Seguimiento GPS de aguiluchos cenizos (*Circus pygargus*) nacidos en cautividad y liberados por el método hacking. El caso de estudio de la población más al sur de Europa

GPS tracking of Montagu's harriers (*Circus pygargus*) born in captivity and released by the hacking methodology. A case study in the southernmost population in Europe

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TUMBABUEY

Los datos empleados en la elaboración de este trabajo han sido recopilados por el Grupo Ornitológico Tumbabuey

Data analysed within this work have been gathered by Tumbabuey Ringing Group

DECLARACIÓN DE ORIGINALIDAD DEL TFG

Dña. Marta Paula Pineda Gil con DNI XXXXXXXXX, estudiante del Grado en Ciencias Ambientales de la Facultad de Ciencias de la Universidad de Málaga,

DECLARO:

Que he realizado el Trabajo Fin de Grado titulado "Seguimiento GPS de aguiluchos cenizos (*Circus pygargus*) nacidos en cautividad y liberados por el método hacking. El caso de estudio de la población más al sur de Europa" y que lo presento para su evaluación. Dicho trabajo es original y todas las fuentes bibliográficas utilizadas para su realización han sido debidamente citadas en el mismo.

Para que así conste, firmo la presente en Málaga, el 30 de noviembre de 2020.

Marta Paula Pineda Gil

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Seguimiento GPS de aguiluchos cenizos (*Circus pygargus*) nacidos en cautividad y liberados por el método hacking. El caso de estudio de la población más al sur de Europa

RESUMEN

En este estudio se han analizado datos GPS pertenecientes a seis aguiluchos cenizos (*Circus pygargus*) nacidos en cautividad y criados mediante el método hacking en 2019 y 2020. Estos aguiluchos son rescatados de diferentes puntos de Andalucía y son llevados a las instalaciones de Tahivilla (Cádiz) para restaurar la población local, muy amenazada. Se han representado gráficamente la distribución espacial en las áreas de cría, las áreas de invernada y los movimientos migratorios mediante el uso de SIG. Para comparar los usos del suelo entre individuos, se adjuntan diferentes estimadores de las áreas de distribución. Todos los resultados se han comparado con estudios que analizan los patrones de individuos criados en condiciones naturales. A pesar del tamaño de la muestra, se puede afirmar que el método hacking ha tenido resultados positivos y se podría considerar su uso como una metodología viable para la reintroducción de esta especie en futuros casos de estudio.

Palabras clave: *Circus pygargus*, aguilucho cenizo, datos GPS, reintroducción, áreas de distribución, KDE.

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ABSTRACT

In this study, GPS datasets belonging to six different Montagu's harriers (*Circus pygargus)* born in captivity and bred by the hacking methodology in 2019 and 2020 have been analysed. These harriers have been rescued from different spots of Andalusia and taken to the installations of Tahivilla (Cadiz) in order to restore the local population, highly endangered. Distribution of breeding areas, wintering areas and migration movements have been graphically represented by means of GIS. For comparing land uses between individuals, different home range estimations have been reported. All results are compared with literature about naturally raised individuals. Despite sample size, hacking had positive results and it could be considered a viable method for reintroducing this species in future studies.

Key words: *Circus pygargus*, Montagu's harrier, GPS data, reintroduction, home range, KDE.

1 INTRODUCTION

1.1 Agricultural and steppe environments

We inhabit a changing world, in which human activities are present in many different ecosystems, leading to a substantial modification of natural spaces and fragmentation (Cuervo and Møller, 2020). This means that many living organisms have adapted their habits to coexist with humans (Morelli *et al*., 2018). This is the case of agricultural landscapes, which are home of many insects, mammals, reptiles and birds and covered 25% of the European land by 2012, not accounting for Russia (European Environment Agency, 2017). However, surface area dedicated to agriculture is decreasing while intensification is rising (European Environment Agency, 2017), driving the biodiversity relying on these environments under risk.

In Europe farmland bird populations have been decreasing during the last decades severely for this cause, in contrast to other bird populations such as forest ones, which are generally increasing their populations as some studies report (Donald *et al*., 2001; Donald *et al*., 2006; Gregory *et al*., 2019; Reif and Vermouzek 2019). Some of the main causes are mechanization, changes to crop varieties that are sown and harvested at different times of the year, the increase of monocultures, greater input of agrochemicals, a higher stock pressure and depletion of non-cultivated areas, between others (Stoate *et al*., 2001; Newton, 2004).

In this context, Spain is the country of Europe that has the largest impact on the conservation status of many European farmland birds. This is mainly due to two reasons: first, because of the large surface of cultivated areas it has, and second, because it hosts important populations of breeding birds and many birds breeding across Europe overwinter in this region (Butler *et al*., 2010). Therefore, any change on the land use or in the management measures applied to the agricultural landscapes of this country may have large impacts, positive as well as detrimental, in the availability of food and breeding resources for many bird species during the whole year. The total surface of land that Spain currently exploits actively for agricultural purposes is slightly higher than 23 million hectares (INE, 2018), which is almost half of the total surface of the country.

1.2 The Montagu's harrier

Harriers (Accipitridae: *Circus*) are diurnal birds which possess genetical but also behavioural characteristics that differentiate them from other raptors. In general, harriers are characterised for having long wings and tail and elongated tarsus (see **Figure 1** as an example). Regarding their mating behaviour, some species are frequently polygynous, which is a trait absent in other genus of raptors (Simmons, 2000). This probably resulted in the pronounced plumage differences between males and females, which is another differential trait (Simmons, 2000). Other singularities are their ground-nesting behaviour (Simmons, 2000), although this habit is shared with some nocturnal raptors, and the practice of aerial food pass, in which a male transfers a hunted prey to its partner while both are flying. During the breeding season, both adults provide prey to their offspring (Watson, 1977; Palmer, 1988). Lastly, they have an enhanced auditory system (Rice, 1982) and adaptations for foraging (Simmons, 2000), characteristics shared again with nocturnal owls. All these distinctive attributes indicate an adaptation to open environments —wetlands for marsh harriers and grasslands for steppe harriers (Thiollay, 1994)— not inhabited by any other raptor (Simmons, 2000).

Figure 1. Montagu's harrier (male). *Photographed by Juan Luis Muñoz. Source: Diputación de Málaga.*

One of the species especially suffering from the intensification of agriculture in our country is the Montagu's harrier (*Circus pygargus*, Linnaeus 1758), a migratory raptor that has a patchy Palearctic distribution (Trierweiler and Koks, 2009). This species breeds, during spring, from North Africa and West and Central Europe across to Russia and Central Asia, and spends the winter in the grasslands of sub-Saharan Africa and southern Asia (del Hoyo *et al*., 1994; **Figure 2**). The 25% of the European population, not including Russian data, breeds in Spain (Arroyo and García, 2007), where it is present from mid-March and early-April (Arroyo and García, 2004). In mid-August and early September, most individuals have left the breeding areas and are on migration (Finlayson, 1992). It is a ground-nesting species that traditionally inhabits open landscapes with dense herbaceous plant communities, including lowland heath, rough grasslands and steppes (Purroy, 1997). However, due to the decreasing surface of grasslands and reedbeds this species has adapted to cereal crops, mainly wheat, barley and rye, for both foraging and breeding, becoming highly dependent on these landscapes (del Hoyo *et al*., 1994). In Spain, cereal crops are its preferred habitat (Ferrero, 1995).

