are increasing in the area outside of SAC designated boundaries including large-scale marine renewable energy construction projects planned in the upcoming years. Such activities have the potential to impact other marine mammals in the area including the resident bottlenose dolphin population of the Moray Firth. The acquisition of benchmark data outside of already protected areas

including abundance estimates and distribution is essential to the protection of the bottlenose dolphin communities that are subject to potential anthropogenic impacts (Louis, 2015).

3.4 Research

3.4.1 The Cetacean Rescue & Research Unit

Based in northeast Scotland the Cetacean Rescue & Research Unit (CRRU), formed in 1997, is a small non-profit research organisation dedicated to the welfare, conservation and protection of whales, dolphins, and porpoises (cetaceans) through scientific investigation, environmental education, and the provision of a 24 hour veterinary service for sick, injured and stranded individuals. Principal studies are focused on the coastal cetaceans frequenting the Moray Firth waters providing baseline data for the implementation of long-term management and conservation strategies in co-operation with universities, research institutions, and international environmental agencies.

Survey efforts carried out by the CRRU research team focus on the study area located in the outer Moray Firth boundaries on the south eastern Moray Firth coast (Figure 1). Adding to the habitat speculations of previous research, results of the CRRU research efforts have reinforced the importance of this area to the entire North Sea bottlenose dolphin community (Culloch & Robinson, 2008).
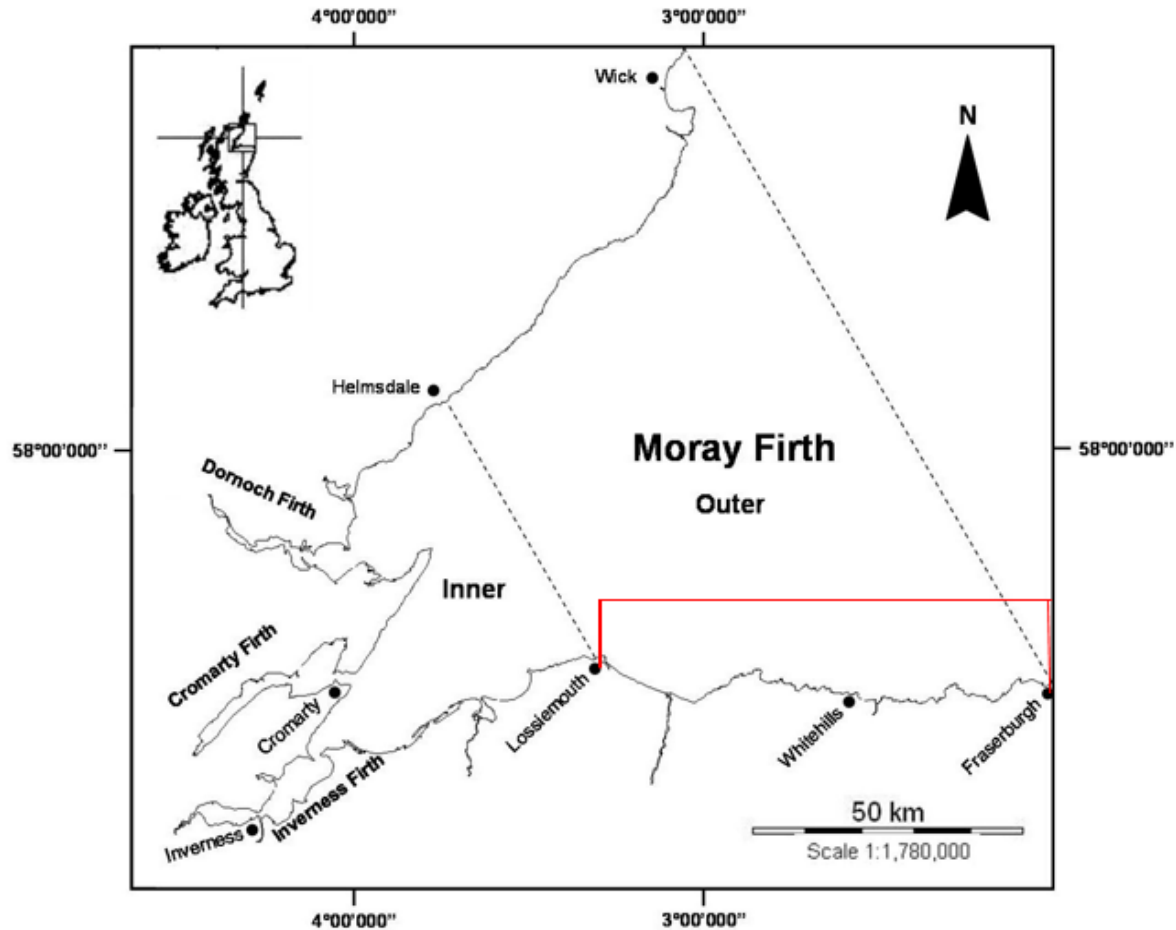
Figure 1: Map of the Moray Firth. This figure illistrates the Moray Firth and its boundaries.This map also displays the smaller connecting firths, ports, and towns along the shoreline. The Inner section of the Moray Firth is a designated SAC. The area within the red line depicts the approximate CRRU study area.

3.4.2 Research Gaps

Distribution, movements, and abundance of these highly mobile marine predators are commonly studied at relatively large spatial scales which presents a challenge as individual animals and groups of individuals' exhibit complex mixtures of distribution and movement patterns varying among different subgroups of the population (Cheney *et al.*, 2012). Studies conducted in North America revealed that a complex mixture of movement among different components of a population is best managed as seasonally variable units

13

(Urain *et al.,* 1999, Hohn, 1997). Studies of bottlenose dolphin populations of the Mediterranean Sea Pelagos also revealed differences in movement patterns. Most dolphins were showing high site fidelity, while a few individuals were found to have more widely distributed ranges (Gnome *et al.,* 2011). Therefore, it is important to investigate smaller components of considerably large populations and overlapping populations. Knowledge of Western Europe bottlenose dolphin population ecology is fragmented stressing the need for fine scale research on these populations.

Further analysis of the abundance and distribution patterns of North Sea bottlenose populations is critical to the understanding of the full extent of habitat use. Abundance and distribution patterns may reveal associated mechanisms of oceanographic, biological, and anthropogenic drivers, providing a basis for solving the temporal mismatch between habitat use and management. A complete understanding of such mechanisms would enhance the foundation of proper placement of protective boundaries around highly mobile marine predators such as the bottlenose dolphin (Wilson *et al.*, 2004). It is acknowledged that accurate cetacean research is limited as their distribution and patterns of movement take place at sea (Cheney *et al.*, 2014).

Another research frontier in cetacean ecology is the role of environmental plasticity within the bottlenose dolphin species. Research generalizations of bottlenose dolphin population dynamics and associated factors are limited as each individual population is unique and much variation exists between populations emphasizing the importance for population-sub population specific knowledge.

3.4.3 Data Acquisition

Identifying individual dolphins in the wild can be accomplished by photographing the dorsal fin while the dolphin comes up for air. Photo identification provides a method of tracking movement of individuals or groups of individuals. Dorsal fins exhibit various shapes, sizes, colours, and scarring patterns, allowing for the recognition of 'recaptureable' (tagged/marked) individuals.

Naturally occurring markings used in the present study for the identification of individual bottlenose dolphins (adapted and expanded from Wilson, 1995 & Culloch 2004) include:

1. Dorsal fin nicks or tears: Pieces of tissue missing from the trailing, and occasionally leading, edges of the dorsal fin.
2. Unusual dorsal shapes: Distinctively broad, narrow, tall, short or leaning dorsal fins.
3. Major scratches or scars: Large scratches or scars on the fins and body flanks of animals.
4. Minor scratches or scars: As with major scratches or scars, but less pronounced and superficial marks from interactions with conspecifics.
5. White fin fringes / areas of depigmentation: Depigmented areas usually observed around the edges of the dorsal fin. Albino animals are also included in this category.
6. Active lesions: Areas of black, cloudy, lunar or orange lesions.
7. Healed lesions: Pale epidermal lesions / skin blemishes often used as an additional feature for differentiating individuals.
8. Deformities (Natural & unnatural): Distortions of the normal body contours, such as a kinked peduncle or tailstock, for example. May be congenital or otherwise, and therefore includes inflicted injuries such as those caused from boat collisions or propeller strikes, for example.

Systematic photo capture and recapture, individual identification, and compilation of this information over time can subsequently provide useful information regarding the dynamics of study populations (Wilson, 1997). One commonly utilized method to obtain small cetacean abundance estimates is closed population mark–recapture. This method is comprised of capture (marking/tagging/photographing), recapture (individual identification/recognition), data translation (individual capture history), and data analysis (population modelling) (Pleslić *et al.*, 2015).

3.5 Abundance Estimation

3.5.1 Closed Populations

The process used in abundance estimation depends upon the nature of the population investigated, which is considered either 'closed' or 'open'. A closed population remains unchanged during the investigation, while an open population is one that can change through such processes such as birth, death and migration. A closed population is theoretically not affected by these processes.

There are six assumptions that must be upheld in a closed population investigation and analysis (Read, 2003; Culloch & Robinson, 2008) which include:

1. No Loss of Marks: Marks on individuals are not lost and considered to be permanent validating that individual identification is solid and reliable.
2. Accurate Mark Recognition: Marks are correctly sighted and individuals are accurately identified and recorded.
3. No Behavioural Response: Capture procedures do not have a behavioural effect on the probability of recapture of an individual.
4. Demographic Closure: No births or deaths have occurred during the study period.
5. Geographic Closure: There is no immigration or emigration of individuals into or out of the population during the study period.
6. No heterogeneity of Capture Probabilities: During each sample occasion, all individuals of the population have an equal probability of being recaptured.

3.5.2 Capture-Recapture

In capture-recapture methodology, the first sample is used to provide 'tagged' or 'marked' animals as the initial capture occasion. Historically, the physical 'tagging' of animals was necessary to keep track of an individual's capture

history which has been replaced in most cases by high quality photography as a non-invasive method of capturing and marking animals. The second sample (second capture occasion) primarily consists of marked and unmarked individual animals. The unmarked animals are then marked and all the animals are released again. This process reveals a capture history for each individual animal that is caught during the experiment. The encounter histories are transcribed into a binary coding system where the number '1' indicates that an animal had been sighted, and '0' indicates that the animal had not been sighted. For example, the capture history, '01101', of an individual means that the individual was captured or sighted and recorded in the second, third, and fifth samples. If an animal is not recaptured it doesn't necessarily indicate mortality of the animal. It is importance to take multiple samples and follow consistent, standardized sampling methodology.

Appropriate capture-recapture methodology is supported by specific underlying assumptions which need careful examination to eliminate any biases. One example is the variation between of an experienced observer and an inexperienced observer in locating or counting individuals on plots. Also, some animals may not be detectable. Some individuals may be disturbed before they are seen or one may even see the individuals in groups. There often is heterogeneity in capture, sighting, and survival probabilities.

Capture-recapture methods have a variety of uses for closed population investigation including the estimation of population size (N). Program MARK (White & Burnham, 1999) is a commonly recognized and reputable capture-recapture abundance estimation data analysis tool.

3.5.3 Program MARK

The development objective of Program MARK was to convey a common interface to the estimation of survival from marked animals. Marked animals can be re-encountered as either alive or dead, in a variety of experimental frameworks.

Capabilities provided by Program MARK include survival estimates from marked animals when they are re-encountered at a later time with basic encounter history inputs for each animal. Survival estimates can be developed as part of a model. This program allows for time intervals between re-encounters to be unequal and for more than one group of animals to be modelled. Program MARK provides parameter estimates from marked animals when they are re-encountered at a later time after initial capture. The re-encounters can be from dead recoveries (e.g., the animal is harvested), from live recaptures (e.g. the animal is re-trapped), or from radio-tracking. The time intervals between re-encounters do not have to be equal. Program MARK can allow for parameters to be constrained to be the same across capture occasions, ages, or groups. Models analyzed in program MARK can include individual animal covariates. Numerical maximum likelihood techniques are utilized by this system to compute the estimated model parameters.

MARK can also provide estimates of population size for closed populations through embedded CAPTURE program. The Program CAPTURE tool embedded within Program MARK is a comprehensive package for fitting models that have a formal likelihood associated with them including the Chao sample coverage models. The program can provide estimates of abundance which was utilized in this study.

The CAPTURE program computes estimates of capture probability and population size for 'closed' population capture-recapture data. Capture (p) and re-capture (c) probabilities for closed models can be modelled by attribute groups, and as a function of time, but not as a function of individual-specific covariates (White & Burnham, 1999).

In closed captures, the parameter space is the probability of capture on an occasion if the animal has never been captured (p), the probability of capture on an occasion given that the animal has been previously captured (c), and the number of animals in the population that are never captured. This value is then added to the number of animals known to be in the population thus providing an estimate of N, the population size. The parameters p and c are nuisance parameters, because generally N is the parameter of interest.

