Post-release movements of translocated White-tailed eagles (*Haliaeetus albicilla*) during the first year of juvenile dispersal

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Abstract

Conservation translocations are increasingly being used as an effective means of species recovery. In order to address the loss of White-tailed eagle (WTE) (*Haliaeetus albicilla*) from its historic range, a conservation translocation commenced with the aim to re-establish a viable breeding population of WTE to the Isle of Wight and across southern England. This project offered the unique opportunity to investigate the initial stages of juvenile dispersal and post-release movements of translocated WTE, using satellite telemetry, from release, up until the end of their first year. Data was utilised from nine birds from two groups during analysis (Cohort 1 and Cohort 2).

The aim of this research was to increase our understanding of what the birds did within the initial post-release period; when did dispersal onset begin, where did they travel and settle, how far away from the release site and on what temporal scale? Ultimately, what insight can this information give us into juvenile dispersal, the translocation process so far and importantly, how could we use this information to support WTE recovery in the UK going forward?

There are a limited number of studies that have investigated aspects of natal dispersal and the ecology of adult WTE but few focus specifically on Juvenile WTE during juvenile dispersal. Prior to this study, first year WTE telemetry data derived from this translocation project had not been investigated in this way.

Movements were characterised by moderately sedentary behaviour in the initial post-release period, with movements away from the release site following dispersal from the Post-Fledgling Area (PFA). Cohort 1, released in 2019, tended to reach dispersal onset quicker than cohort 2, released in 2020, 23 days earlier than cohort 1. Most individuals continued to reside in and move between multiple Temporary Settlement Areas (TSAs) ranging from 1-6, mostly across England and Scotland with a single individual travelling into mainland Europe. Four areas of overlap were identified whereby at least 2 birds used in part the same TSA (spatially if not temporally). Size and residency times for each PFA/TSA varied but a higher proportion of time was spent residing in areas identified as TSAs overall (85%) as opposed to continuous exploratory travel (15%). High levels of inter-individual variation in travel distances were detected, demonstrating some individuals moved greater distances more often than others. Intra-individual travel distances also varied greatly, with a far greater frequency of short than long distance movements. When long distance movements and wider distancing variation did occur (including maximum daily distance and maximum dispersal distance), it was almost exclusively in the final months of the 12-month study period.

Juvenile dispersal in WTE is a long and complex process and has important implications for the conservation of the species. It is likely that there are many influencing factors affecting movements during the transient period and this research adds to the growing body of information relating to juvenile dispersal in raptors. The outcomes from this project could also be utilised to support future translocation projects, as well as highlight areas in the juvenile dispersal process that may require further conservation consideration to ensure juvenile WTE continue to thrive within the landscape and reach recruitment into the breeding population.

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1 Chapter 1: Introduction

1.1 Translocations

In the present era of accelerated ecological change, driven by anthropogenic activities such as climate change, biological invasions, over-exploitation, habitat loss and degradation, the world's biodiversity is experiencing unprecedented pressures (Mee *et al.*, 2016). Many species are experiencing population declines or becoming completely eradicated from their historical ranges. With these challenges it is unlikely that all populations of declining or expatriated species will return to their historic ranges and sustain viable populations through natural range expansion via natural recruitment and dispersal alone (IUCN and SSC, 2013; Seddon, 2010). Conservation translocations are increasingly being used as a proactive and effective means of species recovery and preservation (Muriel *et al.*, 2021; IUCN and SSC, 2013; Seddon, 2010; Berger-Tal, Blumstein and Swaisgood, 2020; Muriel *et al.*, 2015) normally to support preceding conservation measures (IUCN and SSC, 2013).

Conservation translocations are defined by the IUCN/ SCC (2013) Guidelines as the "Deliberate movement of organisms from one site for release in another. It must be intended to yield a measurable conservation benefit at the levels of a population, species, or ecosystem, and not only provide benefit to translocated individuals." Conservation translocations can be categorised into two branches: (i) the reinforcement and reintroduction of a species within indigenous range; and (ii) conservation introductions, consisting of assisted colonisation and ecological function replacement, outside of a focal species' indigenous range (IUCN and SSC, 2013; Seddon, 2010).

The term 'translocation' in isolation is an umbrella term which is often used to encompass a spectrum of human-mediated movements of organisms (accidental or intentional) but according to the IUCN and SSC (2013) definition do not have the same primary conservation motivations as a conservation translocation. Translocation activities that are not driven by conservation motives can include rehabilitation & release, relocation of organisms to reduce in-situ population size, relocation for recreational, political or commercial benefit (Seddon, 2010; IUCN and SSC, 2013).

Owing to the often ambiguous and interchangeable use of the term translocation and conservation translocation to describe both official conservation translocation work and those that fall outside of the description stated, I have adopted the IUCN and SSC (2013) definition of 'conservation translocation' and will continue to use it throughout this study. Those activities that fall under the definition of 'translocation' as described will not be mentioned further.

Despite the popularity of conservation translocation projects as a means of species restoration, most projects will at some stage have some challenges in implementing and achieving desired goals/outcomes. It is therefore imperative that in order to maximise success we learn from collective experiences (Berger-Tal, Blumstein and Swaisgood, 2020; Muriel *et al.*, 2015). Berger-Tal et al. (2020) reviewed six volumes of the Global Re-introduction Perspective Series containing 349 case studies of translocations, 293 describe translocations of animals. They stated that the top three issues recorded were project funding, animal behaviour post-release and difficulties with post-release monitoring. Dispersal and movement behaviours were stated as the most common cause of behaviour related difficulties in conservation translocations across all case-studies (Berger-Tal, Blumstein and Swaisgood, 2020). Lessons learnt and research arising from conservation translocation projects can help inform and improve methods of project implementation for current and future projects (Berger-Tal, Blumstein and Swaisgood, 2020). They can also provide important insights into population ecology and processes, including dispersal in several ways: planned reintroductions are essentially new colonisation events and represent the controlled expansion of a population into a novel environment from a restricted number of release sites (proxy natal site). All individuals are also of known origin and typically marked and monitored over their post-release life span (Whitfield *et al.*, 2009b; Seddon, Armstrong and Maloney, 2006). Monitoring programmes are often a prerequisite of reintroduction licensing and are therefore comprehensively planned and implemented. Lastly, a successful reintroduced population offers the opportunity to study population processes over a wide range of population abundance and competitive influence (Whitfield *et al.*, 2009b; Whitfield *et al.*, 2009a; Seddon, Armstrong and Maloney, 2006).

1.2 Dispersal and movement behaviour in large long-lived Raptors

1.2.1 Post-fledging - Pre-dispersal Dependency Phase

Within the life cycle of an altricial bird species (such as the White-tailed eagle (WTE) after fledging there is a dependence phase (Ramos *et al.*, 2019). This post-fledging period can be defined as the period between fledging and the start of dispersal from the natal area (Balotari-Chiebao *et al.*, 2021); (Morrison and Wood, 2009). During this time there is still a parental dependency whereby the juveniles have fledged the nest but are still reliant on their parents for food provisioning and remain in a Post-fledging Area (PFA) frequented by the parents (Rymešová *et al.*, 2021; Miller *et al.*, 2019) or in the instance of a reintroduced juvenile the area surrounding the release site. Juvenile raptors during this time are developing flight, resource detection and foraging skills as well as learning social cues when interacting with conspecifics as well as exploring new environments (Ramos *et al.*, 2019; Balotari-Chiebao *et al.*, 2021). Often these new environments harbour many anthropogenic and novel hazards, such as road infrastructures, powerlines, wind farms (Balotari-Chiebao *et al.*, 2021). Whether translocated or wild-bred in-situ the early movements of raptors are extremely informative. During this formative period of post-fledging/ release and juvenile dispersal mortality risk is often at its highest of any other time in the live cycle (Muriel *et al.*, 2015). As the juveniles develop physically and flight skills are improved, the period becomes interspersed with short exploratory flights outside of the natal area or post-fledging area, but the birds return for continued parental provisioning (Engler and Krone, 2021; Rymešová *et al.*, 2021; Miller *et al.*, 2019). Once a juvenile has reached independence it is no longer dependent on its parents for food provisions (or human provisioned food in the context of a translocation) and its flight skills have developed enough, the process of natal/ juvenile dispersal begins (Dennis *et al.*, 2019).

1.2.2 Dispersal

Natal dispersal is defined as the movement of individuals between their place of origin (natal site) and first breeding sites (Greenwood and Harvey, 1982) any subsequent movement to new breeding sites is termed breeding dispersal (Greenwood and Harvey, 1982). Breeding dispersal is not covered in the scope of this study. Some large raptor species have delayed maturity, in which natal dispersal may last several years and include a long period of transient behaviour (Ferrer, 1993b; Whitfield *et al.*, 2009b) characterised by extensive movements away from the natal area (Whitfield *et al.*, 2009b). This complex transient period of natal dispersal displayed by juveniles has been coined by many researchers as juvenile dispersal (Whitfield *et al.*, 2009b; Ferrer, 1993b). During a period of juvenile dispersal, the juvenile raptor may spend a considerable period (several years) engaging in long distance exploratory flights, moving between, and residing temporarily in geographically restricted areas (Temporary Settlement Areas (TSAs)) (Rymešová *et al.*, 2021; Del Mar Delgado *et al.*, 2009; Nemček *et al.*, 2016; Morandini *et al.*, 2020) as well as potentially intermittently make returns to its natal area. Mortality risk during this stage is high (Muriel *et al.*, 2015), if the individual survives to reach sexual maturity and beyond the conclusion of the natal dispersal process ends with recruitment into a breeding population (Greenwood and Harvey, 1982).

These behavioural processes from fledging to settlement and dispersal in general are long and poorly understood (Whitfield *et al.*, 2009b; Weston *et al.*, 2013; Ramos *et al.*, 2019), yet it is an important behaviour that influences juvenile survival (Ramos *et al.*, 2019), population dynamics (Weston *et al.*, 2013); gene flow, population expansion (Muriel *et al.*, 2015) and persistence. It is recognised that post-release movements and dispersal (in this context juvenile dispersal) are fundamental elements affecting the success of any conservation translocation/ reintroduction project (Armstrong *et al.*, 2013). Gaining a comprehensive understanding of these movements and dispersal processes is therefore vital to improve the outcome of any current and future conservation translocations (Muriel *et al.*, 2015) .

1.3 Raptor Conservation Translocations and Reintroductions in the UK

There are fifteen diurnal breeding raptor species in the UK, and all historically have suffered extensive population declines. Five of the 15 species (Goshawk (*Accipiter gentilis*), Marsh harrier (*Circus aeruginosus*), Honey buzzard (*Pernis apivorus*), White-tailed eagle (*Haliaeetus albicilla*), and Osprey (*Pandion haliaetus*)) were driven to extinction before the end of the 1918 (RSPB, 2011). Five more species populations (Golden eagle (*Aquila chrysaetos*), Hobby (*Falco subbuteo*), Hen harrier (*Circus cyaneus*), Red kite (*Milvus milvus*) and Montagu's harrier (*Circus pygargus*)) were also decimated at various periods between 1870 – 1970 (reducing breeding pairs to less than 100) with the Montagu's harrier becoming temporarily extinct in the 1970s (RSPB, 2011). The remaining raptors have not been excluded from population declines. All fifteen species have suffered varying degrees due to human induced hazards such as persecution, habitat destruction, land use change, the introduction of organochlorine pesticides and human influenced prey species reduction (RSPB, 2011).

Although direct Raptor persecution, illegal and secondary poisoning still occurs vastly in the UK, with the introduction of some legal protections, extensive conservation work, changes in agricultural practices including banning harmful substances, the reduction of persecution for some species along with some changing of attitudes towards the environment and raptors from private landowners, some UK raptor species populations have recovered to maintain stable populations (RSPB, 2011) via natural recolonisation and recovery and subsequent population expansion. Some species though stable have not reached or cannot reach full population density or expansion potential due to the mechanism of population depression (for example the Golden Eagle) caused by persecution. Other species recovered locally but due to their ecology, ecological barriers or again persecution in some geographical locations have been unable to expand their ranges, whilst other species were unable to re-establish at all such as the WTE (RSPB, 2011).

The Osprey which naturally returned to breed in Scotland (Dennis and Dixon, 2001), the Red Kite who still maintained a small remnant population in Wales (Davis and Newton, 1981) and the Golden Eagle who remained in low density pockets in Scotland (O'Toole, Fielding and Haworth, 2002) were protected by extensive in-situ conservation measures by several conservation bodies and enthusiasts (RSPB, 2011; Taylor, 2011). Although these species were recovering in their respective areas they failed to expand further into other parts of their formative ranges. For all three species translocation and reintroduction projects were planned (Taylor, 2011; RSPB, 2011; O'Toole, Fielding and Haworth, 2002). The Red Kite has subsequently been reintroduced to England, Northern Ireland, and Scotland (Taylor, 2011). The Osprey has been reintroduced to the Midlands in England (Dennis and Dixon, 2001) and have been translocated to the South Coast of England with more reintroductions planned for elsewhere in the East of England (MacKrill, T. personal communications, 2020). As a result of these conservation translocations Osprey have also begun to naturally recolonise in North Wales (Skujina *et al.*, 2021). The Golden Eagle has been reintroduced into areas of its former range in South Scotland and Ireland (Taylor, 2011; RSPB, 2011; O'Toole, Fielding and Haworth, 2002).

Unlike many other UK raptors when the White-tailed eagle (WTE henceforth) became extinct the species failed to re-establish again naturally and therefore extensive conservation measures were required to ensure it returned to the UK including Conservation Translocation. The WTE is a large diurnal raptor. It is a long-lived species (life span approximately 21 years) with delayed maturity reaching breeding age at approximately 4-5 years. WTE are the largest raptor species in the UK (by weight and wingspan). The WTE currently has a wide geographical distribution and can be found throughout south-western Greenland to Europe and Asia, including India, China and Japan (Balotari-Chiebao *et al.*, 2016; Birdlife International, 2015) with breeding population strongholds in Russia and Norway. Russia and Norway alone make up ~55% of the European population (Bird life International. 2004). South-west Greenland through to Denmark, Sweden, Poland and Germany are also important populations. Some of these populations have seen historical declines namely persecution and accumulation effects of organochlorines (Balotari-Chiebao *et al.*, 2021). Current threats and limiting factors that still exist within their vast geographical distribution include illegal persecution (notably lead and other poisonings) as well as environmental and chemical pollution, habitat loss and degradation (Balotari-Chiebao *et al.*, 2021; Evans *et al.*, 2009; Love and Ball, 1979). The WTE became extinct in England and Wales by 1860 (Sophie-lee *et al.*, 2020), it was reported by Lysaght (2004 cited by Mee et al. 2016) that there was no evidence of breeding WTE in Ireland by 1909 and that it was extinct in Scotland by 1916 (Sophie-lee *et al.*, 2020; Evans *et al.*, 2009; Love and Ball, 1979). The last known breeding site of the WTE on the south coast of England was Culver Cliffs on the Isle of Wight in 1780 (Dennis *et al.*, 2019). The complete eradication of the WTE in all UK countries are attributed mainly to intense human persecution (Evans *et al.*, 2009; Love and Ball, 1979; Dennis *et al.*, 2019) and wetland habitat loss (Mee *et al.*, 2016).

1.4 White-tailed eagle reintroduction to the UK

In the context of the WTE reinstatement and recovery in the British Isles extensive conservation efforts during the 1970's and in the following decades have re-establish a self-sustaining population of WTE in Western Scotland (Evans *et al.*, 2009; Love and Ball, 1979; Whitfield *et al.*, 2009b) as well as in Ireland between 2007-2011 (Mee *et al.*, 2016; Dennis *et al.*, 2019). Both were established following large-scale conservation translocation projects of Norwegian wild-bred WTE juveniles (Love and Ball, 1979; Mee *et al.*, 2016). The Current UK breeding population is increasing both in Scotland and in Ireland with an estimated 130+ breeding pairs in Scotland and 10 in Ireland (Dennis *et al.*, 2019).

In response to the historic decline and current issues jeopardising the species survival and expansion, the WTE is currently listed in the Annex I species of the EU's Bird Directive (Directive 2009/147/EC 2009), is a Schedule 1 Species throughout the UK under the Wildlife and Countryside Act 1981 and has also been moved from the Red List to the Amber List in the Birds of Conservation Concern (BoCC) report 5 (2021) based on the current recovery from historic decline in the UK population due to the foundation work of the Scottish and Irish reintroduction projects and the steady natural dispersal within these regions from these reintroduction sites (Stanbury *et al.*, 2021).

However, whilst the populations here in the UK and Europe are increasing there is a limit on natural far-reaching expansion due to the birds (particularly males) strong philopatry (Mee *et al.*, 2016). This prompted the need for a continuation of reintroductions to other parts of the UK. A further conservation translocation and reintroduction was approved and has started on the Isle of Wight, South of England. The Isle of Wight White-tailed eagle Project is a collaborative partnership between The Roy Dennis Wildlife Foundation and the Forestry England (Dennis *et al.*, 2019). The primary aim of the conservation translocation project is to re-establish a viable breeding population of WTE on the Isle of Wight and across southern England (Dennis *et al.*, 2019), through the movement and release of up to 60 young Scottish bred White-tailed eagles at a designated release site on the Isle of Wight over a 5-year period (Dennis *et al.*, 2019). It is also believed that the reintroduction will enhance the long-term survival of WTE by increasing the range and connectivity of the meta-population in southern and western Europe (Dennis *et al.*, 2019) much sooner than would occur by natural dispersal from these populations. It will also provide connectivity between the Scottish (130+ pairs) and Irish populations (10 pairs) and newly expanding populations in the Netherlands (18 pairs) and France (4 pairs) (Dennis *et al.*, 2019).

The project commenced with its first release of its first cohort of birds in August 2019. Followed by a second cohort in July 2020 (Personal communications, Tim Mackrill). Stringent post-release monitoring of all birds after release has been key both in terms of monitoring animal welfare, behaviour and to gauge any impact to existing ecological communities and/or socioeconomics that may occur as a consequence of the release (Dennis *et al.*, 2019). Data produced during the first year of release by the post-release monitoring programme from the first two cohorts released has been used in this research.

This study offers the unique opportunity to gain insight into the conservation translocation of the WTE and reintroduction to part of its historic indigenous range – the Isle of Wight on the South Coast of England, studying their post-release movements and dispersal from release up until the end of the first year which has not been researched before. The overall aim of this study is to support the conservation translocation success of WTE by increasing our understanding of the initial post-release movements, dispersal onset/ movements, activities, patterns, and space use on a temporal scale.

By increasing our understanding of what the birds did within the initial post-release period we can gain insight from questions such as when did dispersal onset begin, where did they travel and settle, how far away from the release site, for how long and was there any indication of a temporal pattern? Ultimately, we can ask what can this insight into juvenile dispersal give us in relation to the translocation process and recovery of the WTE in the UK going forward?

This will be achieved through the following objectives using tracking data of juveniles in their first-year post-release:

1. Quantify changes in the distances between roost sites and the release site and determine the timing of independence from the release site (i.e., the onset of natal dispersal).
2. Investigate distances travelled on a daily and monthly basis to determine temporal / seasonal patterns in distances moved.
3. Identify areas exploited over an extended period of time to quantify the use of Temporary Settlement Areas.

2 Chapter 2: Methods

2.1 Study species

WTE have a wingspan of 200-250cm and weigh approximately 3.5-5kg (male); 4-7kg (female). They reach sexual maturity at approximately 4-5 years of age in established populations after spending several years away from the natal area performing a pattern of transient behaviour (Whitfield *et al.*, 2009a; Rymešová *et al.*, 2021). Except for some populations in Northern European and Asian, territorial WTE pairs are mainly sedentary (Dennis *et al.*, 2019) and generally overwinter within their established territory year-round (Rymešová *et al.*, 2021). In Scotland, WTE are associated with areas along rocky coastlines, estuaries and sea connected lochs (Dennis *et al.*, 2019). They also range extensively inland, particular during the transient stage of juvenile dispersal (Dennis *et al.*, 2019). Generally, birds will settle and breed within 50km of their natal population due to strong male philopatric tendencies (Dennis *et al.*, 2019) making the species an ideal candidate for successful conservation translocation to historic ranges. Females show less philopatry tendencies and tend to settle where a suitable, available male has secured a territory with desirable resources. A bonded pair will build large eyries in the top of tall trees, which are maintained and used annually. In the UK and Ireland egg laying occurs in March to the beginning of April and are incubated for approximately 38-40 days. Nestlings will fledge after approximately 70 days in the nest and will remain dependant on their parents for provisions and protection for a further 5-6 weeks (Dennis *et al.*, 2019).

The WTE is considered an opportunistic, generalist apex predator, predominantly hunting and feeding on fish, small to medium mammals (including lagomorphs and rodents), seabirds, waterfowl, and carrion (Nadjafzadeh, Hofer and Krone, 2016; Nadjafzadeh *et al.*, 2016; Whitfield *et al.*, 2013; Ekblad *et al.*, 2020). Piracy may also be practiced targeting other species for their food items. There is geographical variation in prey item compositions within the diet (Ekblad *et al.*, 2020; Dennis *et al.*, 2019) and seasonal shifts in prey item consumption in response to temporal changes in food availability (Nadjafzadeh *et al.*, 2016; Ekblad *et al.*, 2020). Feeding and hunting strategies and thus predominant food sources in the diet composition are also seen to change across age class (Edgar-Read, S. personal communications, 2024).

2.2 Study individuals

The wild breed WTE nestlings were collected from various monitored nest sites throughout Scotland at around 7-8 weeks of age and transported to the release site on the Isle of Wight. During each year of the translocation, the birds were transported to the Isle of Wight during the same week each year +/- a few days. The project utilises aspects of a soft-release protocol, and as such the birds were transferred to and held in hacking cages at the release site, monitored and fed. The birds were released in small batches across several days when deemed ready based on physical and behavioural development observations (Dennis et al., 2019). Post-release ad lib food provisions were provided at the release site until after all of the birds had reached independence. Provisional feeding after release is to mimic natural parental provisioning and care as well as encourage the individuals to remain in the pseudo-natal site for as long as possible and not disperse too quickly.

Each bird was ringed with a British Trust for Ornithology (BTO) identification leg ring and a monitoring colour leg ring for identifications made in the field. The sex ratio of the birds being investigated is 6 males: 3 Females (2 males :1 female – cohort 1 and 4 males: 2 females – cohort 2).

