



**Predicting calving/nursery areas for bottlenose dolphins
frequenting the outer southern Moray Firth**

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Abstract

Mapping and predicting the distribution of nursery areas is essential in the long-term, effective conservation of the bottlenose dolphin population in the Moray Firth, and has yet to be done along the outer southern firth coastline. To determine the possible locations of these calving areas, the temporal and spatial distributions of 34 female bottlenose dolphins and their 133 respective calves were investigated along the outer southern Moray Firth in northeast Scotland, using data collected by the Cetacean Research & Rescue Unit between May and October (inclusive), from 2001 to 2024, comprising a total 24,074 km of survey effort. The social associations of these 34 mothers were also investigated using SOCPROG 2.10, based on sightings data collected from July 1997 to August 2025.

This study found the number of sightings of mother-calf pairs to fluctuate heavily throughout the study period, even though they were corrected for by effort (sightings per km survey effort). Mother-calf pairs showed the highest site fidelity to the stretch of coastline between the mouths of the two salmon rivers, the River Spey and the River Deveron. The study group as a whole showed a preference for the rocky outcrops along the prominent headlands of this stretch, however the most established mothers (a sub-set of the study group defined as the 10 females with the highest number of sightings in the study area, and having produced at least five calves) were seen to prefer the mouth of the River Spey. The established mothers showed largely overlapping distributions and strong associations to one another, however several were observed to have unique distributions. The 34 mothers were seen to have a low number of strong associations and a higher number of weaker associations, typical of a fission-fusion society. The strongest associations within the population (≥ 0.5 half weight index of association) were determined to be influenced by kin (three of seven pairs) and reproductive state (four of seven pairs).

The knowledge of the temporal and spatial distribution of the critically important nursery habitats along this coastline can help to inform regulators on the potential impacts of ongoing developments (i.e. offshore wind farm installations and oil and gas activities) on this population, and continue to increase the pressure for adequate protections (such as the expansion of the existing Special Area of Conservation within the inner firth) for these protected species in the outer southern Moray Firth.

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1 Introduction

The common bottlenose dolphin (*Tursiops truncatus*) is perhaps the most well-known and well-studied cetacean species, due to its coastal nature and ability to survive in captivity (Shane *et al.*, 1986). The global population is estimated to be around 750,000 individuals and the species is listed as “Of Least Concern” by the IUCN regarding its conservation status (Wells *et al.*, 2019). This status does not negate the need for conservation efforts however, as in the face of a growing human population and changing climate, threats to the marine environment and its inhabitants are ever increasing. As with every species, conservation efforts are essential to prevent the status of bottlenose dolphins from changing. Common bottlenose dolphins are important members of the ocean ecosystem, regulating the fish, squid and crustacean populations through top-down control, and moving nutrients throughout the ecosystem through processes such as bioturbation (churning up of sediment when foraging) and excretion (fertilising the environment for phytoplankton), two forms of bottom-up control (Kiszka *et al.*, 2022). These marine mammals also act as biological indicators of ecosystem health, through their role as top predators, resulting in the concentration of contaminants within their bodies (known as bioaccumulation) which provides scientists with an accurate picture of ecosystem health (Wells *et al.*, 2004).

The effective conservation of cetacean species relies on the collaboration of international bodies, national governments, and global and local research NGOs, establishing policies for sustainable fishing, climate change and pollution, as well as the implementation of Marine Protected Areas (MPAs). An in-depth understanding of their spatial distribution and critical habitats and how these overlap with human activities, is the first step towards informing policies for the creation of protected areas (La Manna *et al.*, 2020). Efforts to protect breeding females and their calves are considered fundamental to population survival and continued growth, with the growth rate of a population being inevitably dependent on the number of sexually-mature females, and the ability of their calves to survive into adulthood.

1.1 Cetacea

Whales, dolphins and porpoises are collectively grouped into the order Cetacea, which is divided into two suborders, the Mysticeti and Odontoceti respectively. The Mysticeti includes

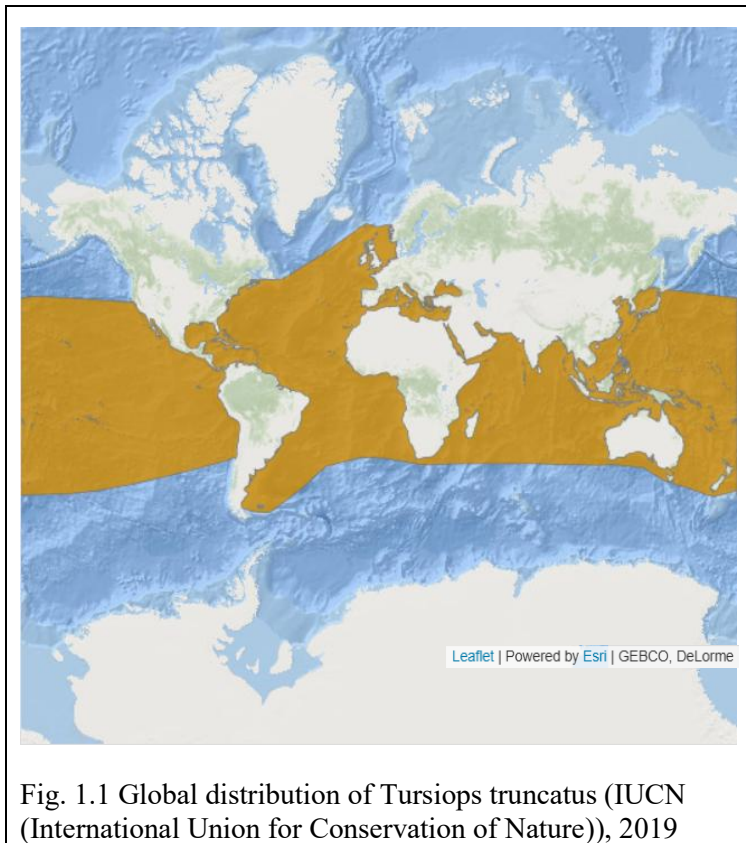
all whales with baleen plates and a filter feeding strategy, whilst the Odontoceti is comprised of toothed whales, which all have the ability to echolocate (Fordyce, 2009), and contains 10 families, 3 of which form the superfamily Delphinoidea – namely the Monodontidae, Delphinidae and Phocoenidae. The further 7 families are divided between the sperm whales, beaked whales and river dolphins (Nikaido *et al.*, 2001). The 4 families of river dolphin are distinct from their oceanic relative delphinoids, as they inhabit and are restricted to their geographically disjunct freshwater river systems, and are inherently phylogenetically and morphologically distinct (Hamilton *et al.*, 2001).

Members of the superfamily Delphinoidea are able to exploit a wide variety of marine habitats, being found in all the world's oceans and seas. The family Delphinidae contains 33 to 35 extant species, with a high degree of variation between species in their external morphology. All species share typical morphological characteristics with the rest of the Odontoceti, such as a single blowhole and a fusiform body shape, but are differentiated from their closest relatives, the phocoenids, by their teeth and skull shape. The teeth of all phocoenids are spade shaped, while those of delphinids are more conical, and the skull of all delphinids has a more distinct vertex (LeDuc, 2009). The morphology within the family Delphinidae is, however, very broad, containing a wide spectrum of tooth counts, rostrum lengths and widths due to the wide range of ecological niches occupied by this family (LeDuc, 2009).

1.2 The common bottlenose dolphin, *Tursiops truncatus*

The most common genus within the family Delphinidae is *Tursiops*. There are multiple species of bottlenose dolphin, including the Indo-Pacific bottlenose dolphin (*Tursiops aduncus*). However, this thesis will be focused on the common bottlenose dolphin (*Tursiops truncatus*), which will hereafter be referred to as the bottlenose dolphin.

1.2.1 Habitat and morphology



Bottlenose dolphins are a cosmopolitan species, widely distributed throughout temperate and tropical waters where they thrive in both coastal and offshore environments. The species is mostly prevalent closer to the shore, around oceanic islands and over the continental shelf, where the water is the warmest. These dolphins are found as far north as the Kuril Islands in the North Pacific and the Lofoten Islands in the North Atlantic, and as far south as New Zealand. Morphologically, they have a

characteristically robust body, with a short rostrum and a centrally placed falcate-shaped dorsal fin. The body colouration is typically dark grey on the dorsal and lateral sides, with a lighter grey ventral side. The species can reach from 2.5 to 4 m in length, however the size (and colouration) is variable between populations depending on their geographical location and habitat (Wells and Scott, 2009).

1.2.2 Life cycle

The age at sexual maturity also varies between geographic location and between sexes in bottlenose dolphins, with females reaching sexual maturity from 5 to 13 years old and males from 9 to 14 years (Wells and Scott, 2009). Female bottlenose have a gestation period of approximately 12 months (Cockcroft and Ross, 1990), with a majority of births taking place from late spring to early autumn, corresponding with warmer average water temperatures (Thayer *et al.*, 2003; Robinson *et al.*, 2017b). However, in tropical waters, births have been recorded year-round (Haase and Schneider, 2001). As social mammals, these dolphins show high levels of maternal care, nursing their young for 18 to 24 months (Cockcroft and Ross, 1990), and showing close association for the first 3 to 6 years of the calf's life (Grellier *et al.*,

2003). The amount of time a youngster spends in close proximity to its mother decreases over the first 7 years of the calf's life, with the calf usually remaining in the same group, but surfacing next to their mother much less frequently over time (Grellier *et al.*, 2003). The interbirth interval has been recorded from 2 to 7 years, and varies between populations, but is most commonly between 3 and 4 years, and is influenced largely by the mother's proximity to reproductive senescence and calf loss (Mann *et al.*, 2000; Robinson *et al.*, 2017b; Blasi *et al.*, 2020).

1.3 Population dynamics and social interactions

Due to their highly social nature, bottlenose dolphins are typically found in groups of 2 to 15 individuals, but can surpass 1,000 in some locations, with larger average group sizes of 140 individuals being recorded in South Africa (Shane *et al.*, 1986). Group size seems to be influenced by water depth and proximity to shore, with larger groups generally found further offshore in deeper waters (Shane *et al.*, 1986) where predation may be more of an issue. Bottlenoses live in a fission-fusion society (first described by Kumer 1971), where the merging (fusion) and separation (fission) of groups and subgroups are common and associations between individuals are relatively fluid. Thus, small units of recurring associations join and leave other units for periods of minutes or hours (Wells, 1987). Factors such as age, sex, kin, status and reproductive state may all determine the composition of these social units (Wells, 1987; Fruet *et al.*, 2015; Robinson *et al.*, 2017b). A review by Shane *et al.* (1986) found that adult males tend to associate in pairs or small groups, moving between groups of females, while subadult males congregate in bachelor groups, only associating with females who enter their range rather than actively seeking them out. Associations between adult females have further been observed based on the presence and/or age of their offspring (e.g. Robinson *et al.*, 2017b). Reproductive state is thought to be the predominant factor in determining associations between female bottlenose, with those ranging from early-stage pregnancy to the newborn period forming associations, as well as those in late-stage pregnancy to having first year calves (Eisfeld and Robinson, 2004; Möller and Harcourt, 2008). These associations are thought to be a form of protection, with males known to injure, kill, or separate young calves from their mothers in some populations (e.g. Robinson, 2014), such that travelling as a group may reduce the chance of directed aggression or sexual coercion from males (Möller and Harcourt, 2008).