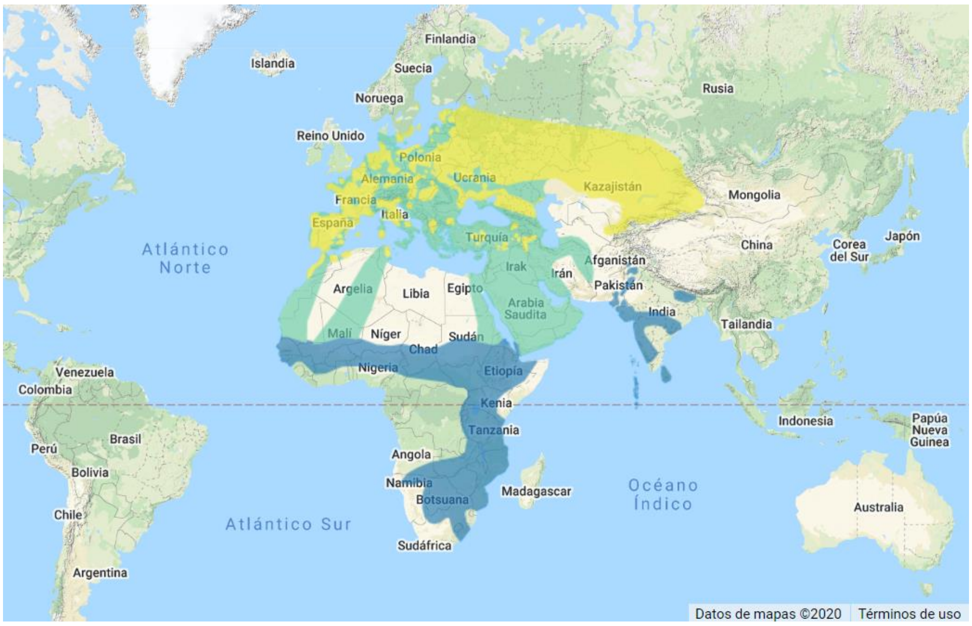


Figure 2. Worldwide distribution map of Montagu's harrier (Circus pygargus). *Source: BirdLife International. Yellow colour represents breeding areas, green stands for areas in which species can be sighted during migration periods, and dark blue corresponds to wintering areas.*

This species plays a significant role in these environments. Because of its feeding regime it contributes to structure biological communities, but also decreases the potential threat that some species could pose to the crops, the farmers and the public health (Singleton *et al*., 2010; Devi 2020). As a raptor, it may also act as an important indicator of environmental changes, such as variations in the levels of their prey populations and pollutants, as well as illegal poaching activities (García-Fernández *et al*., 2008; Helander *et al*., 2008, Molina-López *et al*., 2011).

The mechanization of the harvest is the main conditioning factor for the species survival. In Western Europe, around 60% of nestlings are still unfledged at harvest time. This makes them highly vulnerable to mechanical harvesting, existing an important risk of death when no nest protection measures are taken (del Hoyo *et al*., 1994; Arroyo *et al*., 2002). In the wintering areas, the main threats it has to face are locust control (Leroux and Bretagnolle, unpublished data), droughts in the Sahel (Ferguson-Lees and Christie, 2001) and habitat degradation in different degrees such as wood exploitation, overgrazing and wildfires (Thiollay, 2006). Other causes of its decline are intensification of traditional agriculture (Ferguson-Lees and Christie, 2001), establishment of monocropping (Arroyo and García, 2004) and decreases of its main food sources, affected by these intensification processes (del Hoyo *et al*., 1994, Ferguson-Lees and Christie, 2001). Although more detailed research is needed, it does not seem that wind farms generate unfavourable conditions for nesting (Hernández-Pliego *et al*., 2015).

The European population of Montagu's harrier is estimated to range from 109,000 to 184,000 mature individuals, although data quality within a global context is poor, especially in Eastern Europe. This species is considered under the category “least concern” by the European Red List of Birds (BirdLife International, 2020). For the 27 countries belonging to the European Union, the population is estimated to be decreasing at a rate of <25% in 23.7 years or three generations, not being the decline fast enough (>30% decline over ten years or three generations) to reach the thresholds for “vulnerable”. At a continental scale, its trend is unknown (BirdLife International, 2015).

This species is listed in Annex I of the European Directive 2009/147/EC regarding conservation of wild birds (European Parliament and Council, 2009). As stated in Article 4, the species included in this annex require special conservation measures which should be proposed by each country. The transposition of this directive into the Spanish legislation resulted in the Royal Decree 139/2011, which approves the List of Wild Species under Special Protection Regime (LESPE for its acronym in Spanish) and the Spanish Catalogue of Endangered Species (Ministerio de Medio Ambiente y Medio Rural y Marino, 2011). Under this normative frame, Montagu's harrier is listed as requiring special protection, but it is also catalogued as “vulnerable” at a state level (meaning that measures for its conservation urge), and might have a higher protection status in some regions of the country.

1.3 Bird tracking systems

In order to assess the status of a population and apply the appropriate conservation measurements, monitoring data is required (EURING, 2007). Tracking systems can help with this purpose by providing individual and detailed information about the movement ecology of the tagged individuals. Regarding birds, ringing is an old practice that has been widely used over many years (Newton, 2014) since the first bird was ringed in 1899 by Hans Mortensen in Denmark (Preuss, 2001). Originally meant to study bird movements (López-López, 2016), it has provided large quantities of data that have been useful in many aspects of bird ecology (EURING, 2007). Even though this has led to great advances in bird studies, the retrieval rate of ringed birds is usually quite low, especially for small birds (Newton, 2014). Although the use of wing tags was never as widespread, they were preferred especially for aquatic birds such as ducks (Green *et al*., 2004).

After ringing, another widely used method developed in the late 1950s was conventional ground tracking, which consisted in the emission of very high frequency (VHF) radio signals. These, however, could only be gathered within a short distance from the radio transmitter, and mostly in big animals (LeMunyan*et al*., 1959).

In the 1980s, the first satellite transmitters appeared and with them, receivers that calculated positions at the ground by trilateration (Fuller *et al*., 1984). These satellites tracking devices were mainly based on the GPS navigation system. The main advantages of using a GPS receiver were that the whole track of a movement was recorded precisely and it was not necessary to collect the signal within a short distance anymore, since the data was transmitted to a ground receiving station (Börger, 2016). Still, the first models did not have much storage and battery capacity (López-López, 2016).

A few years later, light level geolocators appeared. These estimated the position of the animal based on the hours of light registered by the device, which was associated with a latitude, and the solar noon, which was bounded to a longitude (Wilson, 1992). They were lightweight, so ideal for small birds (Stutchbury *et al*., 2009), but they had to be retrieved in order to download all the registered data.

It was not until the 2000s when data loggers were developed. These devices registered the location based on the GPS system and stored data in an on-board memory (López-López, 2016).In recent years, they have started incorporating other sensors that determine environmental and biological variables, such as temperature, pressure or heart rate (Tomkiewicz *et al*., 2010). Nowadays, these devices record several thousand locations daily, they can transmit the registered data via satellite or phone networks, and it is possible to adapt their working cycle on demand. These advances have enabled researchers to monitor animals almost in real time (López-López, 2016). The current challenge is to reduce costs, so that large numbers of animals can be marked and monitored.

1.4 Objectives of the research

- To reveal whether rescued individuals of Montagu's harrier bred in captivity are able to survive once they are reintroduced back to their habitat.