Table 1: Identification details for each study bird (Cohort number, Identification code, Sex and Date of release/ first day of data collection, last day of data collection)

Cohort Number	Numeric code/ Identification code	Sex	Release date (first day of data collection)
One	191978 (74)	Male	22/08/2019
One	191984 (18)	Female	21/08/2019
One	191977 (93)	Male	21/08/2019
Two	191980 (05)	Female	30/07/2020
Two	191985 (08)	Male	30/07/2020
Two	191986 (61)	Male	30/07/2020
Two	201446 (63)	Male	31/07/2020
Two	191983 (66)	Female	31/07/2020
Two	201447 (71)	Male	31/07/2020

2.3 Data selection and variables determination

2.3.1 Use of satellite telemetry

As part of the WTE translocation project monitoring programme all juveniles were fitted with a 50g solar powered Global Positioning System (GPS)-GSM tracker: model: OT-50-3GC manufactured by Ornitela shortly prior to release. This was to obtain and monitor the movements of all bird's post-release. The GPS data is collected indefinitely until failure, loss of equipment or demise of the bird. The satellite tags were placed as a backpack with a Teflon harness (Kenward, 2001). Transmitter weight did not exceed 3% of the birds' body mass as recommended by Kenward (Kenward, 2001). Each GPS tag and thus bird was assigned a unique numeric code (Table 1). Resulting data used in this study included date, time, longitude, and latitude (GPS fix).

Within the scope of this study only the first 365 days post-release date of data will be used for each bird therefore only birds with at least one full calendar year of data have been used for analysis in this research.

The transmitters were programmed to send a variable number of GPS fixes per day depending on the individual, daylight hours, time of day, time of year and battery status. The varying sampling rates for each bird also changed throughout the duration of the study. Sampling intervals were set between 30 seconds and two hours during daylight hours and every four hours thereafter using the suns position of -6° below the horizon for the trigger to change frequency (dawn and dusk). Sampling rate also reduced if the solar battery power was significantly low often resulting in a reduction of relocation data received in winter or low light days, which led to some variation among individuals and during certain time periods. As transmitters were set with varying sampling rates some birds had a higher resolution, flightpath accuracy and varying number of GPS relocations within the dataset. Relocation data from was downloaded directly from Ornitela for each bird that met the stipulation of having produced 365 days of data following release.

To account for the variation in sampling rates all data were initially cleaned for erroneous location data. This was completed by firstly visualising the original relocations for each bird in QGIS. Relocations that were visually deemed erroneous such as those on the equator or in unrealistic locations were removed manually from the datasets. Trajectories between relocations were also produced and animated on a temporal scale, for each bird again to indicate if all relocations were logistically feasible. The datasets for each bird was then read into RStudio and filtered to remove all remaining relocations with missing coordinates and entries with duplicate timestamps. This created the cleaned base dataset used in each objective. Due to the varying sample rates across the year and between birds sampling rate regulation was performed to allow inter and intra-individual comparison where applicable, as well as further treatments for calculating specific outputs depending on the objective (all specific data treatment methods are stated below in relation to each specific and relevant objective).

All data variables produced were assessed for normality and descriptive statistics produced. As all data variables were deemed of non-normal distribution, non-parametric results were the best representative of the outcomes.

2.3.2 Objective 1: Roost site distancing and reaching independence from the release site

To determine all-night roost sites R package Adehabitat (Calenge, 2006) was used to characterise daily trajectories from the available cleaned GPS data. Each trajectory was then rediscretized to 60-min interval fixes. Rediscretisation is a function that performs linear interpolation to find new relocations separated by the given time lag. To maintain a constant temporal scale, GPS fixes were filtered to retain one location per day closest to 00:00h. This location was considered to represent a bird's nighttime roost site (00:00h was chosen as a likely part of the night for WTE to be roosting (Mackrill, T., Personal Comms, 2020)). This produced a dataset with 365 all-night roost site locations (roost site henceforth) and corresponding dates for all 9 WTE starting from their release dates. Roost sites were plotted in QGIS and straight-line distances from the release site to each roost site were calculated consecutively in RStudio by using R package sf. Distance between each consecutive roost site was calculated by Haversine distance calculations in metres and then converted to Kilometres using RStudio.

2.3.2.1 Further roost site distancing analysis

To further investigate distancing from the release site during the first 12 calendar months since release, daily roost site distancing from the release site was computed producing descriptive statistics using all distances within a given month. Boxplots were produced one per month for each individual. Boxplots were also produced one per month utilising aggregated data from all birds (n=9).

In preparation for visual representation of distancing per month, two days of data that fell in July have been removed post analysis of descriptive statistics (daily night-time roost sites). Cohort 2 birds were released on the 30th and 31st of July 2020, these two days have been removed so that all birds start the analysis in the same month of August. The two days of data in July didn't represent any notable movements. Daily distancing of roost sites grouped by month consequently starts from the first calendar August of life for all birds (Month 1) and is considered the first month since release for all birds. The data that fell into the second calendar August for cohort 1 was also removed as only the first 12 calendar months are investigated here.

Maximum roost site distance from the release site, date of occurrence and corresponding day of release have also been determined and recorded to determine maximum dispersal distance.

2.3.2.2 Reaching independence

The method used to identify when a juvenile bird has dispersed from its natal site can notably affect results. It is not always possible to compare published results from other studies due to these differences in methods used. This can lead to difficulty in assigning accurate timings and categorisations of the dispersal process (Weston *et al.*, 2013). Therefore, I studied three different methods to calculate dispersal onset and compared the results to demonstrate these differences and to identify a best fit method for this scenario. To estimate when a juvenile had reached independence from the release site, roost site distances from the release site (distances established above) were used in combination with 3 distance threshold-based methods.

Once a roost site had exceeded the threshold distance stated in said method and met additional criteria (such as remaining outside of that distance threshold for a stated number of nights) day number since release of initial occurrence were recorded as the day independence/ onset of dispersal was reached (dates have also been recorded but not used in further analysis due to the scope of the study). Distance threshold-based methods were researched and existing species appropriate methods used and, in some cases, amended from several sources (sources stated next to each method below). Distance threshold-based methods include:

1. First date beyond half the mean neighbour distance (4.45km from release site) and not within that distance for the following two consecutive days (roost site relocations)

   (4.45km = Half the mean neighbour distance; the 4.5km figure has been taken from research conducted specifically on WTE's inter-nest distances in Scotland by Whitfield et al. (2009b; 2009a)

2. First date beyond mean neighbour distance (9.9km from release site) and not within that distance for the following two consecutive days (roost site relocations)

   (9.9km = mean neighbour distance of WTE in Scotland; The 9.9km distance threshold was taken from research conducted specifically on WTE's in Scotland by Whitfield et al. (2009b; 2009a)

3. First date a roost site relocation was beyond 5km from release site and not within that distance for ten consecutive days. The 5km distance threshold was taken and amended from research conducted specifically on Finnish WTE's by Balotari-Chiebao et al. (2018) and used by Rymešová et al. (2021).

2.3.2.3 Further investigation on effects of delayed release

As previously mentioned, both Cohort 1 and 2 were transported to the Isle of Wight during the same week of the year in 2019 and 2020 respectively. Cohort 1 releases began on the 21/08/2019. Cohort 2 birds on the 30/07/2020. This is a difference of approximately 23 days between cohorts. Consequently, Cohort 1 spent more time in the hacking cages prior to release than Cohort 2. To investigate influence of delaying release on the timing that independence was reached (and thus the amount of time spent at the release site post-release), the birds were divided into cohorts and descriptive statistics produced and analysed. The two groups were then compared. Although the distribution of the variables used was not significantly different from a normal distribution (Appendix A), the data were analysed with non-parametric statistics due to the relatively small sample size. Mann-Whitney U tests were used to test for significant differences in the timings of dispersal onset between cohorts.

2.3.3 Objective 2: Distances travelled on a daily and monthly basis

After producing the cleaned base dataset as described previously, further treatment was applied to the dataset. For the calculation of Daily Distances and Daily Area used, days with less than 10 relocations were considered to show an under-representation of the animals' movements (following: (Börger *et al.*, 2006; Giroux *et al.*, 2021) and were therefore excluded.

R package Adehabitat (Calenge, 2006) was then used to characterise daily trajectories for each individual. Each daily trajectory was then rediscretized to 60-min interval fixes, standardising the daily sample size of relocations across all individuals as used in Giroux et al. (2021). Data were then filtered again to only retain hours between 0400 and 2200. These timings were picked as they included all daylight hours (including civil dusk and dawn) throughout the year (based on timings for the Isle of Wight). excluded the data impoverished GPS sleep mode period and would capture daytime movements. This was done to manage the potential effect of the varying daily sample size and give a usable dataset to calculate Daily Distance Travelled and Daily Area Used. Distances covered in a day for each bird was calculated by the sum of all consecutive relocations grouped by date using the AMT package in R. Daily area used in a day for each bird was calculated by producing a minimum convex polygon (95%) around 95% centralised cluster of each day's locations excluding 5% extreme values using AMT and Tidyverse packages in R (Signer and Fieberg, 2021).

2.3.3.1 Further daily movement analysis

To investigate patterns of longer distances, the daily distances for each bird were plotted individually and as a group. To further investigate these movements (daily distance travelled) during the first year of life, boxplots were computed for each month since release and plotted for visual representation.

Cohort 2 birds were released on the 30th and 31st of July 2020, these two days of data have been removed post analysis of descriptive statistics (daily distances) for visual representation (this is so that all birds start the analysis in the same month – cohort 1 was released during August and one/two days of data will not represent anything significant). Daily distance movements (daily distances and area use) grouped by month consequently starts with the first calendar August of life for all birds (Month 1) and is considered the first month since release for all birds. The data that fell into the second calendar August for cohort 1 was also removed as only the first 12 calendar months are investigated here.

2.3.3.2 Addition information – daily area use

Daily area use was also determined and investigated but did not provide any significant insight into the patterns of birds movements than that that had already been identified from investigating daily distance travelled. This section has been removed from the main body of the work and been retained for reference only (Appendix B). It will not be included in any further analysis or discussion.

2.3.4 Objective 3: Use of Temporary Settlement Areas

To identify all Temporary Settlement Areas (TSA) used by each bird during the first-year post-release (first 365 days for each bird), singular all-night roost sites (all-night roost sites deduced from the same data set as used in the Roost Site Distancing from release site section 3.3.2 (n=365 per bird)) were visualised using QGIS. The QGIS Buffer tool was used to create borders with a 5 km radius around each all-night roost point. This enabled visual identification of clusters of roost sites where the points were no more than 10 km distant from each other* and, simultaneously, where individuals had roosted for at least ten nights (periods of residency did not have to be continuous and may have been a combination of multiple returns to the same area). After visually identifying the clusters, all daytime locations (daytime locations are from the same rediscretised dataset used in the daily movement investigations section 2.3.3) with the same dates as the roost sites that make up the point clusters were added, and a minimum convex polygon (MCP 95%) of the collective daytime points was completed to represent a TSA. The first TSA containing the release site has been termed the Post-Fledging Area (PFA). This method is as described by Rymešová et al (2021) with minor alterations. The total number of TSA detected per bird and the area that each covered has been recorded and analysed using descriptive statistics. The total number and percentage of time spent in-situ of each TSA has also been determined from the dates the birds were present in each TSA. Each TSA for each bird was plotted in QGIS for visual representation.

*The justification for using 10km as the distance threshold: The justification for using 10km as the distance threshold distance between roosts in the calculation of TSA's was conducted by calculating a frequency histogram of distances between roosts for all birds (Figure 1). There was a high frequency of distances under 10km (Each band = 10km) as derived from investigating roost site distances in Roost Site Distancing from release site section 2.3.2. This was also the threshold used to identify TSA's in research conducted by Rymešová et al. (2021) on WTE.

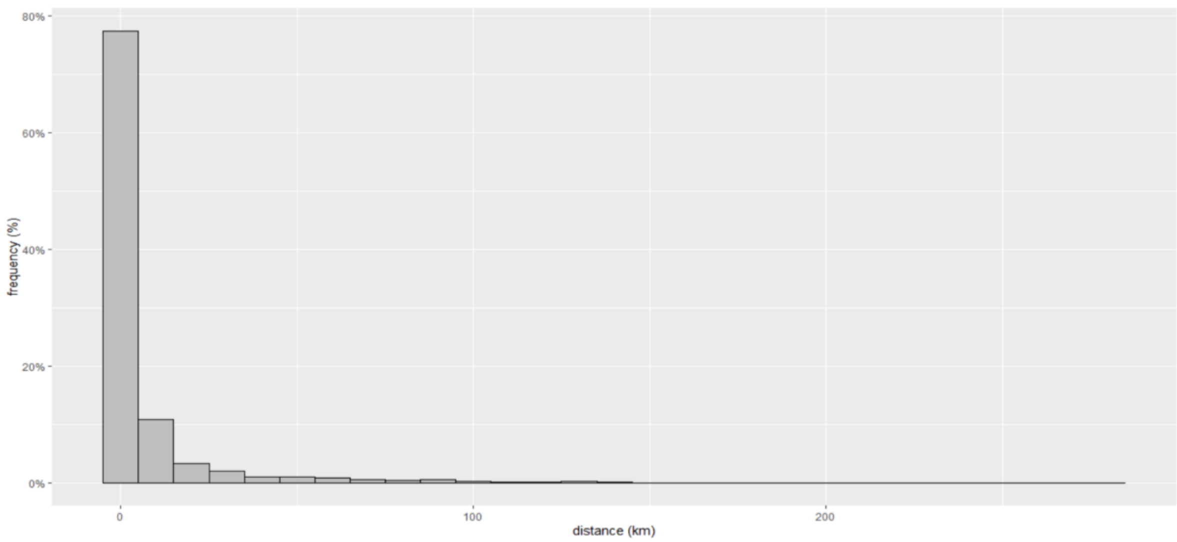


Figure 1: Distribution of distance between consecutive roost sites, for nine WTE during the first 365 days post-release. Distribution of distance of different lengths (distance categories are 10km wide) is shown (n = 3285) (personal collection 2024)

3 Chapter 3: Results

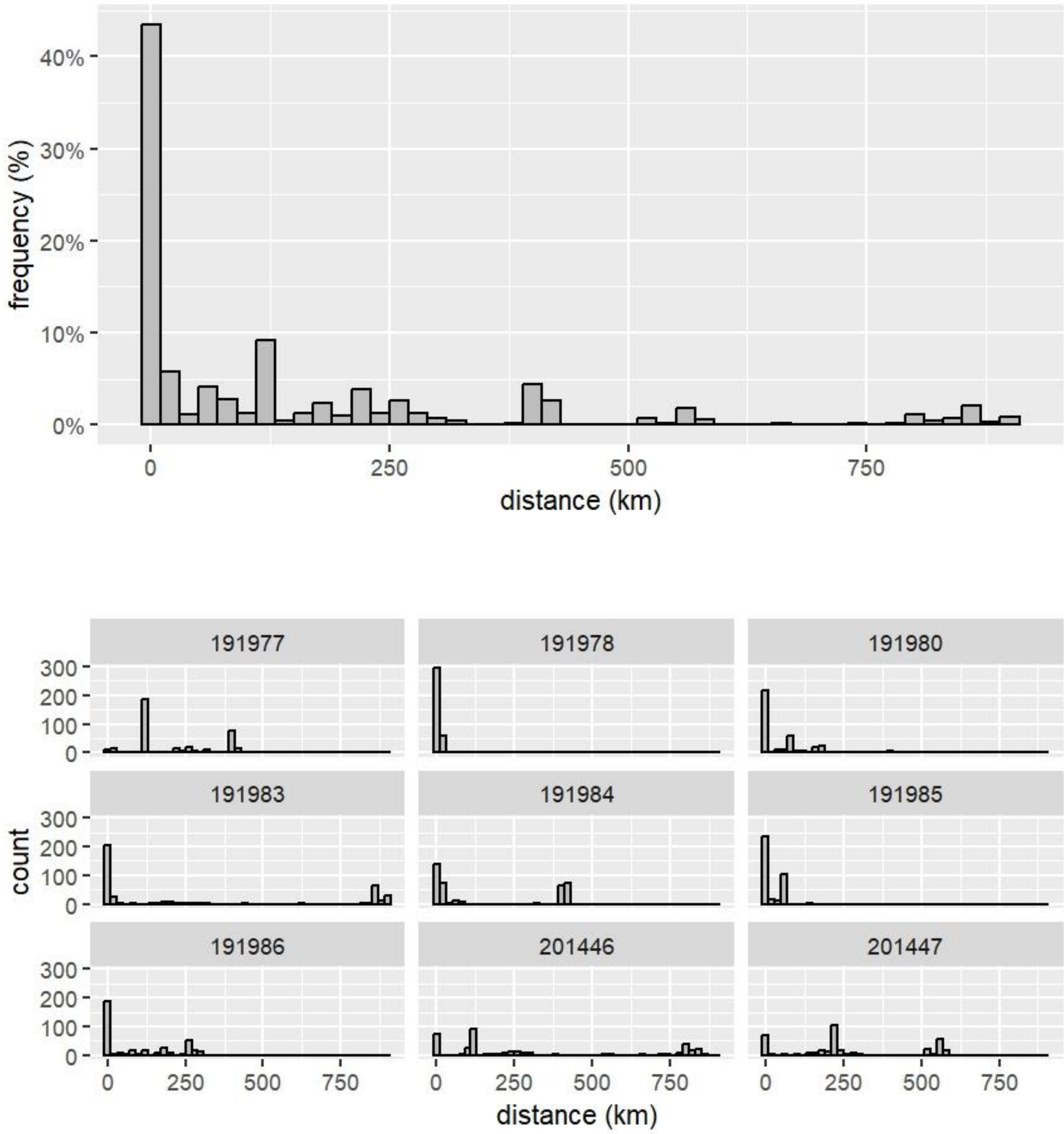
3.1 Objective 1: Roost site distancing, maximum dispersal distance and reaching independence from the release site

All individuals showed high variation of roost site distancing from the release site throughout the year. The median roost site distance of all birds analysed collectively was 46.9 km and indicated high levels of variation among individuals (IQR = 170.1; Table 2). Individual median roost site distances ranged from 5.1km to 216.7km and showed variation across the year post-release for each individual to varying degrees (IQR range across the group = 3.05 to 851.6). Bird 191978 showed the least variation (IQR = 3.05) in distancing from the release site across the year post-release – 95% of his roost sites were within 14.1km of the release site with a median figure of 5.0km (Table 2). Bird 191983 showed the most variation in roost site distancing (IQR = 851.6) and had a median roost site distance of 9.19km (Table 2). Bird 201447 had the largest median roost site distance from the release site - 216.7km with a high indication of variation (IQR = 303.2). Collectively, 25% of roost sites were under 5.88km from the release site, 75% remained under 217km and 95% remained within 797.7km (Table 2). Thus, only 5% of all roost sites were at distances over 797.7km and distances were minimal in the first-year post-release.

Table 2: Descriptive statistics of roost site distances from release site during the first-year post-release. One roost site per night; 365 per bird (n=365), total of 3285 roost sites when analysed collectively.

Id	*Mean roost site distance from release site (km)*	*sd*	*Median roost site distance from release site (km)*	*qu25*	*qu75*	*qu95*	*IQR*
191977	203.3	132.0	118.4	114.1	314.0	409.9	195.6
191978	9.8	20.5	5.0	4.5	8.1	14.1	3.1
191980	59.3	94.0	9.0	6.3	79.7	178.6	70.6
191983	275.4	388.5	9.2	7.3	860.8	898.1	851.7
191984	160.9	194.8	12.5	2.1	408.7	417.1	396.3
191985	24.0	26.5	9.0	5.9	61.3	64.7	52.3
191986	95.4	108.4	9.3	8.5	188.7	271.3	179.4
201446	304.0	314.4	119.7	105.0	723.9	834.9	604.2
201447	268.9	202.3	216.7	169.3	520.0	575.2	303.3
All birds	155.7	228.5	47.0	5.9	217.1	797.8	170.1

When the distribution of roost site distances were analysed collectively (9 individuals; n=3285 roosts) (Figure 2a), 43.5% of the roost sites used during the first 365 days post-release were within 0-20km of the release site. No other distance category independently exceeding 9.3% (binwidth 120-140km) of the total distribution. The collective distribution of distances indicates that a higher percentage of roostsites were closer to the release site during the first year than further away. When analysed individually (Figure 2b), the distribution of distances for 6 of the 9 birds' (66%) followed the collective trend, with the largest number of roostsites occuring within 0-20km of the release site. The distribution patterns for each of the remaining birds vary from one another. Four of the 9 birds accounted for all roost sites distances over 500km, all other birds roosted within 500km of the release site during the entire 365 day period (Figure 2b).



a)

b)

Figure 2: Distribution of Roost site distances *a) Roost site distances from release site, for nine WTE for the first 365 days post-release. Distribution of distances of different length (distance categories are 20km wide) (n= 3285). b) Roost site distances from release site, for all nine WTE individually for the first 365 days post-release. Distribution of movements of different length (distance categories are 20km wide) is shown by occurrence count (n= 365 roost sites per bird) (personal collection 2024).*

3.1.1 Temporal patterns of roost site distancing

Net distances for each roost site were calculated and visualised for each of the 9 WTE for the first 365 days post-release (Figure 3). Whilst all 9 birds spent an initial period of time roosting in relatively close proximity to the release site, the length of time before roosting further away varied among birds. Bird 191977 was the first of the birds to make a distinct and notable movement away from the proximity of the release site at approximately 25 days post-release. All other birds remained in relative closer proximity until at least 75 days post-release (approximate) where by three birds stopped roosting in the immediate area (201446, 201447, 1919186).

Each bird produced distinctly different distancing patterns across the monitoring period with all birds' roost site distances fluctuating to some degree throughout, moving away and closer to the release site, interspersed with periods of relative roost site distancing stability (Figure 3). Stability in distancing (periods of time at approximately the same dispersal distance from the release site) may indicate roosting within a restricted area and the ceasing of wider area exploration for example when using a Temporary Settlement Area (TSA). A notable fluctuation in roost distancing appears to occur at approximately 250 days post-release. Prior to this fluctuation, all of the individuals remained within ~250km of the release site, eight of which generally remained within ~125km and five of those individuals remained under 50km of the release site. A reduction in distancing for some individuals post c.300 days was also detected (Figure 3).