1.4 Site fidelity

Site fidelity is the tendency of an individual to return to and reuse a previously occupied location over time (Switzer, 1993). This behaviour has been studied and documented in many species across 3 phyla, and is determined by factors such as reproductive success, probability of mortality and age (Switzer, 1993, 1997). Predictable and productive habitats allow for high availability of food and resources, along with spatial and temporal familiarity and knowledge of these, leading to higher site fidelity and more restricted movement patterns of individuals (Knip *et al.*, 2012; Passadore *et al.*, 2018). Although not explicitly seen in dolphins, calf survival and reproductive success is also seen to contribute to site fidelity (Lafontaine *et al.*, 2017). In the inner Coffin Bay in southern Australia (Passadore *et al.*, 2018), bottlenose dolphins described as resident were found to have small representative ranges, staying close to their main centre of use. These ranges were linked to highly productive and sheltered habitats. Home ranges of individuals were found to decrease as food became increasingly available, as food can be accessed more easily in a specific area, and the number of individuals in the population increased, due to competition from neighbours causing constraint.

In Western Australia (Sprogis *et al.*, 2016), Indo-Pacific bottlenose dolphins in more sheltered areas, such as bays and estuaries, were found to have smaller home ranges and show greater site fidelity. This was thought to be due both to the availability of prey and the risk of predation. The Leschenault Estuary is highly productive, with a much higher biomass, quality, and abundance of prey, when compared to the open ocean, which means individuals can gain maximum energy without having to expend so much. This is a highly optimal and therefore significant factor in home range selection and subsequent site fidelity. Females in this population were also seen to occupy smaller home ranges than males, who were seen to move widely between groups of females and their home ranges, forming alliances to cooperatively gain access to female cohorts to maximise mating opportunities. During the breeding season, male distribution was influenced by the distribution of females, whereas during the nonbreeding seasons, prey availability was the driver, leading to wide and varied home ranges annually. The most sheltered areas along this coastline, for which females showed the highest site fidelity, showed a significant overlap with areas of highest human activity, greatly increasing the vulnerability of these dolphins to anthropogenic threats, such as vessel strikes, water activity collision, and disturbance from tourism boating activities.

Off the coast of San Diego, California a population of almost 3000 individuals occur less than 1km offshore (Defran and Weller, 1999). Here, the coastline is very open, with minimal protection and a wider distribution of prey. This population is subsequently described as transient to the study stretch of coastline, with known individuals resighted at low rates, and site fidelity of this population to this specific area being low. This is likely due to a combination of the lack of sheltered bays and wide, non-concentrated distribution of prey, contrasting to the factors known to lead to high site fidelity in the two previously mentioned studies.

Individuals and populations that show high levels of site fidelity and smaller ranges are more susceptible to population declines in the face of local anthropogenic threats such as habitat degradation, physical and noise pollution, vessel collision, bycatch, and overfishing (Warkentin and Hernandez, 1996; Gonzalvo *et al.*, 2014). As coastal and marine tourism continues to increase, these threats and the vulnerability of the dolphins will only continue to increase. This highlights the need to conserve highly productive and sheltered areas of coast where populations of bottlenose are known to range.

1.5 Bottlenose dolphins around the UK

Depending on the time of year, bottlenose dolphins can be found all around the UK, however only two locations have been designated as Special Areas of Conservation (SACs) for coastal populations.

1.5.1 Cardigan Bay population

The largest population of bottlenose dolphins in the UK is found in Cardigan Bay, Wales, with over 300 individuals known to use the area (Cardigan Bay SAC, no date). Animals are only present in the summer however, spending the rest of the year within the Irish Sea. For this reason, the population is referred to as semi-resident, but Cardigan Bay is still a very important habitat for them, the dolphins making intensive use of its inshore waters (Pierpoint *et al.*, 2009). An area of Cardigan Bay was designated as an SAC in 2004, to protect the bottlenose dolphins and their summer habitat, as well as other important species such as grey seals, by ensuring any activities taking place are sustainable (Cardigan Bay SAC, no date).

1.5.2 Moray Firth population

The Moray Firth is situated in the northeast of Scotland and is home to the northernmost and only year-round resident population of bottlenose dolphins in the North Sea. Individuals from this population may be present in the firth year-round, although some groups are known to travel further south down the east coast of the UK, past Aberdeen to the Firths of Tay and Forth (Stockin *et al.*, 2006; Quick *et al.*, 2014). Current estimations by Cheney *et al.* (2013) suggest approximately 200 animals utilising the northeast coastline. In 2005, an SAC was implemented in the inner Moray Firth to include the core range of this population, with 90% of known individuals being found to frequent this area. However, an increase in sightings outside of this range since the 1990s, suggests a shift and expansion of this populations core range (Wilson *et al.*, 2004), especially in more recent years.

A significant majority of sightings in the outer southern Moray Firth are found in water depths of 25 m or less (Culloch and Robinson, 2008), contrasting to the population in the inner Firth which are often found at depths of over 50 m (Hastie *et al.*, 2004). The outer southern firth shelf edge has a much shallower gradient and weaker currents than the inner firth. Calves have been recorded in 80% of sightings along the southern coastline of the Moray Firth during late spring to early autumn, with 94% of births taking place from July to September and peaking in August (Culloch and Robinson, 2008; Robinson *et al.*, 2017b). The shallow water depths and relatively high water temperatures during the summer months along this coastline make it an ideal location for mothers to birth and raise their young, explaining the high percentage of mother-calf sightings over this period (Culloch and Robinson, 2008; Robinson *et al.*, 2017b). The population in the outer southern firth has a known calf mortality rate of 10.37%, with a majority dying pre-weaning (year 0-1) (Sim, 2014; Robinson *et al.*, 2017b).

This dolphin population along Scotland's east coast is seen to have the expected fission-fusion society, relying predominantly on short-term weaker associations lasting only a few days, with a few much stronger associations which can last several years (Eisfeld and Robinson, 2004). The formation of the units of association has also been determined to be due to chosen social affiliation, rather than just as a result of shared spatial distributions (Lusseau *et al.*, 2006). Dissimilarly to other bottlenose communities, this population has also been observed to live in large, mixed-sex groups, with up to 70 members, but an average of 22, with strong associations both within and between sexes, and links with all other members of the population, creating a large social network within the population (Eisfeld, 2003; Filan, 2015).

1.6 Study aims

The current project aims to investigate the site fidelity of bottlenose mother-calf pairs and therefore identify potential calving/nursery areas, as well as the associations between these mothers in the outer southern Moray Firth in northeast Scotland using a long-term dataset collated between May and October (inclusive), from 2001 to 2024, by the Cetacean Research & Rescue Unit (CRRU).

The objectives of this study are:

1. To examine the spatial and temporal (intra- and interannual) distributions of bottlenose mother-calf pairs within the study area
2. To investigate the spatial distributions of the most established bottlenose mothers (those with the highest recaptures/calves) when sighted with calves within the study area
3. To determine the associations/alliances between the bottlenose mothers using the study area

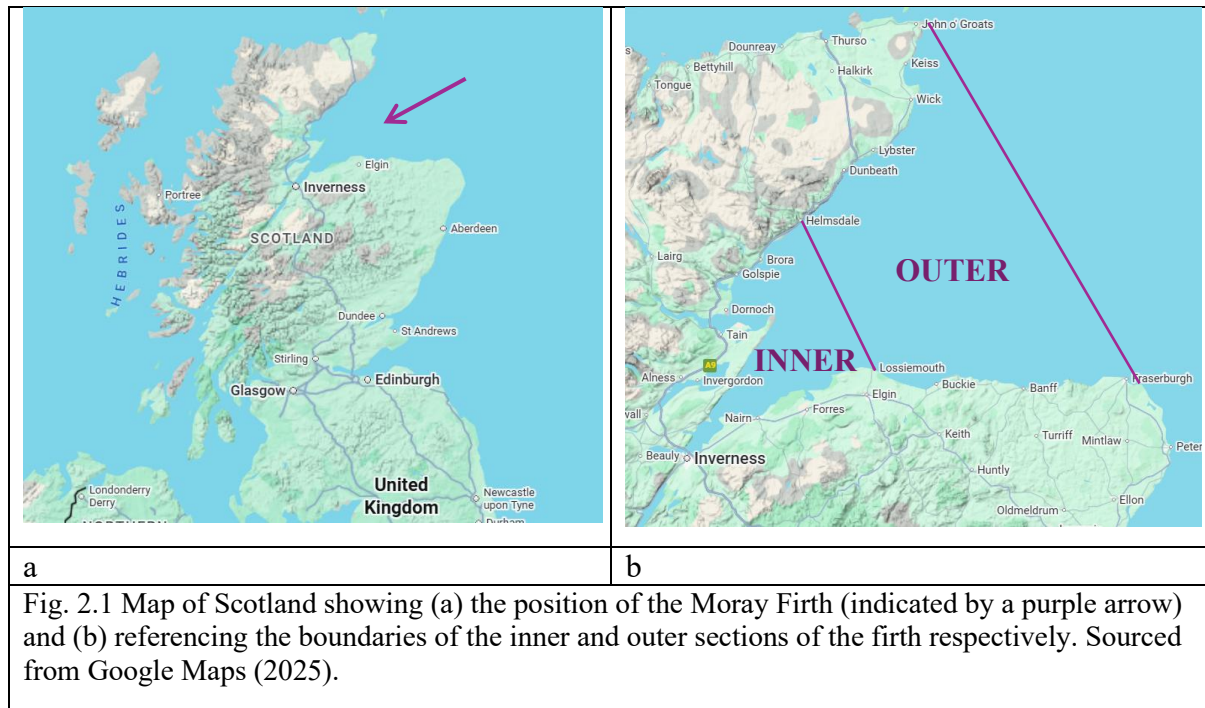
2 Methods

2.1 Study area

The Moray Firth is the largest estuarine inlet in Scotland, extending from Inverness in the southwest, to Fraserburgh in the southeast, and to Duncansby Head in the north, forming a funnel shaped embayment with an approximate size of 5,230 km² (Tilbrook, 1986) (Figure 2.1a). The firth is separated into two sections, the inner firth region, comprising the area to the west of Helmsdale in the north to Lossiemouth in the south, and the outer firth, to the north and east of these locations (Figure 2.1b). The present study uses data collected during dedicated boat surveys along the southern coast of the outer firth, between Lossiemouth and Fraserburgh, an 83km stretch of coastline.

As well as bottlenose dolphins, the Moray Firth is home to a number of other cetacean species. The harbour porpoise (*Phocoena phocoena*) and minke whale (*Balaenoptera acutorostrata*) are commonly sighted along the outer southern coastline (Robinson *et al.*, 2007; MacDougall and Robinson, 2025). Killer whales (*Orcinus orca*), common dolphins (*Delphinus delphis*),

Risso's dolphins (*Grampus griseus*), pilot whales (*Globicephala melas*), Atlantic white-sided dolphins (*Lagenorhynchus acutus*), and humpback whales (*Megaptera novaengliae*) have also been recorded, however these encounters are less common (Robinson *et al.*, 2007; Robinson *et al.*, 2010; Robinson *et al.*, 2017a; Marwood *et al.*, 2022).



2.2 Cetacean Research & Rescue Unit dataset

The data used in this study were collected by the Cetacean Research & Rescue Unit (CRRU) between 2001 to 2024. Dedicated boat surveys for bottlenose dolphins were undertaken along the outer southern Moray Firth coastline between May and October (inclusive) between the coastal ports of Lossiemouth and Fraserburgh (Figure 2.2).