The closed captures datatype consists of 12 different models. Each model consists of the basic parameters previously mentioned, p -- probability of initial capture, c -- probability of recapture given that the animal has been previously captured, and pi -- proportion of the population with a particular mixture. There are 3 basic closed captures models: p and c only (i.e., no mixtures -- the population consists of only a single type), p and pi only (i.e., no difference in recaptures from initial captures), and p, c, and pi (i.e., the most complicated type where mixtures of both p and c are allowed. For each of these 3 models, 2 versions exist including full likelihood and the Huggins version. In the full likelihood version population size (N) is included in the likelihood incorporating the number of animals in the population that were never captured (f). The Huggins version derives population size as a parameter conditioned out of the likelihood and is useful when individual covariates are encoded into data inputs. The capabilities of program CAPTURE can be done within program MARK (White & Burnham, 1999).

3.5.4 Population Size (N) Estimators

When estimating the population size (N) for a closed population, 8 models have been utilized and described as M_0, M_t, M_b, M_{bt}, M_h, M_{th}, M_{bh}, and M_{bht} (Seber, 1992). These subscripts refer to the effects of time, behaviour and heterogeneity. M_0 assumes that probability of capture is constant for all samples.

The sample coverage concept is defined as the sum of the probabilities of capture of all the individuals ultimately caught in the experiment, divided by the sum of these probabilities for the whole population. Using this idea, Anne Chao and colleagues (Chao, Lee & Jeng, 1992; Lee & Chao, 1994) developed estimators of N for all 8 models. Chao and Lee (1993) developed a coverage estimator for M_{th} for continuous-time models which uses only the frequencies of capture. After running simulation studies, they concluded that the Chao estimator is most reliable when there is heterogeneity in capture probabilities (Schwarz *et al.*, 1999). M_{th}, M_t, and M_h models allow for relaxation of typical assumptions violated by cetacean species (Pulcini, 2014; Chao, 1992).

4.0 Project Aims and Objectives

This project was carried out using bottlenose dolphin individual sightings data collected by the CRRU between May and October 2006 to 2014 inclusive, with aims and objectives to:

1. Investigate the fine-scale inter-annual and seasonal changes in the abundance of bottlenose dolphins inhabiting the southern coastline of the outer Moray Firth.
2. Evaluate inter-annual and seasonal changes in individual occurrence, distribution, and site fidelity.
3. Provide annual estimates of abundance for the animals using the outer southern Moray Firth.

4. Determine the proportion of the 195 strong NE bottlenose population are utilizing the outer southern firth coastline.

5. Distinguish and identify the marked individuals' group composition.

6. Discuss reproductive success other factors to substantiate earlier conclusions that this area constitutes an important nursery/calving area for the population will be evaluated and discussed.

7. Evaluate distribution of sightings data a spatial and temporal context.

8. Identify and discuss anthropogenic and environmental factors potentially influencing dolphin abundance and distribution.

5.0 Methods

5.1 Overview

Inclusive, dedicated long-term photo-identification data collected and compiled by the CRRU between May and October 2006 to 2014 was examined to identify inter-annual changes in individual occurrence, population abundance, site fidelity, distribution, and impacts of environmental and anthropogenic factors. Program MARK (developed by Colorado State University) was used for capture-mark-recapture analysis to provide annual population estimates of abundance for the animals using the outer southern Moray Firth. The estimators of the CAPTURE analysis tool, embedded within Program MARK, was utilized to provide population size estimates. To estimate population size (N), a closed population mark–recapture model and a time-dependent heterogeneity (Chao M_{th}) estimator (Chao et $al.$, 1992) were selected. The Chao M_{th} model was considered to be the most appropriate tool for estimating the size of coastal bottlenose dolphin populations, taking temporal and individual heterogeneity into account (Williams et $al.,$ 1993; Wilson et $al.,$ 1999; Bearzi et $al.,$ 2008; Culloch, 2004). All calculations were done using the CAPTURE module of the Program MARK, Version 8.0.

5.2 Data Collection

Data analysed in this study was collected in accordance to the standardized CRRU data collection protocols (after Robinson *et al.,* 2007), confirming data quality control and quality assurance. Principals of the Moray Firth voluntary guidelines on handling boats around dolphins (Scottish National Heritage, 1993) were also used. Regular surveys were conducted in the southern outer Moray Firth using two Avon 5.4 m Searider Rigid Inflatable Boats (RIBs). Surveys of interest took place between May through October from 2006 to 2014. All surveys were conducted at approximately 12 to 15 kilometres per hour, in Beaufort Sea State 3 or less, and in optimal light conditions. Aboard the vessel were two experienced observers and up to four additional trained observers. The crew of observers scanned from the front of the survey vessel to and to the left and right of the track line. If bottlenose dolphins were encountered during a survey, the boat was slowed and the position was recorded using the Global Positioning System (GPS) and Geographical Information System (GIS) instrumentation. The individuals or groups of dolphins were approached and photographs were taken of dorsal fins and other identifying marks. The camera used during this study was a 35 mm Nikon D3 auto-focus camera with a F2.8 300 mm fixed lens. A note taker was designated on the boat to fill out relevant encounter information forms (Appendix III). During an encounter, the animals were counted and the group composition and the age-classes (adults, calves and neonates) of pod members were estimated and recorded (Culloch & Robinson, 2008). Adults were defined by their large size and dark coloration, a calf was defined by its smaller size, lighter colouration, often discernible foetal folds, and usually swimming in close association with an adult, and a neonate was defined as a very small animal, very light in colouration, with very bold foetal folds, and a strong, close association with an adult (Shane, 1990).

5.3 Photo Identification

Individual dolphin identifications were made using natural markings considered long-term or permanent. Photographs were assessed according to their quality in order to minimize

the number of errors associated with incorrect identifications (Wilson *et al.,* 1999, 2000). Only photographs that were in focus, well-lit, and relatively close and parallel to the subject were included in the analysis and all photographs not satisfying these requirements were discarded. Photos were then evaluated in the CRRU office and incorporated into the CRRU bottlenose dolphin catalogue and archive.

5.4 Data Analysis

Data was comprised of the individual capture histories in the binary coding system explained in Introduction Section, 3.5.2, for the animals included in the investigation derived from the encounter histories from 2006 through 2014**.**

Program MARK was used to calculate mark–recapture abundance estimates through the embedded CAPTURE program application. Re-encounters from live recaptures in the form of photographs of individuals were used to create an encounter history for each individual. The time intervals between re-encounters did not have to be equal, but were assumed to be 1 time unit if not specified. The encounter histories transcribed into the binary coding system where '1' indicated that an animal had been sighted, and '0' indicated that the animal had not been sighted was used as the basic input.

The closed capture datatype analysis was selected and interpreted under the closed population assumptions defined in the introduction section 3.5.1 and discussed further in discussion section 7.2.3. The p and c full likelihood model version of a closed capture analysis was selected.

All models were considered in the CAPTURE application which tests for 3 sources of variation in sightings probabilities including that of (i) a time response, which considers the variability of sighting probability between sampling periods but that all animals within each sampling period have the same probability of being sighted (M_t), (ii) a behavioural response, where animals are considered to become 'trap happy' or 'trap shy' after their initial capture (M_b), and (iii) individual heterogeneity, where individuals may vary in their

capture probability (M$_h$). All of the models were based on the principles and combinations of three variation components (M$_{bh}$, M$_{th}$, M$_{tb}$) along with the model where probability of capture remains constant (M$_o$).

The models used in the analysis were selected and interpreted based on a biological grounds discussed in the Discussion, Section 7.0. The Chao time-dependency model (M$_t$), Chao time-dependent heterogeneity (M$_{th}$), null model (M$_0$) were selected for data analysis.

Using these models, the total population size was estimated from the proportion of marked individuals such that (Williams *et al.,* 1993):

$$N= \frac{N-hat}{\theta}$$

$$Variance\ N=\left(\frac{vN-hat}{N-hat^2}+\frac{1-\theta}{n\theta}\right)$$

Whereas:

N = the total population estimate

N-hat = the estimated number of permanently marked individuals

Ɵ = the proportion of permanent marked individuals in the sample

V = the variance of N-hat

n = the total number of animals in the sample

Encounter histories were pooled for each month which served as the capture occasions per year. The term 'capture occasion' is interchangeable with 'trapping occasions'.

Two groups or categories of individual dolphins were run through Program MARK to produce population abundance estimate outputs (Table 2). The first

group of dolphins, 'well-marked individuals', consisted of all animals that were considered to be 'well-marked' in the population with a permanent scarring or distinctive dorsal pattern unlikely to be mistaken. Examples may include dorsal scars, nicks, scratches, or any other fin abnormalities. There were a total of 91 individuals in this group. The second group, 'all marked individuals', included all the 'well-marked individuals' along with additional calves, juveniles, and adults which were all in this case considered to be 'recaptureable' but may not have had extremely distinctive scarring or dorsal markings. Including the group of 'well-marked individuals', there was a total of 219 individuals in the 'all marked individuals' group. Sixty-three (29%) of the total 219 individuals were identified as female, 48 (22%) were male, and 108 were unknown.

Spatial and temporal distribution of sightings GIS (Geographic Information Systems) data were plotted on maps of the study area in the southern outer Moray Firth (Figures 5-6).

6.0 Results

6.1 Efforts

Between years 2006 and 2014, a total number of 265 bottlenose dolphin encounters were recorded, with the maximum value of 45 encounters in 2014 and a minimum value of 19 encounters in 2008. There were a total of 47 capture occasions with the maximum number of 6 capture occasions per year and a minimum of 4 capture occasions. There was a total of 822 survey hours conducted with a maximum hours of 150 hours in 2014 and a minimum of 51 hours in 2009 (Table 1). The maximum average count of 18.58 sightings per encounter was in 2014, followed by 18.33 sightings per encounter in 2010. The maximum average count of 6.41 sightings per survey hour was in 2010 (Figure 2).

Table 1: Efforts. This table displays the summary of data collection efforts from 2006 to 2014.

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	Total
No. Encounters*	27	23	19	20	21	35	39	36	45	265
No. Capture Occasions*	6	5	4	4	6	5	6	5	6	47
Total Survey Hours	84	56	56	51	60	99	134	132	150	822

*Capture/Trapping occasions were pooled by month. (Example: 6 capture/trapping occasions indicate that dolphins were captured and observed 6 months that year.)
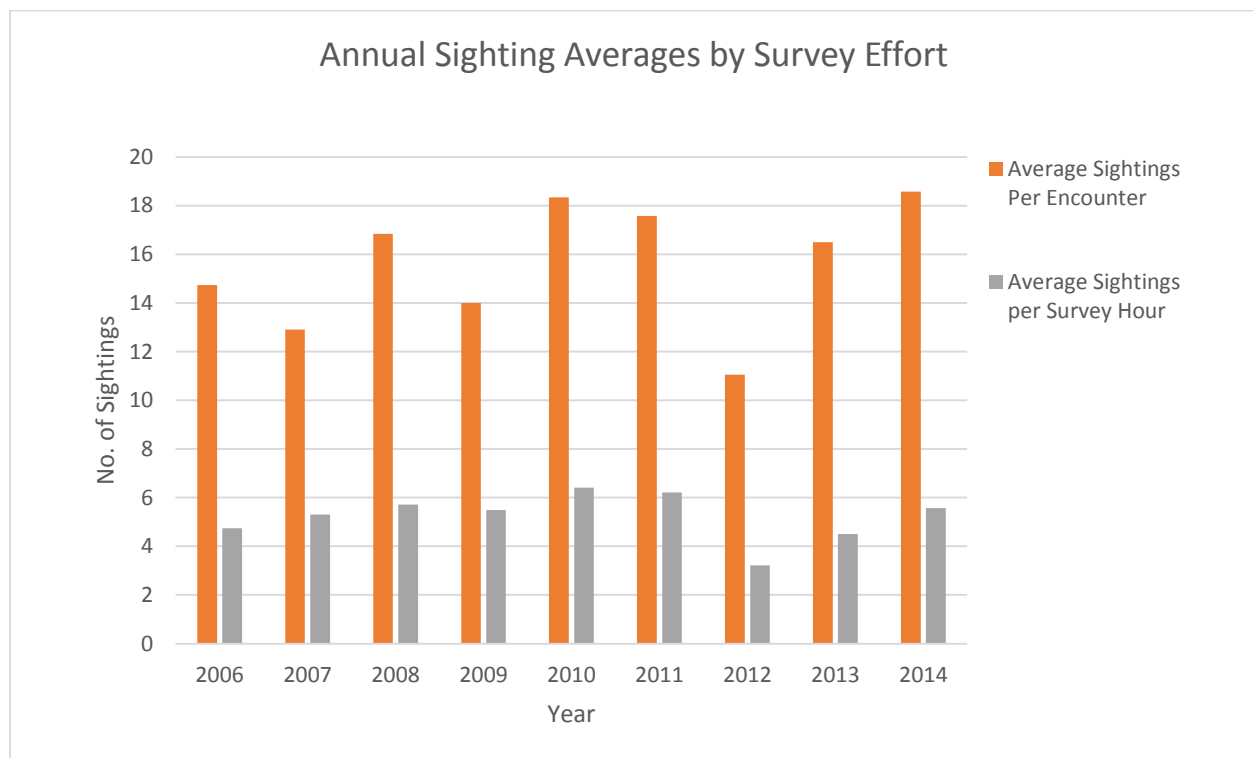
Figure 1: Annual Sighting Averages by Survey Effort. This figure displays the annual average number of sightings per encounter (orange columns) and average number of sightings per survey hour (grey columns).
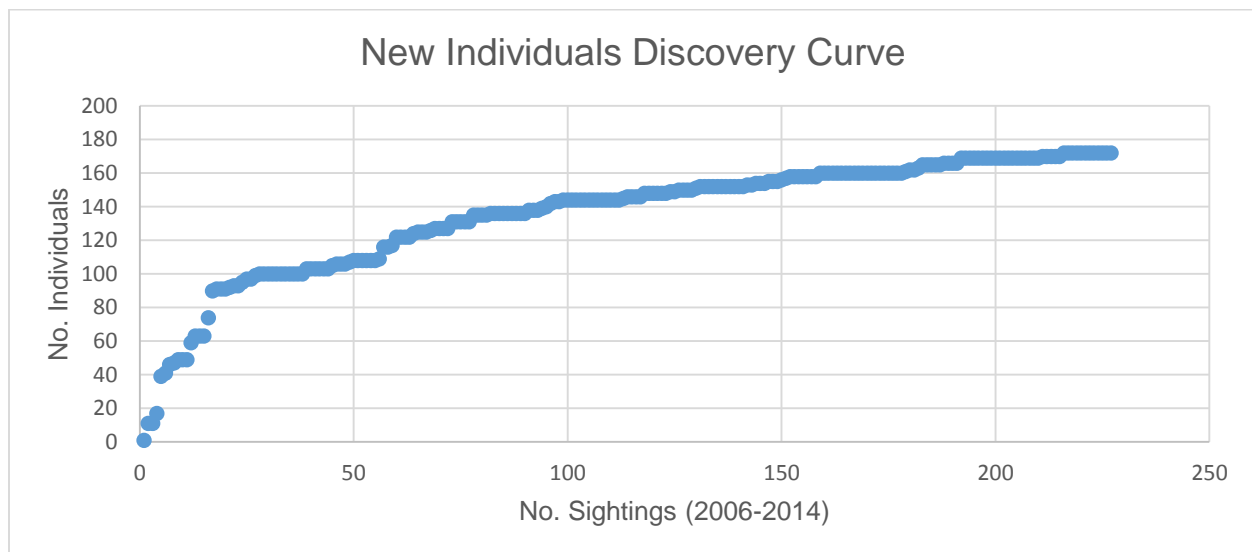
6.2 Population Estimates

