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

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

- John Sawhill

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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 run through a Chao time-dependent heterogeneity model (Mth) 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 ranged 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 (57°400N 3°300W), 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
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 illustrates 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
(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 Mi) estimator (Chao et al., 1992) were selected. The Chao Mi 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 ($M_o$) 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):

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

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

Whereas:

- $N$ = the total population estimate
- $\hat{N}$ = the estimated number of permanently marked individuals
- $\Theta$ = the proportion of permanent marked individuals in the sample
- $\theta$ = the proportion of permanent marked individuals in the sample
- $V$ = the variance of $\hat{N}$
- $n$ = 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.

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

*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 Mth 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.

![New Individuals Discovery Curve](image_url)

**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 ($M_t$) 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 $M_t$: Well-Marked Individuals

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

(B) Chao $M_t$: All Marked Individuals

<table>
<thead>
<tr>
<th>Year</th>
<th>N</th>
<th>P</th>
<th>N-hat</th>
<th>S.E. (N-hat)</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>96</td>
<td>0.33</td>
<td>125</td>
<td>10.46</td>
<td>111-153</td>
</tr>
<tr>
<td>2007</td>
<td>60</td>
<td>0.36</td>
<td>75</td>
<td>6.78</td>
<td>67-94</td>
</tr>
<tr>
<td>2008</td>
<td>89</td>
<td>0.29</td>
<td>165</td>
<td>23.93</td>
<td>131-227</td>
</tr>
<tr>
<td>2009</td>
<td>68</td>
<td>0.39</td>
<td>84</td>
<td>9.36</td>
<td>74-114</td>
</tr>
<tr>
<td>2010</td>
<td>81</td>
<td>0.36</td>
<td>100</td>
<td>7.79</td>
<td>90-121</td>
</tr>
<tr>
<td>2011</td>
<td>97</td>
<td>0.46</td>
<td>119</td>
<td>8.00</td>
<td>109-140</td>
</tr>
<tr>
<td>2012</td>
<td>88</td>
<td>0.37</td>
<td>112</td>
<td>9.00</td>
<td>100-136</td>
</tr>
<tr>
<td>2013</td>
<td>98</td>
<td>0.35</td>
<td>140</td>
<td>14.00</td>
<td>121-177</td>
</tr>
<tr>
<td>2014</td>
<td>107</td>
<td>0.48</td>
<td>127</td>
<td>7.69</td>
<td>117-148</td>
</tr>
</tbody>
</table>
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):
Figures 5.A-5.I. Encounter Distribution by Year: Encounter distribution maps for 2006 to 2014 respectively below:

2006

2007

2008
2009

2010
Figures 6.A-6.F. Encounter Distribution by Month: Encounter distribution maps pooled by month (May to October) from 2006 to 2014 inclusive:
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.
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.

#### 7.2 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 fins 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.

![Marked Individual Categories](image)

**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 Mth estimator (Chao et al., 1992) was selected based on biological grounds. The Chao Mth 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 (Mt) was selected based on the observation of animals being sighted during some surveys and not others. The Chao Mth model was selected based on its ability to take temporal and individual capture probability heterogeneity into account. The null model (M0) was considered to be highly unlikely under natural circumstances. The behaviour-dependency model (Mb) 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
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-threatening 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 known 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


Culloch, R. M. Mark recapture abundance estimates and distribution of bottlenose dolphins (*Tursiops truncatus*) using the southern coastline of the outer Moray Firth, NE Scotland. MSc Thesis, University of Wales, Bangor, (2004).


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

......................................................................................................................
......................................................................................................................
......................................................................................................................
......................................................................................................................
......................................................................................................................
### CETACEAN RESEARCH AND RESCUE UNIT

<table>
<thead>
<tr>
<th>DATE:</th>
<th>16/10/04</th>
<th>OBSERVERS:</th>
<th>KR ND</th>
<th>RC...MT...CM...CP...EC...</th>
</tr>
</thead>
<tbody>
<tr>
<td>START TIME:</td>
<td>15:30</td>
<td>END TIME:</td>
<td>17:50</td>
<td>SURVEY: FULL (PLEASE CIRCLE)</td>
</tr>
<tr>
<td>DEPART FROM:</td>
<td>WHITEHILLS</td>
<td>SEA STATE:</td>
<td>0 1 2 3 4</td>
<td></td>
</tr>
<tr>
<td>GPS - DEPARTURE:</td>
<td>N 57 41 230</td>
<td>W 2 34 527</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**ACTUAL ROUTE COVERED:**
WHITEHILLS → COPESTOWN → WHITEHILLS