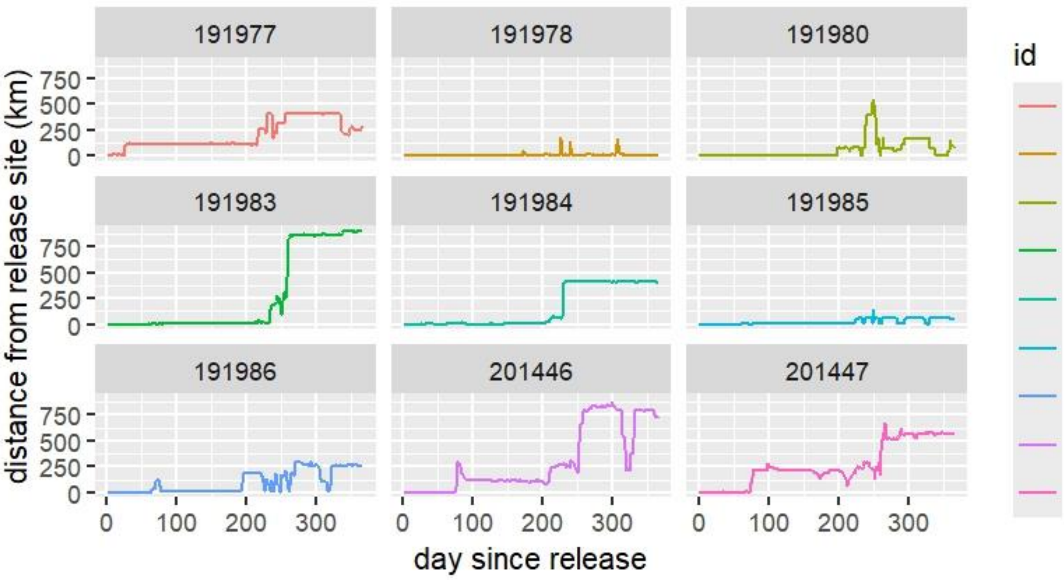
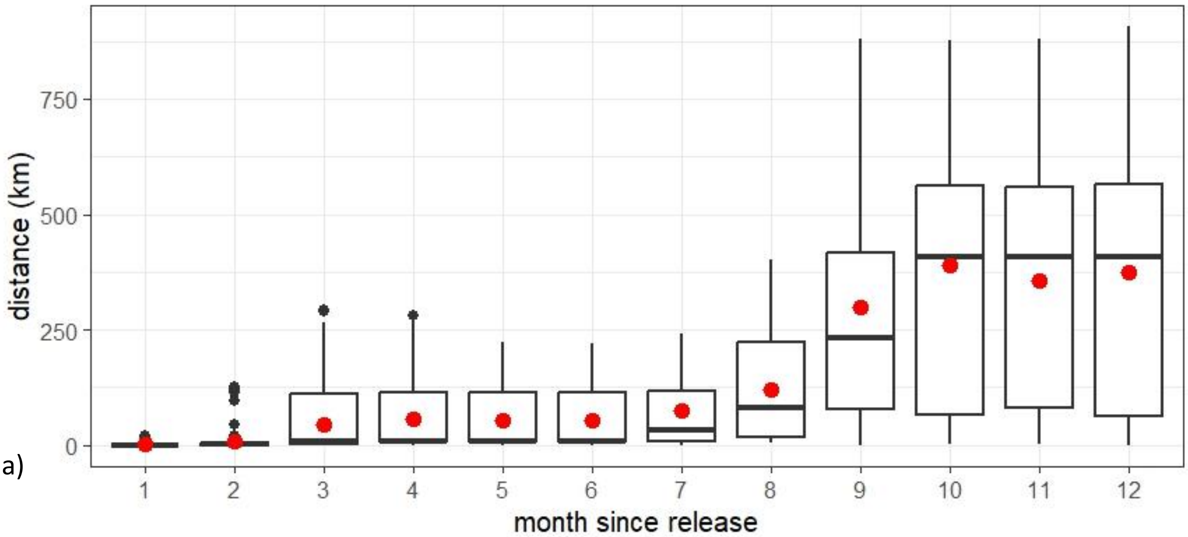
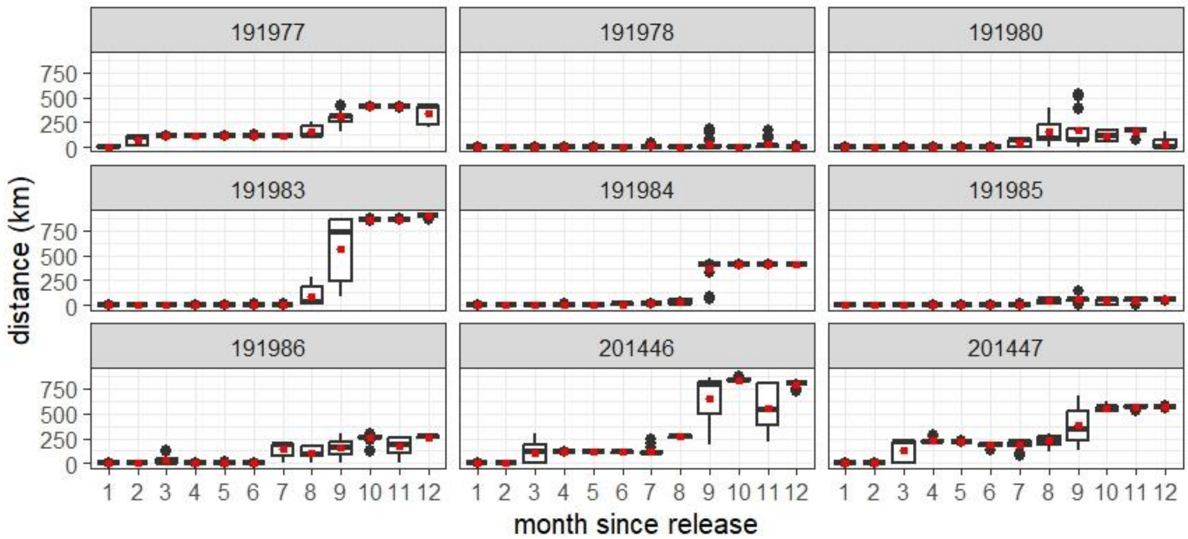


Figure 3: Roost site distancing from release site (one all night roost site per day) for 9 WTE during the first 365 days since release. Day since release "day 1" corresponds to the first day of release (n=365 days per bird) (personal collection 2024).

Aggregating roost distances by month, showed little to no variation in roost site distances range or median for all birds during the first month post-release (Figure 4a) and only one bird showed a small increase in range and distance in month two. Whist some birds began to increase range and fluctuate distance away from the release site during month 3 (3 of 9) most birds remained at a close stable distance up until at least month 7 post-release. The birds that had moved away from the release site in months 2 and 3 remained stable at their respective new distances until month 7 also (month 7-9 show period of notable movement increase for all birds). The collective trend that occurred for all birds in the later stages of the year (between month 7 and 12) was an increase in the range and median distances from the release site. The increase in the physical measure of distance was relative to each bird (Figure 4a & 4b) with some birds showing greater distancing than others that remained relatively close to the Isle of Wight (2 of 9; Figure 4). The differences in the finer distancing patterns between individual birds (Figure 4b) highlights a larger variance in behaviour than is seen when analysed collectively (Figure 4a) and shows a higher proportion of months with little variation in roost site distance from the release site indicating individuals stay in temporary roost site settlements at varying distances from the release site across the year (Figure 4b).



a)



b)

Figure 4: Roost site distancing (one all night roost site per day) from release site grouped by month for the first 12 months since release. a) all birds from both cohorts analysed as one sample (red dot = mean figures) b) each bird individually analysed (red dot = mean figures). Note: For visual representation; July data were removed post analysis for cohort 2 as it only contained one or two days since release (30th and 31st July) and was started instead from the 1st of August. The second calendar August for cohort 1 was also removed at visualisation as this was categorised as month 13 since release. Month 1 corresponds to the month in which the birds were released (approximate – cohort 2) the first calendar August of life (personal collection 2024).

3.1.2 Maximum dispersal distances

The maximum dispersal distances achieved for all birds during the first 365 days post-release ranged from 142.5 to 906.4 km, median 423.7km (IQR 530.5; Table 5). The corresponding date / day since release that each maximum dispersal distances was achieved by the individual varied greatly and ranged from day 225 to day 353 post-release, with a median of day 266 (IQR 85.5; Table 5). Although variable, maximum dispersal distance was achieved by all birds after 225 days post-release which corresponds to a day during or after the 9th month since release (Table 3).

*Table 3: Maximum dispersal distances from release site during the first 365 days post-release and the corresponding date and day since release each distance occurred for all 9 WTE. The first three birds belong to cohort 1 and the following six cohort 2. *Note: 191984 reached maximum distance during month '13' since he was released – this is due to the first 365 days being analysed as opposed to first 12 calendar months and has been use here for illustrative corresponding time purposes.*

Id	Cohort	Maximum Roost Distance	(sd/IQR)	Date of occurrence	Corresponding day since release	(sd/IQR)	Corresponding month since release
191977	One	419.3		08/04/2020	232		9
191978	One	180.5		02/04/2020	225		9
191984	One	423.7		07/08/2020	353		13
191980	Two	542.8		04/04/2021	249		9
191983	Two	906.4		26/07/2021	361		12
191985	Two	142.5		04/04/2021	249		9
191986	Two	301.5		17/05/2021	292		10
201446	Two	871.6		25/05/2021	299		10
201447	Two	671.4		22/04/2021	266		9
Mean all birds	-	495.5	277.5	-	280	49.8	
Median all birds	-	423.7	530.5	-	266	85.5	

3.1.3 Reaching independence

Three different methods were used to determine the timing of reaching the onset of dispersal. The date and corresponding day number since release (1-365) on which independence was deemed to have occurred were recorded for each bird (Table 4). For further analysis, the corresponding day since release figure was used, superseding the use of dates any further. Collectively across the group, whilst analysed by each method, no individuals reached independence on the same day as another (Table 4).

Table 4: Independence dates as determined by determining independence methods 1,2,3. Each date is the first day a roost site was recorded beyond said threshold indicating independence. The corresponding day since release has also been recorded. Method 3 has been used as the standard measure as it is logically the most plausible in representing independence and survival past departure date.

id	Cohort	Sex	method 1: d>=4.45km+2 days	day since release	method 2: d>=9.9km +2 days	day since release	method 3: d>=5km +10 days	day since release	Rank of independence reached (method 3)
191977	One	male	25/08/2019	5	28/08/2019	8	04/09/2019	15	1
191978	One	male	31/08/2019	10	08/02/2020	171	02/02/2020	165	9
191984	One	female	21/10/2019	62	11/11/2019	83	21/10/2019	62	2
191980	Two	female	26/10/2020	89	11/02/2021	197	26/10/2020	89	8
191983	Two	female	18/10/2020	80	27/02/2021	212	18/10/2020	80	7
191985	Two	male	15/10/2020	78	03/03/2021	217	15/10/2020	78	6
191986	Two	male	01/10/2020	64	01/10/2020	64	01/10/2020	64	3
201446	Two	male	11/10/2020	73	14/10/2020	76	11/10/2020	73	5
201447	Two	male	03/09/2020	35	04/10/2020	66	10/10/2020	72	4

Table 5: Summary of independence from release site for all birds (cohort 1&2 collectively) using day since release. Independence calculated by method 1,2,3.

method	Mean (day since release)	sd	median	qu25	qu75	qu95	IQR	minimum	maximum
1	55	31	64	35	78	85	43	5	89
2	122	78	83	66	197	215	131	8	217
3	78	39	73	64	80	135	16	15	165

Table 6: Summary of independence for all birds (cohort 1&2 separately) using day since release. Independence calculated by method 1,2,3.

cohort	method	mean (Day since release)	sd	median	qu25	qu75	qu95	IQR	minimum	Maximum
One (n=3)	1	26	32	10	8	36	57	28	5	62
	2	87	82	83	46	127	162	81	8	171
	3	81	77	62	39	114	155	75	15	165
Two (n=6)	1	70	19	76	66	80	87	14	35	89
	2	139	77	137	69	208	216	139	64	217
	3	76	8	76	72	80	87	8	64	89

3.1.3.1 Method 1 dispersal onset

When all birds from both cohorts were analysed collectively, Method 1 determined that birds reached independence from the release site plus supplementary feeding at a median of 64 days with a high level of variation between individuals, range 5-89 days (Table 5). When the birds were grouped by cohort, cohort 1 reached independence earlier, median 10 days (range 5-62), post-release than cohort 2, median 76 days range 35 – 89 days (Table 6, Figure 5).

3.1.3.2 Method 2 dispersal onset

Method 2 gave later time of independence than method 1. When all birds (n=9) from both cohorts were analysed collectively Method 2 determined that birds reached independence from the release site at a median 83 days, range 8 – 217 days, since release (Table 5). Method 2 Determined independence for Cohort 1 at 8 – 171 since release, median 83, and for Cohort 2 at 64 – 217 days since release, median 136.5 days (Table 6, Figure 5).

3.1.3.3 Method 3 dispersal onset

When all birds from both cohorts were analysed collectively Method 3 determined that birds had reached independence between 15 and 165 days since release, median = 73 days, (Table 5). When analysed by cohort, results again showed great variation between individuals for both cohorts, with cohort 2 showing less variation than cohort 1. The median figures for independence ranged from 15 – 165 days post-release, median = 62 days, for Cohort 1 and 64 – 89 days post-release, median = 76, for cohort 2 (Table 6, Figure 5).

3.1.3.4 Methods variation

For birds 191977, 191978 and 201447, each method used to detect dispersal onset produced a different result for the same individual. 191986 was the only individual whereby each different method used determined independence 64 days post-release. Methods 1 and 3 consistently result in the same onset day for 5 of the 9 birds (Table 4)

3.1.3.5 Release timing

Cohort 1 was held in the hacking cages for a longer period before release compared to cohort 2. Statistically there was a significant result when using method 1 but no significant difference between the timings at which both cohorts reached independence when using method 2 and 3. Cohort 2 was more likely to have later dates of independence than cohort 1 based on the MWU test (Table 7; Figure 5).

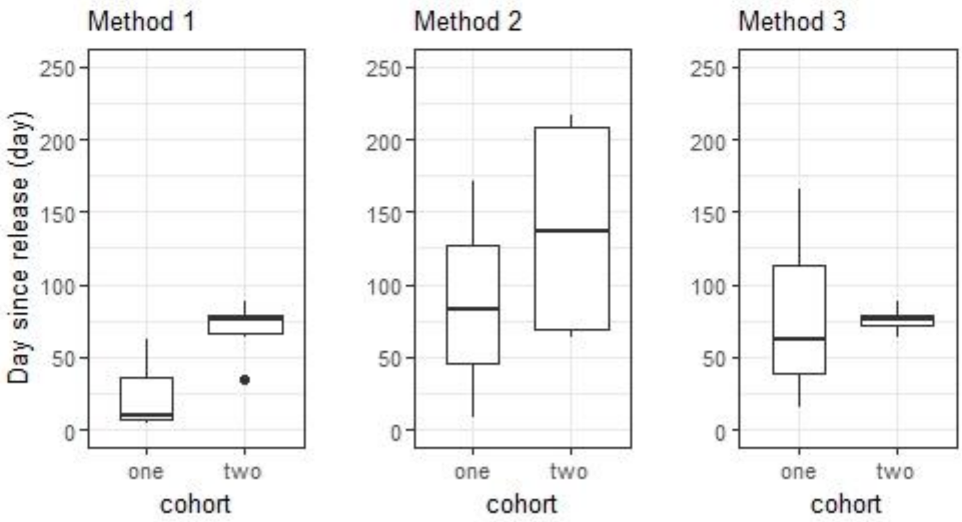


Figure 5: Post-release independence by cohort using methods 1,2 and 3 (note boxplot width relative to sample size cohort 1 n=3 cohort 2 n=6) (personal collection 2024)

Table 7: Mann-Whitney test results using each method 1-3 to detect significant difference between when cohorts reached independence post-release.

Method	*W*	*P value*
1	W = 1	.04762
2	W = 6	.5476
3	W = 6	.5476.

3.2 Objective 2: Investigate distances travelled on a daily and monthly basis over the first year post-release.

Analysed collectively (n=3188 daily distances), distances covered in a day ranged from 0.15 to 512.91km. The median daily distance of all birds analysed collectively was 10.15km (IQR = 16.57). Individuals' median daily distances ranged from 6.8km to 18.85km with the IQRs also indicating variation in daily distances across the year for each bird as well as between individuals (Table 8). Analysed collectively (n=3188 daily distances) 25% of distances remained under 4.58km per and 75% of all distances remained under 26.72km per day (Table 8).

Table 8: Daily distances (km) moved for nine WTE, during the first 365 days since release, across all samples.

id	Number of days in dataset	Total distance (km)	Mean daily distance (km)	Sd	Median daily distance(km)	qu25	qu75	qu95	IQR
191977	364	8456.97	23.23	41.94	9.66	5.85	19.81	86.17	10.15
191978	363	8468.19	23.33	35.99	12	5.8	25.06	68.69	13.06
191980	364	11150.93	30.63	63.48	8.43	4.02	20.39	184.74	11.96
191983	364	8981.36	24.67	51.54	7.44	3.55	23.41	116.59	15.97
191984	307	4803.16	15.65	34.37	6.8	2.57	14.98	49.17	8.18
191985	356	6462.18	18.15	30.47	8.53	3.93	19.3	64.68	10.77
191986	345	11349.85	32.9	53.65	11.93	4.89	29.92	147.75	17.99
201446	361	15558.79	43.1	67.57	18.31	6.42	54.02	152.38	35.71
201447	364	13267.38	36.45	51.83	18.85	6.15	45.93	119.28	27.08
All daily distances collectively	3188	88498.81	27.76	50.27	10.15	4.58	26.72	123.43	16.57

When collectively analysed, the distribution of distance frequency across the 365 days was heavily skewed to higher frequencies of shorter distances travelled in a day compared to very long distances (Figure 6). All individuals had a much higher frequency of shorter distances travelled and a relatively low frequency of large distances travelled (Figure 7). 5-10km per day was the highest frequency of daily distance for all birds (Figure 6).

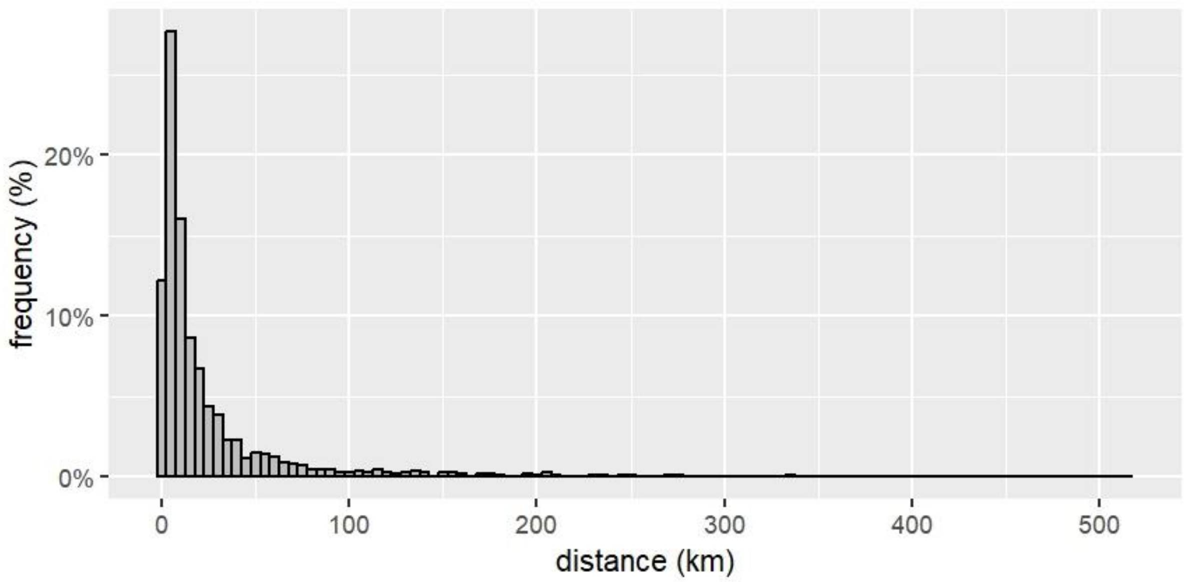


Figure 6: Distances covered in a day by nine WTE. Frequency (distribution) of movements of different length (distance categories are 5km wide) is shown (n=3188) (personal collection 2024).

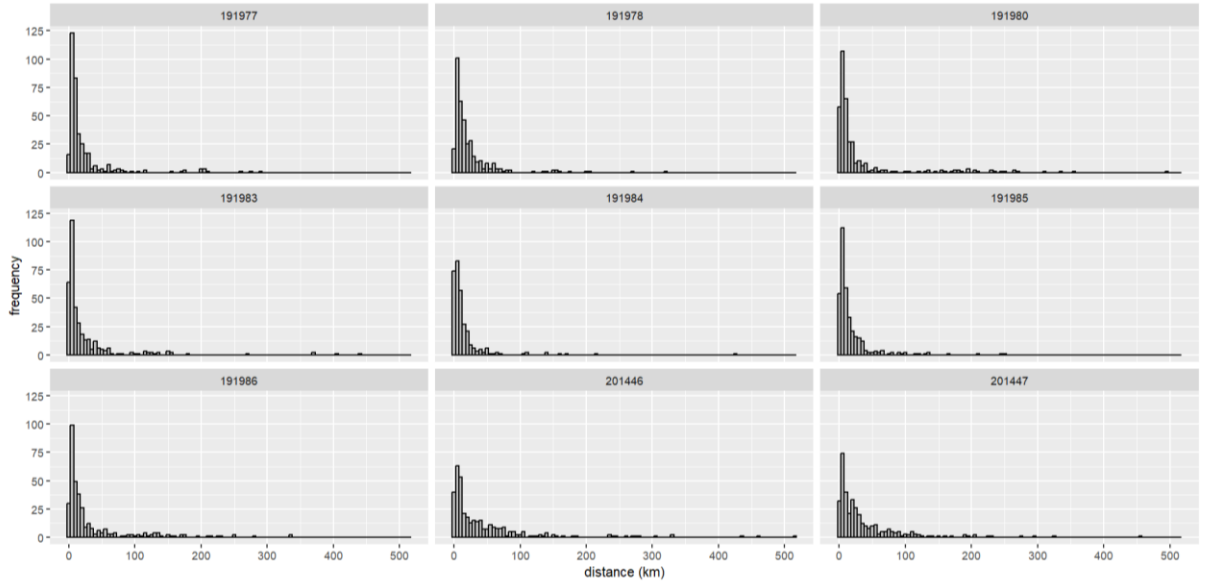


Figure 7: Daily distance travelled by nine WTE, shown as individuals. Frequency (distribution/count) of movements of different length (distance categories are 5km wide) is shown (personal collection 2024).