The first Chao M_{th} analysis group of dolphins, 'well-marked individuals' ,

making up 42% (Figure 8) of the all individuals had an abundance estimate

maximum of 91 (95% CI: 70-138) individuals (Table 2.A) with a standard

error of 16.44, and an individual recording count of 51 animals captured in year 2008. The lowest population estimate of this group was in 2014 at only 44 individuals (95% CI: 41-55), with a standard error of 3.45, and a total recording count of 39 animals captured in 2010.

The second Chao M_{th} analysis group of dolphins, 'all marked individuals' , comprised of 'well-marked individuals' and all 'recaptureable' individuals, had a maximum population estimate at 165 individuals in 2008 (95% CI:131-227), with a standard error of 23.93 and count of 98 animals captured (Table 2.B). The lowest estimate for this group was in 2007 at 75 (95% CI: 67-94) individuals, with a standard error of 6.78, and a total animals captured count of 61.

The newly sighted individuals discovery curve (Figure 3) shows that the population levels out at approximately 170 individual animals recorded in the study area. The decreased slope in the discovery curve supports the notion that all individuals have been sighted, recorded, and confidently accounted for.

Figure 2: New Individuals Discovery Curve.This curve shows the number of individuals sighted plotted against the number of cumulative sightings from 2006 to 2014.

Table 2: Population Estimates. This table displays the Chao time-dependent heterogeneity model (M_{th}) population estimate result outputs from Program MARK which includes the (A) 'well-marked individuals' dataset and (B) the 'all marked individuals' dataset where 'N'= the number of animals captured, 'P' = the mean probability of recapture, 'N-hat' = the population estimate, 'S.E.(N-hat)' = the standard error of N-hat. The 95% confidence interval is also displayed.

(A) Chao M_{th}: Well-Marked Individuals

Year	N	P	N-hat	S.E. (N-hat)	95% CI
2006	67	0.32	90	9.66	78-117
2007	41	0.52	43	3.35	43-57
2008	51	0.32	91	16.44	70-138
2009	39	0.47	43	4.74	40-63
2010	44	0.41	50	4.02	46-63
2011	53	0.45	65	5.82	58-82
2012	39	0.41	47	4.90	42-63
2013	40	0.43	50	5.92	44-69
2014	39	0.52	44	3.45	41-55

(B) Chao M_{th}: All Marked Individuals

Year	N	P	N-hat	S.E. (N-hat)	95% CI
2006	96	0.33	125	10.46	111-153
2007	60	0.36	75	6.78	67-94
2008	89	0.29	165	23.93	131-227
2009	68	0.39	84	9.36	74-114
2010	81	0.36	100	7.79	90-121
2011	97	0.46	119	8.00	109-140
2012	88	0.37	112	9.00	100-136
2013	98	0.35	140	14.00	121-177
2014	107	0.48	127	7.69	117-148

6.3 Distribution

Bottlenose dolphins were sighted during all study months (May-Oct) and years (2006-2014) (Figures 5.A-6.F) throughout the study area (Figure 4.A-4.B) and extending from furthest western boundaries to far eastern boundaries of the study area (Figure 4.C). All dolphins sighted occurred within approximately 3 to 4 kilometres off of the coastline ranging from depths of 4.2 to 23.4 metres.

Figure(s) 4.A, 4 (Below): Study Area. These map figures display the zoomed out (A), zoomed in (B) version of the study area along with the cumulative encounters (circles) distribution and survey routes (lines) of the entire study period (2006-2014):

A)
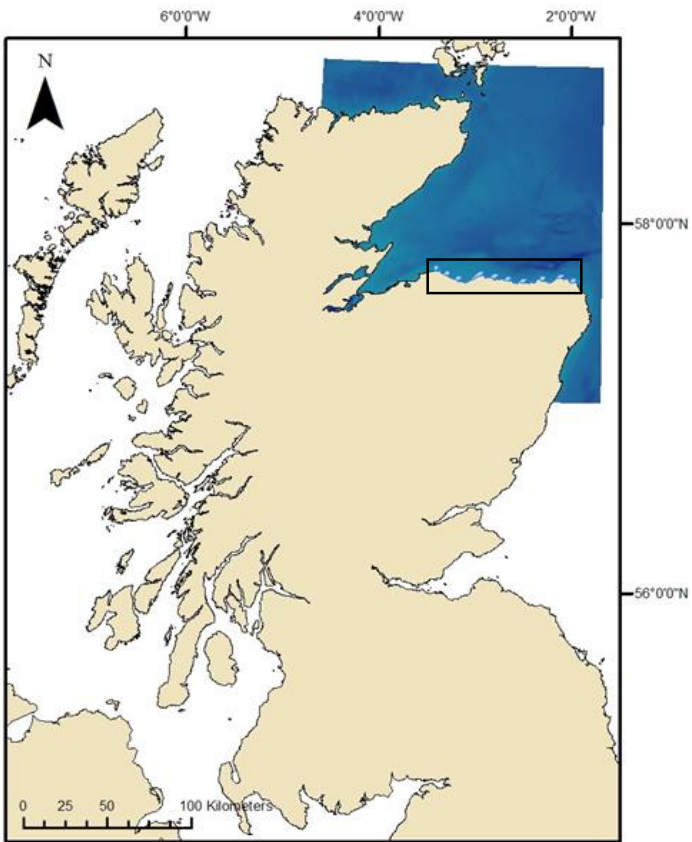
B)
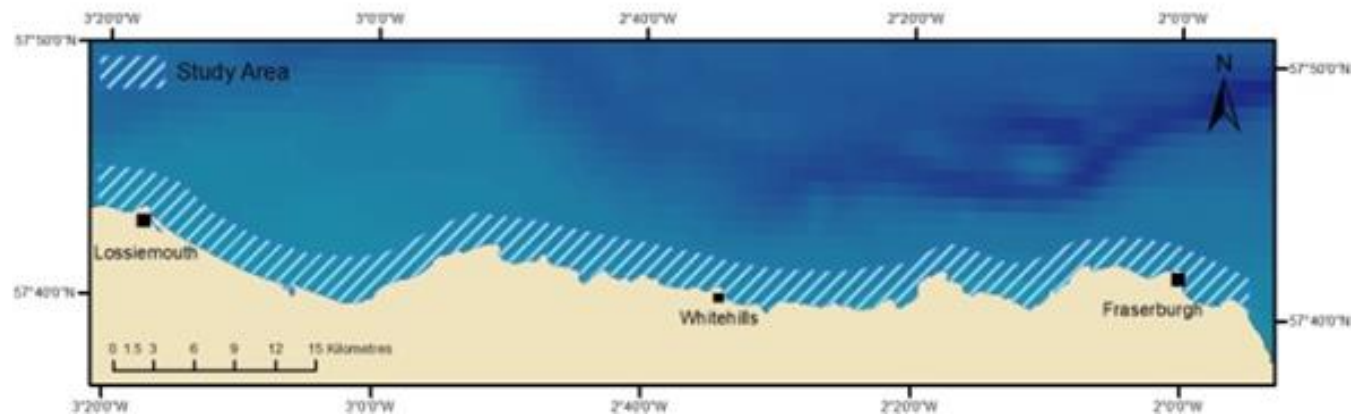
C)
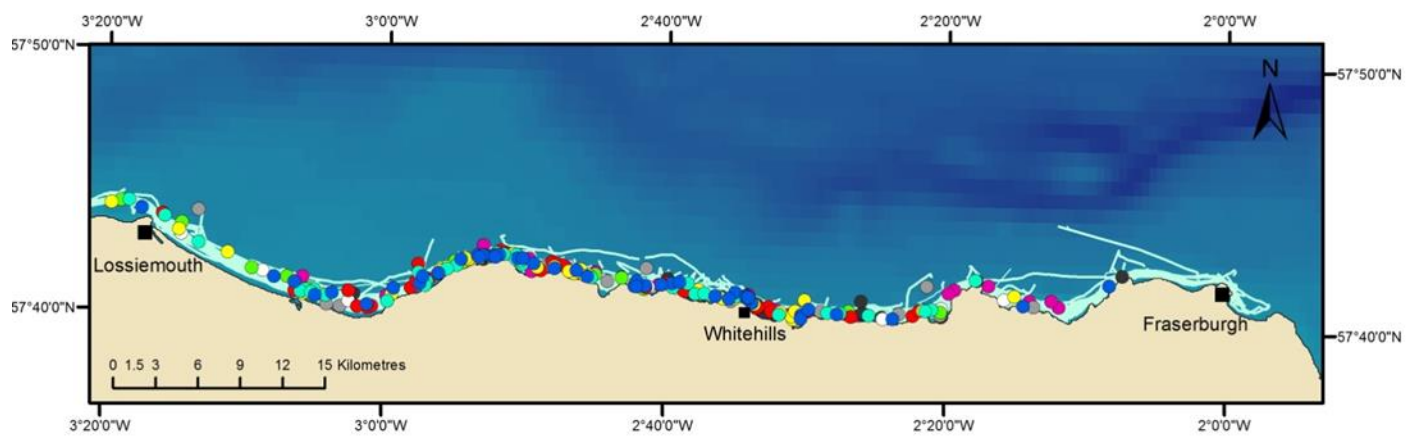
Figures 5.A-5.I. Encounter Distribution by Year: Encounter distribution maps for 2006 to 2014 respectively below:

2006
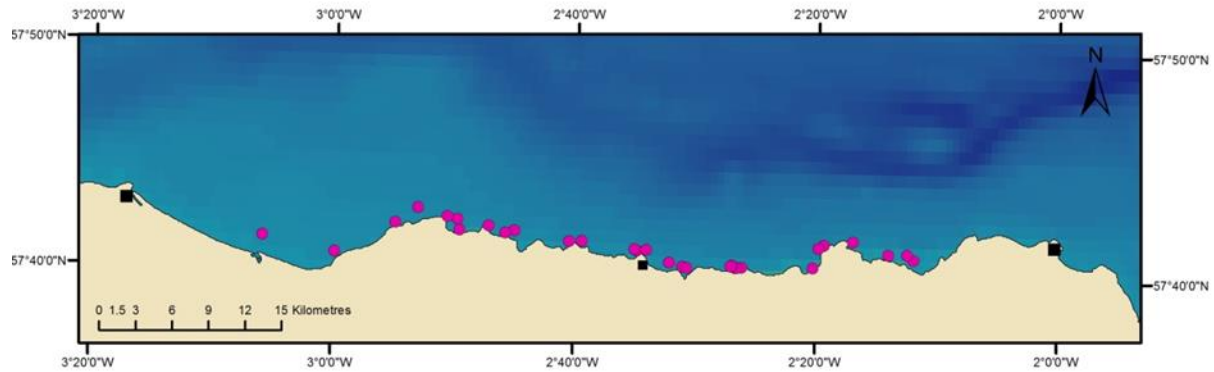
2007
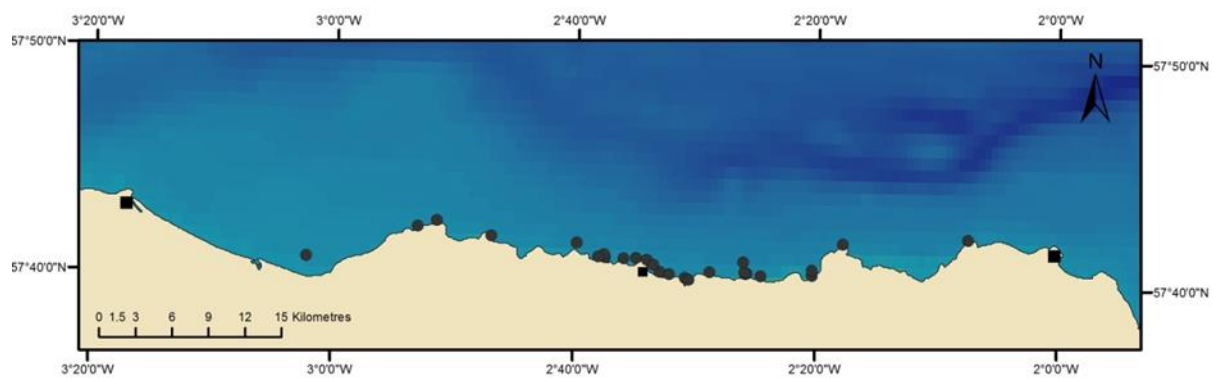
2008
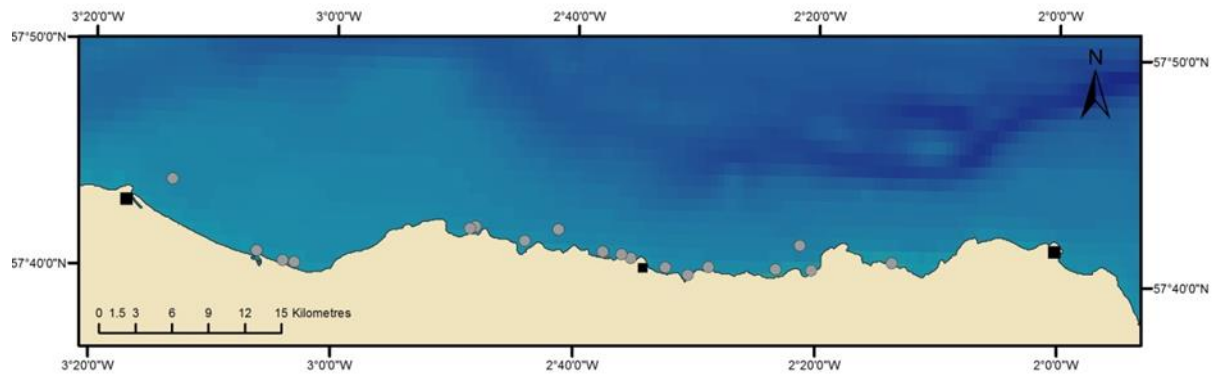
2009
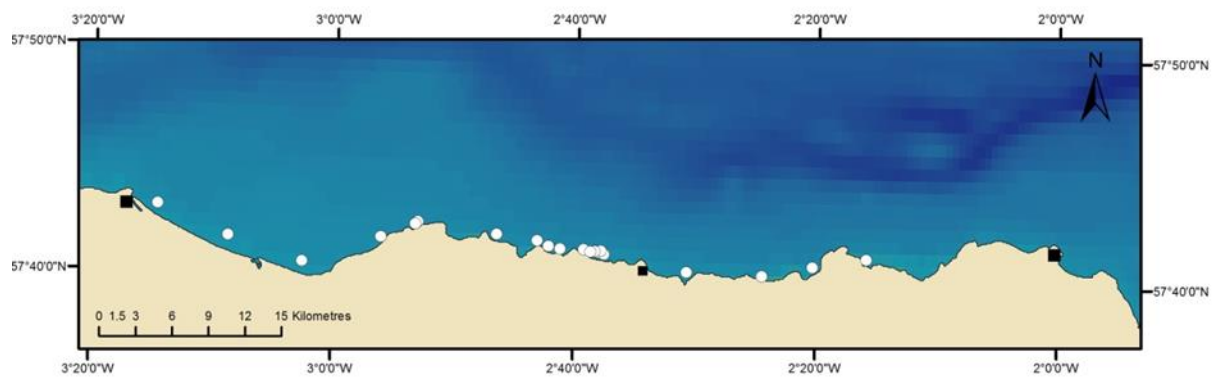
2010
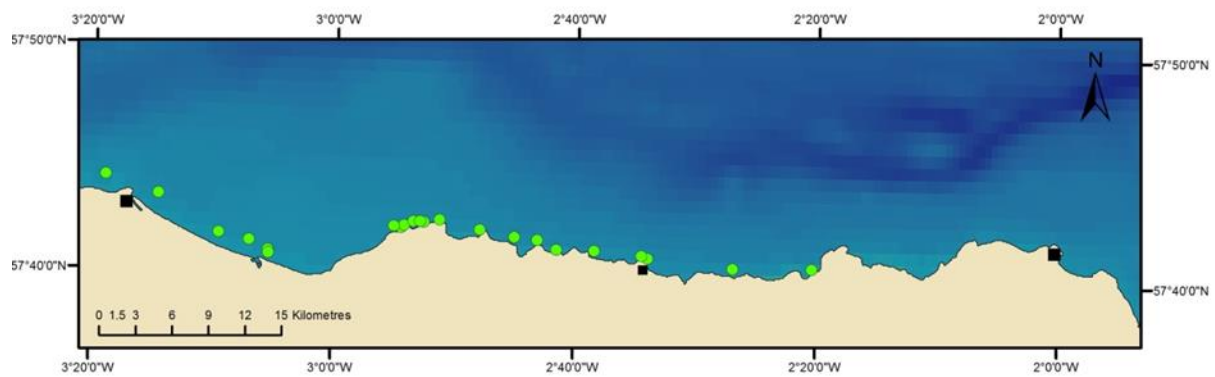
2011
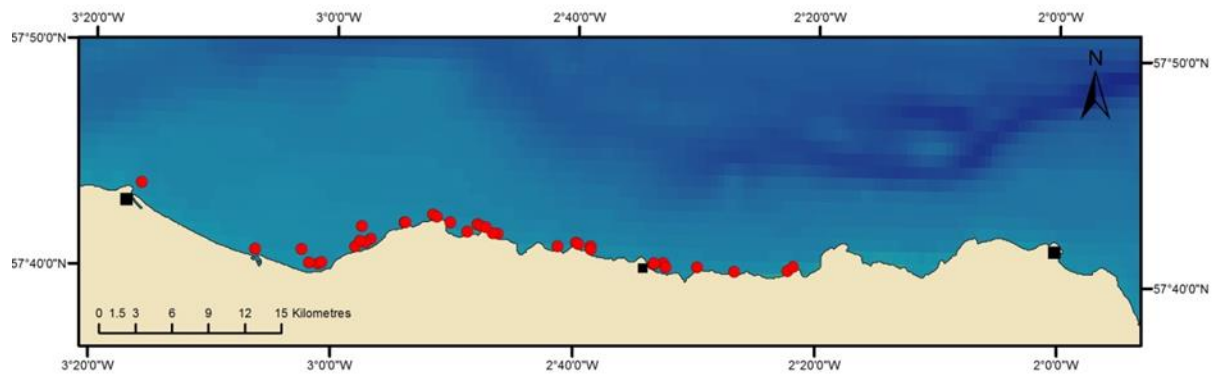
2012
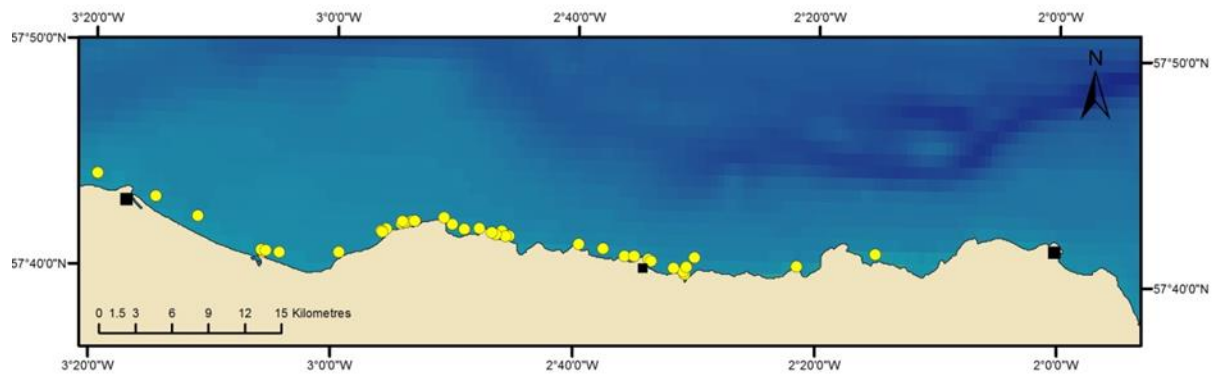
2013
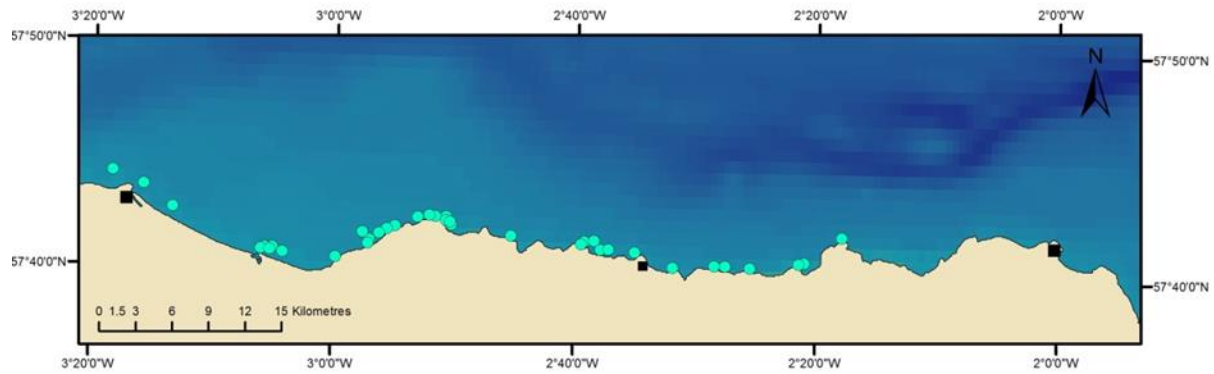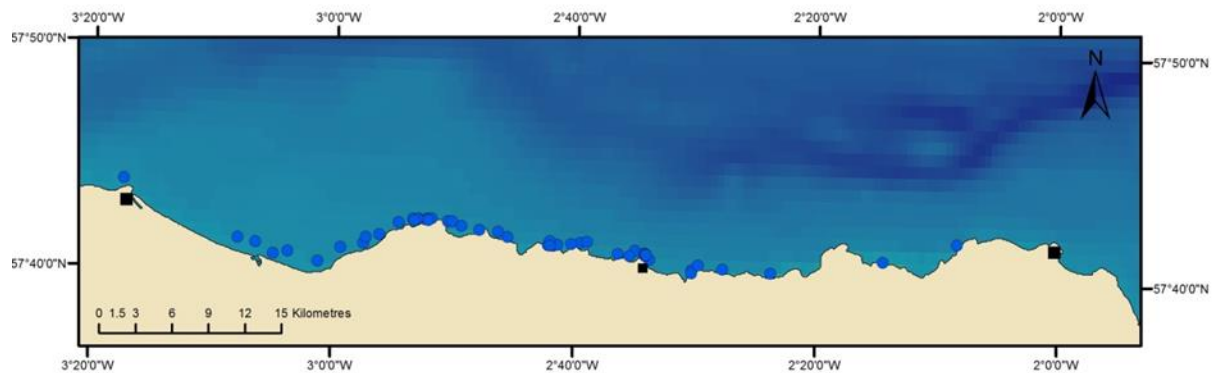
2014

Figures 6.A-6.F. Encounter Distribution by Month: Encounter distribution maps pooled by month (May to October) from 2006 to 2014 inclusive:

May

June

July

36
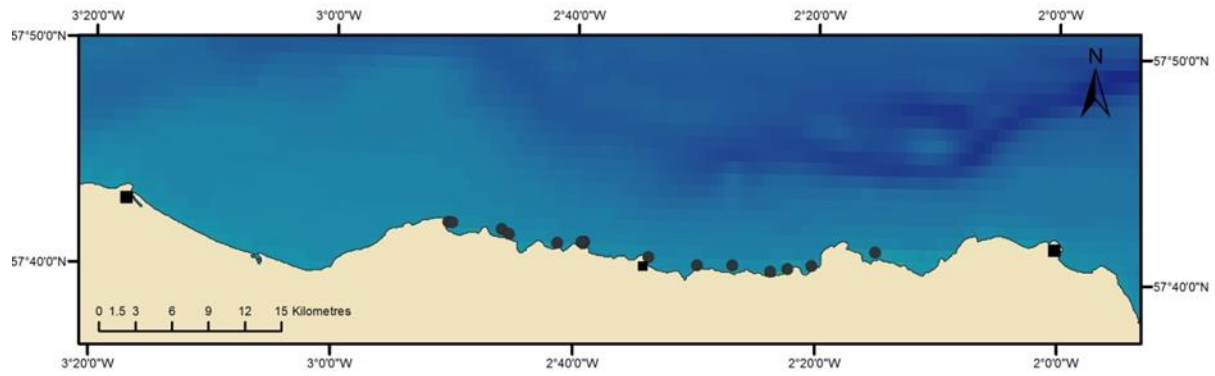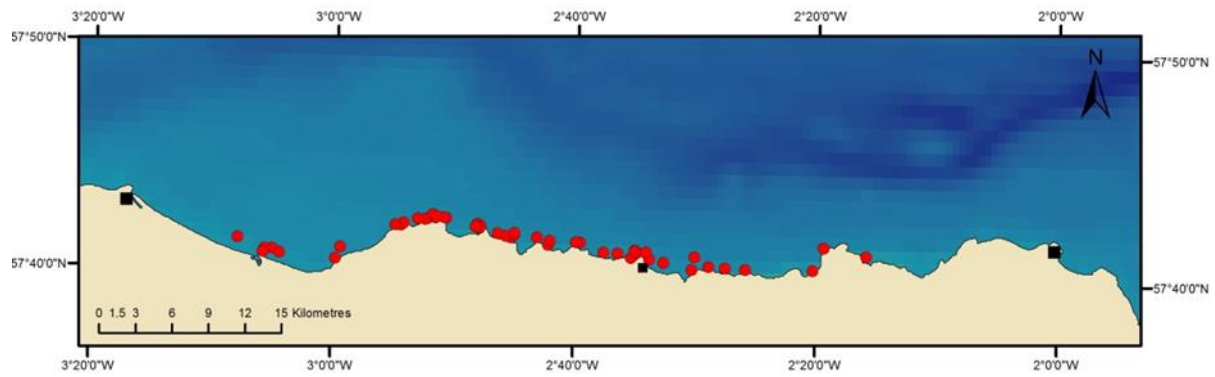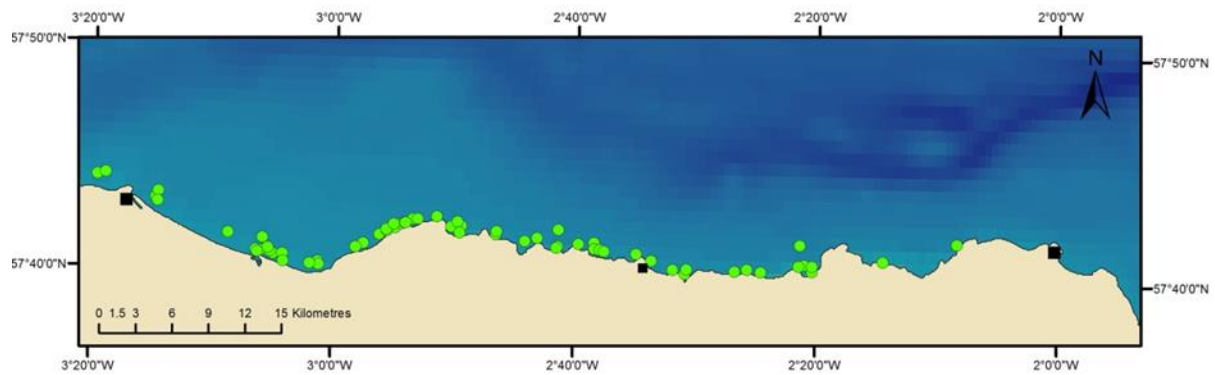
August
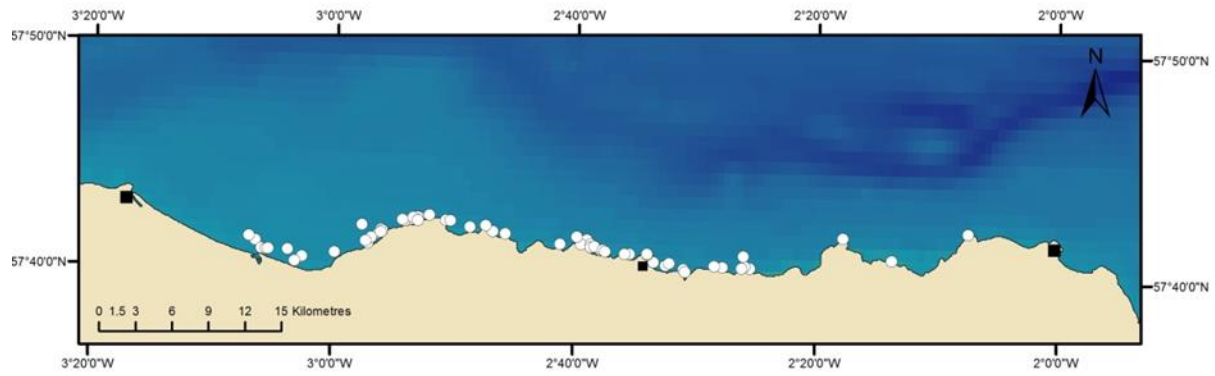
September
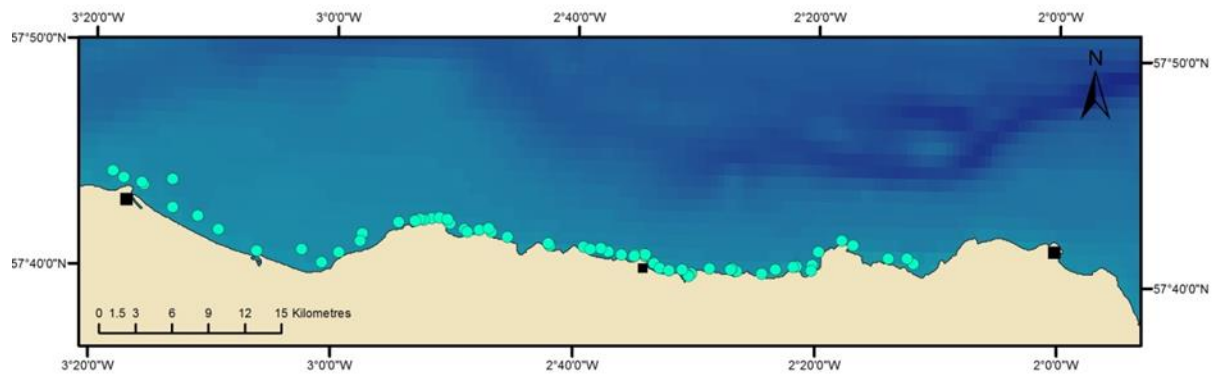
October
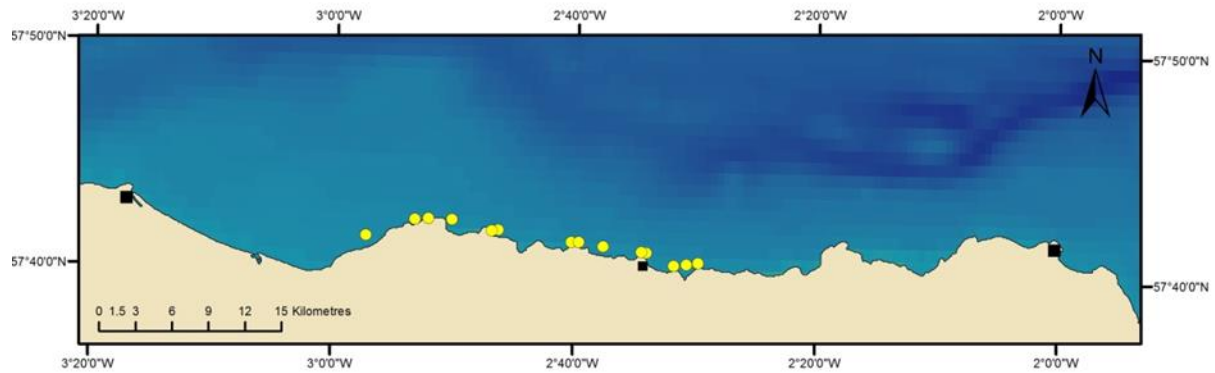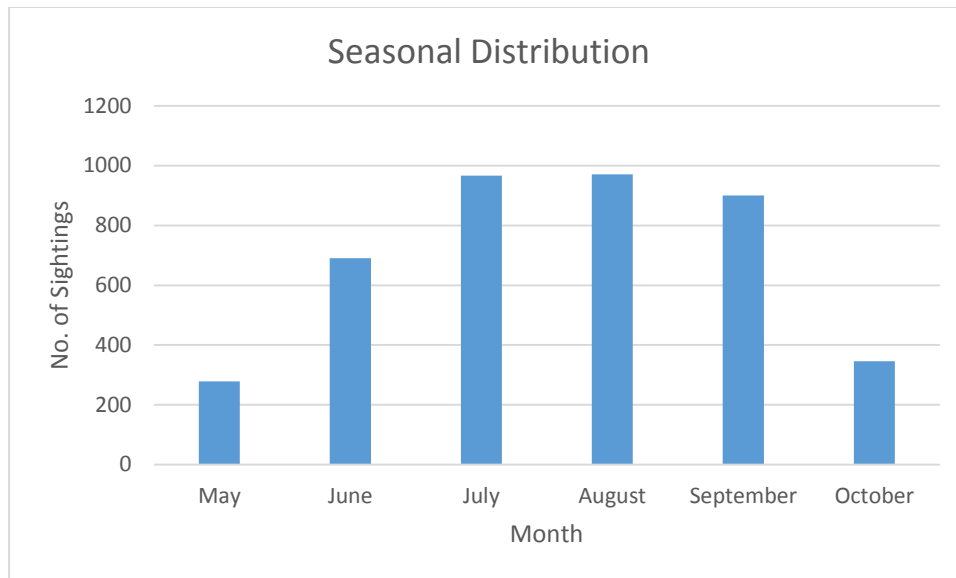
Figure 7. Seasonal Distribution: This figure (above) shows the cumulative number of dolphin sightings each month.

7.0 Discussion

7.1 Overview

Specific concepts and components of project are discussed in this section including:

1. Data collection technique selection and rationale.
2. Marked individual selection criterion.
3. Closed population assumptions and new individuals discovery curve.
4. Closed population p and c full likelihood datatype selection.
5. Chao time-dependent heterogeneity model (M_{th}) selection.
6. Interpretation of abundance estimates, group composition, distribution, and site fidelity.
7. Conservation implications and future prospects.

7.2 Discussion of Methods

7.2.1 Data Collection & Efforts

Data collection efforts were seasonal and limited to 6 months (May through October) out of the year influenced by weather and staff availability as the Moray Firth experiences harsh winter conditions from November through April. Harsh weather conditions decrease the quality of photos as light is limited and large swells decrease visibility. In the recent years of the study period, the role of photo identification software was irrelevant with the modern enhancements of photography technology. Minimizing animal disturbance, the capture of both left and right dorsal fines of individuals was not considered necessary, so long as each individual was photographed. Time spent with large groups was minimized by having experienced observers make positive identifications of well-known marked individuals allowing the photographer to capture the unknown or more subtly marked individuals.

Sightings per survey effort was investigated by looking at the average cumulative number of sightings per encounter and the average cumulative sightings per survey hour (Figure 2). Sightings per encounter and per survey hours were used to avoid discrepancies in variation in survey efforts.

7.2.2 Selection of Individuals

Dolphins incorporated into the analysis were divided into four marked categories (Figure 8). 'Well-marked individuals' were considered to have the most distinguishable, characteristic markings comprised of 91 individuals and 42 percent of the entire analysis group. 'Recaptureable adults' (53 individuals), 'additional calves' (70 individuals), and 'additional juveniles' (5 individuals) were all considered to be 'recaptureable', as such that all were identified as individuals, however lacking highly distinguishable or permanent dorsal characteristics. One analysis was conducted on the 91 well-marked individuals and a second analysis was conducted on all categories of marked individuals, 'all marked individuals', totalling at 219 identified individuals. Analysis of both groups was considered important to reveal an accurate, valuable abundance estimation of the dolphins utilizing

the study area as it is possible that all recaptureable individuals may not be represented in the well-marked individual category.
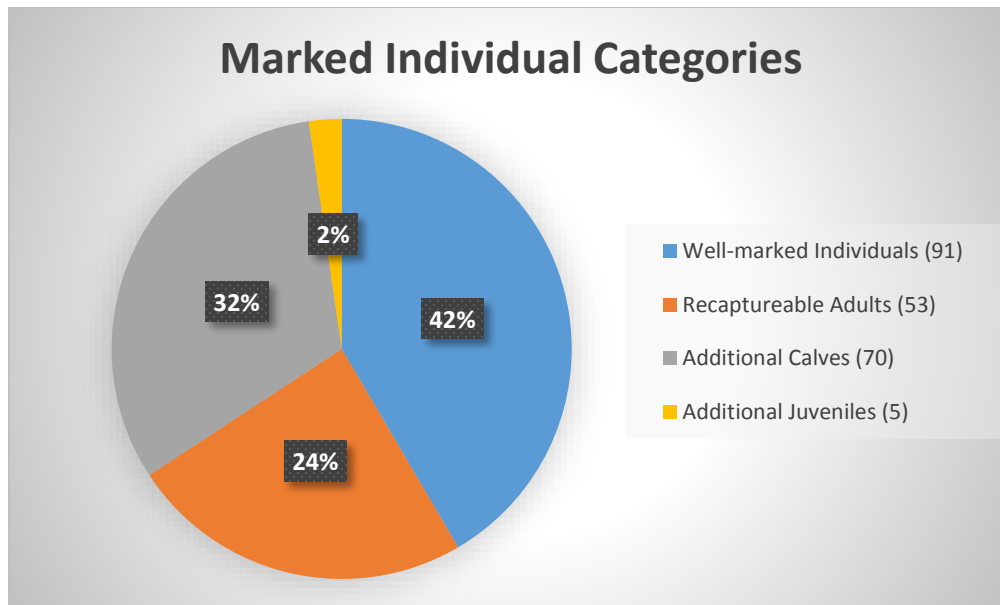
Figure 8: Marked Individual Categories. This chart (above) shows the marked individual category percentages out of the total number of marked individuals sighted during the study period. The number in parenthesis represent the total count of dolphins in that group.