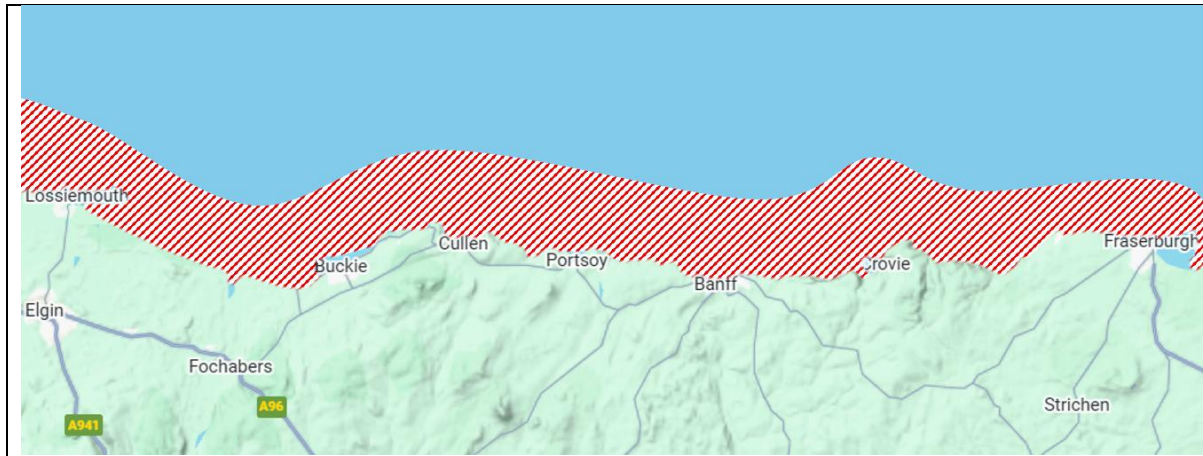


Fig. 2.2 Map of the outer southern Moray Firth coastline showing the CRRU study area from which the bottlenose dolphin sightings used in the present study were recorded. Sourced from Google Maps (2025).

Sightings were largely opportunistic, recording a group whenever it was met. Upon meeting a group, the number of individuals, group composition, and presence of calves were recorded. Photo identification images were taken of the left and right side of each individual's dorsal fin, which were subsequently matched using a database of all recorded individually-identified dolphins. The members of each group were then recorded, allowing for data on when and where each individual was sighted, and who they were sighted with. The behaviours displayed by the group were also recorded, however this data was not necessary for the present study. The dataset contained a vast array of information on each individual dolphin, however the present study only utilised data on the demographics of each female dolphin selected for the following analyses, i.e. the identity and presence/absence of offspring, for each individual sighted.

2.3 Survey effort and data selection

Survey effort undertaken by the CRRU from 2001 to 2024 between May and October (inclusive) was calculated from boat track lines of all positive search effort recorded using the point to line tool in QGIS.

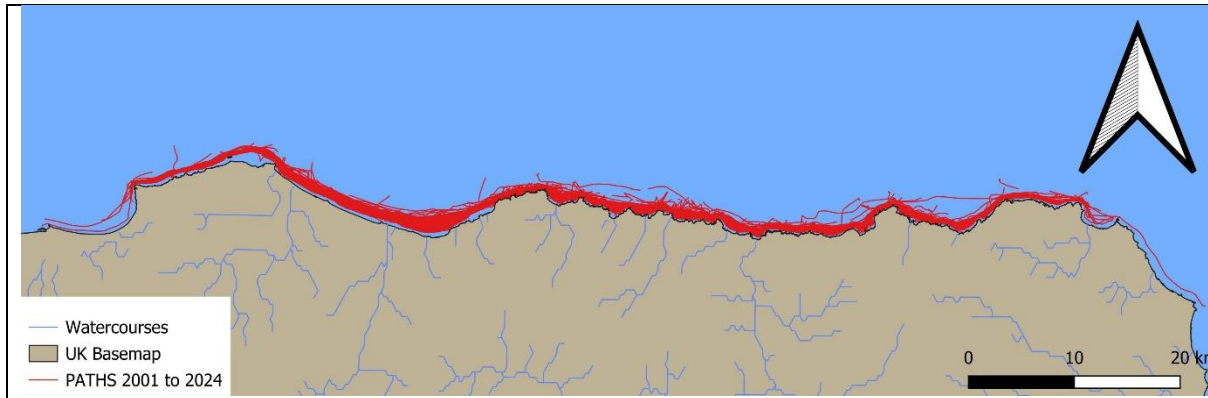


Fig. 2.3 Showing the positive boat survey effort (survey track lines) recorded by the CRRU along the outer southern Moray Firth from 2001 to 2024 from which the total survey effort was determined. This map was generated with QGIS, using EPSG:27700 CRS.

A database of all the bottlenose dolphins known to the CRRU was filtered to show only females. Of these, those regarded as non-resident to the outer southern Moray Firth, due to very low recaptures, or them being known residents to other areas, such as the inner firth, were removed to produce a refined dataset of “resident females” showing high site fidelity for the southern Moray Firth study area. Particular females with low numbers of recaptures were still included in the refined dataset as known offspring of older resident females, known to be resident themselves. Of these selected females, those who had not been recorded having given birth were also removed, resulting in a final study group of 34 well-known, identifiable (naturally marked) female bottlenoses of a variety of ages and with a variable number of calves, which comprised a cumulative total of 1,767 sightings. A total of 133 calves were collectively produced by the 34 females, with the number of calves per mother ranging between 1 and 8 calves. A subset of “established mothers” were selected from this dataset, defined as the ten individuals having five or more calves with the highest number of sightings.

2.4 Data analysis

2.4.1 Demographic data

Demographic information for each mother in the study group, including established age, number of known offspring and kin within the study group, was obtained from the CRRU’s Bottlenose Dolphin Photo ID Catalogue (also available as a simplified online version at: <https://crru.org.uk/research/catalogues?catalogue=bottlenose-dolphin>). Whilst the age of many mothers were known, as they were recorded from birth, for those dolphins who were already

established adults when the CRRU study first began back in 1997, only a minimum age (the number of years since first sighting) estimate was possible. The number of calves produced by each mother during the study period was determined from the CRRU Photo ID Catalogue from the longitudinal sightings data (1997 to present). The identification of any kin within the study group was also determined from examination of established family trees from the database.

2.4.2 Temporal data

The number of with-calf sightings across all the mothers in the study group were calculated for each year of the 2001 to 2024 study period. In order to analyse this data, it had to be corrected for by effort: the number of sightings / the total km surveyed per year.

2.4.3 Spatial data

The spatial data in the present study was displayed using QGIS v3.40.5, projected in EPSG:27700 (OSGB36 / British National Grid). To display the overall spatial distribution of mother-calf sightings, a hexbin map was produced by overlaying a hexagonal grid (with a diameter of 500 m per hexagon) onto the point data of all geographical sightings for the 34 mothers. The QGIS tool ‘Count Points in Polygon’ was used to determine the number of sightings within each 500 m² hexagon. A categorised colour ramp was then applied to the resulting counts, with the darker shades representing higher sighting densities, and lighter shades representing lower sighting densities per hexagon cell. Those hexagons containing zero sightings were removed, in line with presence *versus* absence data cells. Kernel density estimation (KDE) heatmaps with a radius of 1 km and pixel size of 100 (X and Y) were subsequently generated. These displayed the mother-calf pair distributions intra-annually (from May to October respectively) and interannually (from 2001 to 2024 respectively), along with the spatial distributions of the ten most established mothers, selected, as per the criteria above. In order to analyse the spatial preferences of the dolphins, the study area was divided into 8 sub-areas, facilitating a straightforward description of potential hotspots by mothers with calves in tow.

2.4.4 Association data

The software package SOCPROG 2.10 (Whitehead, 2024) was subsequently used to analyse the social structures and associations between the 34 mothers in the study group, using all available encounter data from the entire CRRU Photo ID database, spanning July 1997 to August 2025. A total of 3,032 sightings from 528 encounters were extracted for the 34 selected

female bottlenose. These data were extracted to a Microsoft Excel spreadsheet and filtered to include only those encounters where more than one member of the selected female dolphins were present. This dataset, containing the variables DATE, ENCOUNTER and ID, was thereafter imported into SOCPROG. Both the sampling period and group variable were set as ENCOUNTER, the association as group variable, and the association type as grouped in sampling period. A half weight association index (HWI) was selected as the most commonly used index in the analysis of social structure in cetacean populations, as this reduces bias arising from incomplete sampling which is possible when encountering large groups of dolphins, and when dolphins are more likely to be sighted separately than together (e.g. Cairns and Schwager, 1987). A hierarchical cluster analysis of the HWI matrix was also used to illustrate the social organisation of the study group in a dendrogram graphic (using the average-linkage method, with right hand orientation), with the maximum modularity and cophenetic correlation coefficient alongside this to determine the usefulness and reliability of the dendrogram in displaying the HWI values (after Whitehead, 2009). A network diagram (circular arrangement) was further produced from the HWI, with node colour representing cluster membership derived from the hierarchical cluster analysis.

3 Results

This chapter describes the distribution of mother-calf bottlenose dolphin pairs, 34 mothers with a total of 133 calves, using data collected by the CRRU between May and October (inclusive), from 2001 to 2024. It is separated into temporal analysis, spatial analysis, and analysis of associations, using the project objectives:

1. To examine the spatial and temporal (intra- and interannual) distributions of bottlenose mother-calf pairs within the study area
2. To investigate the spatial distributions of the most established bottlenose mothers (those with the highest recaptures/calves) when sighted with calves within the study area
3. To determine the associations/alliances between the bottlenose mothers using the study area

3.1 Survey effort

Between May and October 2001 to 2024, a total of 24,074 km of dedicated survey effort was conducted for bottlenose dolphins by the CRRU research team (Table 3.1). There was high variability in annual survey effort, with the number of individual dolphins identified ranging from 50 to 120 per year. The number of individual mothers from the study group sighted per year was also variable, ranging from 5 to 23 mothers.

Table 3.1 Showing the annual survey effort (km) and total number of bottlenose dolphin individuals along with mothers from the study group with calves sighted by the Cetacean Research & Rescue Unit from 2001 to 2024 inclusive.

STUDY YEAR	SURVEY EFFORT (KM)	NO. INDIVIDUALS SIGHTED	NO. MOTHERS WITH CALVES FROM THE STUDY GROUP SIGHTED
2001	1109	73	5
2002	1418	50	6
2003	1129	63	7
2004	1299	51	9
2005	869	59	10
2006	1556	95	11
2007	1172	60	8
2008	1142	89	9
2009	1117	68	10
2010	957	81	12
2011	988	97	12
2012	1301	88	16
2013	1404	99	18
2014	891	107	21
2015	1339	120	23
2016	1144	81	18
2017	947	114	18
2018	707	66	13
2019	841	96	18
2020	405	71	12
2021	622	84	17
2022	486	91	21
2023	721	89	19
2024	510	90	19

3.2 Dolphin demographics

The age of some mothers in the study group (Table 3.2) is an approximation, for example mother ID067 is recorded as 27+, as when first sighted in 1997, she was already an adult with a young calf by her side. She is known to be at least 27 years of age, as she was first sighted 27 years ago, however since she had a calf at this time, she must have been at least 5+ years of age, i.e. the age at which bottlenose females in this population are known to reach sexual maturity (Robinson *et al.*, 2017b), but was likely older. Mother ID065 (pictured in figure 3.1) is recorded to be 37 years old, as although the CRRU did not begin recording sightings until 1997, Aberdeen University identified her in 1989 as a young calf, so she was already known to ID databases when the CRRU first identified her with her own calf in 1997. The oldest known mother, ID065, had the highest number of calves (8) out of all the mothers in the study group.



Fig. 3.1 Female ID065 with calf in the outer southern Moray Firth. Photo credit: Kevin Robinson/CRRU.

The ten mothers aged 16 or younger had a maximum of three calves each, the majority having only one or two. 23 of the 34 individuals used in this study group were related – offspring or

mother – to another individual in the group. Three individuals, ID065, ID118, and ID327, had two daughters in the study group each. There was also a tri-generational relation within the group, with mother ID118’s offspring ID253 also having her own offspring present in the group of mothers, ID601. Totalling 223 sightings, mother ID067 was found to have the highest number of total sightings during the study period, as well as the highest number of sightings with a calf present (n=180) (Figure 3.2). Mother ID445 had the highest percentage of her sightings with a calf in tow, at 100%, and mother ID566 had the lowest, at just 15.7%. Mother ID534 had the lowest number of total sightings (n=17), however mother ID514 had the lowest number of sightings with calf (n=5). The ten most established mothers in the group were selected as those with the highest number of sightings in the presence of a calf, having five or more calves, giving the sub-group: IDs 003, 035, 065, 067, 118, 162, 187, 216, 225 and 432.