3.2.1 Temporal patterns of daily distances travelled

Visual inspection of daily distances indicated a comparable temporal trend across all birds and cohorts, with individual variation in the relative increase of daily distances travelled (Figure 8 & 9a). The general trend was characterised by a period of relatively stable short daily distances performed by each bird up until approximately 200 days post-release whereby distances generally increased, reached a peak of longer daily distances, generally followed by an overall downward trend of shorter distances interspersed more regularly with some longer daily distances (Figure 9a & 9b). Five of the nine birds also presented a small peak of greater daily distances between the first 60- 90 days post-release (approximately) before returning to shorter distances (Figure 9b). Average daily distances varied greatly between individual birds (Figure 8, 9a and 9b).

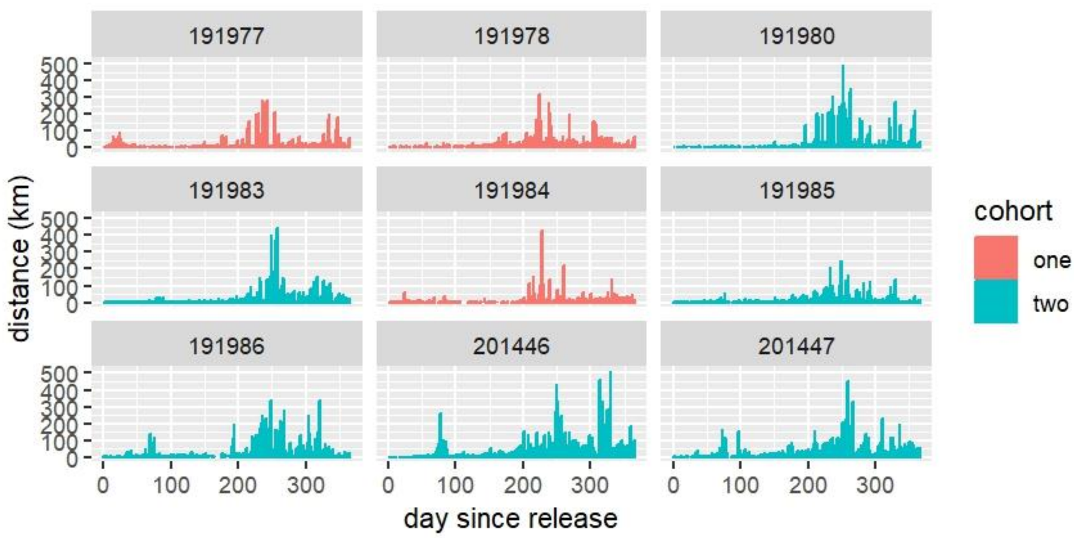


Figure 8: Daily distances moved each day, for all birds, for the first 365 days since release. Graphs coloured in red are birds released in 2019 as part of the first cohort and those in blue are birds release in 2020 part of the second. Day 1 corresponds to the day of release (a gap in the chart corresponds to a day with less than 10 daily relocations and consequently no representative data on that day) (personal collection 2024).

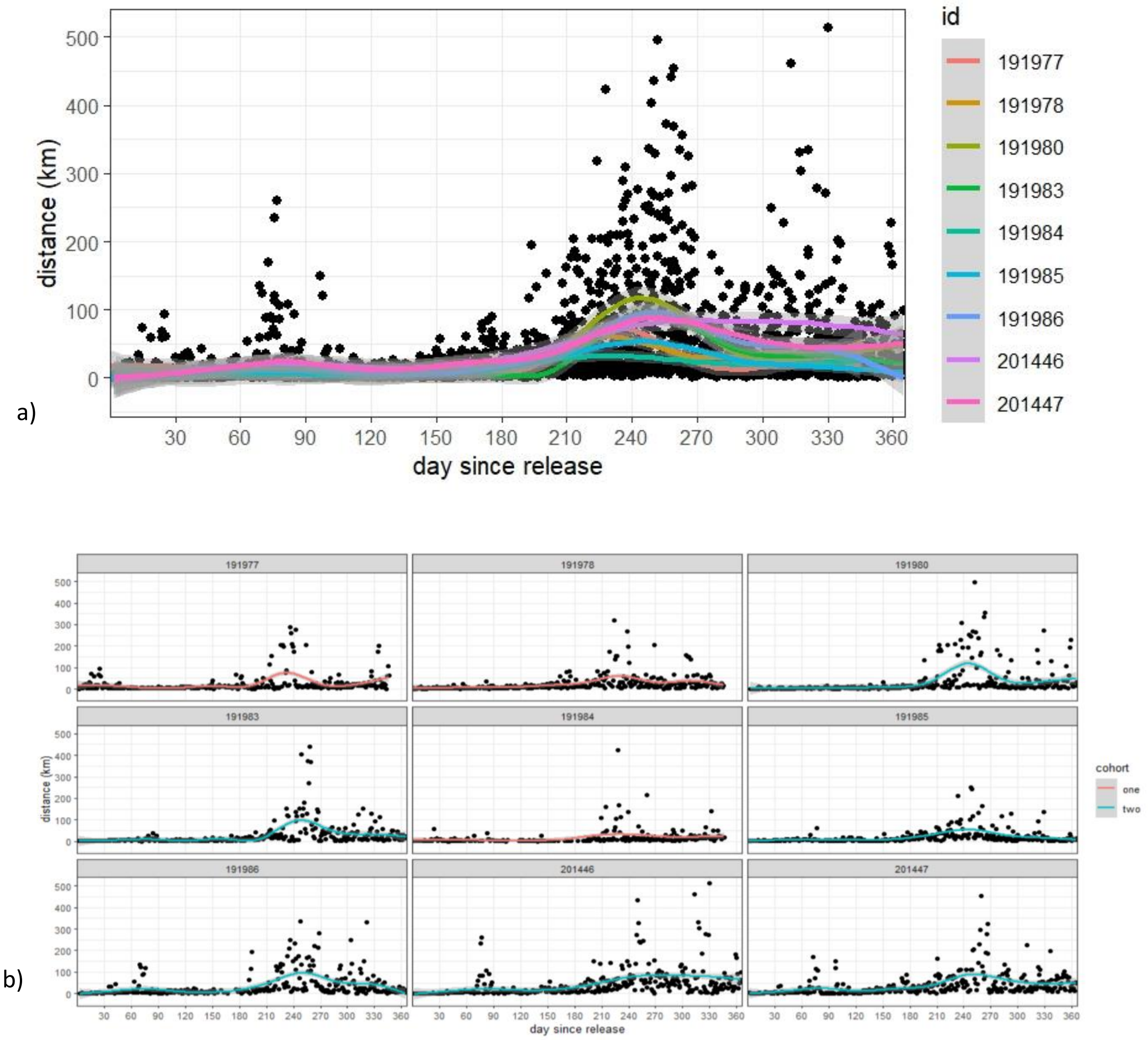


Figure 9: a) Daily distances moved each day, for all birds, b) Daily distances moved each day birds displayed separately for the first 365 days since release. Graphs coloured in red are birds released in 2019 as part of the first cohort and those in blue are birds release in 2020 part of the second cohort. Day 1 corresponds to the day of release (a gap in the chart corresponds to a day with less than 10 daily relocations and consequently no representative data on that day) (personal collection 2024).

To study temporal trends across the year, daily distances were aggregated by month since release across all birds (Figure 10a) and for each individual bird separately (Figure 10b). The general trend across all birds for both cohorts was little fluctuation in the daily distance ranges within the first 6 months since release, with a gradual increase in the median of daily distances travelled. Monthly daily distance ranges increased markedly from month 6 and increased to maximum range during month 9 (April). The median daily distances also reached a peak during month 9. From month 10 (May) daily distance ranges and median figures decreased though did not reduce to previous initial release levels (month 1 to 6) (Figure 10a).

Within cohort 2, 5 of the 6 birds had a small peak in distances in month 3 (October) and 2 of 3 from cohort 1 in month 2 (September) (Figure 6b). Across birds, the highest median monthly daily distances and distance ranges occurred during month 9 since release. Month 9 since release corresponds to the respective first calendar April following release, for both cohorts. This indicates generally daily travel with longer distances occurred within that month. Across all birds, during month 10 median daily distances and range decreased from that of month 9 (Figure 10b).

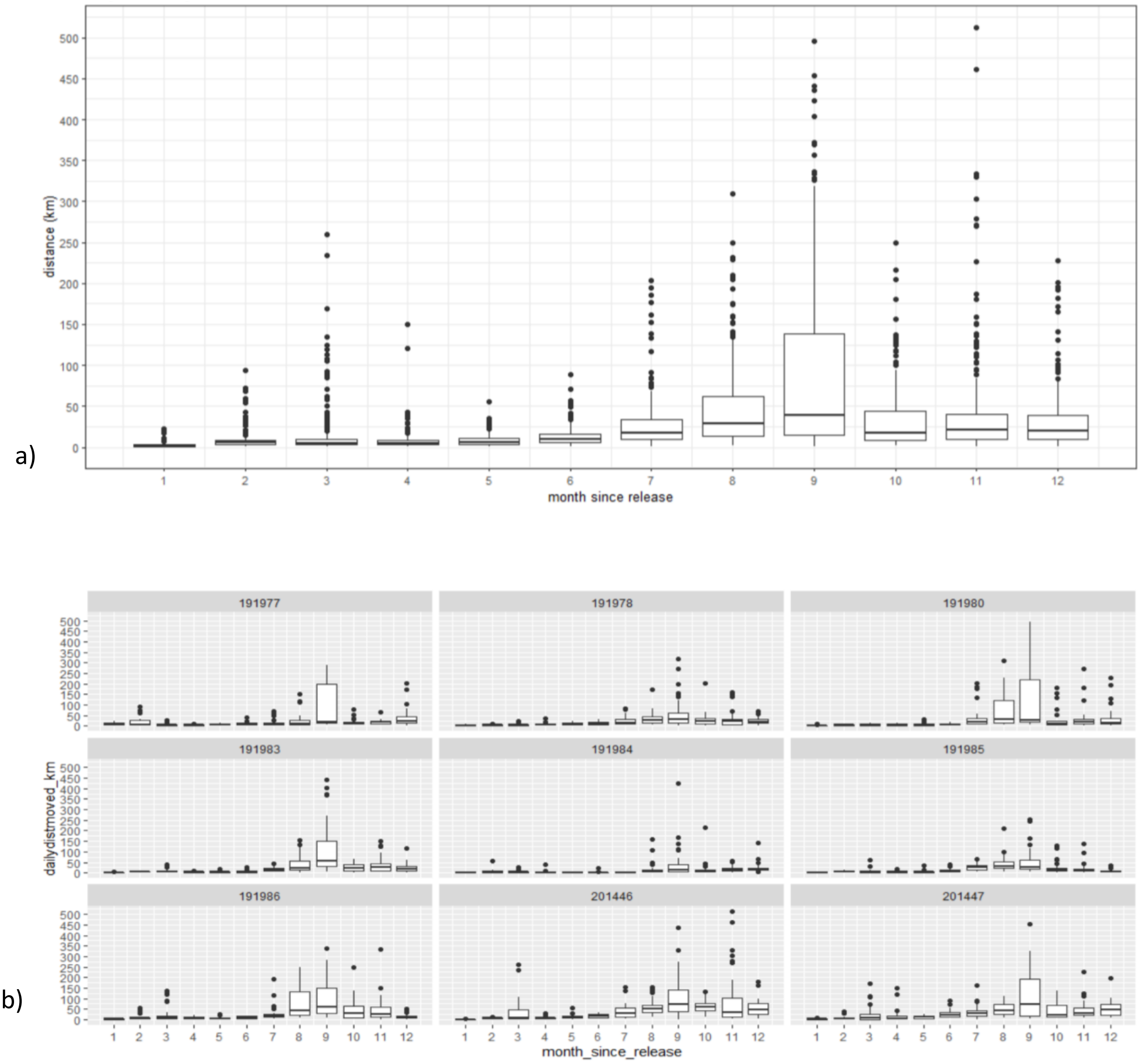


Figure 10: Daily distances moved aggregated by month a) all birds from both cohorts analysed as one sample b) each bird individually analysed. Note: For visual representation; July data was removed post analysis for cohort 2 as it only contained one or two days since release (30th and 31st July) and data was started instead from the 1st of August, and this was considered the first month of release for cohort 2. Cohort 1 birds were released in August. The second calendar August for cohort 1 was also removed at visualisation as this was categorised as month 13 since release and only the first 12 calendar months were investigated (personal collection 2024).

3.2.2 Minimum and maximum daily distances

Minimum daily distances travelled across all birds, ranged from 0.5 to 1.44km. Group median was 0.4 km (IQR = 0.56) with little variance between individuals. Across all birds, the minimal distances occurred across a wide range of time throughout the year, anywhere from day 2 to day 178 post-release (Table 9). The median day since release that the shortest distances were achieved, was day

71 (IQR = 136.5). The corresponding month was month 3 with wide variance across the group (Table 9).

Maximum daily distance achieved by all birds ranged from 252.05km to 512.91km (median = 423.62km, n=9) with a high level of variance between birds (IQR = 170.90). Maximum daily distance within the first 365 days since release was achieved by all birds between day 224 and 330 post-release, median = 248 days (IQR = 26.5) (Table 9). Whilst the actual measure of maximum distances flown by the individual varies greatly, all birds across both cohorts, bar one individual, achieved their individual daily maximum distance within the 9th month following release (IQR = 0). One bird achieved maximum distance in month 11 (Table 9) *Note: month 9 corresponds to the first calendar April since release for all birds for this analysis.

Table 9: Descriptive statistics of minimum and maximum distances travelled in a day for each individual bird and all birds analysed collectively.

Id	*Minimum distance in a day (km)*	*sd/IQR*	*Day since release minimum distance achieved*	*sd/IQR*	*Corresponding month since release (1-12) minimum distance achieved*	*sd/IQR*	*Maximum distance in a day (km)*	*sd/IQR*	*Day since release maximum distance achieved*	*sd/IQR*	*Corresponding month since release (1-12) maximum distance achieved*	*sd/IQR*
191977	1.44		178		7		288.75		236		9	
191978	0.89		2		1		318.55		224		9	
191980	0.42		145		5		495.59		252		9	
191983	0.35		71		3		441.06		258		9	
191984	0.15		139		6		423.62		228		9	
191985	0.5		93		3		252.05		248		9	
191986	0.79		9		1		336.42		248		9	
201446	0.38		2		1		512.91		330		11	
201447	0.21		66		3		453.52		259		9	
Mean All birds	0.6	0.40	78	66.08	3.33	2.23	391.38	94.38	253.66	31.20	9	0.66
Median All birds	0.4	0.56	71	136.5	3	4.5	423.62	170.90	248	26.5	9	0

3.3 Objective 3: Identify and investigate the use of Temporary Settlement Areas during the first-year post-release.

All Temporary Settlement Areas (TSAs) that were formed within the first 365 days post-release were identified for each bird, as were roost sites and flight trajectories. The location and area of each TSA was determined, mapped, and presented for visual interpretation (Figure 11 to 19 - movement maps & Figure 24 (TSA summary)). The first TSAs following release and containing the release site, formed by each bird has been classed as the post-fledging Area (PFA) (Figure 20).

3.3.1 Cohort 1 Individually mapped TSAs – excluding PFAs

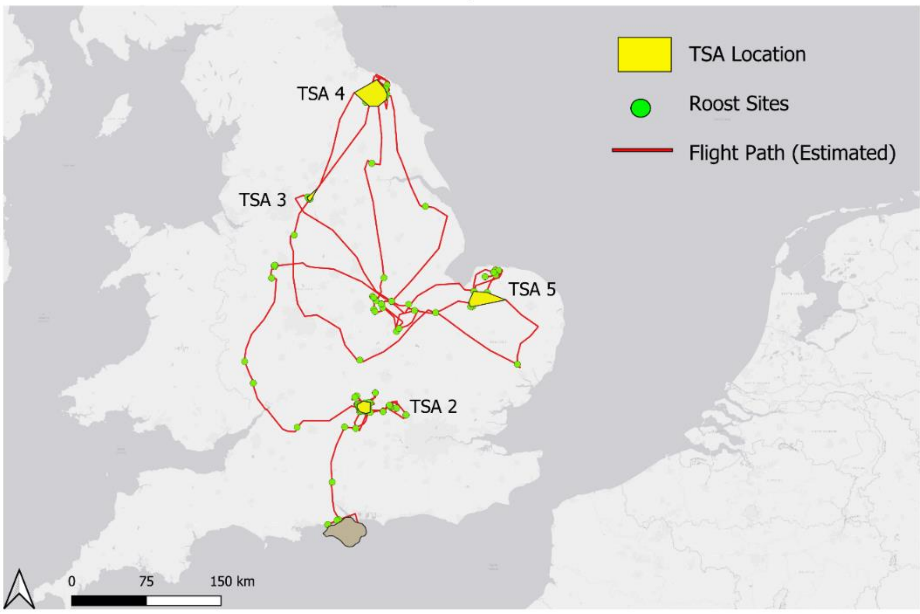


Figure 11: TSAs - bird 191977 (numbered in order of settlement), roost sites and estimated flight paths produced during the first-year post-release. PFA, roost sites and movements on the Isle of Wight have been removed to protect the location of the release site (personal collection 2024).

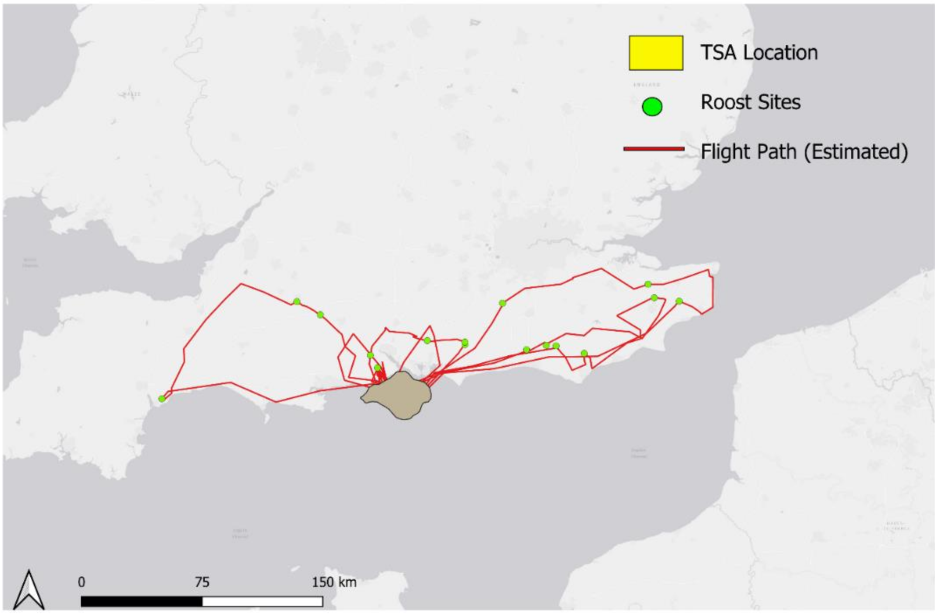


Figure 12: TSAs - bird 191978 roost sites and estimated flight paths produced during the first-year post-release. 191978 only used one TSA which included the PFA this, roost sites and movements on the Isle of Wight have been removed to protect the release site (personal collection 2024).

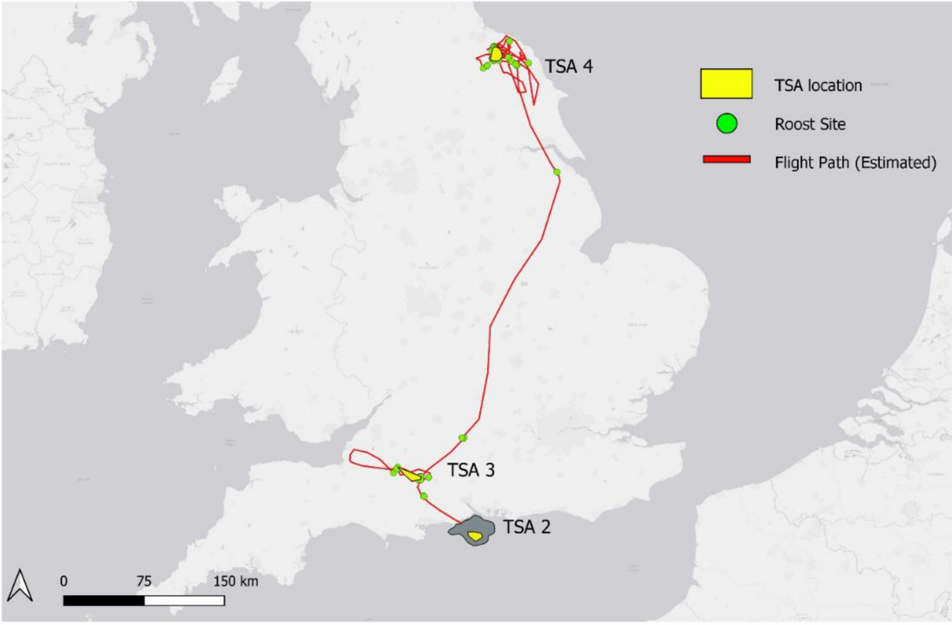


Figure 13: TSAs - bird 191984 (numbered in order of settlement), roost sites and estimated flight paths produced during the first 365 days post-release. PFA and roost sites and movements on the Isle of Wight have been removed to protect the location of the release site (personal collection 2024).