**ADDITIONAL INFORMATION / REMINDER:**

---
---
---
---
---
---
---
---
**GETACEAN RESEARCH AND RESCUE UNIT - Encounter Form v4.0**

<table>
<thead>
<tr>
<th>ENCOUNTER NO.</th>
<th>DATE: 16/10/04</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

| TIME START: 15:45 | GPS START: N 57 40 673 W 2 31 420 |
| TIME END: 17:10  | GPS END: N 57 40 825 W 2 20 471 |

**GENERAL AREA at START:** Banff  
**G. AREA at END:** Gardenstown

**LANDMARK**  
Level with E000 Garage 2 500m

**LMARK at END:** Camrie Bay, Bo Crovie

**INDIVIDUALS PRESENT:** N/A

**PHOTO I.D.:**  
Film Nos. KRO7 / KRO8  
KRO9

**Structure of subgroups:**  
N/A

**Total:** 12

**Activity**  
- FORAGING
- TRANSITING
- AGGRESSION
- MILLING
- HALF BREACHING
- SYNCHRONISED BREACHING
- FEEDING
- TAIL SLAPS
- SPY HOPS
- SHOW RIDING
- FULL BREACHING
- PORPOISING

FISH THROWING
Cetacean Research & Rescue Unit
Bottlenose Dolphin Survey Form

Trip info

DATE: 16/10/04  OBS 1: KEVIN ROBINSON
VESSEL: KEPPO  OBS 2: ROSS CULLEN
START TIME: 15:30  OBS 3: MIKE TATTERS
END TIME: 17:50  OBS 4: CAMERON McPHERSON
AREAS COVERED: 1/1/10, 3/1/10  OBS 5: CAROLINE PASKINGHAM
G. TOWN, C. HILL  OBS 6: ELAINE CALSON

ENC # 1. ENCOUNTER START: 15:45
(24 hrs) ENCOUNTER END: 17:10
(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: GARDEN TOWN
e.g. Cullen Bay

LANDMARK START: LEVERICH WITH THE FLOOR CAGE (2500 m)
e.g. 100m East of Bow Fiddle Rock

LANDMARK END: CROVIE BAY, B.3 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:
q FORAGING  q FEEDING  q TRANSITING  q MILLING
q FULL BREACHING  q SPY HOPS  q TAIL SLAPS  q PORPOISING
q HALF BREACHING  q BOW RIDING  q AGGRESSIVE BEHAVIOUR
q SYNCHRONISED BREACHING  q OTHER q FISH q THREAT

NOTES / SUMMARY:
The group was v. dispersed, making judgement of sub-group v. hard. The calves spent most of the encounter on the bow of the boat. The 2 calf's were seen throwing fish at one point.

ENVIRONMENTAL INFORMATION:

WEATHER: q SUNNY  q CLOUDY BUT BRIGHT  q OVERCAST  q RAIN  q FOG
q OTHER

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

PHOTO ID:  YES  NO  FILM Nos: KRO7/08/09  FRAMES: 1-36/1-36/1-8
KNOWN INDIVIDUALS PRESENT: 17 32 8 19 35 34 4 6
## Encounter Grid

Encounter #: 