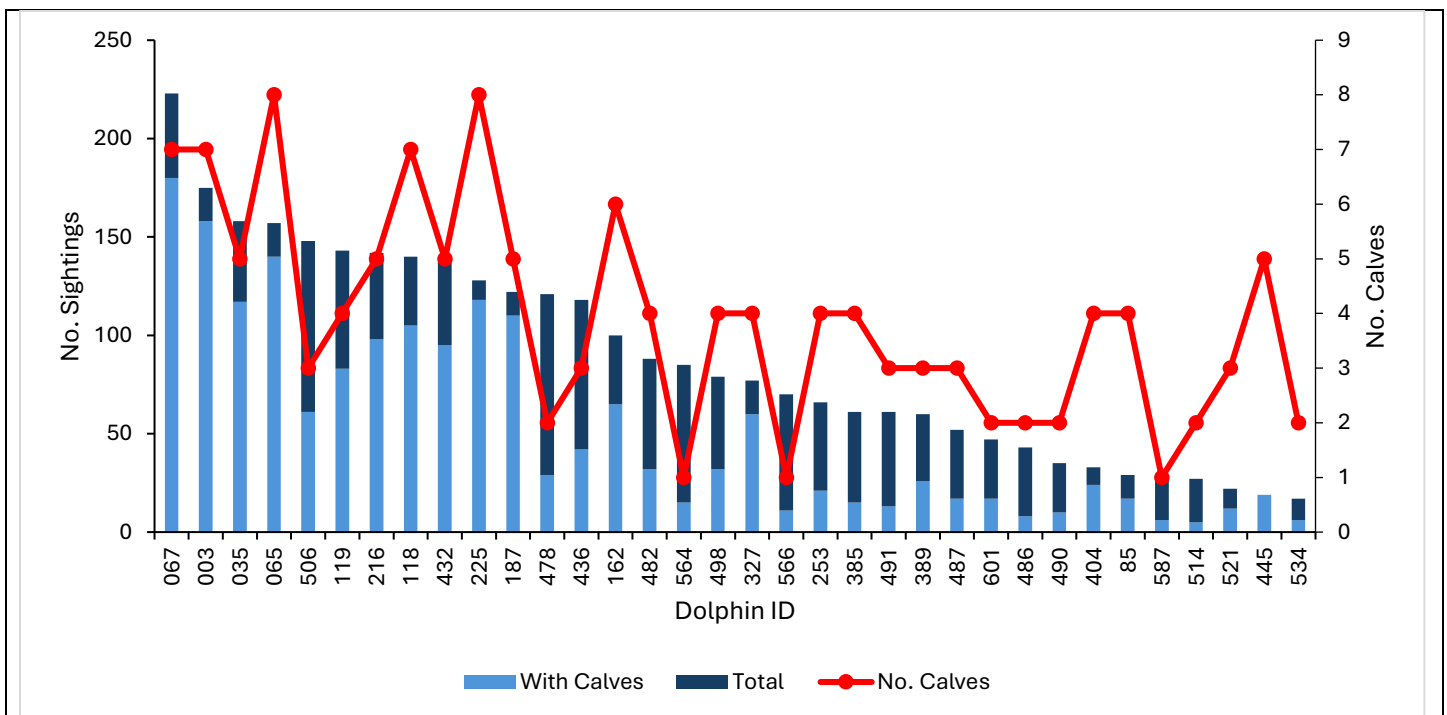


Fig. 3.2 Stacked column chart displaying the total number of sightings of each mother, the number of those where a calf was present, and the number of calves respectively recorded during the 2001 to 2024 study period.

Table 3.2 Showing the bottlenose females selected in this study, their approximate ages, the number of calves respectively recorded, the presence of kin within the study group, and the number of sightings used in this study

MOTHER ID	APPROXIMATE AGE	NUMBER OF CALVES IN STUDY	MOTHER PRESENT IN STUDY GROUP	CALF PRESENT IN STUDY GROUP	NUMBER OF SIGHTINGS WITH CALVES DURING THE STUDY PERIOD
065	37+	8		514, 436	140
067	28+	7			180
003	28+	7			158
035	28+	5			117
432	28+	5		498	95
187	28+	5		478	110
085	28+	4		534	17
119	27+	4		506	83
118	27+	7		566, 253	105
389	27+	3			26
216	26+	5		587	98
162	26+	6			65
225	25+	8			118
327	22+	4		385, 491	60
404	19+	4			24
521	14+	3			12
445	31	5			19
253	25	4	118	601	21
482	24	4		487	32
506	22	3	119	564	61
498	20	4	432		32
487	20	3	482		17
385	19	4	327		15
436	18	3	65		42
478	16	2	187		29
491	16	3	327		13
486	16	2			8
490	16	2			10
514	15	2	65		5
534	14	2	85		6
564	12	1	506		15
566	12	1	118		11
587	11	1	216		6
601	10	2	253		17

3.3 Temporal analysis

3.3.1 Interannual distribution

The number of sightings per unit effort (km) per year was seen to fluctuate throughout the study period, showing high levels of interannual variability (Figure 3.3). However, a general increase in the number of sightings per year was observed. Peaks in sightings per km were observed in 2005, 2011, 2014, 2016, 2019 and 2024. The peak in sightings in 2014 was the greatest, with 0.095 mother-calf pair sightings per km, whilst 2002 had only 0.011 sightings per km surveyed, the lowest in the study period.

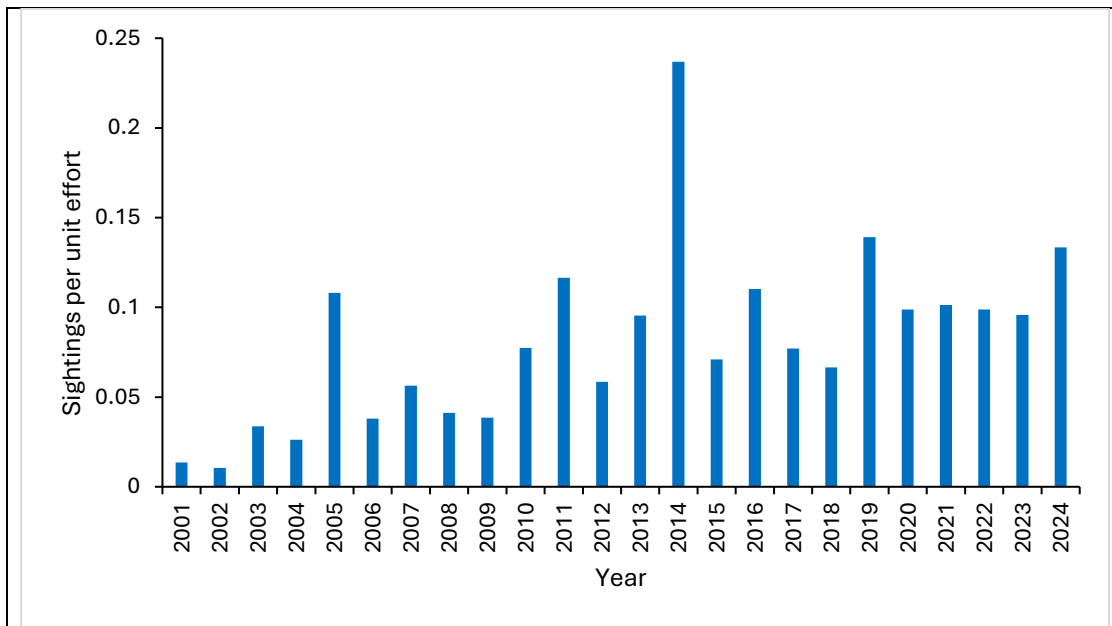


Fig. 3.3 Showing the annual number of mother-calf pair bottlenose sightings per unit of search effort each year of the 2001 to 2024 study period.

3.4 Spatial analysis

The study area was divided into 8 sub-areas to facilitate the ensuing descriptions of the spatial distribution/site fidelity shown by mother-calf bottlenose pairs (see Figure 3.4).

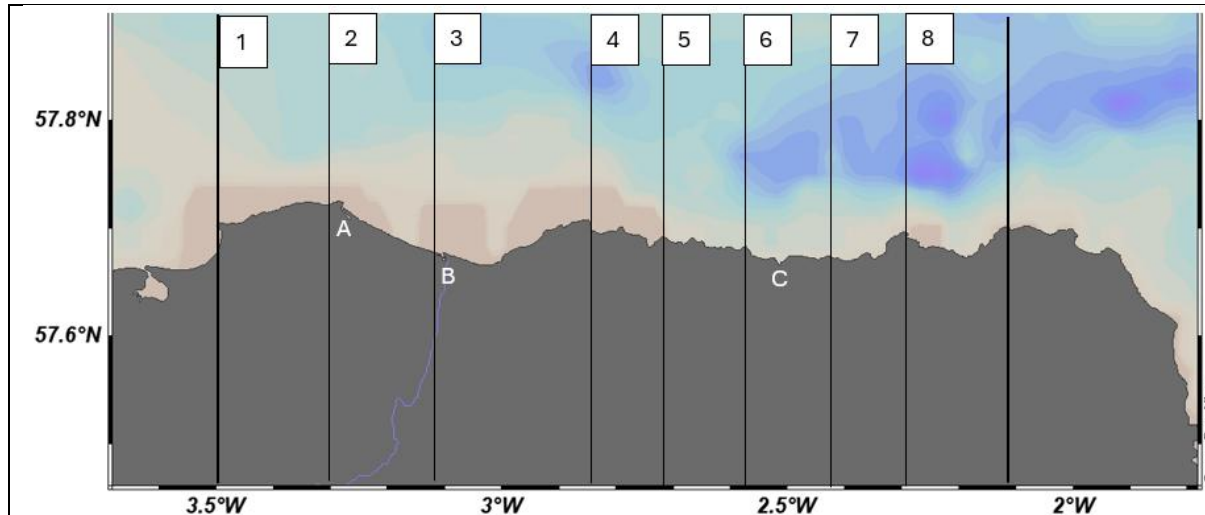


Fig. 3.4 Map of the outer southern Moray Firth study area showing the spatial divisions of the coastline into 8 sub-areas to facilitate descriptions of the spatial distributions of mother-calf pairs. River mouths targeted by the dolphins have been labelled as (A) the River Lossie, (B) the River Spey, and (C) the River Deveron, respectively.

3.4.1 Overall distribution

The number of mother-calf pair sightings recorded in each 500 m² hexagon across the entire 2001 to 2024 study period is displayed using a hexbin map (Figure 3.5). The number of sightings per hexagon were separated into seven classes, with the lightest colour indicating 0 to 6 sightings, and the darkest red from 32 to 37, the greatest possible number of sightings per hexagon. Hotspots of occurrence are therefore indicated by the darker areas, which tended to be concentrated in specific areas, indicating preferences for particular areas of the coastline. These areas of heightened preference were located towards the centre of the survey area, in sub-regions 3 to 6. The sub-areas at the extremes of the study area, i.e. 1, 2, 7 and 8, had the lowest densities of mother-calf sightings, as indicated by the lighter coloured hexagons. Those preferred areas of highest sighting occurrences however were more focally concentrated towards the centre of the survey transect, to the east of sub-area 3 and in sub-area 4, along the rocky shore areas adjacent to the coastal ports of Findochty and Portknockie (two areas represented by 32 and 37 cumulative sightings respectively). A secondary hotspot was further identified on the boundary between sub-areas 5 and 6, to the east of the wider study area (with one area having a cumulative total of 28 sightings).