7.2.3 Data Analysis: Closed Population

Analysis anticipated that the population fit a closed model for our mark–recapture abundance estimates (see assumptions listed in Introduction, section 3.5.1, Closed Populations), as a discovery curve of newly sighted individuals was incorporated into the analysis (Figure 3). It is important to note that because birth and death do occur in the natural environment the discovery curve will never become truly asymptotic. In addition, long-term studies of this population indicate that there is no evidence of immigration or emigration (Parsons *et al.*, 2002) or predation (Wilson, 1995), and abundance estimates have remained similar for more than a decade (Wilson, 1995; Wilson *et al.,* 1999; Durban *et al.,* 2005, Culloch & Robinson, 2008).

All following assumptions were satisfied to validate that the population was closed during this investigation as such that:

1. No Loss of Marks: Marks on individuals are not lost and considered permanent validating that individual identification is solid and reliable. Dorsal marks are widely accepted as permanent (Wilson, 1999).

   Individuals with no permanent distinguishable marks were carefully evaluated and placed into appropriate marking category. For example, an individual was considered to be 'recaptureable' based on precision of photo ID and observer expertise but is not considered to be a 'well-marked individual'.

2. Mark Recognition: Marks are correctly sighted and individuals are accurately identified and recorded.
   Marks were tracked and updated regularly in the CRRU database eliminating the chance of an unnoticed faded or new mark. All photos used in individual identification were taken by one of the two senior staff of the CRRU research team diminishing observer error.

3. No behavioural response: Capture procedures do not have a behavioural effect on the probability of recapture of an individual.

   Photo capture was considered to be a non-invasive method of capture as there is no physical contact with the animal. During surveys, boat position and speed was adjusted based on direction, location, and speed of the encountered group of individuals to avoid collision or influence of natural behaviours. Also, this species is coastal occurring meaning it was most likely previously exposed to the stimulus of boating activities in the area.

Research effects on behavioural response is considered to be unlikely (Read, 2003).

4. Demographic Closure: No births or deaths have occurred during the study period.

   Neonates were not included in the data analysis. Also, the longevity of the bottlenose dolphin greatly exceeds the duration of the study period validating a low occurrence of death in this population.

5. Geographic Closure: There is no immigration or emigration of individuals into or out of the population during the study period.

   Long-term studies of this population indicate that there is no evidence of immigration or emigration (Parsons *et al.,* 2002) or predation (Wilson, 1995), and abundance estimates have remained similar for more than a decade (Wilson, 1995; Wilson *et al.,* 1999; Durban *et al.,* 2005). The new individual discovery curve also validates this assumption with a similar line slope for the past few years peaking at approximately 170 individuals (Figure 3).

6. No heterogeneity of Capture Probabilities: During each sample occasions all individuals of the population have an equal probability of being recaptured.

   Violation of this assumption may arise from unequal photo- identification effort during each capture occasion, behavioural differences among individuals or incomplete mixing of population members between capturing occasions (White *et al.,* 1982; Wilson *et al.,* 1999; Read *et al.,* 2003). The Chao time-dependent heterogeneity M_{th} model is tolerant of heterogeneity in capture probabilities between sampling events and between individuals (Chao 1992; Robinson & Culloch, 2008). To account for heterogeneity in capture probability the M_{th} model was selected and applied,

accounting for individual and temporal variability. In addition, during all sightings, explicit effort was made to 'capture' all the animals present, despite their markings or individual behaviour.

7.2.4 Data Analysis: Population Estimator Selection

The p and c full likelihood version of closed capture analysis of population size (N) was selected based on two factors, (i) this version of closed capture analysis incorporates the number of animals in the population that were never captured (f) and (ii) does not require individual covariate inputs allowing for N to remain as a non-derived parameter (White, 1999). To estimate abundance, population size (N), a closed population mark–recapture model – the Chao M_{th} estimator (Chao *et al.*, 1992) was selected based on biological grounds. The Chao M_{th} estimator is considered to be the most appropriate tool for estimating the size of coastal bottlenose dolphin populations, taking temporal and individual heterogeneity into account (Williams *et al.*, 1993; Wilson *et al.*, 1999; Bearzi *et al.*, 2008; Culloch, 2004).

The Chao time-dependency model (M_t) was selected based on the observation of animals being sighted during some surveys and not others. The Chao M_{th} model was selected based on its ability to take temporal and individual capture probability heterogeneity into account. The null model (M_0) was considered to be highly unlikely under natural circumstances. The behaviour-dependency model (M_b) was also considered to be highly unlikely since photo-identification techniques are considered to be non-invasive eliminating the possibility of an animal becoming 'trap happy' or 'trap shy'.

7.3 Discussion of Results

7.3.1 Abundance Estimates

The first analysis group of dolphins, 'well-marked individuals', had an abundance estimate maximum of 91 with a 95 percent confidence interval of 70 to 138 individuals in 2008. As this is a conservative population estimate as it represents the abundance and occurrence of individuals that are well marked and highly distinguishable resident animals. However, as a 'well-marked' animal may ensure the verification individual identification, there are animals that may be 'recaptureable' or distinguishable that are subject to exclusion from the population size estimation process. In order to produce a population estimate that represents all 'recaptureable' animals, another analysis group, or 'category', was created to provide an estimate of all individuals. This is a much larger estimate accounting for more individuals of the population. The second analysis group of dolphins namely, 'all marked individuals', comprised of 'well-marked individuals' and all 'recaptureable' individuals, had a maximum population estimate at 165 individuals in 2008 with a 95 percent confidence interval of 131 to 227 individuals utilizing the outer southern Moray Firth study area. The estimate of 165 individuals is also close in comparison to the asymptotic value of the new individual discovery curve which is around 170 individuals. Many factors were attributing to this high value including a low (relative to the other probabilities in the sample) mean probability of recapture of 0.29 (P). Studies investigating the abundance of this population are limited to the analysis of only well-marked individuals while the present study takes all recaptureable animals into consideration.

The 'all marked individuals' population estimate of 140 individuals in the year 2013 is also a useful value in such that it represents the most recent estimate of the population size (N). The individuals represented by this value are not limited to animals that are considered to be 'well-marked'. The population estimate of 140 individuals implicated that 70 percent of the estimated 195

individuals (Cheney *et al.*, 2014) of the resident bottlenose dolphin population of the Moray Firth waters are occupying the study area.

With a current estimate of 195 animals (Cheney *et al.,* 2013), this North Sea bottlenose dolphin community is considered to be one of the largest in Europe after the estimated 420 (95% CI: 331–521) individuals in the Normano-Breton Gulf, English Channel and 300 to 350 individuals off the coast of Spain (Louis *et al.*, 2013; Chico Portillo *et al.*, 2011). There is great variance in size of most coastal communities with group sizes ranging from around tens of individuals (Iroise Sea, Brittany, France—Liret, 2001; Sound of Barra, Outer Hebrides, Scotland—Grellier and Wilson, 2003; Sado Estuary, Portugal—Augusto *et al.*, 2011), to 100-250 individuals in the Shannon estuary, Ireland and Cardigan Bay England (Berrow *et al.*, 2012; Pesante *et al.*, 2008).

The overall abundance of the Moray Firth bottlenose dolphin does not appear to be in immediate threat of population decline, however this population could face challenges of genetic isolation as that the movement and exchange of individuals between populations is limited. Genetic analyses have shown some genetic isolation between animals found on the east and west coasts of Scotland, England, and Ireland (Parsons *et al.,* 2002, Thompson *et al.,* 2011*).* A study of a coastal bottlenose dolphin population in the Bay of Islands, New Zealand revealed an annual rate of population decline was likely attributed to a shift in habitat use, calf mortality, and low recruitment (Tezanos-Pinto & Constantine, 2013). This implies potential concerns and information gaps as the Moray Firth population, estimated at a smaller abundance as the Bay of Islands population, has shown shifts in habitat use (Cheney *et al.,* 2014) with the uncertainty of recruitment and, or exchange of individuals between populations (Cheney *et al.,* 2013).

7.3.2 Distribution

From the western most end to the eastern most end of the study area, bottlenose dolphins were observed during all study years (2006-2014) and all study months (May-Oct) (Figures 6.A-6.I, 6.A-4.F). All dolphins sighted occurred within approximately 3 to 4 kilometres of the coastline ranging from depths of 4.2 to 23.4 metres. The highest count of sightings was at a depth of 13.1 metres. This could be considered to be a relatively shallow depth when comparing to studies conducted in the inner Moray Firth where dolphins were observed at their highest abundance at depths over 50 metres (Hastie *et al., 2004)* and depths between 30 to 50 metres in the Shannon estuary of Ireland (Ingram & Rogan, 2002). In contrast with the estuarine-type habitats of the inner Moray Firth and Shannon Estuary, the outer southern Moray Firth resembles more closely that of an open-ocean-type habitat. Studies conducted off the coasts of Florida, California, and Argentina have revealed shallow depth preferences similar to the bottlenose dolphin population in this study (Defran & Weller, 1999; Wursig & Harris, 1990; Scott *et al.*, 1990). There have been cases of no depth preference within coastal occurring bottlenose dolphin communities. A bottlenose community in the Gulf of Mexico was observed at depth ranges of 65 metres up to 1,316 metres. Regions such as the Gulf of Mexico with a high depth variability often have segregated coastal and pelagic communities (Mullin *et al., 2004).* Pelagic-type occurrences within the Moray Firth population has never been observed or recorded, suggesting that the dolphins in the present study prefer the shallower waters and are not segregated into separated communities (Wilson *et al.;* Weir & Stockin; 2001, Culloch; 2004).

Trends in seasonal temporal distribution is demonstrated by the highest number of sightings in July and August and lowest in May and October (Figure 7). This suggests that the dolphins may be using the outer southern Moray Firth mainly during summer months and moving to other resource-rich areas during the winter months. Studies conducted on the inner Moray Firth have revealed similar trends (Wilson *et al.,* 1997). Past studies of regions including the coasts of Wales, Southern United States, and Mexico have also revealed changes in seasonal distribution of bottlenose dolphin populations (Bristow & Rees, 2001; Maze & Würsig, 1999; Shane, 1980; Balance, 1990; Weigle, 1990). The present study along with past studies of the bottlenose dolphins show that they are most prevalent in the Moray Firth during summer months travelling south in the winter, returning back to the area during the spring. Spatial and temporal variation occurs in the distribution of bottlenose dolphin groups within the southern outer Moray Firth. Attributing factors that may influence distribution include limitations of survey efforts along with biological drivers such as mating, calving, predation, prey movement, and anthropogenic factors such as fishing, ecotourism, and construction (Wilson, 1995; Wilson *et al.,* 2004; Louis, 2015).

7.3.3 Group Size

Group size appeared to vary as sighting records indicated that group sizes ranged from 1 to 70 individuals with an average value of 22 individuals. However, the most commonly observed maximum group size count was 30 individuals. Other studies on coastal bottlenose dolphin group sizes revealed similar group size averages of 26 individuals in Normandy (Louis, 2015) and 20 individuals in California (Defran & Weller, 1999). However, these group size numbers could be considered large when compared to the common group size numbers between 5 to 8 individuals shown by numerous studies on coastal habitats worldwide (Wells *et al.,* 1987; Wiszniewski *et al.,* 2009; Bouveroux & Mallefet, 2010; Ansmann *et al., 2012;* Fury *et al.,* 2013; Fruet *et*

al., 2015). Large mean group sizes together may allow for a higher level of cooperation and efficient information transfer in a habitat with scarce resources or large predators (Lusseau *et al.*, 2003). However, this does not seem to be the case for the individuals of the present study as there are no large dolphin-threating predators in the area. Bottlenose dolphin group sizes of the Moray Firth have been smaller in years where less salmon was available, which has been observed in Killer whales of British Columbia (Lusseau *et al.,* 2004). It is likely that fishery activities could be effecting the group sizes. Studies have indicated that larger group sizes can also be the result of predictable resource availability. Group sizes of dolphins interacting with fishery trawler discards were larger than group sizes of those not interacting with fisheries (Chilvers & Corkeron, 2001; Ansmann *et al.,* 2012*).* Group size of the individuals of the present study is likely to be influenced by many resource-related factors but there is not enough current evidence to confidently explain the drivers of group size composition.