- To find out whether reintroduced Montagu's harriers behave similarly as harriers bred in natural conditions would do, regarding migration patterns and use of space in breeding and wintering grounds.

- To assess whether the hacking methodology is an effective technique for restoring a population of this raptor species.

2 MATERIAL AND METHODS

2.1 Study area

Due to the abundance of agricultural areas, Spain is a country of great importance for this species. The most significant populations are found in Castile-Leon, Extremadura, Castile-La Mancha and Andalusia (Arroyo et al., 2019), representing 86% of the total population of the country.

Andalusia holds the second biggest population, consisting in around 1000 couples (15% of Spanish population) by the census of 2017 (Arroyo *et al*., 2019). Within this region, all provinces but Almeria have a population of more than 100 pairs. The province of Seville has the bigger number of mates: between 258 and 275 (26% of the Andalusian population). On the other hand, Almeria only holds two couples. In comparison with census of 2006, severe decreases in the number of couples were detected in the provinces of Cordoba (-46%) and Cadiz (-45%). In the case of Cadiz, this decline is more critical as its total population is smaller (between 105 and 108 mates by 2017; Arroyo *et al*., 2019). Within Cadiz, the reduction in the population of Montagu’s harrier is especially dramatic in the area of Tahivilla, in which the number of nests identified diminished 93% by 2019 —with only two nests found— compared with data of 2008 (Tumbabuey, 2020).

Tahivilla is a small village located in the municipality of Tarifa, in the province of Cadiz (**Figure 3**). On the east side it borders with the Alcornocales Natural Park, and 15 kilometers north-west, the Janda lake is found. The Strait of Gibraltar is located about 15 kilometers to the south. Tahivilla hosts the southernmost European population of Montagu's harrier.

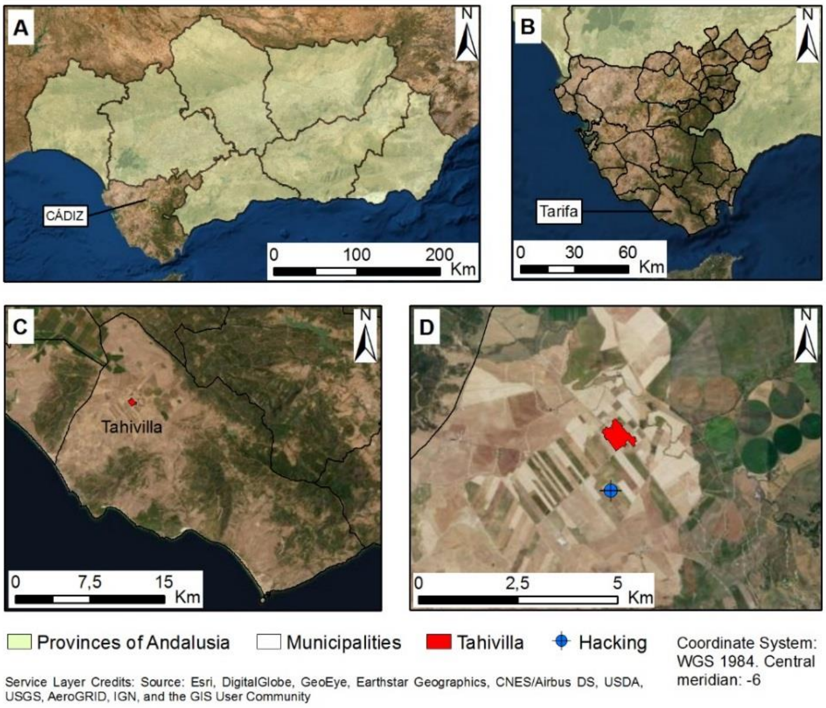


Figure 3. Study area and location of the hacking installations. *Data source: IGN and DERA. A: location of Cadiz within Andalusia; B: location of Tarifa within Cadiz; C: location of Tahivilla within Tarifa; D: representation of the area of Tahivilla and location of the hacking installations in which harriers are raised.*

Figure 4 shows the populations established nearby, and the predominant land uses. Tahivilla is the bigger population of the area, with a size of 429 inhabitants (INE, 2019). The most predominant land use is non-irrigated arable lands. These are mainly hay and cereals to a lesser extent. Other open landscapes found nearby are natural grasslands and pastures.

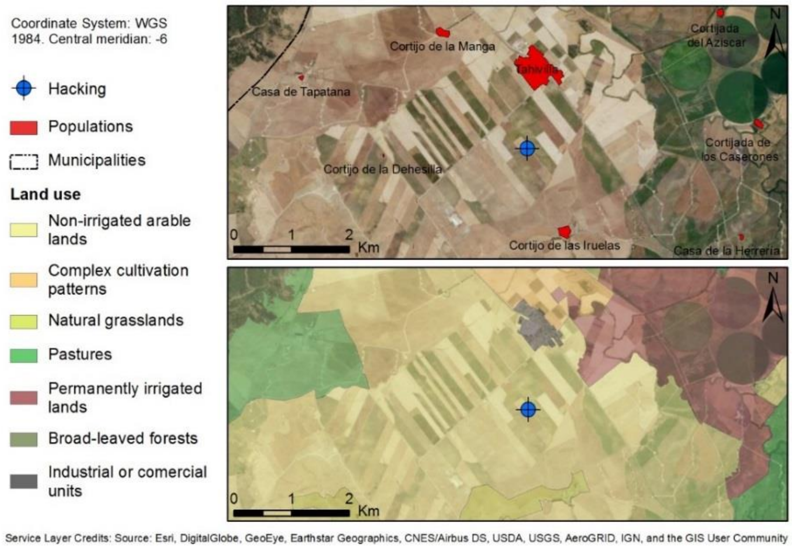


Figure 4. Populations and land uses of the study area based on the Corine Land Cover classification. *Data source: DERA.*

2.2 **Study species**

The Montagu's Harrier (*Circus pygargus,* Linnaeus 1758) is one of the three species of harriers that can be found in Spain (de Juana and Varela, 2005) It is a middle size raptor, between 43-47 centimetres long and between 105-120 centimetres of wingspan (Morillo, 1984). It is the smallest harrier —345 grams (Simmons, 2000)— with long, narrow, pointed wings, and very long tail and tarsus. In this species males and females are sexually dimorphic in plumage and size (Morillo, 1984). As shown in **Figure 5**, the female is bigger, with dark brown back side, white rump, and pale yellow-brown underparts. The male is grey, with black wing tips and characteristic black bands across the secondaries, which allow to differentiate this harrier from other ones. In both females and males the tail has dark brown stripes, which are more evident in the female. Their belly and underneath coverts are lighter with brown stripes. In the female this pattern may extend to the breast. Melanistic individuals can be found, which are darker than their regular variant (very dark brown in females and dark grey to almost black in males). The juvenile looks similar to the female, but its belly and underneath coverts are plain and coloured in reddish brown (Morillo, 1984).

Figure 5. Different individuals of Montagu's harrier. *Author: Olegario del Junco. 1: female adult, which in average as a chocolate-brown color; 2: male adult, with grayish coloration; 3: melanic male adult, in a very dark gray; 4: juvenile individual, similar to adult female, but with a paler coloration.*

It feeds on a wide variety of prey, but it specialises on the most abundant ones at a local scale (Arroyo, 1997). Small mammals are an important part of the diet in the places where they act as a plague. Otherwise, small birds (Sánchez and Calvo 1998), insects (Hiraldo *et al*., 1975, Corbacho *et al*., 1995, Franco *et al*., 1998) and hare and rabbits (Castaño, 1995; Arroyo, 1997) are the main element of its diet, depending on their abundance in the different populations of Spain. In their wintering areas in West Africa, survival is highly tied to the abundance of locusts (*Locusta migratoria*), being the populations negatively affected in the years in which there is a lower density (Leroux and Bretagnolle, unpublished data).