Date: 10/10/04

No. dolphins: 12  
Calves: 2  
Time: 15:45

<table>
<thead>
<tr>
<th></th>
<th>67</th>
<th>328</th>
<th>☺</th>
<th>69</th>
<th>*</th>
<th>66</th>
</tr>
</thead>
<tbody>
<tr>
<td>RD</td>
<td>KRO7 3, 4</td>
<td>KRO8 32, 34</td>
<td>KRO7 10</td>
<td>KRO7 13, 15</td>
<td>KRO7 16</td>
<td>KRO8 35, 36</td>
</tr>
<tr>
<td>LD</td>
<td>KRO7 5, 7</td>
<td>KRO8 3, 6, 24</td>
<td>KRO8 11, 12</td>
<td>KRO9 1, 2</td>
<td>KRO8 17, 18, 20</td>
<td>KRO8 20, 22, 29</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>35</th>
<th>344</th>
<th>△</th>
<th>□</th>
<th>+</th>
<th>△</th>
</tr>
</thead>
<tbody>
<tr>
<td>RD</td>
<td>KRO7 22, 23, 24</td>
<td>KRO7 26</td>
<td>KRO7 6, 7</td>
<td>KRO9 33, 35</td>
<td>KRO7 15, 16, 30</td>
<td>KRO8</td>
</tr>
<tr>
<td>LD</td>
<td>KRO8 27, 28</td>
<td>KRO7 27, 28</td>
<td>KRO8 7, 26</td>
<td>KRO7 36</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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)  (A C) (A C) A A A
   ID: (67 328) (35 344) 66 69 89

NUMBERS:

AGE: (AD, SUB-A, CALF)  SA SA A A 103
   ID: 290 322 48 85 A

NUMBERS:

AGE: (AD, SUB-A, CALF)
   ID:

# SUBGROUPS: \( \sqrt{ } \)
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

\( \checkmark \) Info entered into "Sightings" database?
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(i) = 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(i) = 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

WMI: Chao M(th)

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

ALL: Chao M(th)

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

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  114

Frequencies of capture, f(i)

i=  1  2  3  4  5  6
f(i)=  11  7  9  2  6  4
<table>
<thead>
<tr>
<th>Estimator</th>
<th>Gamma</th>
<th>N-hat</th>
<th>se(N-hat)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.3331</td>
<td>47.22</td>
<td>4.90</td>
</tr>
<tr>
<td>2</td>
<td>0.2978</td>
<td>45.55</td>
<td>4.47</td>
</tr>
<tr>
<td>3</td>
<td>0.3318</td>
<td>47.16</td>
<td>4.91</td>
</tr>
</tbody>
</table>

\(p\)-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

**ALL:** Chao M(th)

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)

\(i=\ 1\ 2\ 3\ 4\ 5\ 6\)

\(f(i)=\ 29\ 13\ 17\ 12\ 9\ 8\)

<table>
<thead>
<tr>
<th>Estimator</th>
<th>Gamma</th>
<th>N-hat</th>
<th>se(N-hat)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.3677</td>
<td>111.79</td>
<td>8.94</td>
</tr>
<tr>
<td>2</td>
<td>0.3358</td>
<td>108.16</td>
<td>8.32</td>
</tr>
<tr>
<td>3</td>
<td>0.3671</td>
<td>111.72</td>
<td>8.96</td>
</tr>
</tbody>
</table>

\(p\)-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**

WMI: Chao M(th)

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)

\(i=\ 1\ 2\ 3\ 4\ 5\)

\(f(i)=\ 15\ 6\ 11\ 17\ 4\)

<table>
<thead>
<tr>
<th>Estimator</th>
<th>Gamma</th>
<th>N-hat</th>
<th>se(N-hat)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.2443</td>
<td>63.06</td>
<td>5.34</td>
</tr>
<tr>
<td>2</td>
<td>0.2169</td>
<td>61.22</td>
<td>4.95</td>
</tr>
<tr>
<td>3</td>
<td>0.2681</td>
<td>64.67</td>
<td>5.82</td>
</tr>
</tbody>
</table>

\(p\)-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)

\[
i = 1 \quad 2 \quad 3 \quad 4 \quad 5
\quad f(i) = 27 \quad 11 \quad 23 \quad 26 \quad 10
\]

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

\[
p-hat(j) = 0.22 \quad 0.45 \quad 0.41 \quad 0.55 \quad 0.66
\]
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)

\[
i = 1 \quad 2 \quad 3 \quad 4 \quad 5 \quad 6
\quad f(i) = 11 \quad 10 \quad 7 \quad 8 \quad 8 \quad 0
\]

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

\[
p-hat(j) = 0.60 \quad 0.30 \quad 0.50 \quad 0.42 \quad 0.52 \quad 0.14
\]
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)

\[
i = 1 \quad 2 \quad 3 \quad 4 \quad 5 \quad 6
\quad f(i) = 26 \quad 16 \quad 12 \quad 12 \quad 15 \quad 0
\]