7.3.4 Site Fidelity

During years 2006 through 2014, 21 individual dolphins have been seen in the study area consecutively each year. Forty one individuals have been sighted consecutively each year in the past four years (2011-2014), and 51 individuals have been sighted consecutively in the past 5 years (2010-2014). Sixty individuals were sighted at least 6 years out of the 9 year-long study period. These numbers paired with seasonal distribution suggests that the dolphins may be leaving the area during the winter period, but a large proportion of the dolphins are occupying the area every year may be returning to breed in this area every spring season. Thus, it is highly likely that the outer southern Moray Firth an area of bottlenose dolphin breeding site fidelity.

Evidence of reproductive success in the outer southern Moray Firth is apparent and has been evaluated in a relatively detailed extent. According to Robinson *et al.* (2015), reproductive success (RS) was highly variable in the population of interest from one

year to the next, ranging from 0.50 to 1.0 (50 to 100% success) with a mean RS of 0.88 ± 0.12 (88% survival). Individual RS was also highly variable between multiparous females, with six of the most productive mothers (each producing three or more calves) successfully raising all of their offspring to weaning (n=20 calves, plus another four 1 to 2 year olds that are still alive), whilst one mother (ID#216) only managed to raise one of three known calves during the study period. In contrast to tropical regions where births are recorded in the same area throughout the year (Wells & Scott, 2002), births are occurring mostly during the early summer months in the temperate waters of the Moray Firth (Wilson, 1995) suggesting a shorter duration of time in which females are in oestrus. Shorter oestrus cycles reinforce the importance calving/nursery site preferences. Continued monitoring of calf rearing activities and reproductive success is recommended to further to increase certainty of the breeding/calving habitat value of this area.

7.4 Protection and Management

7.4.1 Anthropogenic Disturbance and Implications

Conservation of marine mammal species, such as bottlenose dolphins, is one of the most prevalent environmental management challenges as humans and marine animals both utilize and occupy overlapping regions of coastline waters. Marine construction, fisheries, ecotourism, and industrial harbour activities can negatively impact these animal populations mainly in the form of boat traffic, anthropogenic noise, and overfishing. Species conservation status and importance is not always agreed upon as environmental value is complex and difficult to measure and quantify.

Several large-scale marine renewable energy constructions are planned in the upcoming years in the United Kingdom. Bottlenose dolphin societies associate in groups with a rapid changes in composition multiple times a day. As a highly mobile species, spatial distribution is ever changing influenced by diet specializations, foraging and

breeding strategies. Both feeding and social strategies are mainly dependent upon the dolphins' acoustically-based ability to echolocate, (Louis, 2015). Loud sounds associated with pile-driving events of wind farm construction in the North Sea were linked to the displacement of the distribution of harbour porpoises (*Phocoena phocoena*) (Carstensen *et al.,* 2006; Tougaard *et al.,* 2009). Similar impacts on bottlenose dolphins is highly likely and indisputable as distinct social clusters may respond differently to human activities or environmental changes.

Another common anthropogenic activity know to impact cetacean populations is fisheries management. Fishing activities are permitted within the boundaries of the Marine Protected Areas (MPAs) in Scotland at different levels of restrictions, impacting the fishing industry unevenly throughout sectors. Implementation of fishing restriction zones within Scottish inshore waters was established by the Inshore Fishing (Scotland) Act of 1984. Areas are closed either permanently or temporarily depending on the type of fishing gear, vessel size, or target species. Fishermen have a collectively different opinion on the closed area management. This proposes an enforcement problem for management attempts to protect fish stocks and decrease fisheries conflict. Survey results conducted in 2012 from Pita *et al.* (2013) revealed that the fishery industry had an approximate two-fold increase of vessel and fisherman count outside of the SAC of the inner Moray Firth. The increase in fishing activity may be expected outside of a protected area however this is concerning when considering the extensive habitat use of the bottlenose dolphins in the study area in the outer southern Moray Firth.

Industrial and tourism boat traffic is another potential threat to cetacean species as it may cause a change in 'normal' behaviours of the animals. Studies on the effects of boat traffic within the inner Moray Firth showed a positive correlation between dolphin breathing synchrony and boat presence, causing animals to surface more frequently at an energetically inefficient rate (Hastie *et al.,* 2004). Effectiveness of foraging and mating strategies are expected decrease under circumstances of energy inefficiencies. Bottlenose dolphins in the inner Moray Firth are from the same population as the

dolphins in the outer Moray Firth and it would be expected that they would experience the same energy loss. Avoidance or modified behaviours can lead to fatalities in the form of animal strandings (Louis, 2015).

In depth environmental assessment and an increased level marine mammal protection is recommended to establish and maintain a thriving population of bottlenose dolphins in the Moray Firth and connecting habitats. Development and implementation of effective species protection management practices and accurate protected area designations can serve as a long-term management cetacean conservation solution. Continuous monitoring of abundance, distribution, and reproductive success of the bottlenose dolphins in the outer southern Moray Firth is advised to increase the overall effectiveness of environmental conservation management practices in the area.

8.0 Conclusion

The results of this investigation utilizing mark and recapture abundance estimation and distribution analysis indicated that over 70 percent of the Moray Firth/North Sea bottlenose dolphin population is utilizing all extents of the study area within approximately 4 metres, at depths ranging between 4.2 metres to 23.4 metres off of the coastline from May through October from 2006 to 2014. Results suggest that this is an important region of this population's home range, continuous monitoring and protection of this area would be beneficial to this community of bottlenose dolphins as well as other marine species of the Moray Firth, Scotland and surrounding waters of the North Sea.

9.0 References

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10.0 Appendices
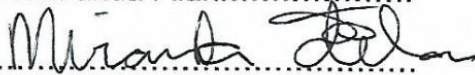
Appendix I: Data Protection Form

DATA PROTECTION ACT 1998
CONSENT FORM: ALL STUDENT PROJECTS/REPORTS/DISSERTATIONS
[EXCEPT PhDs]

Part A – to be completed by all students

I confirm that this project is all my own work. I understand that my written permission is required for the University to make copies of my project/report/dissertation, available to future students for reference purposes and that my name may be evident. I hereby give my consent to my named work being made available. I confirm that my work is not confidential. [see Part B]

Print name...Miranda Filan.........................

Signature.. Date......8/3/15.................

FACULTY: Health, Life and Social Sciences
SCHOOL: Life, Sport and Social Sciences
MODULE NO: BMS11102 .....MSc Research Project...........

TITLE....Mark recapture abundance estimates and distribution of bottlenose dolphins (*Tursiops truncates*) using the southern coastline of the outer southern Moray Firth

LOCATION IN WHICH TO BE HELD: School of Life, Sport and Social Sciences, Sighthill

Part B – to be completed in all cases where the student has had work placement experience

The above named student has completed her project/report/dissertation (delete as appropriate) whilst on assignment with our company/firm. I understand that the work is to be made available for reference purposes and that the company/firm name may be evident. I hereby confirm that this is acceptable and that the work is not confidential as far as the company/firm is concerned.

Name of Company/Firm/ Departmental Head...

Signature.. Date.....................................

Company/firm stamp   Name & Address of External Supervisor

                                        ....

                                        ....

                                        ....

                                        ....

Appendix II: Survey Forms

a)

CETACEAN RESEARCH AND RESCUE UNIT

DATE: (DD/MM/YY)	16/10/04	OBSERVERS : (PLEASE CIRCLE)	(KR) ND (ADD OTHERS:)	RC, MT, CM, CP, EG
START TIME: (HH:MM 24 hrs)	15:30	END TIME: (HH:MM 24 hrs):	17:50	SURVEY: (PLEASE CIRCLE) (PART) / FULL
DEPART FROM:	WHITEHILLS	SEA STATE: (CIRCLE AS APPROPRIATE:	0 (1) 2 3 4 0-Calm, 1-Ripples, 2-Slight wavelets, 3-Larger waves, 4-Choppy, many white caps)	
GPS - DEPARTURE: (N 00°.00'.000 W 00°.00'.000)	N 57 41 230 W 2 34 527			

ACTUAL ROUTE COVERED:
(WHITEHILLS-CROVIE-PENNAN ETC.)   WHITEHILLS ——> GARDENSTOWN ——> WHITEHILLS

ADDITIONAL INFORMATION / REMINDER :

b)

CETACEAN RESEARCH AND RESCUE UNIT - Encounter Form v4.0

ENCOUNTER NO. (e.g. #1, #2 etc.)	1	DATE: (DD/MM/YY)	16/10/04	OBSERVERS: (KR) ND KD RC MT CM CP EG

TIME START: (HH:MM 24 hrs):	GPS START: (N 00°.00".00 W 000°.00".00)	TIME END: (HH:MM 24 hrs):	GPS END: (N 00°.00".00 W 000°.00".00)
15:45	N 57 40 673 W 2 31 420	17:10	N 57 40 825 W 2 20 471

GENERAL AREA at START: (e.g. Buckie harbour)	BANFF	G. AREA at END:	GARDENSTOWN
LANDMARK (e.g.100m NW of harbour entrance)	LEVEL WITH ESSO GARAGE ~ 500M	L.MARK at END:	GAMRIE BAY, BJ CROVIE

INDIVIDUALS PRESENT		PHOTO I.D.	
Structure of subgroups: (e.g. 3A (1C) + 6A + 2A) Total:	N/A 12	Film Nos. (e.g.KR61 & ND3 etc)	KR07 / KR08 KR09 .

Activity
(PLEASE TICK)

☑ FORAGING	☑ TRANSITING	☐ AGGRESSION	☐ MILLING	☑ HALF BREACHING	☑ SYNCHRONISED BREACHING
☑ FEEDING	☐ TAIL SLAPS	☐ SPY HOPS	☑ BOW RIDING	☑ FULL BREACHING	☐ PORPOISING

☑ OTHER (PLEASE SPECIFY) OR COMMENTS

FISH THROWING .

Cetacean Research & Rescue Unit
Bottlenose Dolphin Survey Form

Trip info

DATE: 16/10/04 OBS 1: KEVIN ROBINSON

VESSEL: KETOS OBS 2: ROSS CULLOCH

START TIME: 15:30 OBS 3: MIKE TETLEY

END TIME: 17:50 OBS 4: CAMERON McPHERSON

AREAS COVERED: W/HILLS → OBS 5: CAROLINE PASSINGHAM

G/TOWN → W/HILLS OBS 6: ELAINE GALSTON

ENC # 1. ENCOUNTER START 15:45 ENCOUNTER END: 17:10
(24 hrs) (24 hrs)

GPS START: N 57 40 673 GPS END: N 57 40 825

W 2 31 420 W 2 20 471

AREA START: BANFF AREA END: GARDENSTOWN
e.g. Cullen Bay

LANDMARK START: LEVEL WITH THE ESSO GARAGE (~500m)
e.g. 100m East of Bow Fiddle Rock

LANDMARK END: GAMRIE BAY, B/ CROVIE

MAX NO DOLPHINS: 12. [NO. SUBADULTS: 2. TOTAL CALVES: 2. NO. NEONATES: 0]

NO. SUBGROUPS: N/A SUB-GROUP STRUCTURE (e.g. 3 + 2 + 3+5): N/A

ACTIVITY:

☑ FORAGING ☑ FEEDING ☑ TRANSITING ☐ MILLING
☑ FULL BREACHING ☐ SPY HOPS ☐ TAIL SLAPS ☐ PORPOISING
☑ HALF BREACHING ☑ BOW RIDING ☐ AGGRESSIVE BEHAVIOUR
☑ SYNCHRONISED BREACHING ☑ OTHER FISH THROWING

NOTES / SUMMARY:

THE GROUP WAS V. DISPERSED, MAKING JUDGEMENT
OF SUB-GROUPS V. HARD. THE CALVES SPENT
MOST OF THE ENCOUNTER ON THE BOW OF THE BOAT.
THE 2 SA's WERE SEEN THROWING FISH AT ONE
POINT.

ENVIRONMENTAL INFORMATION:

WEATHER: ☑ SUNNY ☐ CLOUDY BUT BRIGHT ☐ OVERCAST ☐ RAIN ☐ FOG

☐ OTHER

SEA STATE (Beaufort scale e.g. 1-2): 1 TIDAL STATE (e.g. HWS, LWN):

PHOTO ID: (YES) NO FILM Nos: KR07/08/09 FRAMES: 1-36/1-36/1-8

KNOWN INDIVIDUALS PRESENT: 67, 328, 69, 35, 344, 66

Encounter Grid

Enc #: .1....

No. dolphins: .12..   Calves: .2....