3.3.2 Cohort 2 - Individually mapped TSAs – excluding PFAs

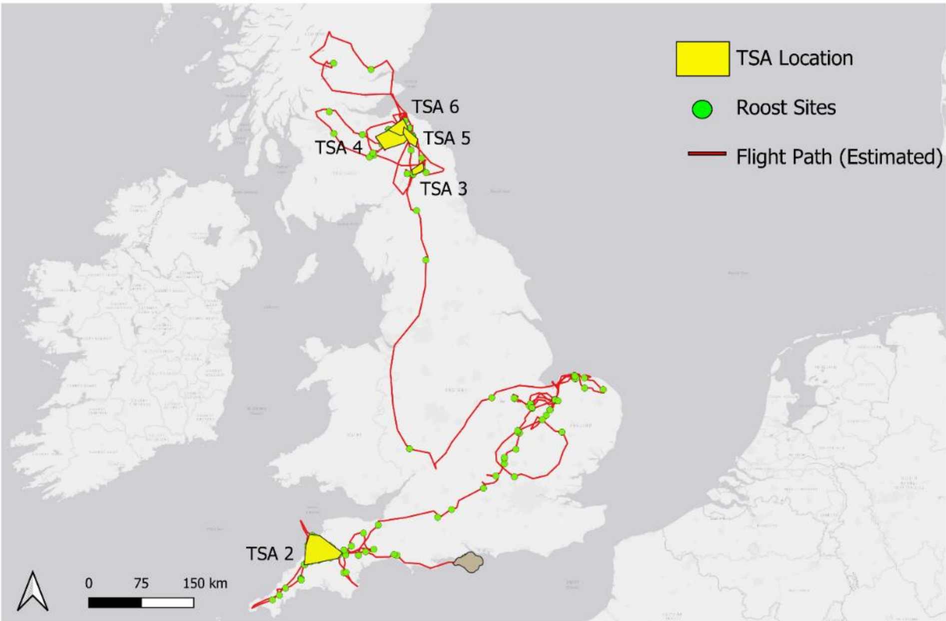


Figure 14: TSAs bird 201447 (numbered in order of settlement), roost sites and estimated flight paths produced during the first 365 days post-release. PFA and roost sites and movements on the Isle of Wight have been removed to protect the location of the release site (personal collection 2024).

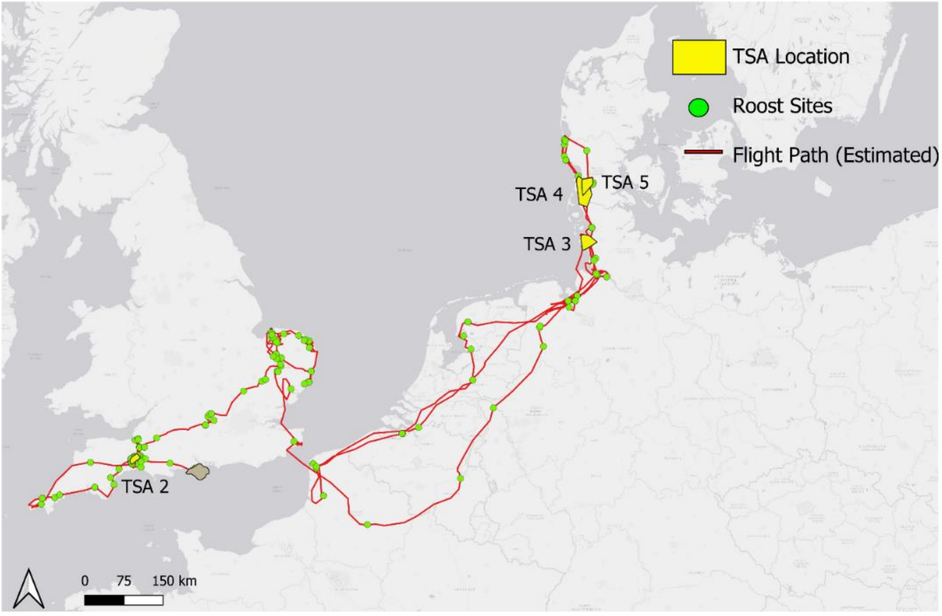


Figure 15: TSAs - bird 201446 (numbered in order of settlement), roost sites and estimated flight paths produced during the first 365 days post-release. PFA and roost sites and movements on the Isle of Wight have been removed to protect the location of the release site (personal collection 2024).

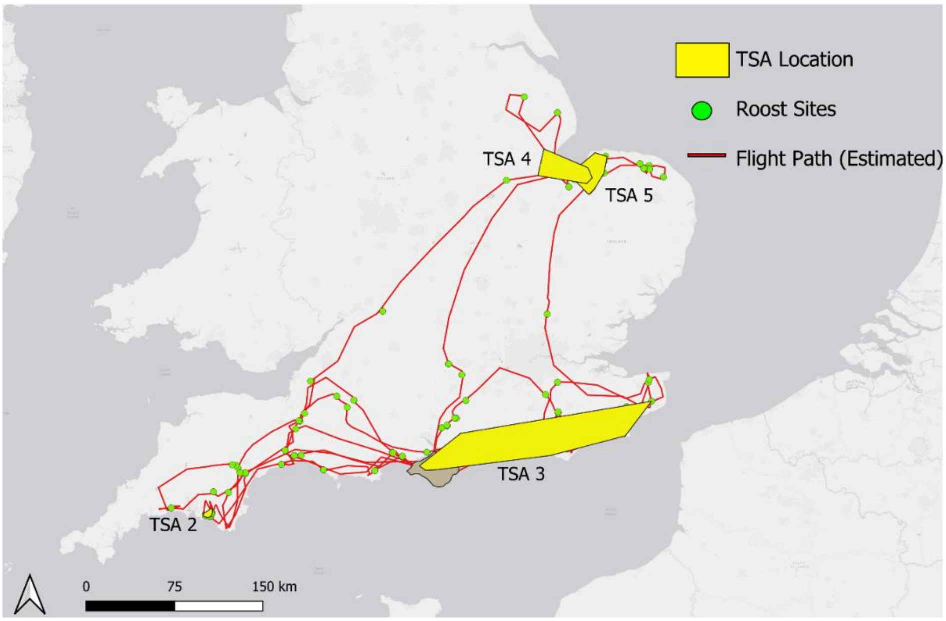


Figure 16: TSAs - bird 191986 (numbered in order of settlement), roost sites and estimated flight paths produced during the first 365 days post-release. PFA and roost sites and movements on the Isle of Wight have been removed to protect the location of the release site (personal collection 2024).

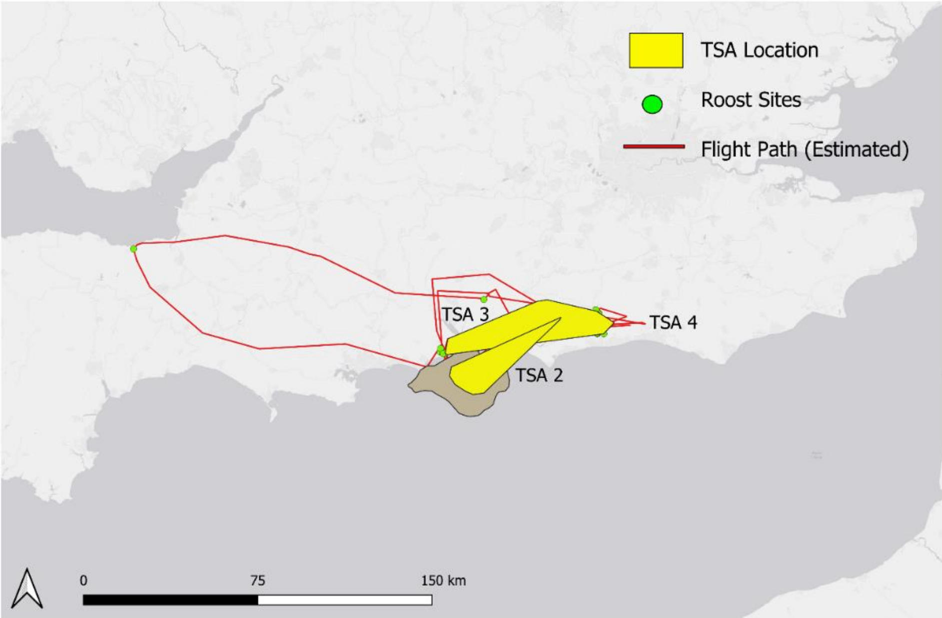


Figure 17: *TSAs - bird 191985 (numbered in order of settlement), roost sites and estimated flight paths produced during the first 365 days post-release. PFA and roost sites and movements on the Isle of Wight have been removed to protect the location of the release site (personal collection 2024).*

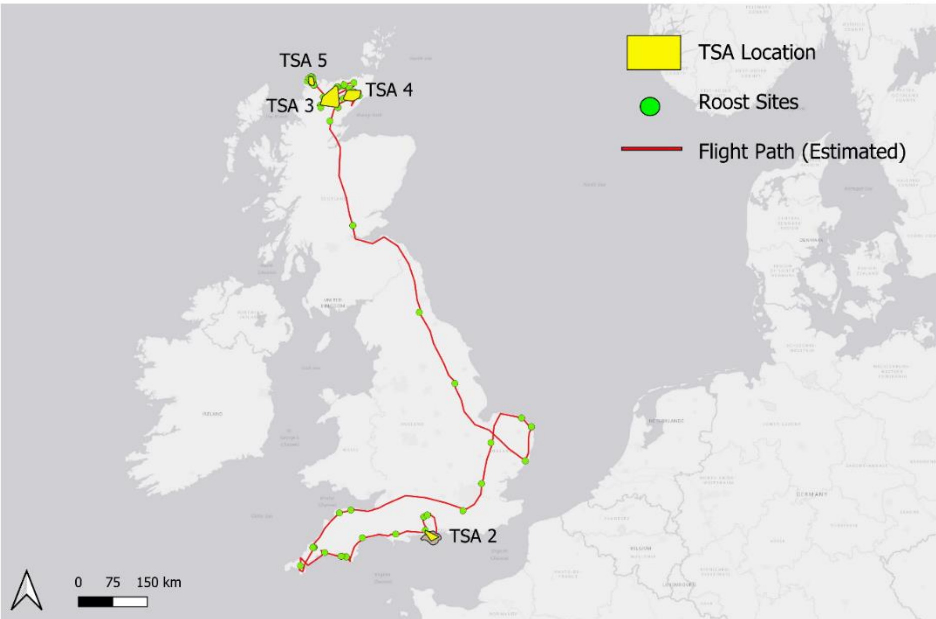


Figure 18: *TSAs - bird 191983 (numbered in order of settlement), roost sites and estimated flight paths produced during the first 365 days post-release. PFA and roost sites and movements on the Isle of Wight have been removed to protect the location of the release site (personal collection 2024).*

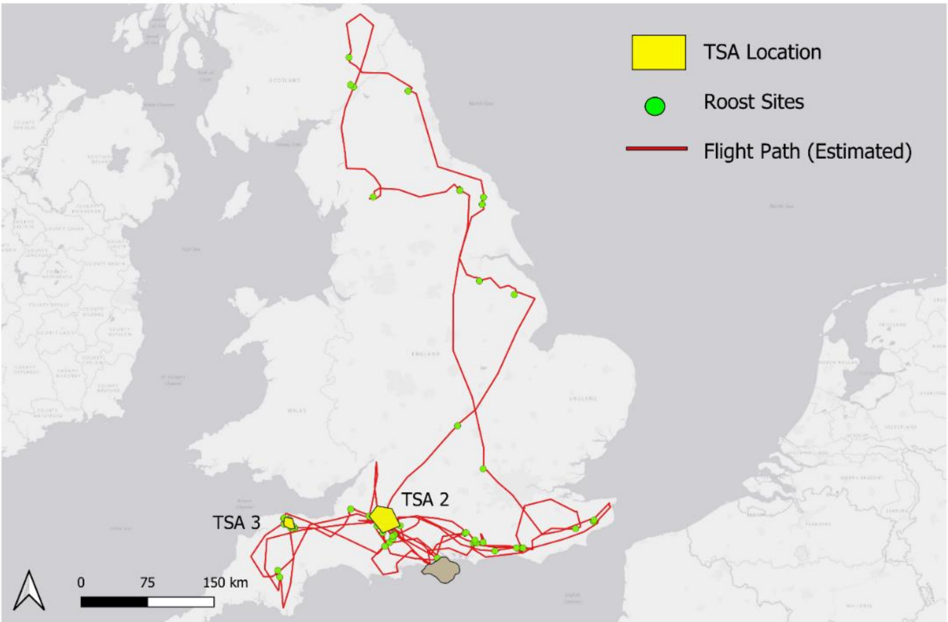


Figure 19: *TSAs - bird 191980 (numbered in order of settlement), roost sites and estimated flight paths produced during the first 365 days post-release. PFA and roost sites and movements on the Isle of Wight have been removed to protect the location of the release site (personal collection 2024).*

3.3.3 Post-fledging areas (PFAs)

All birds had a defined PFA identified which incorporated the release site on the Isle of Wight and all the PFAs identified overlapped with one another to varying degrees. All birds' PFAs varied visually in exact shape and size but, generally, most birds from cohort 2 shared a similar shape of PFAs formed and covered the same general land area and projection. Cohort 1 PFAs varied more in size, shape and PFA projection within the cohort and compared to cohort 2 but still incorporated the same general area with in their respective PFAs (Figure 20).

Figure 20: *Post Fledging Area footprints for all 9 WTE (personal collection 2024).*

The amount of time (characterised by number of roosting nights and days spent in consecutive residence within PFA boundaries) each bird spent within their PFA varied greatly from one bird to another (Table 10 & 11). The number of nights spent in each PFA ranged from 11 – 349 nights (median = 187 nights, IQR = 144; Table 11). Number of nights in each PFA was converted to percentage of total nights post-release (365 days since release). The time spent by each bird in their respective PFAs ranged from 3 – 95.6% of their first year with great variance between birds (Table 10). Bird 191977 spent the least number of days in its PFA totalling 11 nights (only 3% of its total first year nights post-release.) Bird 191978 spent the longest in its PFA totalling 349 nights out of 365 (95.6%). Collectively, the median percentage of nights was 51.23 % of nights spent in the birds' PFAs within the first 365 days post-release.

Table 10: Post-fledging area (PFA) nights spent in PFA for each WTE and the Post-Fledging Area (PFA) area.

Id	*Number of nights spent in PFA*	*% of time during first year spent in PFA*	*Area size of PFA (km2)*
191977	11	3.0	762.9
191978	349	95.6	453.7
191984	137	37.5	54.9
191980	216	59.2	148.5
191983	212	58.1	173.1
191985	233	63.8	191.1
191986	187	51.2	184.7
201446	72	19.7	5.9
201447	72	19.7	217.1

Table 11: Post-fledging area (PFA) Summary – number of nights spent residing in PFA (n=9)

N =	*Total PFA nights*	*Mean nights spent residing in PFA*	*sd*	*median*	*qu25*	*qu75*	*qu95*	*IQR*	*Minimum nights residing in PFA*	*Maximum nights residing in PFA*
9	1489	165.4	103.4	187	72	216	302.6	144	11	349

3.3.4 Post-Fledging Area size

The median PFA area size across all birds was 184.7 km^2 (IQR = 68.6; Tables 10 & 12). PFA area sizes differed between birds, ranging from 5.9 – 762.9 km^2. Bird 201446's PFA was the smallest of all birds (5.9 km^2), although this bird did not spend the least time in its PFA. Bird 201447 spent the same number of nights within its PFA as bird 201446 yet the size of its PFA was 217.1 km^2. The largest PFA (762.9 km^2) belonged to bird 191977, who spent the smallest amount of time in a PFA (11 nights) of all birds (Table 10). A Pearson correlation coefficient was computed to assess the relationship between PFA area size and number of nights in residence. No significant correlation between the two variables was found (r = -0.128 (95% c.i. -0.730 to 0.586); df = 7, p =0.7426) (Figure 21).

Table 12: Post-fledging area (PFA) size summary for 9 WTE. The first TSA containing the release site has been termed the Post-Fledging Area (PFA)

n =	*Total PFA area (all birds)*	*Mean PFA area size (km2)*	*Sd*	*Median area (km2)*	*qu25*	*qu75*	*qu95*	*IQR*	*Minimum PFA area*	*Maximum PFA area*
9	2191.9	243.5	231.0	184.7	148.5	217.1	639.2	68.6	5.9	762.9

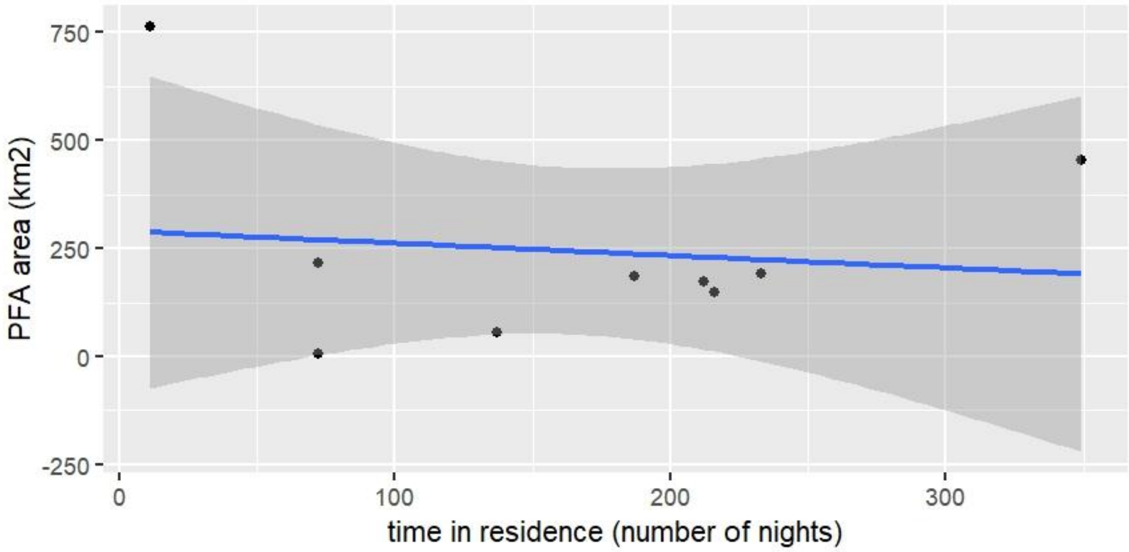


Figure 21: Relationship between area size and nights spent in PFAs all birds (n=9) (personal collection 2024)

3.3.5 Number of Temporary Settlement Areas used by each bird

In addition to the 9 PFAs recorded (one per bird) an additional 29 Temporary Settlement Areas (TSAs) were identified across the group (Figures 11-19 & 24). The number of distinct TSAs used (including PFAs) by each bird ranged from 1 – 6 (Table 13 & 16), mean ± sd = 4.2 ± 1.4) during the first 365 days post-release (median = 5, IQR = 1; Table 16). There was little variation between the number of TSA's used by each bird. Bird 191978 was the only bird observed to use just one TSA (its PFA) within the first year (Figure 12). Bird 201477 was the only bird to use 6 different TSAs (Figure 14). Four of the nine birds used 5 TSAs (Table 13 & 16).

3.3.6 Temporary Settlement Area residency timings

Time spent in each individual TSA (both number of nights and percentage of overall time) was calculated for each bird (analysis includes PFAs – TSA number 1 for all birds; Table 13).

Table 13: Summary of each Temporary settlement area (TSA) used by 9 WTE during the 365 days post-release: Area covered, and residency time spent within each (number and percentage of night roosts within TSA). The first TSA for each bird (TSA 1) is classed as a post-fledging area (PFA).

Id	*TSA Number*	*Number of nights resident (out of 365 nights)*	*% Residency time*	*Area size of each TSA (km2)*
191977	1	11	3.0	762.9
	2	175	48.0	316.6
	3	11	3.0	85.7
	4	85	23.3	1284.5
	5	10	2.7	796.4
191978	1	349	95.6	453.7
191984	1	137	37.5	54.9
	2	71	19.5	192.3
	3	11	3.0	243.6
	4	126	34.5	265.9

191980	1	216	59.2	148.5
	2	58	15.9	1578.4
	3	36	9.9	296.8
191983	1	212	58.1	173.1
	2	15	4.1	715.3
	3	47	12.9	2989.8
	4	13	3.6	1619.9
	5	28	7.7	519.9
191985	1	233	63.8	191.1
	2	15	4.1	1168.0
	3	16	4.4	2139.7
	4	99	27.1	113.4
191986	1	187	51.2	184.7
	2	27	7.4	90.5
	3	13	3.6	11720.5
	4	46	12.6	1446.4
	5	20	5.5	1831.8
201446	1	72	19.7	5.9
	2	101	27.7	487.0
	3	33	9.0	1294.7
	4	14	3.8	2621.2
	5	11	3.0	1062.8
201447	1	72	19.7	217.1
	2	117	32.1	3621.7
	3	13	3.6	398.1
	4	36	9.9	651.4
	5	14	3.8	2435.8
	6	13	3.6	894.6

For all birds with multiple TSAs (191978 only had 1 TSA so was excluded from this part of the analysis) an average TSA residency time was also calculated (Table 14). Residency time within each TSA showed inter- and intra-individual variation (Tables 13 & 14), ranging from 11 – 98.5 nights per TSA across the group. Intra-individual variation showed interquartile ranges between 20 and 116.75 (Table 14).

Table 14: Temporary settlement area (TSA): Average residence time spent within individual TSAs during the first 365 days post-release for each individual WTE

Id	*mean nights roosting in a TSAs (including PFA)*	*sd*	*median*	*qu25*	*qu75*	*qu95*	*Interquartile range*	*Minimum nights spent in a TSA*	*Maximum nights spent in a TSA*
191977	58.4	72.70	11	11	85	157	74	10	175
191978	349	NA	349	349	349	349	-	349	349
191980	103.33	98.19	58	47	137	200.2	90	36	216
191983	63	84.39	28	15	47	179	32	13	212
191984	86.25	57.88	98.5	56	128.75	135.35	72	11	137
191985	90.75	102.68	57.5	15.75	132.5	212.9	116.75	15	233
191986	58.6	72.82	27	20	46	158.8	20	13	187
201446	46.2	39.11	33	14	72	95.2	58	11	101
201447	44.17	42.42	25	13.25	63	105.75	49.75	13	117

Six of the nine birds (including 191978) spent the highest portion of their time situated in their first TSA (PFA). The remaining three birds spent the highest portion of their time in their second TSA (Table 13 & Figure 22).