Regarding maturation time, females are able to produce offspring after one year of life, and males after two years (Arroyo, 2002). However, females usually have their first lying in their second year and males in the third year of life (Arroyo, 2002; Leroux and Bretagnolle, unpublished data). This species nests in colonies (Krogulec and Leroux, 1994; Arroyo, 1995). The female incubates the eggs for a month, and the chicks make their first flyings 32 days after hatching. Three weeks later, the fledglings become independent (Arroyo, 2002).

Due to the low philopatry of the species —less than 5% of individuals breed within 10 kilometers from their born site (Limiñana *et al*., 2011)—, estimation of survival rates is particularly difficult (Arroyo, 2002). Survival rates of adults in some French populations varied between 57% and 75% in 14 years of data (Millon and Bretagnolle, 2008). For juveniles, survival is around 35%-65%, as a study with data from 6 to 12 years of French and Spanish populations revealed (Arroyo *et al*., 2002).

2.3 GPS devices

Two GPS transmitters were used to track the different harriers. The first model that was tried is the OrniTrack-10, developed by Ornitela (**Figure 6**). It is a solar powered tracker, with a backpack design that only weighs 10.5 grams. It's extreme-weather proof and can register and share positions via GMS (2G), GPRS (2,5G) or 3G network in selectable intervals. The other transmitter that was tried is the Lego-Small, developed by INTERREX-RINGS (**Figure 7**). It has similar characteristics that the OrniTrack-10, but only weights 9 grams and has the ability of storing data in its internal memory up to 24 months.

Figure 6. GPS transmitter OrniTrack-10, used for tracking Sacapuntas, Compás and Botellín. *Source: Tumbabuey ringing group*

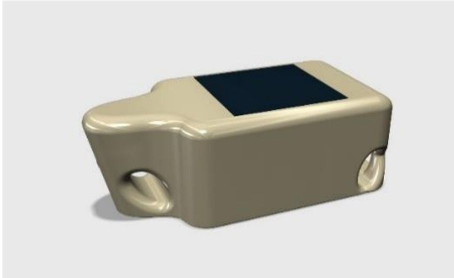


Figure 7. GPS transmitter Lego-small transmitter, used for tracking Jaramago, Tahivilla and Tahivilla JR. *Source: colour-rings.eu.*

The selected frequency for logging positions under normal circumstances was 10 minutes. During night (from 20:40 to 06:30 UTC time) the frequency was reduced, and a position was stored every 90 minutes. In case the battery was under 50%, the interval was 100 minutes. Geo-fences in which data is collected differently were defined as well. In this case, when crossing the Strait of Gibraltar, positions were stored every 1 second. With every GPS position, other information is stored such as UTC date and time, altitude, speed and instant acceleration in the three axes.

2.4 Management of tagged birds and release method

Nestlings of Montagu's harrier rescued in different places of Andalusia are taken to the conservation centre in Tahivilla, where they are reared and reintroduced back to nature. Usually, they come from areas in which harvesting takes place before they are completely developed. In case eggs haven't hatched by harvest time, they are hatched in captivity and then taken to these installations. In Tahivilla, they follow the hacking methodology (Sherrod *et al*., 1982), which consists in raising the chicks inside hacking boxes by providing them food as their parents would do in natural conditions, avoiding any human direct contact (**Figure 8**). At the end of their development they are set free, but food is still provided in the hacking area.

Figure 8. Hacking boxes used to breed Montagu's harrier individuals rescued in Tahivilla*.* *Source: Tumbabuey ringing group*

This is the first time GPS transmitters are attached to birds raised by the hacking methodology and released to their natural habitat. The devices were attached to the birds with the help of a falconry hood (**Figure 9)**. This was done several days before liberation in order to make sure the devices were working correclty and they were properly fastened. In spring of 2019, a GPS transmitter was put to two of the liberated harriers. The same was done in the spring of 2020. Since each year one of the tagged harriers died close to the hacking area, the GPS were retrieved and attached to the next harrier that was set free. Thus, data belonging to six different harriers are being analysed in this work. In **Table 1**, basic information of the six tagged harriers is summarised.

Figure 9. Female of Montagu's harrier being tagged with the OrniTrack-10 transmitter. *Source: Tumbabuey ringing group*

Table 1. Basic information of the six harriers tagged in the springs of 2019 (grey) and 2020 (green)

Harrier ID	**Gender**	**Weight**	**GPS model**	**Notes**
Sacapuntas	Female	350 grams	OrniTrack-10	
Compás	Male	280 grams	OrniTrack-10	Died
Botellín	Male	270 grams	OrniTrack-10	Same transmitter as Compás
Jaramago	Female	330 grams	OrniTrack-10	
Tahivilla	Male	285 grams	Lego-Small	Died
Tahivilla JR	Male	265 grams	Lego-Small	Same transmitter as Tahivilla

2.5 Processing of spatial data

For the maps and graphs included in the result section, different softwares were used. The handling and display of the spatial data as well as graphics were done with ArcMap 10.2.2 (ESRI, 2014). Isopleths of all heatmaps and line representation of the datasets were made with the Geospatial Modelling Environment software (Beyer, 2012). This works as an extension of ArcGIS providing extra tools. The used GME version was 0.7.3, built together with R version 3.5.3 (R Core Team, 2019).

Before working with the spatial locations registered by the GPS devices, verifications of the quality of the data itself were made. In case part of the recorded information were false location as (0,0) (due to inability of the device to locate satellites) or information likely recorded by humans (i.e. data recorded in an urban area or on a road), these were cleared from the dataset after making sure they were misleading.

For the analyses of the spatial data, different projected coordinate systems have been used for distance and for area calculations. Because of the longitudinal extension of some of the datasets, coordinate systems that did not cause distortion have been chosen. All data that was going to be used for calculating distances has been projected in Cassini (world or ellipsoid based, WKID: 54028) and data that was meant for area calculations has been projected in WGS 1984 (WKID: 32629 for the specific UTM Zone 29N). Both projections can be equally used in Europe and in Africa. In all cases, the central meridian was adjusted, so the distortion at the dataset edges was minimised. For analyses of summer movements, central meridian -6 was chosen. For analyses of winter movements, each dataset was assigned the central meridian which adjusted better (-5.5 for Sacapuntas and -13.5 for Botellín).

Regarding treatment of the temporal information, the basic unit of analysis was a civil day, defined as a 24-hour period from midnight to midnight. All datasets were analysed entirely. For Sacapuntas, which is still alive and emitting spatial information, only one-year cycle (366 days) was considered, starting from the day of its liberation from the hacking installations.