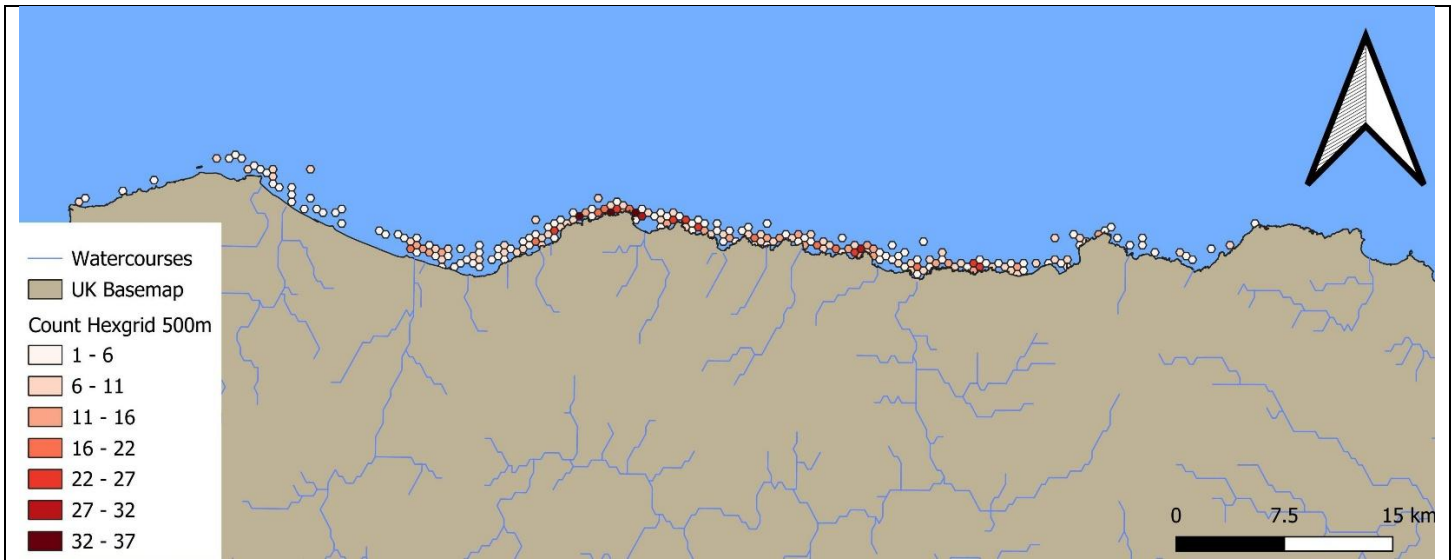
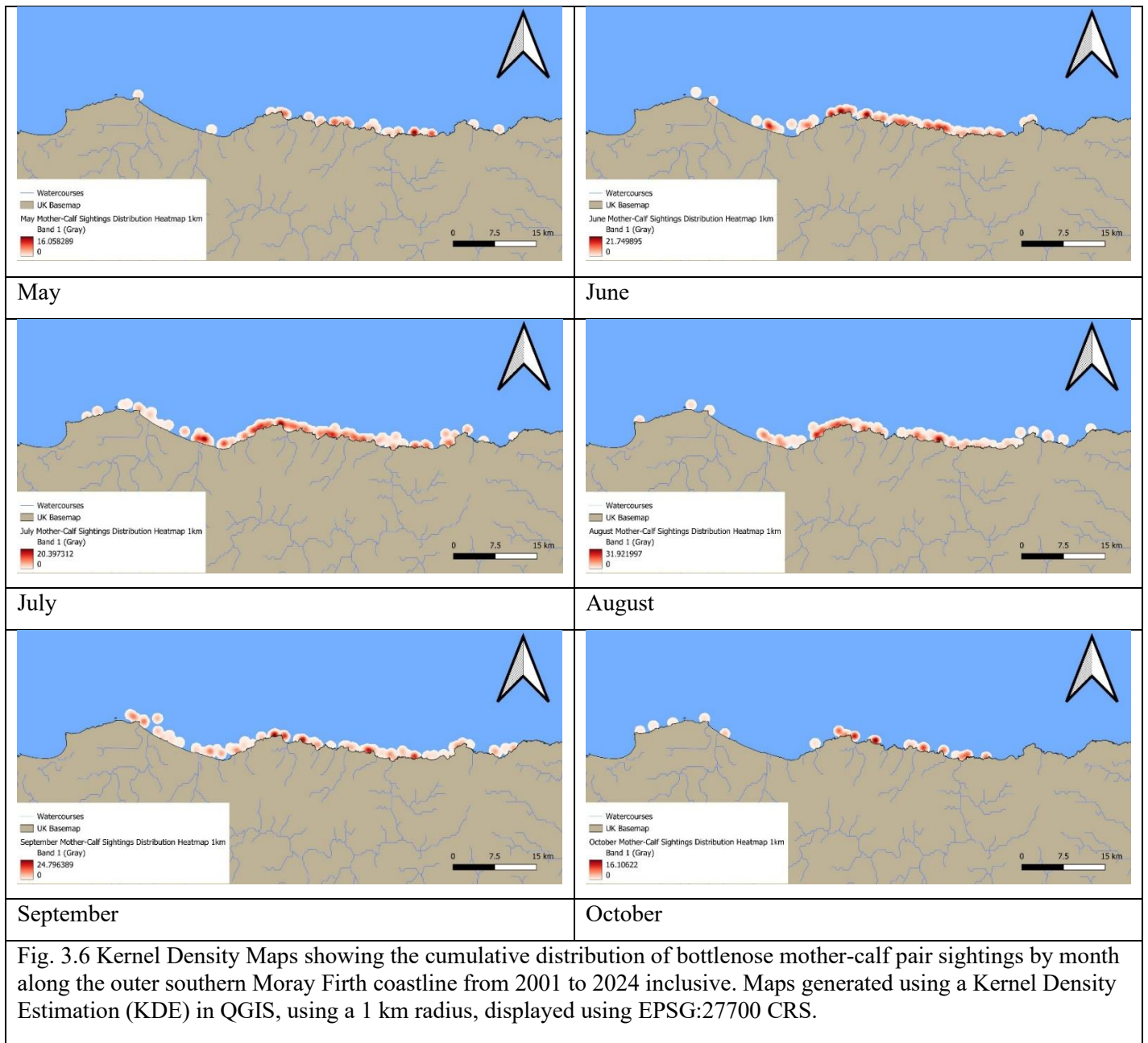


Fig. 3.5 Showing the spatial density of mother-calf bottlenose dolphin sightings along the outer southern Moray Firth coastline from 2001 to 2024 inclusive. The hexbin map displays the concentration of recorded sightings within a 500 m diameter hexagon. This map was generated with QGIS, using EPSG:27700 CRS.

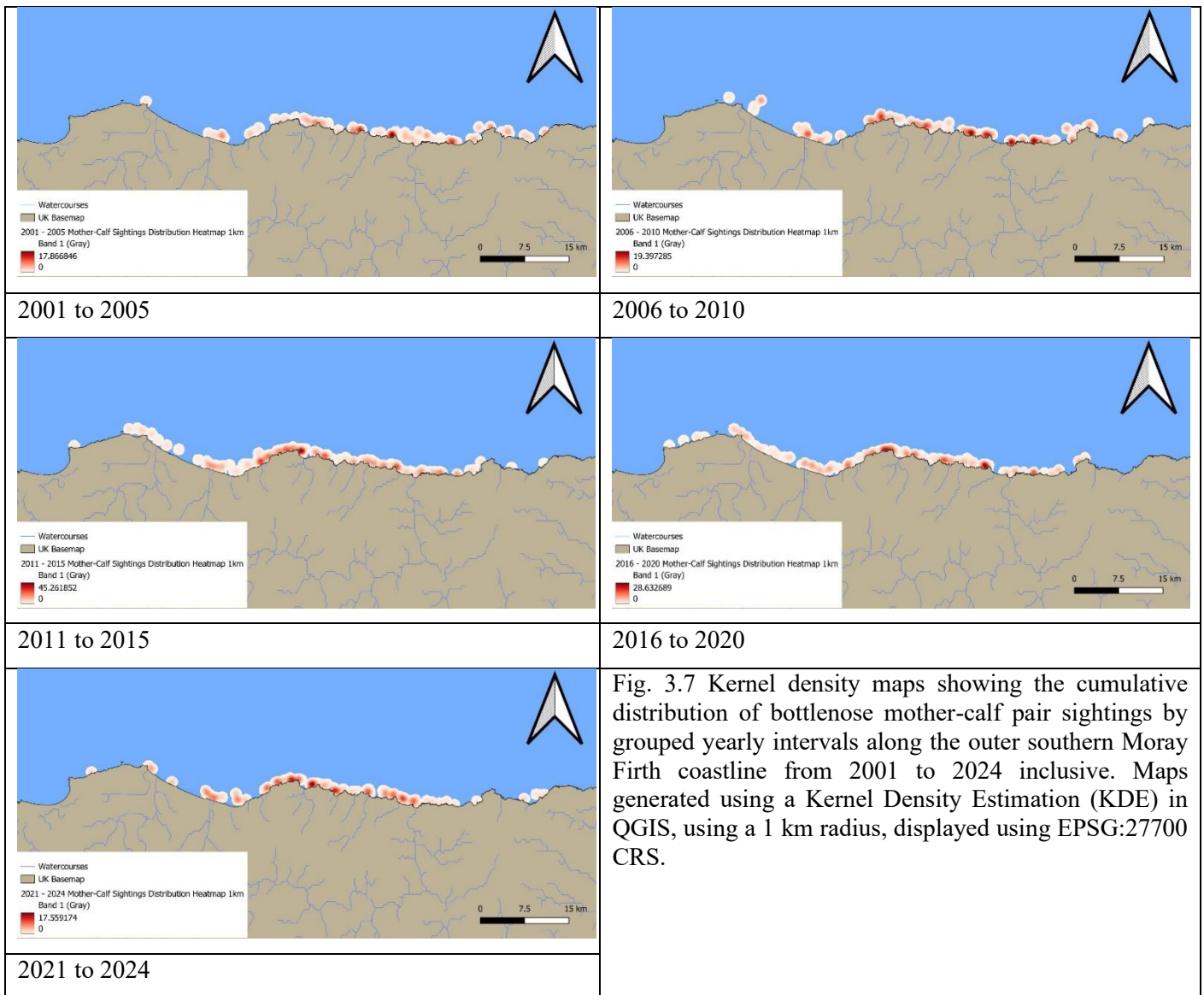
3.4.2 Intra- and interannual distribution

Figure 3.6 shows monthly kernel density plots of mother-calf sightings in the outer southern Moray Firth study area. Generally, sightings were concentrated to the east of the study area in sub-areas 6 and 7 during May, then in sub-areas 3 and 4 throughout June and July, and back towards the east again from August to October, reflecting temporal changes in the distribution of the animals. However, from June to October inclusive, the dolphins were predominantly distributed between the river mouths of the Spey and Deveron, moving between these bay areas along the connecting rocky shore (sub-areas 3-5). The distributions of sightings were much more spatially continuous through June to August compared with May, September and October, which exhibited spatially patchy hotspots of occurrences along the study area.