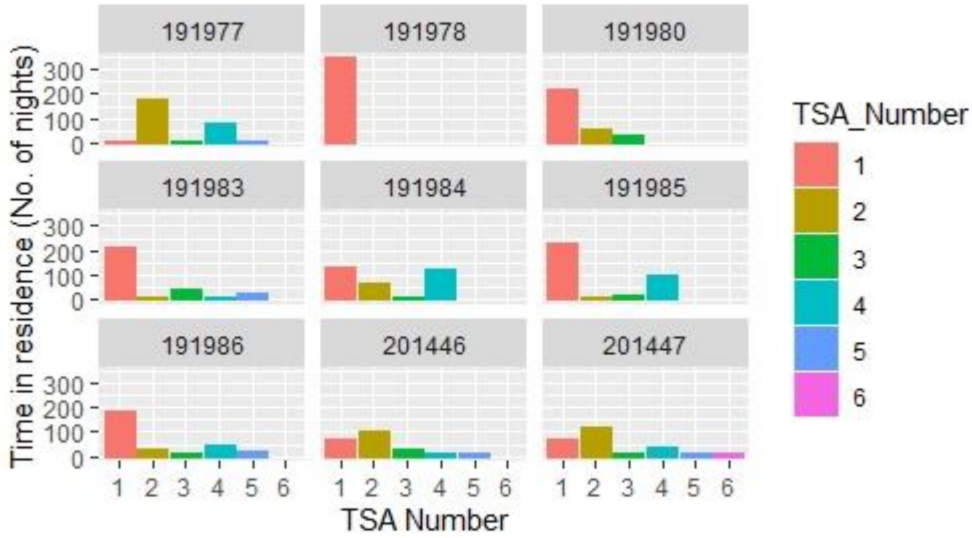


*Figure 22: Visualisation of time spent roosting in each TSA by each bird. *note: time spent is measured in nights roosting in a TSA (personal collection 2024)*

When all TSAs were analysed collectively (n=38, including PFAs) the median number of nights spent in a TSA was 36 nights with an indication of high variation (IQR = 86.5) (Table 15).

Table 15: Number of nights summary based on all PFAs and TSAs produced across the year (n=38).

Number of TSAs (including PFAs)	*Mean number of nights in a TSA*	*Sd*	*median number of nights in a TSA*	*qu25*	*qu75*	*qu95*	*IQR*	*Minimum number of nights in a TSA*	*Maximum number of nights in a TSA*
38	72.71	80.37	36	14	100.5	218.55	86.5	10	349

3.3.6.1 Total Temporary Settlement Area residency (including PFAs) vs wandering behaviour

Total number of nights roosted within each of a bird's respective TSAs across the year across the group ranged from 231 to 363 nights (median 310 nights, IQR = 53) out of 365 (63.3 - 95.6%; median 84%; Table 16).

Bird 191985 spent 99.5% of time within identified TSAs, the highest of all the birds. Bird 201446 spent the least time in TSAs (63.3% of nights), indicating longer periods of time undertaking travelling/ exploratory behaviour (Table 16).

Table 16: Temporary settlement area (TSA) time spent in residence included PFAs: Number of TSA identified, Total residence time spent within TSA's generally (percentage of nights spent in TSAs), during the first 365 days post-release for each individual WTE.

id	*No. TSA*		*Total nights roosting in TSAs*		*Total % of nights roosting in TSAs n=365 per bird*		*Total number of nights spent outside of identified TSA's (time when not in TSA)*		*Total % of nights spent outside of identified TSAs (travelling) n=365 per bird*	
191977	5		292		80.0		73		20.0	
191978	1		349		95.6		16		4.4	
191980	3		345		94.5		55		5.5	
191983	5		310		84.9		50		15.1	
191984	4		315		86.3		20		13.7	
191985	4		363		99.5		2		0.5	
191986	5		293		80.3		72		19.7	
201446	5		231		63.3		134		36.7	
201447	6		265		72.6		100		27.4	
		sd		*sd*		*Sd*		*sd*		*sd*
All birds mean	4.22	1.48	307	42.39	84.11	11.61	58	42.39	15.89	10.95
		IQR		IQR		IQR		IQR		IQR
All birds median	5	1	310	53	84.93	14.5	55	53	15.06	14.52

3.3.7 Temporary Settlement Area Size

TSA area size (km^2) for each TSA was calculated for each bird in order of occurrence (Table 12) in addition to overall descriptive statistics for the TSAs (n=38; Table 17). Median size of TSA area across the group ranged from 296.8km^2 to 1446.4km^2. Each individual that produced multiple TSAs during the year showed high degrees of variation in size among each of their respective TSAs (Table 17).

Table 17: TSA size summary per individual: including PFA for each of the 9 WTEs used within the first 365 days post-release.

id	*No. TSA*	*Total TSA area (Including PFA)*	*Mean TSA area size (km2)*	*Variation among TSA size (sd)*	*Median*	*qu25*	*qu75*	*qu95*	*IQR*	*Minimum TSA area*	*Maximum TSA area*
191977	5	3246.1	649.2	465.4	762.9	316.6	796.4	1186.9	479.8	85.7	1284.5
191978	1	453.7	453.7	NA	453.7	453.7	453.7	453.7	-	453.7	453.7
191980	3	2023.7	674.6	786.2	296.8	222.7	937.6	1450.2	714.9	148.5	1578.4
191983	5	6018.1	1203.6	1132.6	715.3	519.9	1619.9	2715.8	1100	173.1	2989.8
191984	4	756.6	189.1	94.7	217.9	157.9	249.2	262.5	91.3	54.9	265.9
191985	4	3612.2	903.0	953.9	679.6	171.7	1410.9	1993.9	1239.2	113.4	2139.7
191986	5	15273.9	3054.8	4904.1	1446.4	184.7	1831.8	9742.8	1647.1	90.5	11720.5
201446	5	5471.5	1094.3	990.7	1062.8	486.9	1294.7	2355.9	807.8	5.9	2621.2
201447	6	8218.6	1369.8	1358.1	773.0	461.4	2050.5	3325.2	1589.1	217.1	3621.7

Bird 191986 produced the largest singular TSA at 11720.5 km^2 of all birds, bird 201447 produced the smallest at 5.9km^2 if including PFAs size (Table 13 & 17). If excluding PFAs from the analysis, 85.7km^2 was the smallest TSA (bird 191977). Excluding bird 191978 from the analysis, none of the birds produced their largest TSA in their first settlement areas post-release (PFAs) (Table 14 & Figure 23).

Amalgamated TSA areas per bird ranged from a total of 453.7 to 15273.9 km^2 (Table 17). When analysed collectively the median TSA area size of all the TSAs (n=38) was 585.65 km^2. A high level of variation between TSA size was indicated (IQR = 1209.9) (Table 18).

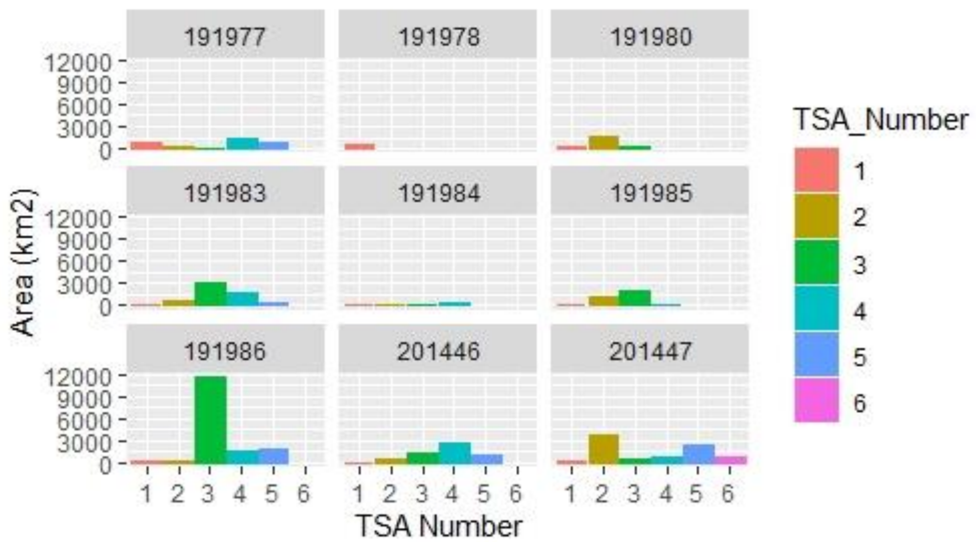


Figure 23: visualisation of TSA area size produced by each bird in order of occurrence throughout the year post-release (personal collection 2024)

Table 18: Summary of all TSA/PFA areas used as one dataset.

n=	*Mean TSA area*	*sd*	*median*	*qu25*	*qu75*	*qu95*	*IQR*	*Min area*	*Max area*
38	1186.17	1973.51	585.65	198.5	1408.48	3084.59	1209.98	5.9	11720.5

3.3.8 TSA locations and overlap between birds

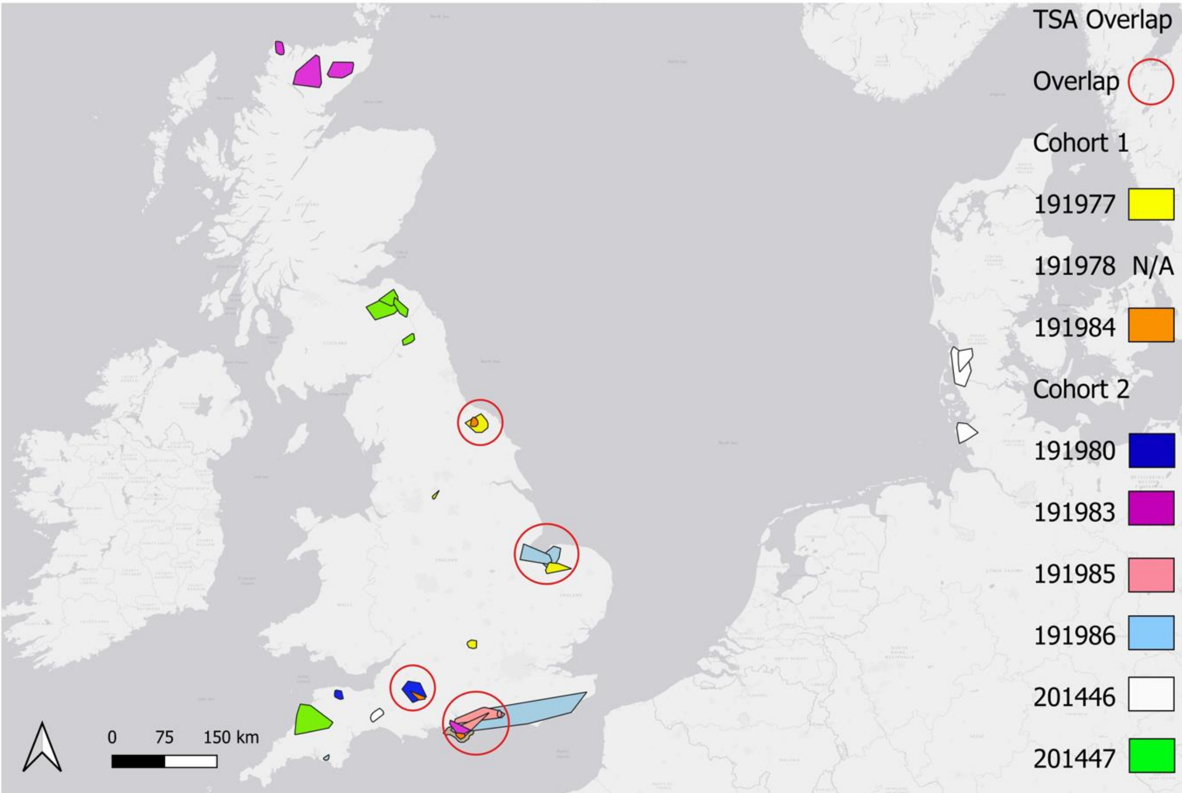


Figure 24: Identified Temporary Settlement Areas (TSA) used and TSA areas with spatial overlap used by multiple birds (at least two) at some point during their respective first 356 days since release. Post-fledging areas (PFAs) have been removed prior to visualisation to protect the location of the release site. 191978 only had one TSA (which includes the PFA) so this has also been removed prior to mapping (personal collection 2024).

A total of 38 separate PFAs/TSAs were identified: 9 PFAs (one per bird) and 29 TSAs (Figure 24, Table 13).

All but one of the nine birds TSAs remained within England and Scotland during their respective first year post-release. TSAs were predominantly identified in and along the South Coast and East Coast of England as well as Northern Scotland. No birds established TSAs in Ireland or Wales. Bird 201446 was the only bird from either cohort to leave the UK during the first year establishing TSAs in Denmark and Germany as well as on the East Devon/ Somerset border (Figure 11-19 & 24).

All 9 birds' PFA's overlapped the same spatial area on the Isle of Wight to varying degrees (PFAs mapped but removed from the report to protect the active release site location). A total of 21 out of the 29 TSAs (72.4%) were sites used in part by multiple birds that qualified as an established TSA and not just a site visited in passing (Figure 24 & Table 19).
Excluding PFA use (with the exception of 191978 whose PFA is also considered his only TSA), 2 of the 9 birds did not establish TSAs that overlapped with any other bird during their respective first year post-release; the remaining 7 birds did overlap at least one of their TSAs spatially with at least one other bird (to be considered overlap, a PFA or TSA will have been used by an individual and its area boundary will have overlapped spatially to some degree with that of at least one other bird; Table 19). Four main areas of overlap were identified using visual analysis of mapped TSAs (excluding PFA use; Figure 24). Main areas were identified where clusters of at least two TSAs from different birds were found to spatially overlap. Spatial overlap may have occurred in the same year from birds of the same cohort or by a bird from a different cohort the previous year but respectively still a bird's first year post-release.

There were two instances where birds temporally overlapped in their TSAs as well as spatially (see appendix D – TSA residency dates). Birds 191977 (male/ cohort 1) and 191984 (male/ cohort 1) frequented an overlapping area (intermittently) in North York Moors during the 2019/20 season. In all other instances no other tagged bird from the project was physically occupying and settled at a TSA area at the same time as another (although visitation may have occurred). Temporal considerations have not been considered more past this observation within the scope of this study.

Table 19: Summary of PFA/TSA overlap per bird and specific TSA

id	*TSA Number*	*Has the area or partial area been used as a TSA by another bird within their first year (spatial visual analysis only – temporal overlap not considered here)*	*TSA overlap and the specific TSA number*
191977	1	PFA – yes	
	2	No	
	3	No	
	4	Yes	Bird 84 (TSA 4)
	5	Yes	Bird 86 (TSA 4)
191978	1	PFA and only TSA for bird - yes overlap with other birds PFA's and TSA's	Bird 84 (TSA 2), 83 (TSA 2), 85 (TSA 2), 86 (TSA 3)
191984	1	PFA – yes	
	2	Yes	Bird 78 (pfa - only one TSA), 83 (TSA 2)
	3	Yes	Bird 80 (TSA 2)
	4	Yes	Bird 77 (TSA 4)
191980	1	PFA – yes	
	2	Yes	Bird 84 (TSA 3)
	3	No	
191983	1	PFA – yes	
	2	Yes	Bird 84 (TSA 2), 78 (TSA 1), 85 (TSA 2), 86 (TSA 3)
	3	No	
	4	No	
	5	No	
191985	1	PFA – yes	
	2	Yes	Bird 84 (TSA 2), 78 (TSA 1), 83 (TSA 2), 86 (TSA 3)
	3	Yes	Bird 86 (TSA 3)
	4	Yes	Bird 86 (TSA 3)
191986	1	PFA – yes	
	2	No	
	3	Yes	Bird 85 (TSAs 2,3,4), 78 (TSA 1), 83 (TSA 2)
	4	Yes	Bird 77 (TSA 5)
	5	No	
201446	1	PFA – yes	
	2	No	
	3	No	
	4	No	
	5	No	
201447	1	PFA – yes	
	2	No	
	3	No	
	4	No	
	5	No	
	6	No	

4 Discussion

I investigated White-tailed eagles (WTE) juvenile dispersal movement patterns, and space use on a spatio-temporal scale, spanning their first-year post-release. I described dispersal onset and subsequent movements for nine translocated juvenile WTE. The eagles showed a capacity for long distance travel both in terms of daily movements and distancing from the release site, however generally movements post-release were characterised by periods of moderately sedentary behaviour interspersed with gradual movement across the landscape following dispersal from the PFA (Post-Fledgling Area). They continued to reside in multiple TSAs (Temporary Settlement Areas), mostly across England and Scotland with a single individual travelling into mainland Europe. High levels of inter-individual variation in travel distances were detected, demonstrating some individuals moved greater distances more often than others. Intra-individual travel distances also varied greatly, with a far greater frequency of short than long distance movements. Long distance movements did occur but almost exclusively in the final months of the 12-month study period. Some of the findings are consistent with results from previous studies on the same or similar species, both from wild and reintroduced populations (Whitfield *et al.*, 2009b). This investigation is novel in investigating first year data from the Isle of Wight WTE translocation project in this level of detail.

4.1 Roost site distancing and reaching independence from the release site including onset of natal dispersal and the influence of release timing.

4.1.1 Roost site distancing

Inter- and intra-individual variation in distancing patterns was notable across the monitoring period, with roost site distances from the release site increasing and fluctuating to some degree throughout, interspersed with periods of relative stability at TSAs. Generally, patterns suggest limited movement and closer proximity to the release site in the first six months post-release and a trend across all individuals of an increase in distancing with time. Fluctuations in distancing were most notable between months 7-9 post-release (c.~250 days) corresponding with February/March – April/May. This corresponds to findings from Engler and Krone (2021), studying wild juvenile WTE in Germany. The greatest variation in distance from the natal site occurred in spring, c. 300 days post-fledging followed by a reduction in distance (Engler and Krone, 2021). The reduction of distance from release site toward the end of the study period was also observed in Isle of Wight eagles, but only for some of the individuals' movements. Natal returns were not covered in this study but did occur for some individuals (Edgar-read, S., 2022, personal communication). Exact distances, measure of fluctuation and timings of sedentary behaviour varied considerably between individuals, some showing a higher tendency for exploratory behaviours than others. High levels of variation have been noted in other similar studies (Soutullo *et al.*, 2006a; Cadahía *et al.*, 2010; Weston *et al.*, 2013).

My results match the expected characteristic, explore and temporarily settle movements of WTEs during juvenile dispersal during the transient period (Dennis *et al.*, 2019; Engler and Krone, 2021). The more localised distances in the initial dependent months is likely a reflection of different stages in WTE ontogeny (Balotari-Chiebao *et al.*, 2021; Cadahía *et al.*, 2010; Weston *et al.*, 2018) as found in Golden Eagles (*Aquila chrysaetos*) (Soutullo *et al.*, 2006b). Periodic stable distances are likely a reflection of more sedentary behaviours seen with TSA usage after dispersal from the PFA (see Appendix C for visualisation of dispersal onset in relation to roost site distancing and likely TSA usage periods). This stage is then interspersed with periods of increased distancing and fluctuation as well as an increase in distances travelled, particularly in the later stages of the first year, demonstrating the species well known, longer distance dispersal capabilities.

The period of post-fledging dispersal and the initial stages following dispersal onset, are complex and not widely researched in WTEs. Investigating distancing from the release site during these early periods offers a unique opportunity to gain new insight into best practice for translocations, and the associated behaviours of dispersal onset. I would recommend further analysis of the data used here, to specifically investigate pre-dispersal movements on a finer scale and to include focus on excursive behaviours and distancing movements from the release site. This would facilitate the visualisation and study of the ontogeny of movement during this relatively short but important period and the relationship to movements after the onset of dispersal.

4.1.2 Maximum juvenile dispersal distance

Maximum juvenile dispersal distances in my study ranged from 142.5km to 906.4km; median 423.7km with high levels of inter-individual variation. MJDD occurred between day 225 and 353 post-release, for all individuals, corresponding to dates after the 9th month post-release.

Whitfield (2009a) determined that the longest dispersal distances are completed early in the dispersal process before the birds reach maturity and suggests that the juvenile dispersal period may be used, in part, to assess potential breeding sites as opposed to early dispersal behaviours being simply directed at survival alone (Whitfield *et al.*, 2009b). Whitfield's (2009a) maximum juvenile dispersal distances (MJDD) ranged from 18km to 200km (n=154) within the first two years with no differences between wild bred and reintroduced WTE. Using the maximum dispersal distance (MDD) as a measure of dispersal only (as within my study), Rymesova et al.'s, (2021) results ranged from 93km to 433km, median of 187km (n=29) in the first year and occurred between July and March. In my study MJDD had a substantially higher median and higher minimum maximum range values than both those studies and MJDD occurred much later, yet over a shorter time frame between April – August of the second calendar year. In studies based on similar species, reintroduced individuals with no adult influence produced double the MDD measurements than those of individuals within the vicinity of adult birds (Muriel *et al.*, 2015; Antoni *et al.*, 2013). This fits the 'social (conspecific) attraction theory' but not the 'local experience theory' (Morandini and Ferrer, 2017; Antoni *et al.*, 2013; Muriel *et al.*, 2015). This could be an explanation for the much longer MJDD measures found in my study compared to other WTE studies including those of Whitfield (2009a) and Rymesova et al. (2021). All of the birds would have had limited contact with other WTE within the vicinity of the release site apart from fellow cohort members. Cohort 1 would not have had any conspecifics in the landscape at the time of release until the following year with the release of cohort 2, by which time only a couple of birds from cohort 1 had returned and were present in the landscape intermittently but were not breeding. Conversely Whitfield et al (2009a) did not find any difference in MJDD between translocated and wild bred WTEs.
Soutullo et al. (2006b) investigated timings of MDD in a one-year study on the Golden Eagles post-dependency period. For all individuals MDD was achieved towards the latter end of the monitoring period. This too was observed in my study. It is possible that the longer distances and timings of MJDD found in my study reflect interaction between the WTE long distance flight capabilities and other key, biotic and abiotic influences such as seasonal weather conditions facilitating long distance travel (Vansteelant *et al.*, 2015) or social behavioural cues. Whitfield et al. (2009b) (using observational data only) determined that MJDD within the first two years dispersal onset had a significant positive relationship with natal dispersal distance. Rymesova (2021) determined the first year of dispersal data could potentially be used to indicate natal dispersal distances in young WTE

(Rymešová *et al.*, 2021) therefore the MJDD's reached here could be used to make inferences about how far from the release site future breeding sites could materialise.

I would suggest further study of the dispersal/natal distance association, using more birds and potentially a longer study period to identify any relationships, particularly as the project has recently seen its first successful breeding territory established. It would also be of benefit and a unique opportunity to determine the effects of successive releases on MJDD year on year for new cohorts with more conspecifics in the landscape.

4.1.3 Reaching independence

Dispersal is a key, yet complex behavioural process (Weston *et al.*, 2013; Engler and Krone, 2021). It is not always possible to directly compare results from published studies on the same species due to differences in understanding and methods used to determine the start of dispersal (Balotari-Chiebao *et al.*, 2016; Rymešová *et al.*, 2021). The method used can notably affect the resulting dispersal dates as has been seen in this study and others. This leads to difficulty in assigning accurate timings and categorisations of the dispersal process (Weston *et al.*, 2013). Therefore, I studied three different methods derived from current literature to calculate dispersal onset, compared and examined the results.