For estimating use of space in the breeding and wintering grounds separately, Minimum Convex Polygons (MCP) and Kernel Density Estimations (KDE) were calculated for each harrier and for each specific season (defined for each harrier by its non-migratory movements). These are the most widely used methodologies for estimating home ranges in movement ecology studies (Laver and Kelly, 2008). The MCP (Harris *et al*., 1990) is the smallest polygon with a convex shape that contains all registered locations in the studied dataset, and it is formed by joining the outer most locations. KDE is a non-parametric method of estimating the Probability Density Function of any continuous variable (Rosenblatt, 1956), in this case the distribution of an animal. From some input data, it extrapolates a complete distribution range. By calculating specific volume contours of the KDE, as 50% and 90%, one can obtain the boundary lines containing the exact volumes in which those percentages of the distribution range are estimated to be found (Beyer, 2012). The 50% contour or isopleth has been traditionally recognised as the core area of activity of the animal and the 95% contour or isopleth as the home range (e.g. López-López *et al.*, 2014; Rühmann *et al*., 2019). However, Börger *et al*. (2008) suggested avoiding the use of the 95% isopleth, demonstrating the 90% isopleth gave considerably less biased results even at low sample sizes. For this reason, in this work the 90% contour has been used as representation of the home range.

For obtaining the MCP, the ArcGIS tool “Minimum Bounding Geometry” was used selecting the option “convex hull”. In order to estimate the home ranges several steps were carried out. First, ArcGIS function “Kernel Density” was used. This applies an adaptive kernel in which the search radius or bandwidth is calculated by the software following the h_{ref} method and the basis of the quartic distribution described by Silvermans (1986). After that, the “isopleth” tool form GME was run specifying 0’90 and 0’50 as quantiles. This resulted in two boundaries representing the areas in which 90% and 50% of the distribution during each complete season was expected to be found. These results were represented in two-dimensional maps.

For determining transitions between non-migratory and migratory movements, several criteria were applied. These are a combination of spatial threshold (S) and absolute displacement (AD) methods. The S method implies crossing a latitude or boundary to define the start or end of migration (Monti et al., 2018). The AD method assumes a distance threshold to determine the different periods. The day the bird reaches this travelling distance determines the start or end of migration (Burnside et al., 2017). These methodologies can be combined, as Rotics et al. did (2016).

In this case, autumn or postnuptial migration started when birds began to cross the Strait of Gibraltar. This included any trial of crossing, even if they returned back to Cadiz because of wind conditions. In the same way, spring or prenuptial migration finished when birds crossed the Strait of Gibraltar and arrived to Spanish lands. The end of postnuptial migration was set on the first day of three consecutive days in which the daily travelled distance was below 125 kilometers and registered movements were mainly intended for foraging and not for displacement, as long as this occurs after having crossed the Sahara desert. On the other hand, the start of prenuptial migration was defined as the first day of three consecutive days in which daily travelled distance was above 125 kilometers, with movements focused at northward displacement.

3 RESULTS

3.1 General results

From the three harriers tagged in the spring of 2019, Compás died several days after its release, Botellín completed its postnuptial migration, but its transmitter stopped sending data on the 8th of April, and Sacapuntas completed its first year cycle and its currently on its second year migration. From the three harriers tagged in the spring of 2020, Jaramago started its migration but died in Morocco, Tahivilla died several days after its release, and Tahivilla JR started migrating, but its transmitter stopped emitting when crossing the Strait of Gibraltar. These events are summarised in **Table 2** for each Montagu's harrier.

Table 2. Releasing dates and current status of each Montagu's harrier.

Harrier ID	Releasing date	Status
Sacapuntas	19 June 2019	Still alive
Compás	26 July 2019	Was found dead on a wire fence on 5 August 2019.
Botellín	10 August 2019	Stopped emitting on 8 April 2020 when it still was in the Sahel.
Jaramago	18 June 2020	Was found dead in Morocco on 21 September 2020. Unknown cause.
Tahivilla	12 June 2020	Was found dead in a well. Last precise locations were sent on 16 June 2020.
Tahivilla JR	25 June 2020	Stopped emitting when crossing the Strait of Gibraltar on 17 August 2020.

Spatial data recorded for each of the six harriers is represented in **Figure 10**. Only three out of the harriers registered locations from Africa, only two of them arrived at wintering grounds, and only one of them completed the spring migration and got back to Spain.

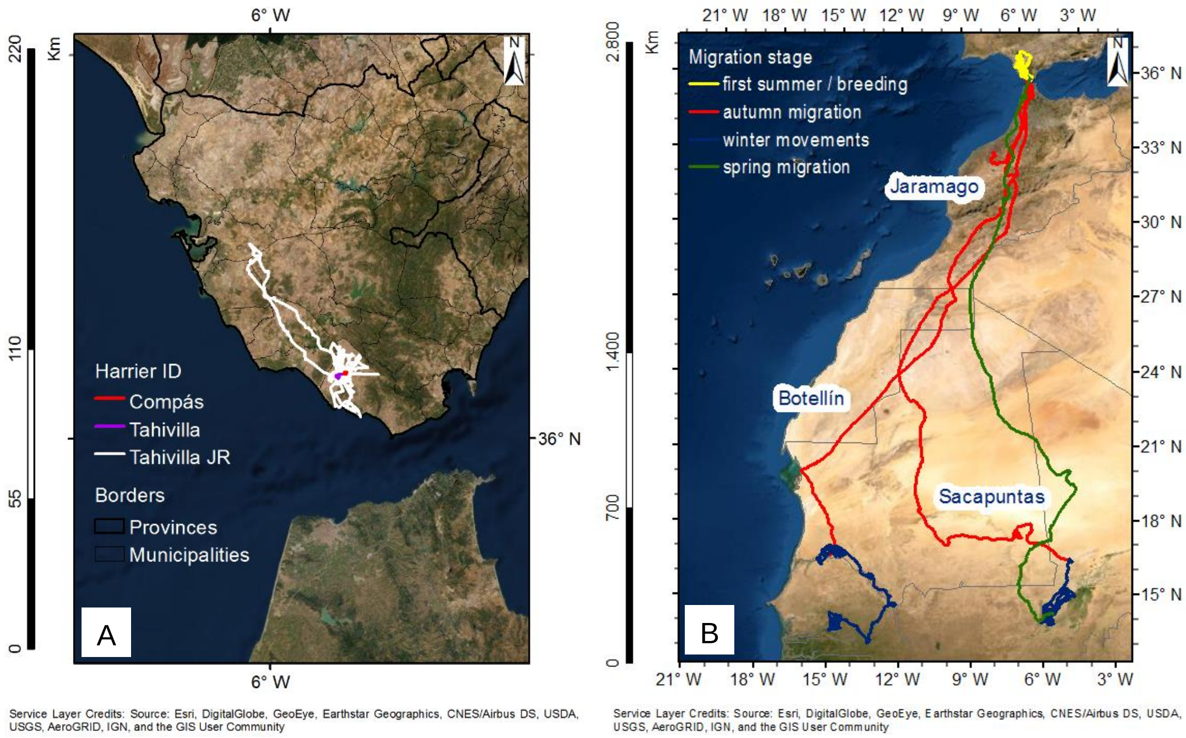


Figure 10. Recorded tracks. A: Movements of harriers which died or stopped emitting before leaving Spain. *Each color represents a harrier.* ***B: Tracks recorded for each of the six harriers.*** *Yellow represents movements in breeding grounds, red stands for postnuptial migration, blue symbolizes movements in wintering areas and green depicts prenuptial migration.*

Figure 11 represents how much time each harrier spent on each migratory stage. Regarding the period after their release (first summer) Sacapuntas spent 62 days exploring the area before migrating, Botellín 32 days, Compás 9 days, Jaramago 60 days, Tahivilla 5 days, and Tahivilla JR 49 days. For migrating, Sacapuntas devoted 12 days (although it first tried to migrate 7 days before it physically crossed the Strait of Gibraltar, which adds up to 19 days), Botellín 9 days, and Jaramago 6 days, before it was found dead in Morocco. In the Sahel, Sacapuntas spent 212 days while Botellín used 202 days, until its transmitter stopped emitting. It took 27 days for Sacapuntas to migrate back to Spain in spring, and it spent the rest of the year cycle, 52 days, close to the hacking area for breeding.