Date: 16/10/04

Time: 15:45

	67	328	☺	69	✳	66
R D	kR07 3, 4 kR08 8, 9	kR08 32, 34	kR07 10	kR07 13, 15 kR08 21	kR07 16	kR08 35, 36
L D		kR07 5, 7 kR09 4	kR08 3, 6, 24		kR08 11, 12 kR09 1, 2	kR07 17, 18, 20 kR08 20, 22 29

	35	344	△	□	+	▽
R D	kR07 22, 23 kR09 8	kR07 24	kR07 26 kR08 17	kR09 6, 7	kR07 33, 35	kR08 15, 16, 30
L D		kR08 27, 28		kR07 27, 28 kR08 7, 26		kR07 36

67

Summary Encounter Sheet

DATE: 16/10/04   ENC #: 1

START TIME: 15:45   END TIME: 17:10

GROUP STRUCTURE:

NUMBERS:

AGE:
(AD, SUB-A, CALF)

$$\begin{pmatrix} A & C \\ 67 & 328 \end{pmatrix} \begin{pmatrix} A & C \\ 35 & 3+4 \end{pmatrix} \quad \begin{matrix} A \\ 66 \end{matrix} \quad \begin{matrix} A \\ 69 \end{matrix} \quad \begin{matrix} A \\ 89 \end{matrix}$$

ID:

NUMBERS:

AGE:
(AD, SUB-A, CALF)   SA   SA   A   A   103

ID: 290   322   48   85   A

NUMBERS:

AGE:
(AD, SUB-A, CALF)

ID:

SUBBROUPS: N

SUBGROUP STRUCTURE:
e.g. {3 + 5 + 2}   N/A

WHOLE GROUP (Y/N): Y

TOTAL NO. WITH DEM'S: 9

GENERAL: 12 animals, including 2 older calves.

☑ Info entered into "Sightings" database?

68

Appendix III: Output Files

Program MARK: CAPTURE

2014

WMI: Chao M(th)

Number of trapping occasions was   6

 Number of animals captured, M(t+1), was   39

 Total number of captures, n., was   136

 Frequencies of capture, f(i)

   i= 1 2 3 4 5 6

 f(i)= 8 6 9 1 5 10

Estimator   Gamma   N-hat   se(N-hat)

   ----

     1   0.2897   43.90   3.40
     2   0.2660   42.89   3.11
     3   0.2927   44.03   3.45

 p-hat(j) = 0.41 0.57 0.45 0.50 0.55 0.61

Bias-corrected population estimate is   44 with standard error   3.4502

Approximate 95 percent confidence interval   41 to   55

ALL: Chao M(th)

Number of trapping occasions was   6

Number of animals captured, M(t+1), was   107

Total number of captures, n., was   365

 Frequencies of capture, f(i)

   i= 1 2 3 4 5 6

 f(i)= 29 17 14 5 12 30

 Estimator   Gamma   N-hat   se(N-hat)

   ----

     1   0.3886   128.48   7.91
     2   0.3611   125.08   7.33
     3   0.3780   127.16   7.69

 p-hat(j) = 0.35 0.50 0.40 0.49 0.54 0.61

Bias-corrected population estimate is   127 with standard error   7.6915

Approximate 95 percent confidence interval   117 to   148

2013

<u>WMI: Chao M(th)</u>

Number of trapping occasions was   5

Number of animals captured, M(t+1), was   40

Total number of captures, n., was   107

Frequencies of capture, f(i)

  i= 1 2 3 4 5

f(i)= 13 9 5 4 9

Estimator	Gamma	N-hat	se(N-hat)
1	0.3917	51.33	6.23
2	0.3281	48.09	5.41
3	0.3627	49.84	5.92

p-hat(j) = 0.26 0.40 0.56 0.42 0.50

Bias-corrected population estimate is   50 with standard error   5.9159

Approximate 95 percent confidence interval   44 to   69

<u>ALL: Chao M(th)</u>

Number of trapping occasions was   5

Number of animals captured, M(t+1), was   98

Total number of captures, n., was   244

Frequencies of capture, f(i)

  i= 1 2 3 4 5

f(i)= 41 17 10 11 19

Estimator	Gamma	N-hat	se(N-hat)
1	0.5243	143.63	14.65
2	0.4630	134.96	13.17
3	0.4985	139.94	14.10

p-hat(j) = 0.21 0.31 0.47 0.34 0.41

Bias-corrected population estimate is   140 with standard error   14.1009

Approximate 95 percent confidence interval   121 to   177

2012

<u>WMI: Chao M(th)</u>

Number of trapping occasions was   6

Number of animals captured, M(t+1), was   39

Total number of captures, n., was   114

 Frequencies of capture, f(i)

  i= 1 2 3 4 5 6

f(i)= 11 7 9 2 6 4

```
Estimator     Gamma     N-hat        se(N-hat)
    --------------------------------------------------
        1       0.3331    47.22          4.90
        2       0.2978    45.55          4.47
        3       0.3318    47.16          4.91
```
p-hat(j) = 0.40 0.43 0.45 0.51 0.26 0.38

Bias-corrected population estimate is   47 with standard error   4.9080

Approximate 95 percent confidence interval   42 to   63

<u>ALL: Chao M(th)</u>

Number of trapping occasions was   6

Number of animals captured, M(t+1), was   88

Total number of captures, n., was   247

Frequencies of capture, f(i)

  i= 1 2 3 4 5 6

f(i)= 29 13 17 12   9 8

```
Estimator     Gamma     N-hat        se(N-hat)
    --------------------------------------------------
        1       0.3677    111.79         8.94
        2       0.3358    108.16         8.32
        3       0.3671    111.72         8.96
```
p-hat(j) = 0.38 0.37 0.33 0.47 0.24 0.42

Bias-corrected population estimate is   112 with standard error   8.9557

Approximate 95 percent confidence interval   100 to   136

2011

<u>WMI: Chao M(th)</u>

Number of trapping occasions was   5

Number of animals captured, M(t+1), was   53

Total number of captures, n., was   148

 Frequencies of capture, f(i)

  i= 1 2 3 4 5

f(i)= 15   6 11 17   4

```
 Estimator     Gamma     N-hat        se(N-hat)
    --------------------------------------------------
        1       0.2443    63.06          5.34
        2       0.2169    61.22          4.95
        3       0.2681    64.67          5.82
```
p-hat(j) = 0.23 0.46 0.43 0.52 0.63

Bias-corrected population estimate is   65 with standard error   5.8157

Approximate 95 percent confidence interval   58 to   82

ALL: Chao M(th)

Number of trapping occasions was   5

Number of animals captured, M(t+1), was   97

Total number of captures, n., was   272

Frequencies of capture, f(i)

  i= 1 2 3 4 5

f(i)= 27 11 23 26 10

Estimator   Gamma   N-hat   se(N-hat)

  ----

    1   0.2546   115.32   7.20
    2   0.2270   111.98   6.66
    3   0.2861   119.18   7.99

p-hat(j) = 0.22 0.45 0.41 0.55 0.66

Bias-corrected population estimate is   119 with standard error   7.9900

Approximate 95 percent confidence interval   109 to   140

2010

WMI: Chao M(th)

Number of trapping occasions was   6

Number of animals captured, M(t+1), was   44

Total number of captures, n., was   124

Frequencies of capture, f(i)

  i= 1 2 3 4 5 6

f(i)= 11 10 7 8 8 0

Estimator   Gamma   N-hat   se(N-hat)

  ----

    1   0.2323   51.09   4.25
    2   0.1901   48.85   3.71
    3   0.2119   50.00   4.02

 p-hat(j) = 0.60 0.30 0.50 0.42 0.52 0.14

Bias-corrected population estimate is   50 with standard error   4.0245

Approximate 95 percent confidence interval   46 to   63

ALL: Chao M(th)

 Number of trapping occasions was   6

 Number of animals captured, M(t+1), was   81

 Total number of captures, n., was   217

 Frequencies of capture, f(i)

  i= 1 2 3 4 5 6

f(i)= 26 16 12 12 15 0

Estimator   Gamma   N-hat   se(N-hat)

1	0.3244	101.61	8.11
2	0.2815	97.09	7.31
3	0.3053	99.58	7.79

p-hat(j) = 0.58 0.31 0.39 0.40 0.38 0.11

Bias-corrected population estimate is   100 with standard error   7.7875

Approximate 95 percent confidence interval   90 to   121

2009

WMI: Chao M(th)

Number of trapping occasions was   4

Number of animals captured, M(t+1), was   39

Total number of captures, n., was   80

Frequencies of capture, f(i)

  i= 1 2 3 4

 f(i)= 9 19 11   0

Estimator	Gamma	N-hat	se(N-hat)
1	0.0723	44.68	3.68
2	0.0000	37.29	1.27
3	0.0477	43.41	4.74

p-hat(j) = 0.07 0.65 0.37 0.77

Bias-corrected population estimate is   43 with standard error   4.7377

Approximate 95 percent confidence interval   40 to   63

ALL: Chao M(th)

Number of trapping occasions was   4

Number of animals captured, M(t+1), was   68

Total number of captures, n., was   131

Frequencies of capture, f(i)

  i= 1 2 3 4

 f(i)= 22 29 17   0

Estimator	Gamma	N-hat	se(N-hat)
1	0.1808	86.50	7.84
2	0.0029	69.48	4.79
3	0.1560	84.05	9.36

p-hat(j) = 0.04 0.49 0.31 0.73

Bias-corrected population estimate is   84 with standard error   9.3597

Approximate 95 percent confidence interval   74 to   114

2008

WMI: Chao M(th)

Number of trapping occasions was   4

Number of animals captured, M(t+1), was   51

Total number of captures, n., was   117

Frequencies of capture, f(i)

  i= 1 2 3 4

f(i)= 24 3 9 15

Estimator   Gamma   N-hat   se(N-hat)

  ----

    1   0.5510   80.80   13.12

    2   0.5184   78.13   12.48

    3   0.6773   91.50   16.44

p-hat(j) = 0.24 0.29 0.26 0.49

Bias-corrected population estimate is   91 with standard error   16.4411

Approximate 95 percent confidence interval   70 to   138

ALL: Chao M(th)

Number of trapping occasions was   4

 Number of animals captured, M(t+1), was   89

 Total number of captures, n., was   189

 Frequencies of capture, f(i)

  i= 1 2 3 4

f(i)= 44 10 15 20

Estimator   Gamma   N-hat   se(N-hat)

  ----

    1   0.5881   149.74   19.94

    2   0.5183   139.33   18.04

    3   0.6850   164.76   23.93

p-hat(j) = 0.19 0.25 0.24 0.47

Bias-corrected population estimate is   165 with standard error   23.9347

Approximate 95 percent confidence interval   131 to   227

2007

WMI: Chao M(th)

Number of trapping occasions was   5

 Number of animals captured, M(t+1), was   41

 Total number of captures, n., was   119

 Frequencies of capture, f(i)

  i= 1 2 3 4 5

f(i)= 8 8 10 10 5

Estimator   Gamma   N-hat   se(N-hat)

```
--------------------------------------------------
   1      0.1658    45.38       3.10
   2      0.1253    43.46       2.60
   3      0.1764    45.88       3.36
```

p-hat(j) = 0.35 0.61 0.57 0.67 0.39

Bias-corrected population estimate is   46 with standard error   3.3643

Approximate 95 percent confidence interval   43 to 57

ALL: Chao M(th)

Number of trapping occasions was   5

Number of animals captured, M(t+1), was   60

Total number of captures, n., was   159

Frequencies of capture, f(i)

  i= 1 2 3 4 5

f(i)= 18 10 14 11 7

```
 Estimator    Gamma    N-hat        se(N-hat)

   --------------------------------------------------
    1      0.2783    73.31       6.33
    2      0.2345    69.94       5.66
    3      0.2967    74.74       6.78
```

p-hat(j) = 0.29 0.44 0.45 0.60 0.33

Bias-corrected population estimate is   75 with standard error   6.7751

Approximate 95 percent confidence interval   67 to   94

2006

WMI: Chao M(th)

Number of trapping occasions was   6

Number of animals captured, M(t+1), was   67

Total number of captures, n., was   172

Frequencies of capture, f(i)

 i= 1 2 3 4 5 6

f(i)= 25 11 10 11 9 1

```
Estimator    Gamma    N-hat        se(N-hat)

   --------------------------------------------------
    1      0.4357    91.14       9.89
    2      0.3940    87.31       9.11
    3      0.4222    89.89       9.66
```

p-hat(j) = 0.01 0.33 0.27 0.37 0.61 0.32

Bias-corrected population estimate is   90 with standard error   9.6637

Approximate 95 percent confidence interval   78 to   117

ALL: Chao M(th)

Number of trapping occasions was   6

Number of animals captured, M(t+1), was   96

Total number of captures, n., was   246

Frequencies of capture, f(i)

  i= 1 2 3 4 5 6

f(i)= 34 17 15 18 11 1

 Estimator   Gamma   N-hat   se(N-hat)

  ----

     1   0.3854   126.60   10.74

     2   0.3424   121.02   9.81

     3   0.3705   124.66   10.46

 p-hat(j) = 0.01 0.33 0.28 0.38 0.62 0.35

Bias-corrected population estimate is   125 with standard error   10.4618

Approximate 95 percent confidence interval   111 to   153