Estimator  Gamma  N-hat  se(N-hat)
---------------------------------------------
<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>0.3244</th>
<th>101.61</th>
<th>8.11</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.2815</td>
<td>97.09</td>
<td>7.31</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.3053</td>
<td>99.58</td>
<td>7.79</td>
<td></td>
</tr>
</tbody>
</table>

\[ p\text{-}hat(j) = 0.58 0.31 0.39 0.40 0.38 0.11 \]

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, \(f(i)\)

\[
\begin{array}{cccc}
   & i= & 1 & 2 & 3 & 4 \\
f(i)= & 9 & 19 & 11 & 0 \\
\end{array}
\]

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

\[
\begin{array}{cccc}
   & 1 & 0.0723 & 44.68 & 3.68 \\
   & 2 & 0.0000 & 37.29 & 1.27 \\
   & 3 & 0.0477 & 43.41 & 4.74 \\
\end{array}
\]

\[ p\text{-}hat(j) = 0.07 0.65 0.37 0.77 \]

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, \(f(i)\)

\[
\begin{array}{cccc}
   & i= & 1 & 2 & 3 & 4 \\
f(i)= & 22 & 29 & 17 & 0 \\
\end{array}
\]

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

\[
\begin{array}{cccc}
   & 1 & 0.1808 & 86.50 & 7.84 \\
   & 2 & 0.0029 & 69.48 & 4.79 \\
   & 3 & 0.1560 & 84.05 & 9.36 \\
\end{array}
\]

\[ p\text{-}hat(j) = 0.04 0.49 0.31 0.73 \]

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)
\[ i = 1 \quad 2 \quad 3 \quad 4 \]
\[ f(i) = 24 \quad 3 \quad 9 \quad 15 \]

<table>
<thead>
<tr>
<th>Estimator</th>
<th>Gamma</th>
<th>N-hat</th>
<th>se(N-hat)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>0.5510</td>
<td>80.80</td>
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<tr>
<td></td>
<td>2</td>
<td>0.5184</td>
<td>78.13</td>
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<tr>
<td></td>
<td>3</td>
<td>0.6773</td>
<td>91.50</td>
</tr>
</tbody>
</table>

\[ \hat{p}(j) = 0.24 \quad 0.29 \quad 0.26 \quad 0.49 \]
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)
\[ i = 1 \quad 2 \quad 3 \quad 4 \]
\[ f(i) = 44 \quad 10 \quad 15 \quad 20 \]

<table>
<thead>
<tr>
<th>Estimator</th>
<th>Gamma</th>
<th>N-hat</th>
<th>se(N-hat)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>0.5881</td>
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<td>2</td>
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<tr>
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<td>3</td>
<td>0.6850</td>
<td>164.76</td>
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</tbody>
</table>

\[ \hat{p}(j) = 0.19 \quad 0.25 \quad 0.24 \quad 0.47 \]
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)
\[ i = 1 \quad 2 \quad 3 \quad 4 \quad 5 \]
\[ f(i) = 8 \quad 8 \quad 10 \quad 10 \quad 5 \]

<table>
<thead>
<tr>
<th>Estimator</th>
<th>Gamma</th>
<th>N-hat</th>
<th>se(N-hat)</th>
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</thead>
<tbody>
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<td></td>
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</tr>
<tr>
<td></td>
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<td>Gamma</td>
<td>N-hat</td>
<td>se(N-hat)</td>
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<tr>
<td>1</td>
<td>0.2783</td>
<td>73.31</td>
<td>6.33</td>
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<tr>
<td>2</td>
<td>0.2345</td>
<td>69.94</td>
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<tr>
<td>3</td>
<td>0.2967</td>
<td>74.74</td>
<td>6.78</td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th></th>
<th>Gamma</th>
<th>N-hat</th>
<th>se(N-hat)</th>
</tr>
</thead>
<tbody>
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<td>9.89</td>
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<tr>
<td>2</td>
<td>0.3940</td>
<td>87.31</td>
<td>9.11</td>
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<tr>
<td>3</td>
<td>0.4222</td>
<td>89.89</td>
<td>9.66</td>
</tr>
</tbody>
</table>

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