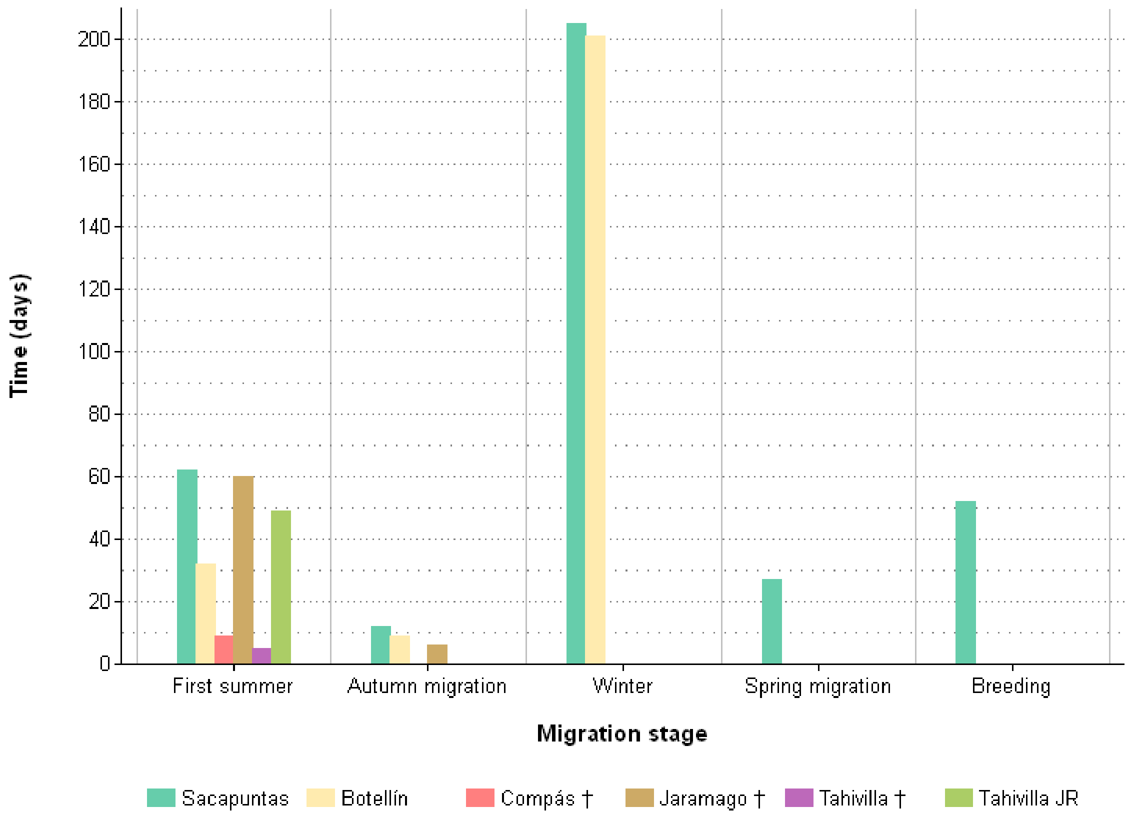


***Figure 11. Time spent in each migratory stage for each of the six harriers**. Colours show the harrier the data belongs to: green for Sacapuntas, light yellow for Botellín, pink for compás, brown for Jaramago, purple for Tahivilla and green for Tahivilla JR. † stands for harriers which passed away.*

In general, Botellín is the harrier that spent less time in the hacking area before migrating and also the harrier which took less time to complete the autumn migration. On the other hand, Sacapuntas and Jaramago are the harriers that spent more time exploring the hacking area before migrating.

Figure 12 shows the total travelled distance in each migratory stage by each harrier. After their liberation, Sacapuntas travelled 1453'63 km, Botellín 494'72 km, Compás 16,44 km, Jaramago 1733'79 km, Tahivilla 26 km and Tahivilla JR 1366'03 km. During postnuptial migration, Sacapuntas flew 3783'89 km, Botellín 2724'3 km and Jaramago 630,69 km. In the Sahel, Sacapuntas moved 7293'34 km while Botellín covered 8227'88 km in total. During prenuptial migration, Sacapuntas flew 3635'27 km and back in Tarifa, it travelled 956'15 km until completing one-year cycle.

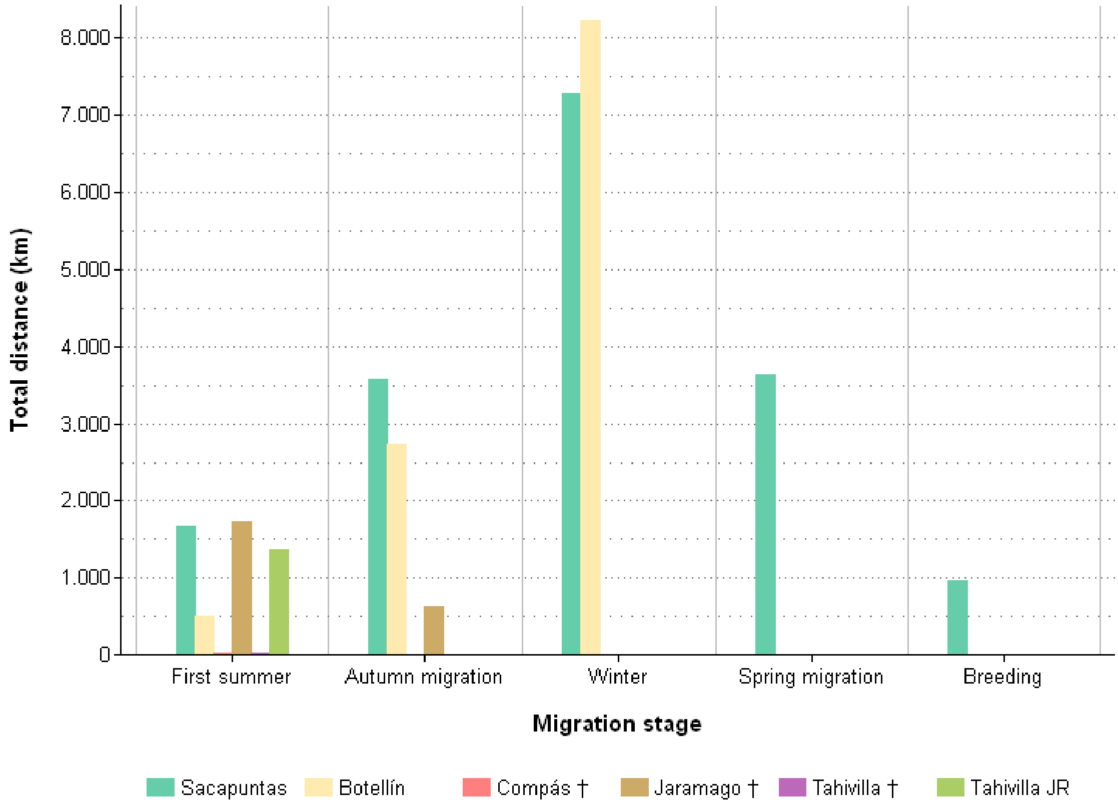


***Figure 12. Travelled distance in each migratory stage for each of the six harriers**. Colours show the harrier the data belongs to: green for Sacapuntas, light yellow for Botellín, pink for compás, brown for Jaramago, purple for Tahivilla and green for Tahivilla JR. † stands for harriers which passed away.*

In this case, Jaramago and Sacapuntas are the harriers that covered most distance after the releasing period. Tahivilla JR travelled several hundred kilometres less at the same stage. Botellín covered a considerably shorter distance. During the autumn migration, Sacapuntas travelled the most, and Jaramago summed the least kilometres. In the Sahel, Botellín travelled around one thousand more kilometres than Sacapuntas did.