The distributions of mother-calf pairs across five multi-year periods from 2001 to 2024 are shown in figure 3.7. Relatively high densities of sightings were observed in sub-areas 3 and 4 across all periods, with the exception of 2001 to 2005, which had lower densities of sightings in this portion of the survey area. Instead, the highest concentration of mother-calf pair sightings was largely observed within sub-areas 4 and 7, with the animals utilising the protected headlands and sheltered bays along the rocky shoreline. However, across the whole period,

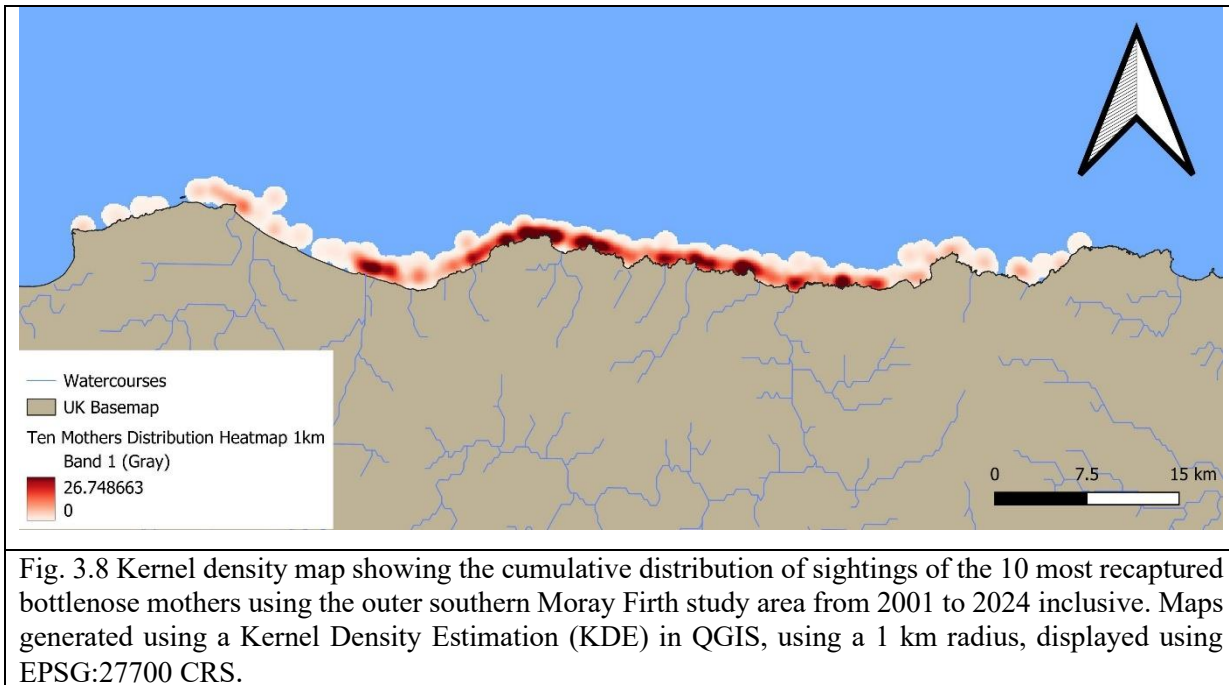
2001 to 2024, as expected, the animals showed temporal shifts in view of their preferred hotspots.



3.4.3 Established mother distributions with calves

Upon filtering the dataset to examine the most established mothers with calves, i.e. the ten females most commonly sighted in the study area with five or more calves, a much stronger defined distribution was observed (Figure 3.8). These females showed a more definitive, continuous distribution throughout the study area, exhibiting high site fidelity for the central study area between sub-areas 3 to 7 inclusive. When examined independently, however, the individual mothers showed subtle differences in their preferred areas of distribution (Figure

3.9). Whilst all ten mothers showed relatively high affinity to the east of sub-area 3 into sub-area 4, seven of the ten mothers showed a distinct preference for the Spey river mouth in sub-area 3, and four for the Deveron river mouth in sub-area 6. Mother 162 had an outlying preference for the shallow waters in Aberdour Bay in sub-area 8, which none of the other nine mothers shared. So, although the ten mothers shared a generally similar distribution, preferred areas specific to each individual were identifiable.



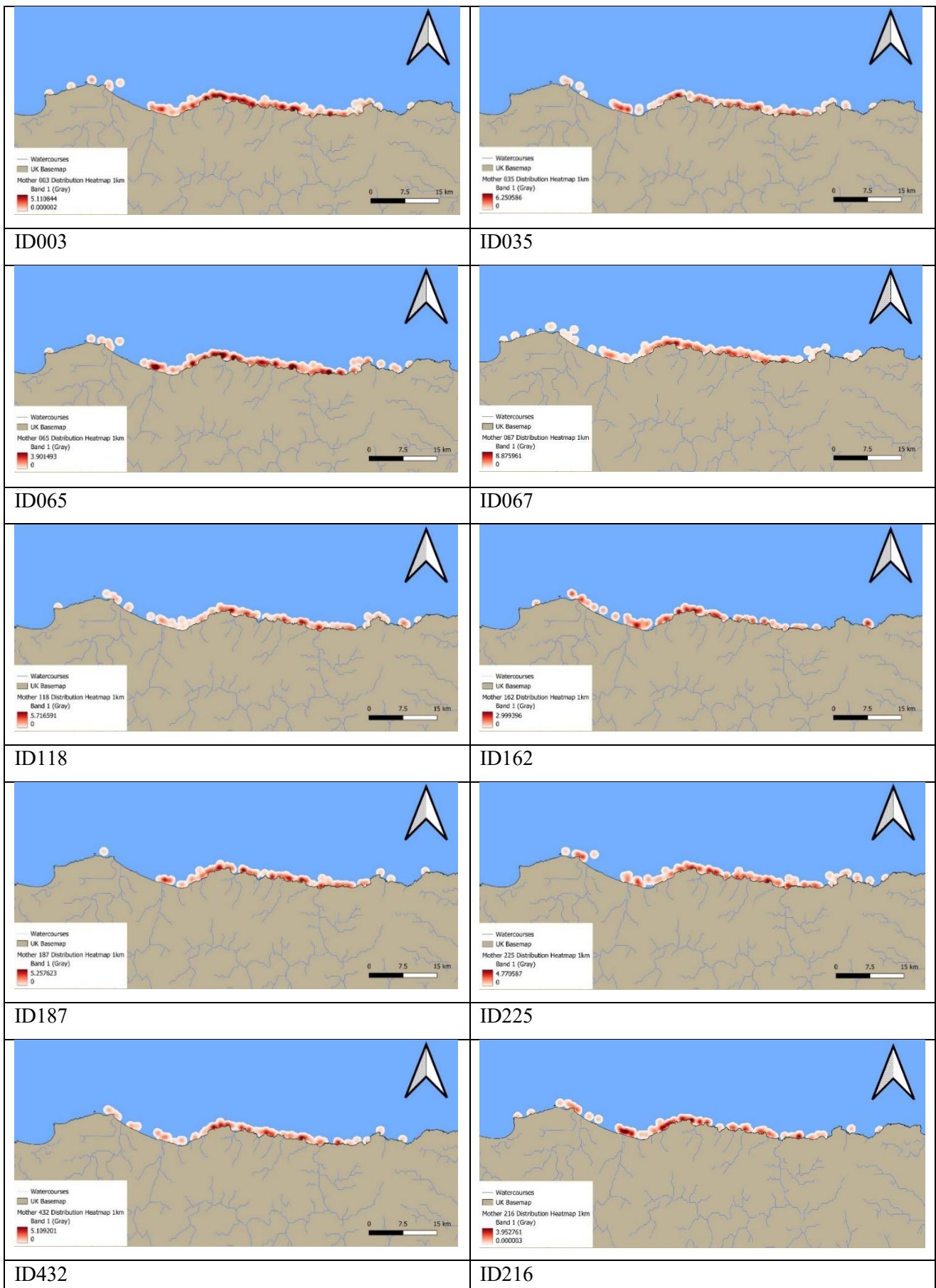


Fig. 3.9 Kernel density maps showing the distributions of sightings of the 10 most recaptured bottlenose mothers using the outer southern Moray Firth study area from 2001 to 2024 inclusive. Maps generated using a Kernel Density Estimation (KDE) in QGIS, using a 1 km radius, displayed using the EPSG:27700 CRS.

3.4.4 Associations between mothers

The half-weight index of association for each bottlenose can range from 0.00, indicating an individual was not sighted with another member of the group during the study period, to 1.00, all of their sightings involved at least one other member of the study group. The mean half-weight index of association for each individual in the study set ranged from 0.054 (5.4% - ID534) to 0.281 (28.1% - ID506), with a variety of values in between (Table 3.3). Female ID506 displayed the highest association strength with all other individuals within the study group, suggesting she is the most social individual. Mothers ID506 and ID119, the former being the offspring of the latter, shared the highest maximum HWI of 0.536 (53.6%), as they are each other's strongest associate, and the strongest association within the group. The lowest HWI came from mother ID514, with a value of 0.231 (23.1%), meaning her strongest association is relatively much lower than that of the other mothers in the group.

Table 3.3 The mean and maximum HWI of association for the 34 mother bottlenose dolphins in the study group (output from SOCPROG 2.10).

ID	MEAN HWI	MAXIMUM HWI
118	0.263	0.506
119	0.253	0.536
162	0.202	0.464
187	0.197	0.471
216	0.249	0.464
225	0.234	0.444
253	0.194	0.432
003	0.278	0.531
327	0.189	0.459
035	0.276	0.493
385	0.16	0.459
389	0.156	0.293
404	0.144	0.298
432	0.272	0.479
436	0.268	0.502
445	0.123	0.326
478	0.259	0.523
482	0.195	0.5
486	0.136	0.404
487	0.141	0.5
490	0.135	0.326
491	0.181	0.333
498	0.208	0.38
506	0.281	0.536
514	0.122	0.231
521	0.096	0.349
534	0.054	0.256
564	0.156	0.386
566	0.198	0.429
587	0.115	0.309
601	0.132	0.429
065	0.269	0.531
067	0.246	0.459
085	0.08	0.326

The strongest pair-wise association, as indicated by the two mothers sharing a maximum HWI, was seen between ID506 and 119 (0.536), followed by ID065 and 003 (0.531), who are unrelated but were two of the oldest known females in the group, with several of their offspring having the same or closely similar ages (see Appendix 1) (Table 3.4). Of the 528 between

mother associations, 14 had a HWI of 0, meaning 14 pairs of mothers were never sighted together. Seven pairs of mothers had a HWI of 0.5 or greater.

The clustering of females based on their pairwise associations with individuals and groups of individuals is displayed using a dendrogram (Figure 3.10). The strength of association is indicated by the association index at which individuals are joined by vertical lines. Six clusters were identified, the largest of which (depicted in purple) contained 16 of the 34 individuals, as well as the two closest associations, IDs 506 and 119, and 065 and 003 respectively. The closest triad also occurred in this cluster, between IDs 065, 003, 118, all of which were first recorded in 1997. The second largest cluster (in red) contained seven individuals, and a pair with a HWI of 0.5 (IDs 487 and 482 - another mother and offspring) forming a triad with ID486. The yellow cluster contained 4 of the mothers, and no associations over 0.5 HWI. The closest association occurred between IDs 601 and 566, ID566 being the sibling (i.e. younger sister) of ID601's mother, ID253 (see Appendix 1). Both the blue and green clusters contained 3 dolphins each, the closest associations being 0.326 for IDs 085 and 445 (in blue), with no familial relations but a similar approximate age, and IDs 490 and 491 (in green), who again share no relation, but were both aged 16, and so were possibly raised together. The final cluster includes only mother ID514. Her closest associate was ID436, her older sister from the purple cluster, 0.231 (Table 3.4), however she was not seen to associate closely enough with any other females in the study group to be considered a part of their cluster. For the hierarchical cluster analysis, the cophenetic correlation coefficient (scale 0-1), was calculated to be 0.8322, and the maximum modularity to be 0.10175.