Whilst Methods 1 and 2, are based on legitimate thresholds, they are formed on Scottish WTE population level, nesting adult territorial parameters (Whitfield *et al.*, 2009b; Whitfield *et al.*, 2009a), and may not necessarily be biologically meaningful distances for a translocation scenario particularly in the earlier stages of translocations where no adult influence or territories are present (Whitfield *et al.*, 2009b). Methods 1&2 also have a smaller no return caveat of two days than method 3. It is possible that a juvenile could make an exploratory flight that would last outside of the threshold distance and return before having to find food for itself – predicting dispersal when the individual is still be relying on the release site for sustenance (or parental provision in a wild setting). Method 3, however, used a 10 day no return caveat to determine dispersal. This amount of time is a good indication that an individual is able to remain away from supplementary feeding source and forage for itself as it is unlikely to survive a 10day period without feeding without serious detriment to its wellbeing (Weston *et al.*, 2013). Method 3 was the most logical method and only the outcomes for method 3 are used for the rest of the discussion.

Rymešová's (2021) study used the same distance threshold and timings (>5km + 10 days) to detect dispersal onset and therefore direct comparisons could be made. First flight in wild bred nestling WTEs originating from Czech Republic, Hungary and Austria occurred from May to July and onset of dispersal was detected to occur 8 – 165 days post fledging; median 82 days (n=29) (July through to November) (Rymešová *et al.*, 2021). Although some birds in that study fledged earlier than the birds in this study were released, the time period for reaching dispersal is very similar, (15 – 165 days post-release; median of day 73; n=9) and the median only slightly lower.

4.1.4 Timing of releases in relation to dispersal time

Whilst the range of time spent in the post fledging period from release to dispersal onset seems to generally fit within normal time ranges found in other studies (Rymešová *et al.*, 2021; Engler and Krone, 2021). Cohort 1 was released approximately 23 days later than cohort 2 the following year. Cohort 1 tended to reach independence earlier than cohort 2 (median day 62 and 76 days post-release respectively), whilst cohort 2 showed less inter-individual variation between dispersal onset dates (cohort 1: day 15-165; cohort 2: day 64-89, post-release). This meant cohort 2 generally remained at the release site longer than cohort 1 which is preferable (Engler and Krone, 2021) and advantageous for translocated and wild juveniles as it is thought to boost an individual's condition and thus survival (Hemery *et al.*, 2023). These inter-cohort differences were, however, not statistically significant. Based on these results alone however, it cannot be concluded if earlier/later dispersal was or was not due to differences in release timings.

Researchers have suggested that young raptors, in good condition and 'high quality' may be expected to have shorter post-fledging dependency periods, disperse earlier and over longer distances (Whitfield *et al.*, 2009b; Ferrer, 1993b; Walls, Kenward and Holloway, 2005). This could explain the trend as cohort 1 will have received 23 days more of ad libitum food sources improving nutritional condition (Ferrer *et al.*, 2023) and be further along on the course of development (older age – more physically capable) than cohort 2 at the time of release. Still, cohort 2 would also have been in prime nutritional condition when released and it is known that prior to release, WTE naturally reduce nutritional intake, which is thought to be a natural precursor to fledging and flight preparation (Ferrer *et al.*, 2023)). Conversely, other studies have noted that individuals of 'lower quality' are displaced by higher quality individuals triggering dispersal from the natal area instead. It is highly likely that there are other factors influencing dispersal onset (Engler and Krone, 2021). In translocated birds the genetic origin could also influence dispersal tendencies (Whitfield *et al.*, 2009a) as can environmental factors; weather (Balbontín and Ferrer, 2009; Walls, Kenward and Holloway, 2005) prevailing release environment (Whitfield *et al.*, 2009a; Weatherhead and Forbes, 1994; Engler and Krone, 2021), particularly resource accessibility (Engler and Krone, 2021) high levels of inter-individual variation in large raptor dispersal strategies (Weston *et al.*, 2013) behavioural cues (Engler and Krone, 2021; Whitfield *et al.*, 2024) innate behaviours (Whitfield *et al.*, 2024), including conspecific inter-, intra-cohort interaction and/or competition and social attraction (Ferrer, 1993a; Morandini and Ferrer, 2017) and methodology used to determine dispersal onset (Weston *et al.*, 2013). It has recently been deemed that timing of departure from the natal site is not constrained by the acquisition of flight skills as this occurs notably prior to departure although some species may continue to enhance flight skills over a long period of time post departure (Hemery *et al.*, 2023).

I would recommend further and wider investigation of release timings using subsequent years of data which have now been produced as well as including individuals that failed to qualify for this study e.g., died before the end of their first calendar year. Investigating other influencing factors such as those mentioned above may also offer to strengthen findings from this study and give further insight into dispersal onset and survival as well as add practically to translocation best practice methodology.

4.2 Distances travelled on a daily and monthly basis over the first-year post-release.

Having an understanding of the daily distances covered by an individual is key for gaining insight into common behavioural activities such as foraging, migration, social interaction, and habitat selection (Soutullo, Urios and Ferrer, 2006; Cadahia, Urios and Negro, 2007) and ultimately survival (Cadahia, Urios and Negro, 2007). This is particularly warranted for individuals transitioning through early critical life history stages from pre- and post-dispersal through to the early transient period particularly for conservation purposes (Cadahia, Urios and Negro, 2007). During this time frame WTE young lack flight experience and are naïve to environmental dangers (Ruaux, Lumineau and de Margerie, 2020) they mature physically, (Ruaux, Lumineau and de Margerie, 2020) explore novel surroundings, make conspecific interactions, learn and develop flight (Hemery *et al.*, 2023) and foraging skills for survival (Balotari-Chiebao *et al.*, 2021; Dahl *et al.*, 2012; Bevanger *et al.*, 2011; Ruaux, Lumineau and de Margerie, 2020).

Studies looking specifically at daily distances covered with regards to WTE are limited but include a studies on a migratory population of WTE including juvenile movements in Central Asia (Bragin *et al.*, 2018) and movements of breeding and non-breeding adults (Mirski and Anderwald, 2023). Studies on the daily distances of other similar species have been conducted: Bald Eagles (Miller *et al.*, 2019), Golden Eagles (Soutullo, Urios and Ferrer, 2006), Bonelli's Eagles (Cadahia, Urios and Negro, 2007), various Vultures species (Garcia-Ripolles, Lopez-Lopez and Urios, 2011; Mandel *et al.*, 2008; Antoni *et al.*, 2013; Subedi *et al.*, 2020), Waterfowl (McDuie *et al.*, 2019). Most have been conducted over a shorter time frame than this study but still offer some transferable insights.

Distances travelled in a day varied across the year for all individuals in this study as well as between them. The distribution of distances travelled were generally characterised by relatively short distance daily travel (particularly the first six months) interspersed with longer flights demonstrated later in the year. Minimum distances were performed throughout the year suggesting, whilst the WTEs developed the capacity for longer distance travel, generally the highest frequency of daily distances remained relatively small). Bragin et al, (2018) studied migratory juvenile WTE individuals who travelled on average 25-108km/day (n=3). Collectively 25% of distances in my study remained under 4.58km per day and 75% remained under 26.72km per day. Median distances per individual per day in ranged from 6.8km/d to 18.85km/d, considerably shorter than results found in Bragins' (2018) study. This is to be expected as the two populations are different in sedentary nature, UK WTE are not migratory as opposed to the Central Asia population (Bragin *et al.*, 2018) and would not be expected to travel such far distances on a regular daily basis. Length of the studies and data set size also differed considerably and potentially affected the ability to compare results reliably. It should also be considered that daily distances calculated from satellite telemetry data is heavily influenced by sampling intervals and may not represent exact distances travelled due to tortuosity of movement paths (Mirski and Anderwald, 2023; Nathan *et al.*, 2008; Soutullo, Urios and Ferrer, 2006) again highlighting potential issues in comparing results with other studies.

Within my study an indication of a comparable temporal trend was identified groupwide - daily distances peaked during month nine post-release (the first April post-release) and showed substantial inter-individual variation in the relative increase of distances measured. Mirski and Anderwald (2023) detected a minor two peak trend within a WTE population in Poland, whereby the daily distance increased seasonally in mid-April and mid-August each year. The peaks in distances travelled were considered to be associated with exploratory behaviours or shifts in foraging opportunities (Mirski and Anderwald, 2023). First year movements of juvenile birds were not used in the study, so direct comparison should not be made but the 'floater adults' studied were noted as producing distances similar to juvenile WTEs (Mirski and Anderwald, 2023) therefore results may be transferable or offer insight into seasonal similarities. Whist the peak in activity around April in this study could be partly attributed to exploratory or foraging behaviour as seen in the Mirski and Anderwald (2023) study, I would suggest that the variation in daily distances travelled across the year, varies for a number of reasons.

From time of release up until post-fledging dispersal the restricted movements would primarily be related to ontogenic developments at that early stage in life, such as developing and learning life skills (Hemery *et al.*, 2023). Nonetheless, as seen in other areas of the investigation, for example the increase in distancing from the release site and influences of dispersal timing as considered in the discussion of objective 1, it is likely that other co-influencing factors have resulted in the patterns seen across the rest of the year. Factors considered important include change in weather conditions facilitating longer flights (as seen seasonally) (Vansteelant *et al.*, 2015; Whitfield *et al.*, 2024), wider food resource availability (along with the ability to exploit them (Hemery *et al.*, 2023)) and exploratory behaviours driving further travel toward the end of the study period.

I would recommend separating distance results into distinct sections of distances travelled during pre-dispersal, when settled in TSAs and when identified as wandering (as has been presented in Bragin et al. (2018)). This would offer greater insight into the stages of distance development and give more robust information on the likely future movements of reintroduced individuals during dispersal.

4.3 Identify and investigate the use of Temporary Settlement Areas during the first-year post-release

Not many comparative studies are found in current literature regarding juvenile WTE and Temporary Settlement Areas. Most similar studies focus on other large, long lived eagle species with similar ecologies, namely Bonelli's Eagles (Cadahía *et al.*, 2010), Golden Eagles (Soutullo *et al.*, 2006a; Weston, 2014), Spanish Imperial Eagle (Ferrer and Harte, 1997; Morandini *et al.*, 2020), Saker Falcon (Nemček *et al.*, 2016), Spanish Imperial Eagle (Cadahia, Urios and Negro, 2007). One study that has delineated and characterised TSA use by juvenile WTE in Europe was conducted by Rymešová et al. (2021) and the methods to do so have been used in this study as well as drawing insight from proxy species.

My study is the first to delineate TSAs for the Isle of Wight Translocation Project and thus WTE in England. All birds but one remained in England and Scotland mostly settling in the south and east coast of England and northern reach of Scotland. A single bird established TSAs in Denmark and Germany as well as England during the first year post-release. 9 PFAs and 29 TSAs were identified with each individual using between 1-6 TSAs (average=4.2). This range was nearly identical to the range identified by Rymešová et al (2021) (range = 1 – 7, n=29) across three interconnected European WTE populations. The number of TSAs used by proxy species was species-specific but most used multiple sites throughout the transient phase of dispersal with some inter-individual variation (Morandini *et al.*, 2020; Cadahía *et al.*, 2010; Soutullo *et al.*, 2008).

It is thought that attraction to a TSA for these species, is likely due to high prey abundance (Cadahía *et al.*, 2010). Research conducted in Spanish Imperial Eagles concluded that hunting success ratio depleted from the beginning of TSA settlement, until abandonment despite increased hunting efforts indicating that food sources are located and exploited after which sites are abandoned (Ferrer, 1993c; Morandini *et al.*, 2020). Other attracting features may be ample resources including desirable habitat such as forested areas and wetlands, (Balotari-Chiebao *et al.*, 2021), weather influencing flight paths via thermal uplift, and or strong winds (Vansteelant *et al.*, 2015), innate behaviours (Whitfield *et al.*, 2024), preliminary search in the later stages of the transient period for potential breeding sites or conspecific attraction (Morandini and Ferrer, 2017). Further research into why an individual will settle in a specific geographical location would help to understand attraction to sites and help to predict movements of individuals/ future populations and consider conservation measures as required.

All PFAs overlapped to varying degrees and 72.4% of TSAs were used by at least two birds. Several areas of overlap have been identified which suggests multiple birds do spatially use parts of the same geographical areas as TSAs. This result has also been strengthened by anecdotal evidence.

Birds from subsequent releases, unidentified individuals, a ringed wild bred Dutch juvenile, and a tracked juvenile from The Irish White-tailed Eagle Reintroduction Programme have also frequented the same geographical locations in recent years, as identified in my research (Edgar-read, S, personal communications 2024). Conversely evidence produced by Cadahia et al. (2010) study of Bonelli's Eagles stated that TSA overlap very rarely occurred during the first year of life.

Generally, in my study, a higher proportion of time was spent residing within the limits of an individual's identified TSAs (63.3 - 95.6%) as opposed to demonstrating constant or substantial wandering behaviours (4.4 – 36.7%). A wide level of inter-individual variation was identified, some individuals had higher exploratory tendencies than others. Bragin et al, (2018) studied three juvenile WTE on migration and found that the studied individuals produced results that varied widely from one another. The migratory birds time spent in stop overs ranged from 30-81% and 19-70% in transit (Bragin *et al.*, 2018). The differences between the upper levels of transient behaviour between the two studies is likely due to the inherent difference between the two populations. Central Asian WTE are a migratory population (Bragin *et al.*, 2018) and are predisposed to migratory patterns of dispersal whereas the European WTE in Britain are non-migratory (Dennis *et al.*, 2019). Both studies again highlighted the common inter-individual variation among the birds in their respective studies.

All of the individuals from this study, spent their longest proportion of time settled within TSA 1 (PFA) or TSA 2, which may reflect when juveniles are still maturing, learning and developing skills in the initial post-fledging stage (Hemery *et al.*, 2023). Still, even after flight acquisition, wild populations show a tendency to remain in the PFA vicinity for as long as possible, boosting condition and potential survival as deduced in the recent study by Hemery et al. (2023) on Golden Eagles and another by Rymešová (2019) on juvenile WTE. Time of year and weather could also influence longer residency times within the initial TSAs once established (Vansteelant *et al.*, 2015). Within Spanish imperial Eagle age only slightly affected the time spent dedicated to residing in temporary settlements (Balbontín and Ferrer, 2009).

PFA size calculated by a study on WTE in Europe ranged from 0.4 - 2963 km^2; median 383km^2 (n=29) and indicated wide inter-individual variation among birds (Rymešová *et al.*, 2021). The sizes of PFAs in my study also showed high levels of inter-individual variation but PFA sizes were far smaller than those identified by Rymešová (2021), the medium PFA in my study being approximately half of that found by Rymešová (2021). TSAs in this study, generally showed wide inter- and intra-individual variation in size and no correlation was found between size of PFAs and length of residency.

Although sizes were found to vary greatly, the amount of time the birds are spending in reasonably restricted geographical areas reflects the importance of TSAs for young WTE. This study and others have highlighted the importance of TSAs to juvenile WTEs, and this presents an interesting conundrum concerning protection offered. Protection of TSAs is particularly important as they are visited during a vulnerable time in their life and can often encompass areas with anthropogenic dangers such as direct and indirect persecution or hazardous infrastructure, for example overhead powerlines, roads and train tracks (Cadahía *et al.*, 2010). If particular TSA sites become 'sinks' as opposed to 'sanctuaries', there is likely to be an impact on the species recovery process within England and the UK as a whole. With a lack of overlap and use of specific sites Cadahía et al. (2010) suggested that conservation efforts should be landscape wide and not focus on delimited geographical sites, however if certain features of particular non-breeding areas were used frequently by juveniles, year on year, during their transient dispersal phase, as identified in the short term in this study, some in-situ protection that aims to reduce juvenile mortality in these areas would thus boost eventual recruitment into the breeding population would be beneficial in continuing to support the re-establishment of a viable population of WTE in England and consequently neighbouring populations. Measures that could offer protection whilst in a TSA could include permanent changes to dangerous infrastructure or be as simple as on the ground engagement with local communities and stakeholders particularly if there is a perceived possibility for conflict or persecution. As concluded by Rymešová et al., (2021), any future conservation efforts for WTE or any endangered species with small populations should look to protect not only traditional breeding grounds but also the most important (most frequented) TSAs, which could attract many non-breeding individuals particularly juveniles (Rymešová *et al.*, 2021).

Translocations are a unique opportunity to gain insight into important elements of a juvenile WTE dispersal process, colonisation processes as well as highlight the potential need for conservation initiatives in the UK and internationally to offer some protection to juvenile WTE during the transient stage.

Using this study as a basis and with more years of data now available I would recommend investigating further use of TSAs for the original individuals to look at the development and use of new and old TSAs up until territories were established. Several project individuals have since paired and hold territories including one pair that successfully bred in 2023 at a site close to where a bird from my study had previously established a TSA. This further research would give insight into relationships between TSA use throughout the whole of the transient period and any influence they may have on eventual breeding site establishment. I would also recommend introducing a further temporal investigation element to the PFA/TSA section, to understand timings of when in the first year they are utilising settlements and if there are any identifiable patterns.

Generally, I would also recommend integrating and analysing data produced by subsequently released individuals into all of the recommendations I have made for further research as this would help to identify patterns and results with more comprehensive scientific rigor.

5 Conclusion

With accelerated levels of anthropogenically driven biodiversity loss, ecological change and habitat degradation, conservation translocations are increasingly being used as an effective means to address population declines and losses by repatriation of species to their historical ranges. In order to address the loss of White-tailed eagle (*Haliaeetus albicilla*) from its historic range, the Isle of Wight White tailed Sea Eagle translocation project commenced in 2019 with the aim to re-establish a viable breeding population of WTE to the Isle of Wight and across southern England.

It is recognised that dispersal processes are fundamental elements influencing the success of a translocation. Gaining a comprehensive understanding of such processes is therefore vital to improve translocation outcomes. Juvenile dispersal is complex and poorly understood, yet an important behaviour that heavily influences juvenile survival at a time of high mortality risk. In order to support the success of the Isle of Wight conservation translocation and increase our understanding of post-release movements, several aspects of juvenile dispersal, as revealed by satellite telemetry, have been investigated and described for nine translocated juvenile WTE, from release, up until the end of their first year. Investigated aspects of the juvenile dispersal process in this research included quantifying changes in roost site distances from the release site, determining the timing of dispersal onset, investigating daily distances travelled, determine temporal patterns, as well as investigating and identifying areas that qualified as Temporary Settlement Areas (TSAs).

This research has concluded that movements were characterised by limited travel in the initial period following release, with movements away from the release site following dispersal from the Post-Fledgling Area (PFA). Cohort 1 released in 2019, 23 days later than cohort 2 in 2020, reached dispersal onset quicker than cohort 2. The timings of the releases are not thought to be the sole influence of the differences seen but rather a result of other co-influencing factors. Most individuals continued to reside in and move between multiple geographically restricted Temporary Settlement Areas (TSAs), mostly across England and Scotland with a single individual travelling into mainland Europe. Size and residency periods for each PFA/TSA varied but a higher proportion of time was spent residing in areas identified as TSAs as opposed to continuous exploratory travel. High levels of inter-individual variation in travel distances were detected, demonstrating some individuals moved greater distances more often than others. Intra-individual travel distances also varied greatly, with a far greater frequency of short than long distance movements. When long distance movements and wider distancing variation did occur (including maximum daily distance and maximum dispersal distance), it was almost exclusively in the final months of the 12-month study period. Whilst these juvenile WTEs have demonstrated the capacity for long distance movements and prospecting behaviours most of the movement seen within the first year was periods of localised movement behaviours interspersed with an increase in distance from the release site.

Juvenile dispersal has important implications for the conservation of a species. This research adds a comprehensive first insight on the movements of the translocated birds in essentially what is a colonisation event. This work adds to the limited body of information relating to WTE juvenile dispersal and highlights the potential importance of TSA's during the transient phase, although further research is needed. In addition to the objective-specific recommendations set out in the discussion, I would make two additional, broader recommendations moving forward. The first being whilst investigating nine translocated individuals has given a good basis of information, it is a relatively small sample size negating the use of more powerful statistical analysis. Increasing the number of birds utilised in this study would increase scientific rigour and allow more reliable inference of behaviours at a population level. In the intervening years since the project started, analysing data derived from subsequently released birds would make this recommendation easy to achieve. I would also recommend building on the work produced here and investigating the causality of the movements highlighted in this research. It is likely that there are many influencing factors effecting movements during the transient period and by examining potentially influencing factors such as weather, seasonality, habitat associations and social behaviour, a more comprehensive picture can be built and questions of why, when, and how may be answered more thoroughly.