3.2 Speed and distance during migration

Figure 13 represents daily distances and average speeds of Sacapuntas during autumn migration. The starting date (20 August 2019) corresponds to the successful crossing of the Strait of Gibraltar. However, the autumn migration for Sacapuntas started on the 13th of August, since it first tried to cross the Strait on this day. Following the criteria stated in the Methods section, the last day of migration in this case is the 31st of August.

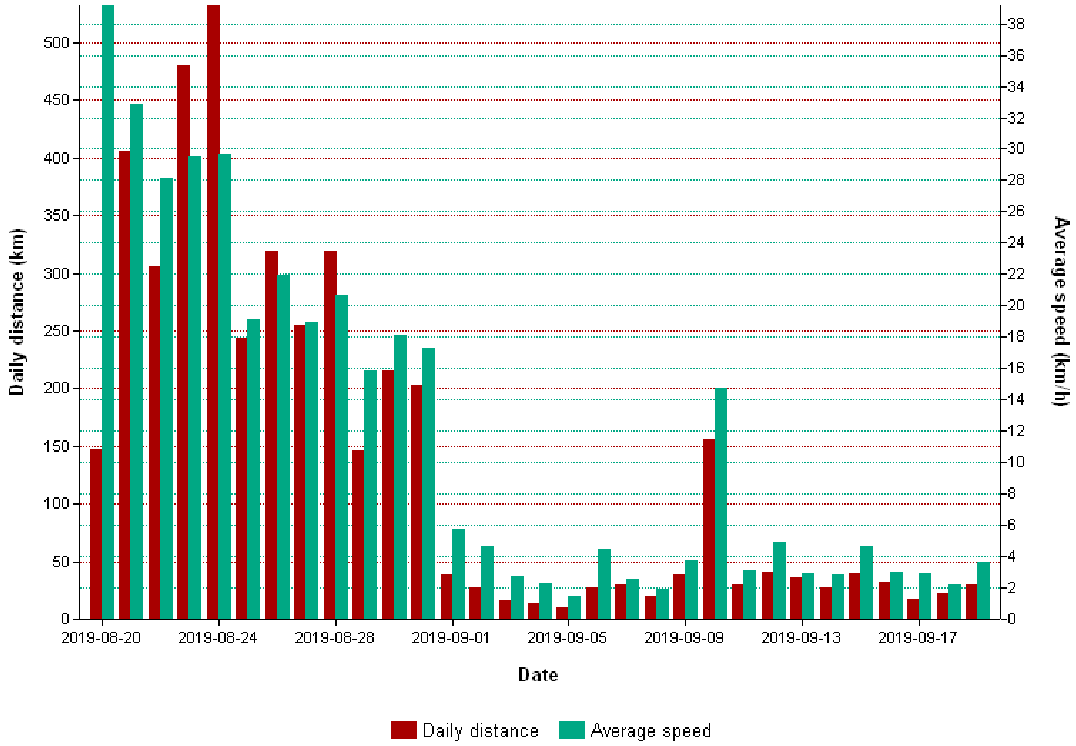


Figure 13. Daily travelled distance (red) and daily average speed (green) of Sacapuntas during autumn migration.

On the 20th of August, the crossing day, it reached the highest speed. This was also the day in which its travelled distance was the lowest. Travelled distances varied from 150 km to almost 550 km during migration. On the 23rd and 24th of August, the days it covered the most distance, it was already flying over the Sahara Desert. From the 1st of September, both daily distance and average speed reduced considerably. The 10th of September, they increased again. This change corresponded to a movement southwards in order to settle in other foraging area. On the following days, the same pattern of lower distances and speeds can be observed.

Figure 14 shows distances and speeds of Botellín during autumn migration. The starting date (11 September 2019) corresponds to the crossing of the Strait of Gibraltar. Following the criteria stated in the Methods section, the last day of migration in this case is the 19th of September.

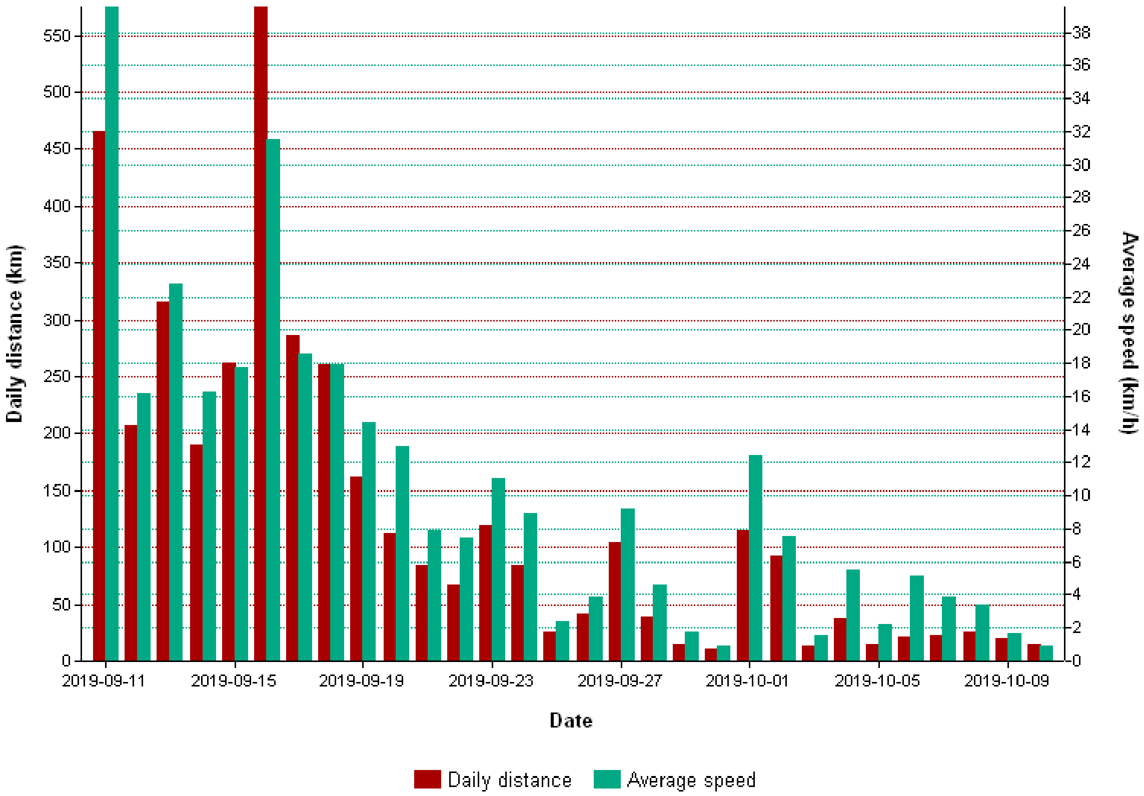


Figure 14. Daily travelled distance (red) and daily average speed (green) of Botellín during autumn migration.