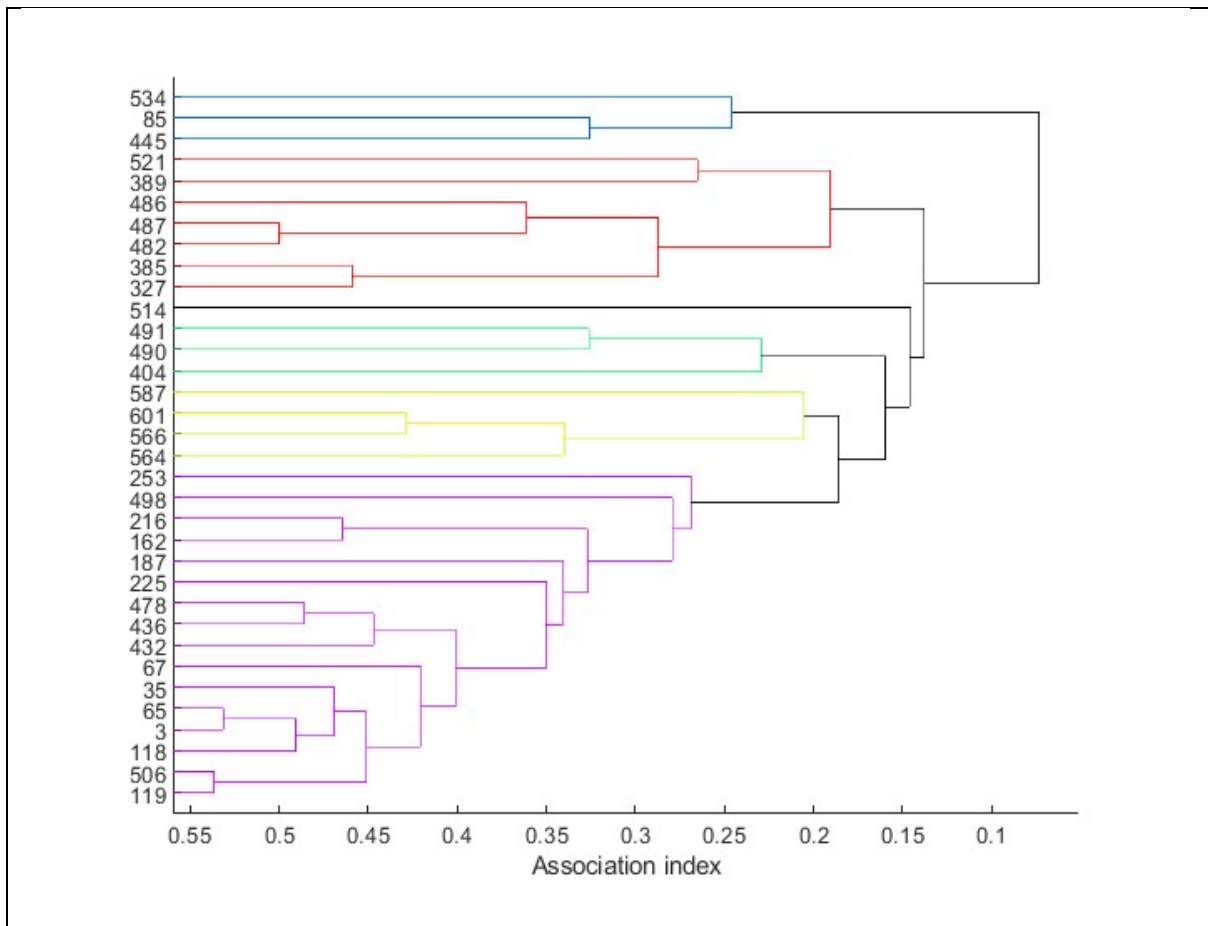


Fig. 3.10 Dendrogram (hierarchical cluster analysis) showing the average-linkage cluster analysis of associations between the 34 identified bottlenose dolphin mothers using the outer southern Moray Firth (generated using SOCPROG 2.10).

The strength of associations between mothers is indicated by the thickness of the lines connecting known associates (Figure 3.11). All mothers were found to have social connections within the study group, as indicated by the high number of lines within the figure. As well as displaying the strength of intra-cluster associations, figure 3.11 also shows the number and strength of inter-cluster associations, of which there were many. Whilst ID514 was seen to form her own cluster in the previous figure (3.10), the sociogram displays many lines of association between herself and other females within the group, particularly those within the purple cluster. A vast majority of individuals showed at least some level of association with all 33 other mothers in the study group, as only 14 pairs of mothers, just 2.7%, showed no association, meaning associations were not restricted to perceived clusters, matching the fission-fusion social nature of this population.

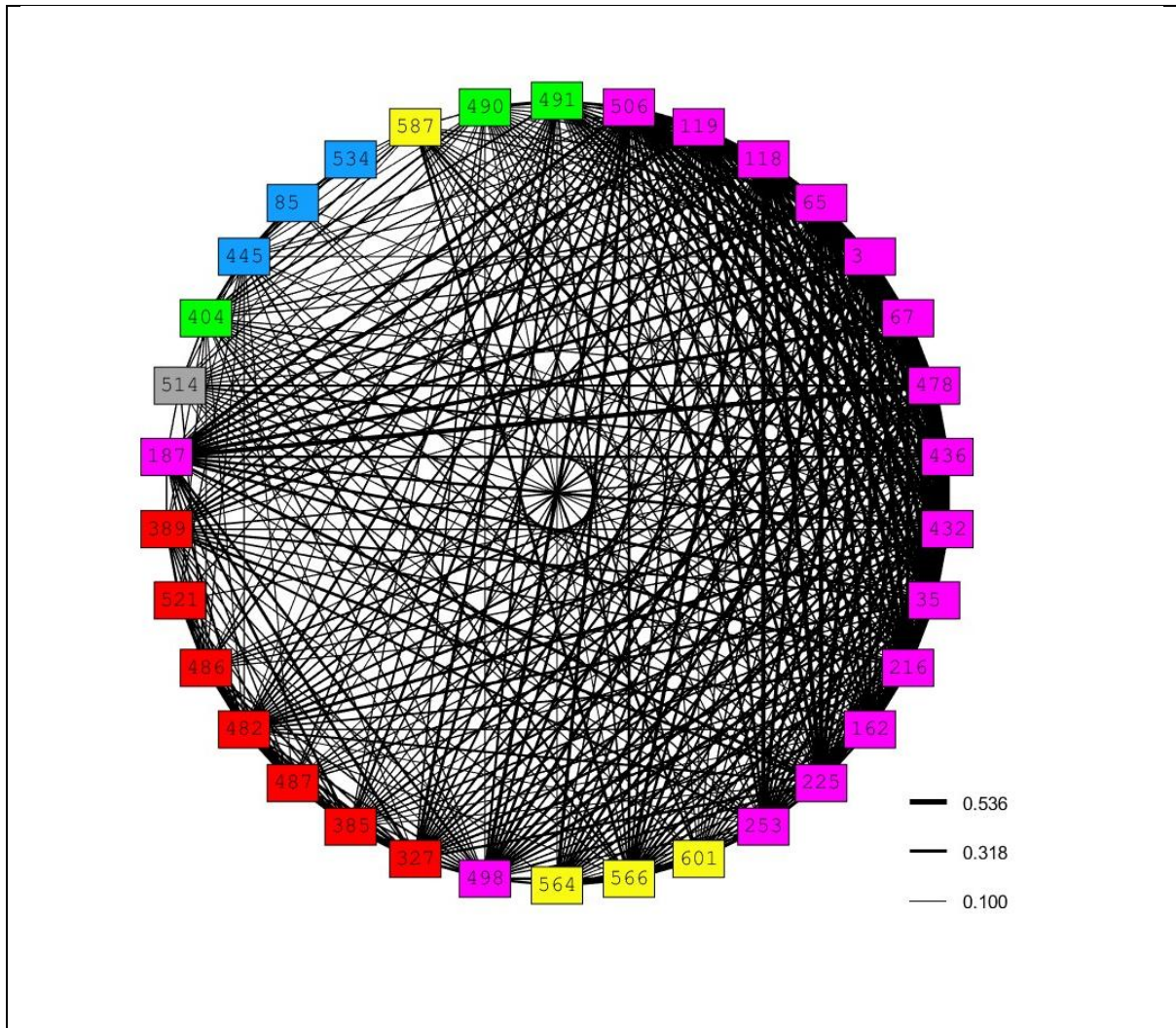


Fig. 3.11 Sociogram (network diagram) representation of the 34 bottlenose dolphin mothers examined in the Moray Firth dataset, based on their recorded associations by the CRRU along the outer southern Moray Firth (generated using SOCPROG 2.10).

4 Discussion

This study aimed to examine the spatial and temporal distributions of bottlenose mother-calf pairs frequenting the southern coastline of the outer Moray Firth. It also aimed to determine the existence of any associations/alliances between identified mothers in the study group, comprising of 34 selected mothers having produced between them a total of 133 calves from 2001 to 2024. The mapping of these distributions and analysis of these associations aimed to identify potential calving/nursery areas, and the environmental and social factors influencing these.

The present results showed high levels of variability in the number of individual dolphins sighted from one year to the next. Even when corrected for by effort (sightings per km survey effort), the total number of mother-calf pairs sighted was highly variable. Mother-calf pairs were further seen to show higher site fidelity to some areas of the coastline over others. Previous studies in the area have found the river mouths along the southern firth coastline to be of particular importance to foraging animals (e.g. Culloch and Robinson, 2008; Filan, 2015), however the present study suggests site fidelity for these regions may be temporal, individualistic, and possibly based on social associations, with the rocky headlands between these mouths being of similar importance to this study group of dolphins.

Although corrected for by effort, the number of sightings of mother-calf pairs still fluctuated heavily throughout the study period. This was potentially due to interannual changes in the availability and distribution of targeted prey within the study area. Bottlenose dolphins are opportunistic feeders, targeting cod (*Gadus morhua*), saithe (*Pollachius virens*), whiting (*Merlangius merlangus*), haddock (*Melanogrammus aeglefinus*), and Atlantic Salmon (*Salmo salar*) within Scottish waters (Santos *et al.*, 2001). The concentrations of these species peak at variable times of the year, and anthropogenic and environmental factors can lead to peaks in prey abundances both intra- and interannually. Historic exploitation of the fish species important to bottlenose has occurred in the firth, including haddock, cod, and whiting stocks (Hopkins, 1986). A number of these species continue to face overfishing pressures within the North Sea (Oceana UK, 2025). A significant decline in primary productivity within the North Sea has occurred over the past 25 years, and rising sea temperatures have led to shifting distributions of almost two-thirds of available fish species in latitude and/or depth (Perry *et al.*, 2005; Pinnegar *et al.*, 2020). These changes in abundances and distributions may have led to the dolphins spending more time at the extremes of the survey area, which were statistically surveyed less often, or possibly even areas outside of the fine-scale survey area, such as within the inner firth, or further down the northeast coast.

Studies have previously found that dolphins show site fidelity for specific areas when conditions are favourable, such as shallow and sheltered waters where food and resources are productive and predictable (Knip *et al.*, 2012; Passadore *et al.*, 2018). Multiple studies have established that bottlenose dolphins show heightened site fidelity for sheltered sandy bays, particularly adjacent to river mouths, due to their productive, predictable and sheltered nature

(Sprogis *et al.*, 2016; Passadore *et al.*, 2018). In the present study the highest density of sightings occurred between the two major salmon rivers, the River Spey and River Deveron respectively, where migrating salmon are evidently targeted along the rocky headlands (K.P. Robinson, pers. obs.). Atlantic salmon are a key and predictable food source for the study population (Santos *et al.*, 2001), and the rocky outcrops along the prominent headlands, where high numbers of sightings were observed in the present study, may aid the dolphins when foraging, facilitating barrier feeding. Barrier feeding is a technique used by bottlenose in other locations, where migrating fish are herded around inshore structures in shallow habitats, allowing easier detection and more efficient capture of prey (e.g. Weiss, 2006). Efficient foraging is essential for females with young offspring, as nursing mothers must consume up to 200% more calories than non-pregnant females (Reddy *et al.*, 1991).

The headland outcrops along the outer southern firth coastline may also provide important nearshore nursery areas, ideal for monitoring and raising young offspring while they learn essential skills, as well as providing refuge from vessel traffic and noise. In western Australia, a dominant factor in why bottlenose dolphins chose sheltered bays and shallower waters was for protection from predators, such as sharks (e.g. Sprogis *et al.*, 2016; Passadore *et al.*, 2018). While predation risk may not constitute a central factor in the distribution of mother-calf pairs observed in the present study, potential predation of small cetaceans by grey seals (*Halichoerus grypus*) and killer whales (*Orcinus orca*) may be of some significance here (Leopold *et al.*, 2015; Robinson *et al.*, 2017a).