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7 Appendices

7.1 Appendix A – Methods test of normality

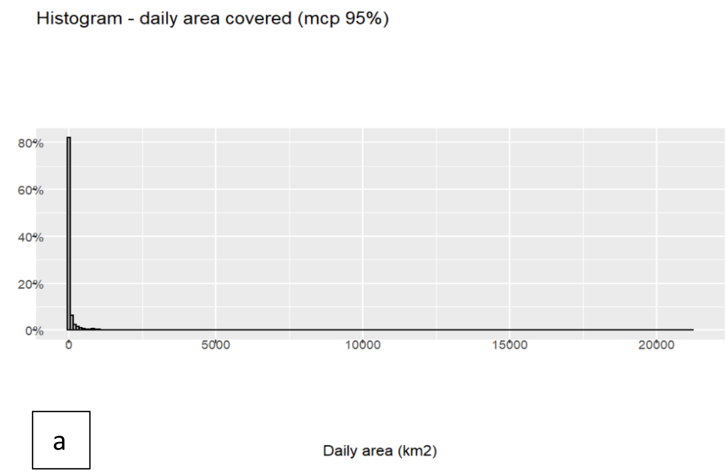
RStudio: Notebook Output

```
        Shapiro-Wilk normality test

data:  allbirds$day_since_release_m1
W = 0.86844, p-value = 0.1183

        Shapiro-Wilk normality test

data:  allbirds$day_since_release_m2
W = 0.87908, p-value = 0.1536

        Shapiro-Wilk normality test

data:  allbirds$day_since_release_m3
W = 0.83455, p-value = 0.05021
```

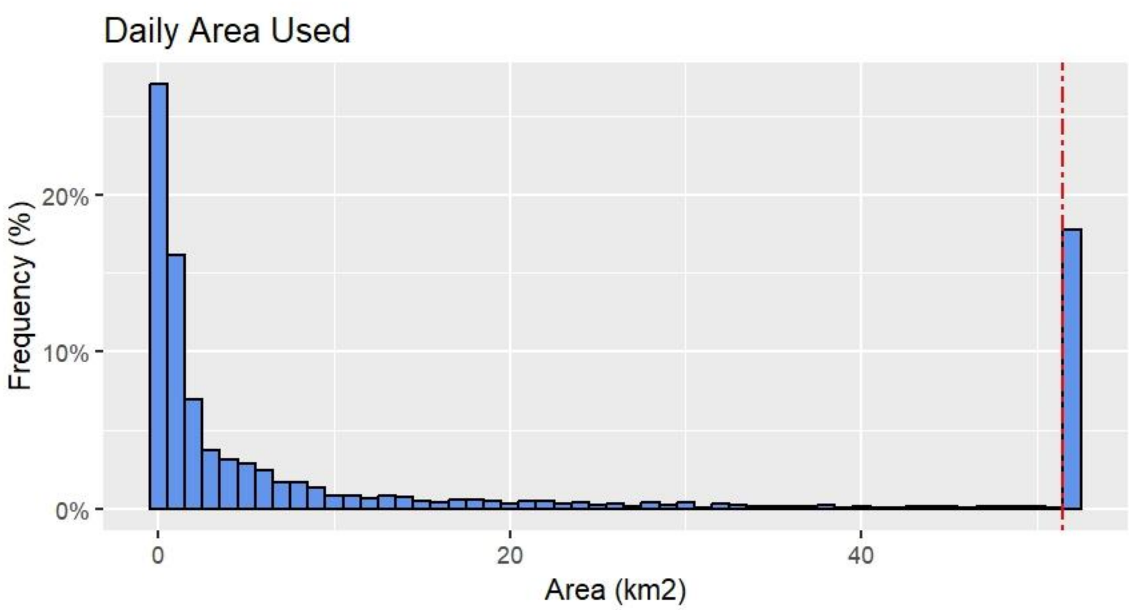
7.2 Appendix B – Area use

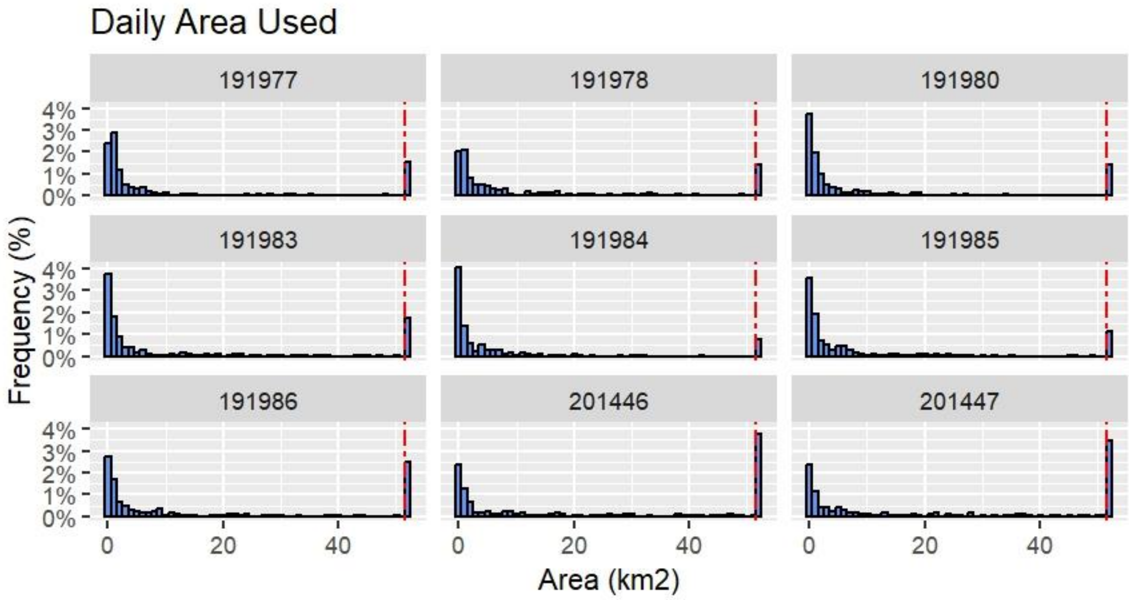
Summary - daily area use (km^2)

id	days_in_dataset	total_area	mean_area	sd	median	qu25	qu75	qu95	min	max
191977	364	54493.35	149.71	685.21	1.80	0.62	9.24	452.08	0.04	6064.53
191978	363	34803.79	95.88	491.83	3.84	0.82	19.61	172.82	0.01	6000.43
191980	364	134314.14	368.99	1527.33	1.55	0.32	8.91	2330.03	0.00	16791.20
191983	364	75343.12	206.99	1392.67	1.66	0.26	16.71	733.08	0.00	21160.75
191984	307	17947.00	58.46	481.88	0.87	0.17	6.03	159.89	0.00	8108.56
191985	356	26160.78	73.49	391.04	1.64	0.35	8.52	201.65	0.00	5246.60
191986	345	104701.49	303.48	1157.15	3.32	0.50	32.52	1448.87	0.02	11381.22
201446	361	132593.81	367.30	1564.74	10.19	0.78	119.95	1496.89	0.00	18507.11
201447	364	106795.91	293.40	1265.80	9.05	0.79	81.25	913.86	0.00	15820.95
All birds	**3188**	**687153.39**	**215.54**	**1106.38**	**2.48**	**0.44**	**21.38**	**898.03**	**0.00**	**21160.75**

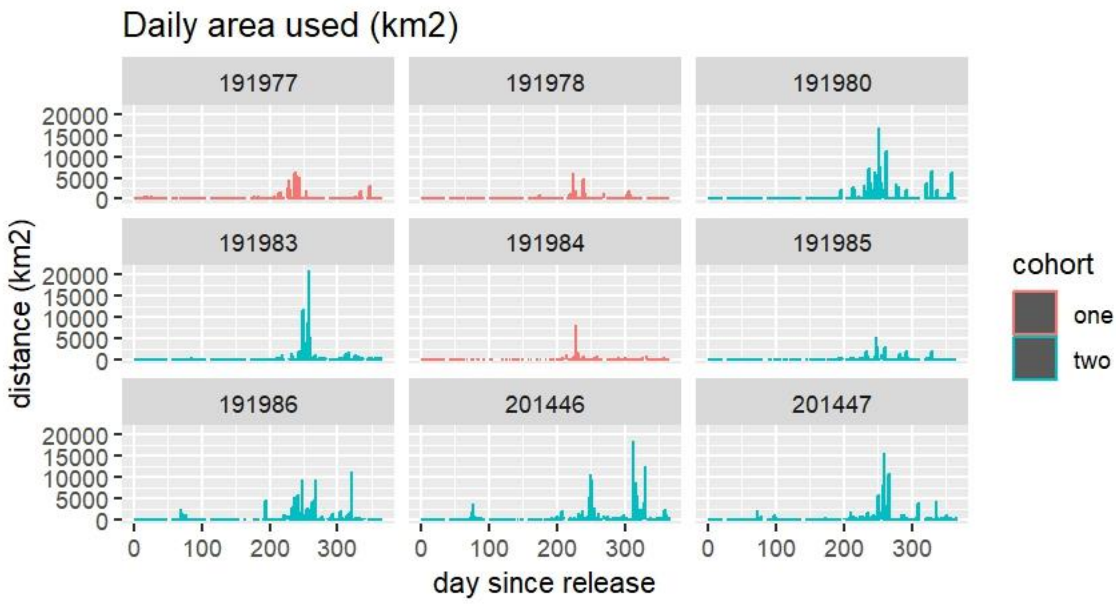


Distribution of daily area (km^2) used for all birds analysed a) collectively and b) separately (personal collection 2024)

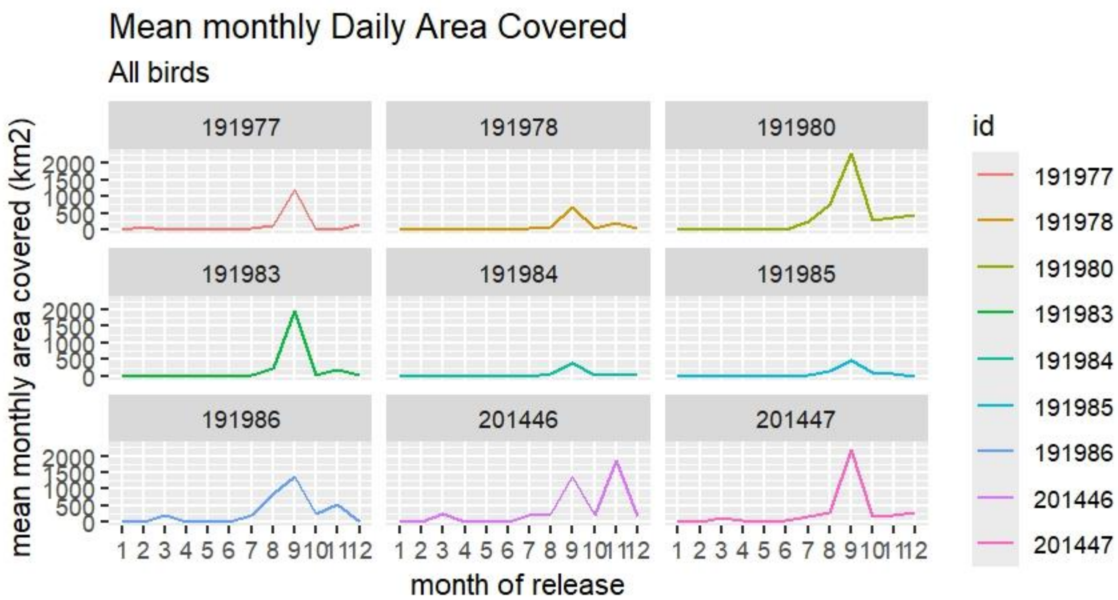




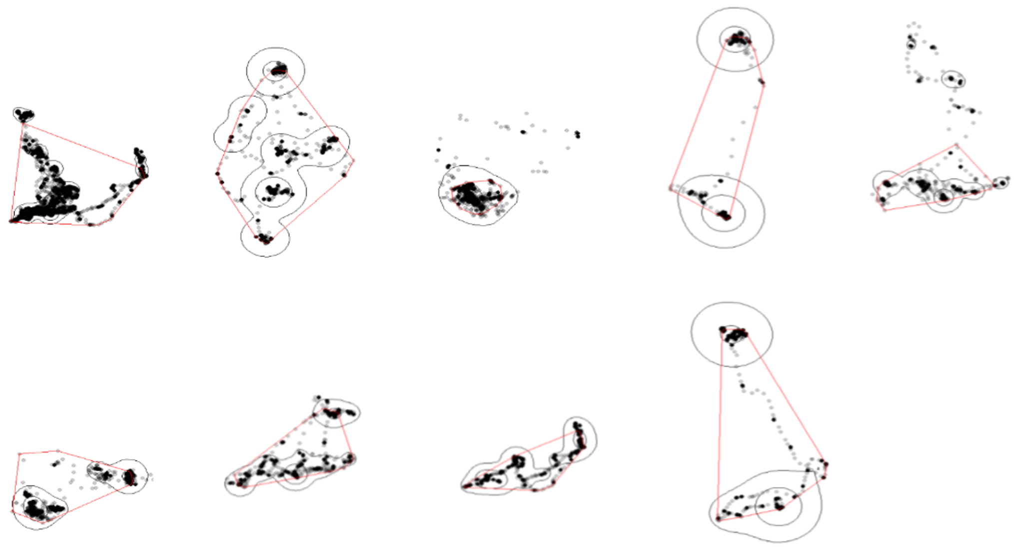
Distribution of daily area covered (km^2) for all birds a) collectively and b) as per individuals; measures of daily area use that measured over 52km^2 have been aggregated into one bin (indicated by the red line) to show finer visual detail of the majority of frequency occurrence under this measure (personal collection 2024).



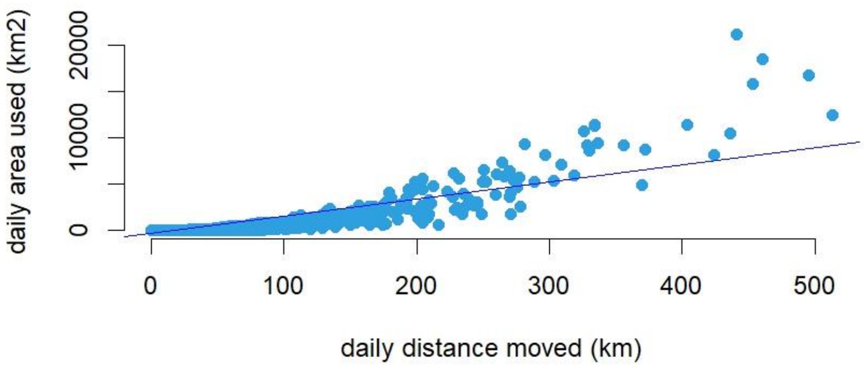
Daily area covered per individual since day of release (day 0-365) – indication of temporal patterns (km^2). Day 1 corresponds to the day of release (a gap in the chart corresponds to a day with less than 10 daily relocations and consequently data was deemed not representative of movement on that day and was omitted from analysis) (personal collection 2024)



Mean daily area covered (km²) for each month post release, per individual (personal collection 2024)

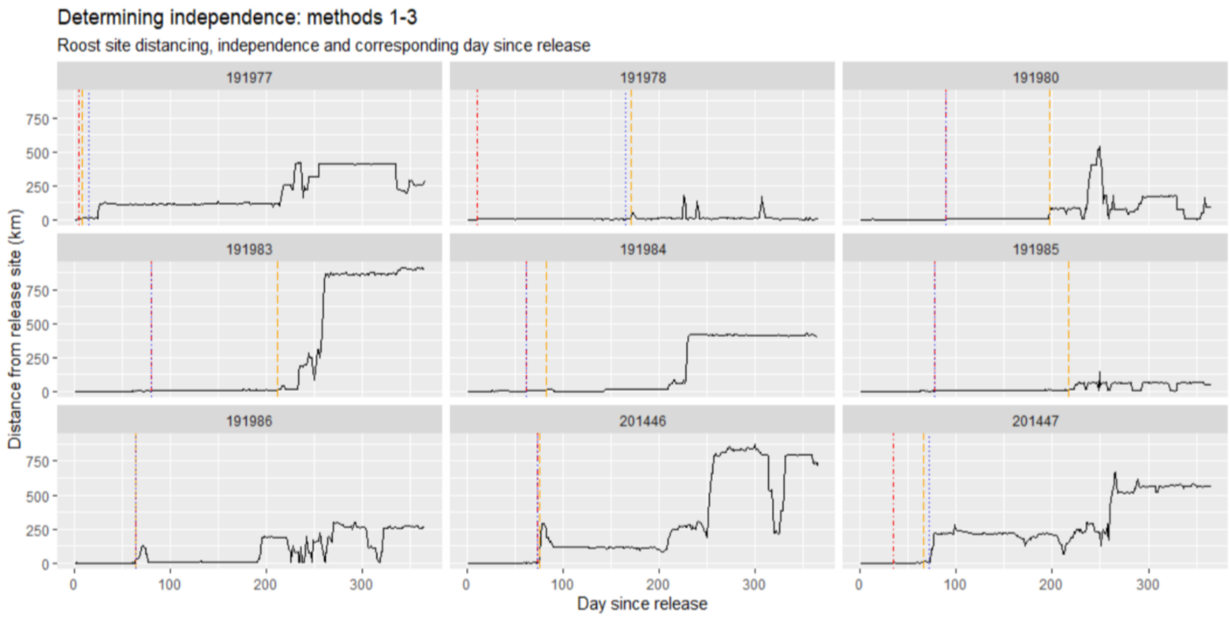


Kernel density estimation - KDE and Minimum Convex Polygon - MCP (95% - red outline). First image – all birds collectively, followed by a KDE/MCP for each individual (personal collection 2024).



Relationship between daily area covered and daily distance moved (personal collection 2024)

7.3 Appendix C - Dispersal onset in relation to roost site distancing



Appendix C: Visual representation of when independence was reached by each bird determined by each dispersal onset method in relation to roost site distancing across the year. Method 1 - d>=4.45km+2 days (red dot-dash line), Method 2 - d>=9.9km +2 days (orange dashed line), Method 3 d>=5km +10 days (blue dotted line). Method 3 has been used as comparative onset timing for discussion (personal collection 2024).

7.4 Appendix D - Temporary Settlement Area residency dates

77 TSA number	Dates present in each TSA
1	21/08/2019 – 27/08/2019 03/09/2019 09/09/2019 - 10/09/2019 13/09/2019
2	16/09/2019 – 19/09/2019 23/09/2019 – 16/01/2020 18/01/2020 – 12/02/2020 20/02/2020 – 13/03/2020 15/03/2020 – 20/03/2020
3	20/04/2020 – 30/04/2020
4	06/04/2020 – 12/04/2020 01/05/2020 – 06/06/2020 09/06/2020 – 23/06/2020 25/06/2020 – 19/07/2020
5	15/04/2020 08/08/2020 – 11/08/2020 13/08/2020 – 17/08/2020

78 TSA number	Dates present in each TSA
1	22/08/2019 – 08/02/2020 13/02/2020 – 01/04/2020 05/04/2020 – 15/04/2020 19/04/2020 – 20/06/2020 26/06/2020 – 07/08/2020 09/08/2020 – 20/08/2020

84 TSA number	Dates present in each TSA
1	21/08/2019 – 10/11/2019 17/11/2019 – 10/01/2020
2	12/11/2019 – 16/11/2019 11/01/2020 – 16/03/2020
3	19/03/2020 – 21/03/2020 24/03/2020 – 31/03/2020
4	08/04/2020 – 06/05/2020 08/05/2020 – 17/07/2020 20/07/2020 – 06/08/2020 09/08/2020 – 16/08/2020

80 TSA number	Dates present in each TSA
1	30/07/2020 – 10/02/2021 17/03/2021 – 19/03/2021 14/04/2021 03/07/2021 – 18/07/2021
2	12/02/2021 – 26/02/2021 02/03/2021 – 08/03/2021 10/03/2021 – 15/03/2021 20/03/2021 – 22/03/2021 15/04/2021 – 17/04/2021 19/04/2021 – 02/05/2021 12/05/2021 – 14/05/2021 24/06/2021 – 30/06/2021
3	18/05/2021 – 15/06/2021 17/06/2021 – 23/06/2021

85 TSA number	Dates present in each TSA
1	30/07/2020 – 06/02/2021 08/02/2021 – 09/02/2021 11/02/2021 13/02/2021 – 27/02/2021 01/03/2021 – 02/03/2021 03/04/2021 12/04/2021 – 13/04/2021 15/04/2021 08/05/2021 – 17/05/2021 17/06/2021 – 23/06/2021
2	07/02/2021 10/02/2021 12/02/2021 28/02/2021 03/03/2021 – 09/03/2021 20/03/2021 – 22/03/2021 14/04/2021
3	10/03/2021 – 12/03/2021 02/04/2021 16/04/2021 18/05/2021 – 19/05/2021 15/06/2021 – 16/06/2021 23/07/2021 – 29/07/2021
4	13/03/2021 – 19/03/2021 23/03/2021 – 01/04/2021 06/04/2021 – 11/04/2021 17/04/2021 – 07/05/2021 20/05/2021 – 14/06/2021 24/06/2021 – 22/07/2021

86 TSA number	Dates present in each TSA
1	30/07/2020 – 30/09/2020 14/10/2020 – 06/12/2020 09/12/2020 – 05/02/2021 20/03/2021 – 21/03/2021 23/03/2021 – 25/03/2021 02/04/2021 – 03/04/2021 16/04/2021 10/06/2021 – 12/06/2021
2	09/02/2021 – 07/03/2021
3	13/03/2021 15/03/2021 – 19/03/2021 26/03/2021 – 27/03/2021 30/03/2021 – 01/04/2021 17/04/2021 – 18/04/2021
4	03/05/2021 – 13/05/2021 23/05/2021 – 27/05/2021 20/06/2021 22/06/2021 – 23/06/2021 27/06/2021 – 29/06/2021 06/07/2021 – 29/07/2021
5	15/05/2021 – 16/05/2021 19/05/2021 – 22/05/2021 28/05/2021 16/06/2021 – 18/06/2021 21/06/2021 24/06/2021 – 26/06/2021 30/06/2021 – 05/07/2021

46 TSA number	Dates present in each TSA
1	31/07/2020 – 10/10/2020
2	27/10/2020 – 25/01/2021 27/01/2021 – 02/02/2021 08/02/2021 – 10/02/2021
3	20/04/2021 01/06/2021 – 07/06/2021 28/06/2021 – 29/06/2021 01/07/2021 – 08/07/2021 10/07/2021 – 24/07/2021
4	26/04/2021 03/05/2021 – 10/05/2021 13/05/2021 – 16/05/2021 29/05/2021
5	02/05/2021 11/05/2021 – 12/05/2021 17/05/2021 – 19/05/2021 21/05/2021 – 24/05/2021 28/05/2021

83 TSA number	Dates present in each TSA
1	31/07/2020 – 16/10/2020 18/10/2020 – 26/02/2021 13/03/2021
2	27/02/2021 – 01/03/2021 07/03/2021 – 12/03/2021 14/03/2021 – 19/03/2021
3	18/04/2021 – 20/04/2021 22/04/2021 24/04/2021 - 07/05/2021 10/05/2021 – 21/05/2021 24/05/2021 – 31/05/2021 02/06/2021 08/06/2021 – 12/06/2021 29/06/2021 – 01/07/2021
4	13/06/2021 – 21/06/2021 23/06/2021 – 26/06/2021
5	02/07/2021 – 12/07/2021 14/07/2021 – 30/07/2021

47 TSA number	Dates present in each TSA
1	31/07/2020 – 05/10/2020 07/10/2020 – 11/10/2020
2	15/10/2020 17/10/2020 – 04/11/2020 14/11/2020 – 17/01/2021 21/01/2021 24/01/2021 – 04/02/2021 06/02/2021 – 19/02/2021 21/02/2021 - 22/02/2021
3	25/04/2021 – 29/04/2021 03/05/2021 – 05/05/2021 08/05/2021 – 09/05/2021 03/06/2021 – 05/06/2021
4	19/05/2021 – 02/06/2021 06/06/2021 – 17/06/2021 30/06/2021 – 01/07/2021 17/07/2021 – 19/07/2021 27/07/2021 – 30/07/2021
5	17/05/2021 – 18/05/2021 03/07/2021 – 10/07/2021 16/07/2021 20/07/2021 – 22/07/2021
6	18/06/2021 – 21/06/2021 24/06/2021 – 29/06/2021 11/07/2021 – 13/07/2021