Calving in the Moray Firth occurs from June to October, peaking in July and August, corresponding to the peak in water temperature (Culloch and Robinson, 2008; Robinson *et al.*, 2017b). The highest density of sightings within the shallow and sheltered waters of Spey Bay (the most extensive inshore bay in the study area, straddling sub-areas 2 and 3) was observed in July, at the beginning of the calving period. This would be the period when mothers are likely seeking shelter for themselves and their newborns, which would partially explain the temporal trend in mother-calf pair sightings at this location. Whilst Spey Bay was not necessarily identified as a hotspot for the study group as a whole, the bay was seen to be important for each of the ten most established mothers, their frequent use indicating the significance of this area as a favourable location for calf rearing.

Female bottlenose dolphins, and particularly those with young calves, are known to form associations to protect themselves and their offspring from aggressive adult males (Möller and

Harcourt, 2008; Robinson, 2014). These associations between females may be short-lived and do not necessarily imply true altruism, as there are many advantages to forming female alliances, such as cooperative corralling of prey, co-raising of infants, as well as protection from unwanted sexual advances and potential infanticide threat from males (Smuts and Smuts, 1993; Rossbach, 1999; Robinson, 2014). All of the most established mothers examined were found to show strong associations with one another during the study period. Two of the most established mothers (IDs 003 and 065) formed the second strongest association seen within the study group, and formed a triad with another established mother (ID118), contrasting to other studies where only males have been seen to show such strong affiliations (e.g. Connor *et al.*, 2022).

Although the ten most established mothers showed site fidelity to very similar areas as highlighted earlier, the distributions of several individuals were unique. This is likely a form of niche partitioning. If all mothers along this coastline were confined to the same specific areas, there might be greater competition and they may be more vulnerable to cumulative threats. One example of this is in Barataria Basin in Louisiana USA, where high site fidelity is shown to a restricted location where frequent oil spills, anthropogenic contaminants, and harmful algal blooms occur, leading to the population as a whole suffering severe adverse health effects, and subsequent reproductive failure (Takeshita *et al.*, 2021). In Sarasota Bay, Florida USA, female bottlenose show differences in their distributions due to their differing foraging techniques and specialisations being better suited to different areas and prey types, reducing competition and maximising resources available to the mothers (Rossman *et al.*, 2015). In the outer southern Moray Firth, there is a wide variety of prey available to the population (Santos *et al.*, 2001), likely resulting similarly in different individuals and subgroups targeting different preys based on their individual food preferences and preexisting associations, exploiting the coastline differently, based on the distribution of their prey. In this context, individual specialisation by different animals may be beneficial in terms of their conservation, helping the stability of the population and their evolutionary diversification (Robinson *et al.*, 2023).

The fission-fusion nature of this population has been found to rely on short-term, more casual associations lasting a few days, with only a small proportion of associations persisting over the long-term (Lusseau *et al.*, 2006). This society structure is exemplified by the high number of weaker associations, and lower number of strong associations between the mothers in the study

group within their identified clusters, but also between individuals of different clusters. Although certain individuals tended to form sub-groups and favour particular associations in the present study, the whole population was seen to be highly interconnected, as similarly found by Eisfeld (2003) and Filan (2015), and these sub-groups of more strongly associated individuals, likely travel up and down the coast, joining other sub-groups on their travels. Whitehead's SOCPROG manual (2024), states a cophenetic correlation coefficient (CCC) value over 0.8 implies the average-linkage dendrogram is a good and reliable representation of association among the members of the study group, and so the dendrogram output presented in this study (CCC=0.8322) can be used in interpretations. With a value of 0.10175, however, the maximum modularity was low, suggesting all of the mothers were relatively well-connected in the present study, indicating overlapping social networks rather than discrete social units (Lusseau *et al.*, 2006).

The factors with the strongest influence on associations within the study group were found to be kin and reproductive state. The three pairs of mothers (IDs 119 and 506, 065 and 436, and 482 and 487) showing strong associations due to kin were all mothers and offspring, rather than siblings. This tendency towards such familial associations has previously been documented by Wells *et al* (1987). For those remaining pairs of mothers with a HWI of 0.5 or more, reproductive state is hypothesised to be the predominant factor for their associations. Mother pairs IDs 065 and 003, 065 and 118, 478 and 506, and 118 and 119 were all seen to have had numerous calves of approximately the same age or within one year of age, and/or were typically found to be the same age as their associates. In the Moray Firth, associations between animals of a similar age and reproductive state are commonly observed (Eisfeld and Robinson 2004). Bonds are seen to establish in infancy, resulting in the females choosing to associate with the daughters of their mothers' closest associates in their own motherhoods, as they grew up/spent time with them as juveniles, leading to familiarity (Möller and Harcourt, 2008; Robinson *et al.*, 2017b). Previous studies in Australia also found that age and reproductive state are the most influential factors in determining associations (Möller and Harcourt, 2008), in support of the present findings.

As the association data includes all recorded sightings of each mother from 1997, for the mothers and calves present in the group, their association indices included sightings for when the calves were young and still dependent upon their mothers which could hypothetically lead to bias in the results. This study group included 14 pairs of mothers and offspring, but only

three were found to have a HWI of 0.5 or greater, demonstrating that kin does not always lead to strong associations, and so present kin associations may be due to the formation of preferred adulthood associations. As observed by Möller *et al* (2006) in southeastern Australia, whilst kinship may influence female associations within bottlenose dolphin populations, it is not necessarily a prerequisite for associations, with other forces acting on the sociality of female alliances.

5 Conclusion

The present study provides new and important information on the spatial and temporal distribution of bottlenose dolphin calving/nursery areas in the outer southern Moray Firth, and the presence of associations between the mothers in this North Sea population.

This study found mother-calf pairs using the outer southern firth coastline to show temporal site fidelity to the mouths of the two salmon rivers, the River Spey and River Deveron, which has been recorded previously in the area. However, high site fidelity was also shown to the rocky outcrops around the prominent headlands in between, a location not previously known to be of importance to these mothers. This is possibly due to easier and more predictable foraging via barrier feeding, and sheltered shallow conditions away from vessel traffic, creating ideal nursery areas. There was found to be a disparity in the spatial use of the study area, with the most established mothers predominantly choosing Spey Bay, having a much higher occurrence at this shallow bay than the population as a whole. Presence at Spey Bay was found to be temporal, with the highest number of cumulative sightings during the study period occurring in July, coinciding with the known peak in newborns in the outer firth (Robinson *et al.*, 2017b).

Nursing females using the outer southern firth coastline were found to be highly interconnected, with most forming weak associations, but a core number of females forming strong associations. Strong associations were particularly evident between mothers with their former offspring but also between females who had potentially grown up together and had shared reproductive states, with there being considerable advantages to coordinating calving times, beneficial for cooperative calf care and communal raising of young.

Calving/nursery habitats provide refuge for mothers and their calves and are essential for the survival of a species. Knowledge of the distribution of these areas is therefore vital, as it enables targeted conservation and protection of these habitats of particular vulnerability and critical importance, thereby supporting the conservation of the population as a whole, as calf survival determines population success.

The continued monitoring of this Moray Firth population remains necessary to provide robust estimates of populations parameters to improve our understanding of their habitat use, and advance the conservation of these animals in our UK coastal waters. This will serve to inform regulators regarding the potential impacts of proposed and ongoing developments (i.e. offshore wind farm installations and oil and gas activities) on these animals in northeast Scottish waters. Where regulators are under increasing pressure to ensure adequate protection for protected species, such as the bottlenose dolphin, the need for appropriate long-term monitoring of long-lived species within identified critical habitats becomes an increasing priority. The present study supports that particular areas of the outer southern Moray Firth coastline provide important habitats for nursing females with calves, and are therefore of highest conservation and management priority to support the long-term viability of this northeast population.

The identification of potential calving/nursery areas is highly desirable for conservation efforts to protect of this population of bottlenose, so future studies into these are crucial. Further studies might choose to focus on the presence of calving/nursery areas adjacent to the outer southern Moray Firth, using wider and integrated datasets to look at the northern population as a whole. This would enable a holistic approach to conserving all possible nursery areas used by the Moray Firth population, as individuals are known to travel outside of the range used in this study. It may also be informative to incorporate environmental variables such as sea surface temperature, bathymetry and seabed slope, chlorophyll-a concentration, and prey distribution in future studies into these calving areas, especially in the face of climate change. An assessment of the overlap of these areas with anthropogenic activities such as vessel traffic and, as previously mentioned, coastal offshore developments, would be beneficial to evaluate potential disturbance risks, and subsequently inform the expansion of the existing SAC in place in the inner firth to include these critical nursery habitats within the outer southern firth.

6 References

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7 Appendix

Appendix 1. Table showing the ID and age of all the offspring of each female in the study group sighted during the study period.

ID	OFFSPRING ID	AGE (YEARS)
065	297	23
065	436	18
065	514	15
065	541	13
065	585	11
065	643	9
065	679	6
065	745	2
067	328	23
067	392	19
067	484	16
067	562	Born 2013. Deceased (Age 0-1)
067	599	Born 2015. Deceased (Age 1-2)
067	676	7
067	724	3
003	329	23
003	421	19
003	488	16
003	565	12
003	638	9
003	680	6
003	723	3
035	344	23
035	479	17
035	581	12
035	659	8
035	697	5
432	498	20
432	448	17
432	589	11
432	675	7
432	714	4
187	170	26
187	355	Born 2004. Deceased (Age 2)
187	390	19
187	478	16
187	537	13
085	534	14
085	611	11
085	686	7
085	746	2

Appendix 1. (Continued)

ID	OFFSPRING ID	AGE (YEARS)
119	506	22
119	395	19
119	513	Born 2010. Deceased (Age 0-1)
119	538	13
118	253	25
118	377	20
118	489	17
118	525	Born 2011. Deceased (Age 0-1)
118	566	12
118	668	8
118	715	4
389	358	Born 2004. Deceased (Age 0-1)
389	542	13
389	708	4
216	331	Born 2002. Deceased (Age 0-1)
216	523	14
216	587	11
216	661	8
216	709	4
162	Unknown	Unknown (2001)
162	394	20
162	524	14
162	605	Born 2015. Deceased (Age 2)
162	662	8
162	733	3
225	204	25
225	359	21
225	431	18
225	519	15+
225	583	11
225	660	8
225	700	5
225	744	2
327	385	19
327	491	16
327	535	14
327	678	11
404	495	16
404	584	11
404	703	5
404	751	1
521	540	13
521	652	10
521	705	4

Appendix 1. (Continued)

ID	OFFSPRING ID	AGE (YEARS)
445	510	19
445	508	16
445	547	Born 2012. Deceased (Age 0-1)
445	580	11
445	725	4
253	571	Born 2013. Deceased (Age 0-1)
253	601	10
253	684	6
253	726	3
482	487	20
482	536	Born 2012. Deceased (Age 0-1)
482	582	11
482	654	8
506	564	12
506	639	9
506	681	6
498	572	12
498	614	Born 2016. Deceased (Age 0-1)
498	693	5
498	730	3
487	588	11
487	702	5
487	747	2
385	563	12
385	687	8
385	704	5
385	749	2
436	604	10
436	667	7
436	734	3
478	609	10
478	685	6
491	669	8
491	698	5
491	748	2
486	539	Born 2012. Deceased (Age 0-1)
486	600	10
490	658	8
490	735	2
514	727	4
514	742	1
534	677	7
534	728	4
564	739	2
566	706	4

Appendix 1. (Continued)

ID	OFFSPRING ID	AGE (YEARS)
587	721	3
601	712	4
601	741	1