On the first day of migration it also reached the highest speed. Travelled distances varied from 190 km to 575 km during migration and decreased to 160 km in the last day of migration. After this moment, although daily distances and speeds did not decrease as clearly as in the case of Sacapuntas, movements were mostly around a specific area and did not have southwards orientation. This pattern occurred until the 15th of October, when it started moving southwards again in order to switch foraging area.

Figure 15 depicts distances and speeds of Jaramago during autumn migration. The starting date, 17 August 2019, it crossed the Strait of Gibraltar. On the first day of migration it reached the highest and travelled the longest distance (more than 400 km) until stopping in around a hundred kilometres before the Atlas Mountains in Morocco. The following days, the travelled distance reduced considerably to less than 80 daily kilometres. In this period, Jaramago flew over surrounding areas without directing to the south. On 22nd and 23rd of August, registered distances and speeds were minimal. This harrier died in the afternoon of the 22nd and days later its body was found and the GPS device was picked up.

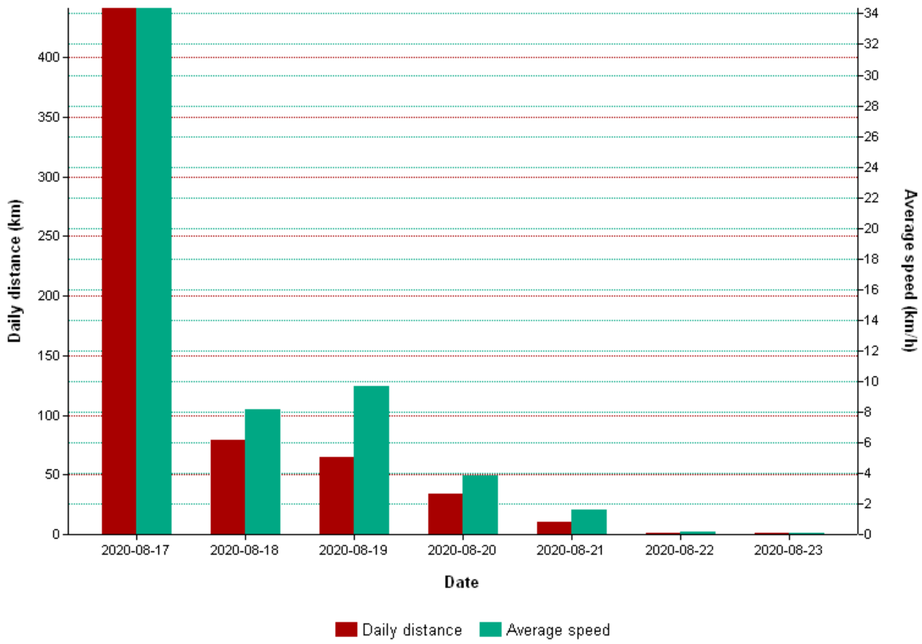


Figure 15. Daily travelled distance (red) and daily average speed (green) of Jaramago during autumn migration.

Figure 16 represents daily distances and average speeds of Sacapuntas during spring migration. The end date (27 April 2020) corresponds to the crossing of the Strait of Gibraltar and arrival to Tarifa. Following the criteria stated in the Methods section, the first day of migration in this case is the 1st of April. Again, the highest speed was reached during the cross of the Strait of Gibraltar. Travelled distances varied from 14 km to 609 km. On the 7th and 8th of April Sacapuntas flew the higher distances (399 and 609 km respectively), corresponding with desert areas. From the 10th of April, both daily distance and average speed reduced considerably while the bird was in the northern side of the Atlas Mountains in Morocco. The movements registered on days 20, 22 and 23 corresponded to northwards displacements until arriving to north Morocco. On the 27th, it finally crossed the Mediterranean Sea.

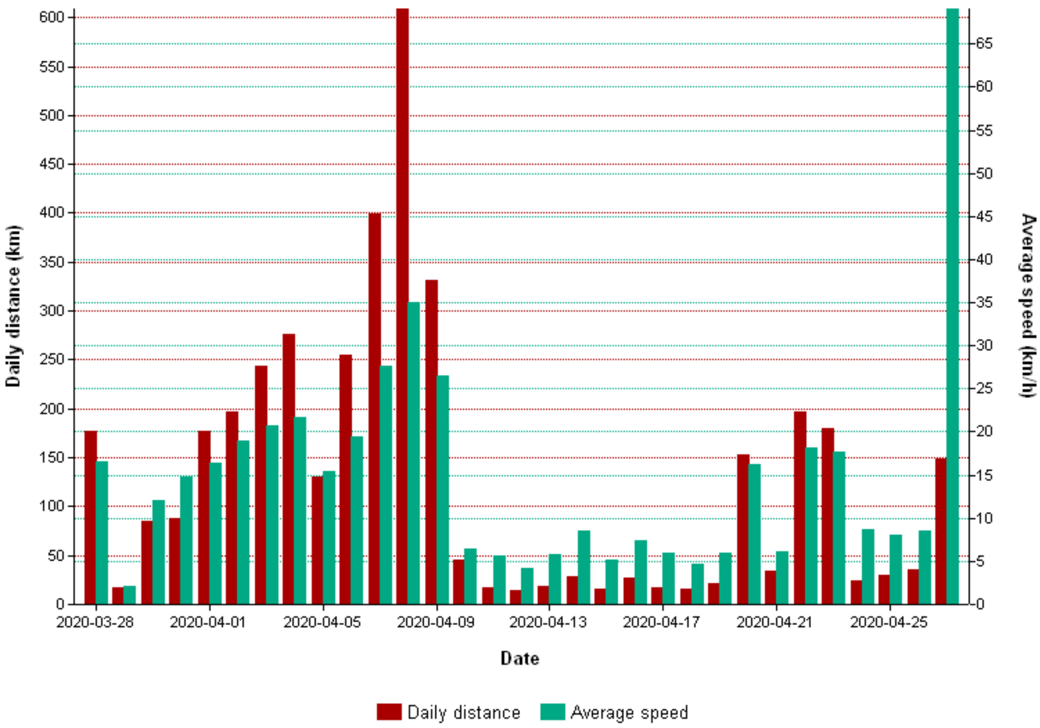


Figure 16 Daily travelled distance (red) and daily average speed (green) of Sacapuntas during spring migration.

3.3 Land use in breeding grounds

Home range estimations were calculated for the breeding period for each harrier following the kernel density approach. Representation of these estimations within the Minimum Convex Polygons are found in **Figure 17**. In most cases, the extension of the MCP is much larger than the actual home range. Sacapuntas and Jaramago are the harriers which explored a bigger area, exceeding the borders of Cadiz province. Only in the cases of Compás and Tahivilla (Figures 17.C and 17.E), which died soon after being liberated, the extension of the MCP and the home range is more similar. The total home ranges (90% KDE) fall mainly in the area of Tahivilla. The core areas of activity (50% KDE) fall within the hacking installations for the three birds tagged in 2019 (Sacapuntas, Botellín and Compás). For the harriers tagged in 2020 (Jaramago, Tahivilla and Tahivilla JR) the core areas fall one-kilometre eastwards from the installations. In both cases, this is related with the spots in which food was being provided to the harriers after liberation. Sacapuntas is the harrier that has a core activity area the furthest form the hacking installations, north from the towns of Bolonia and el Lentiscal.

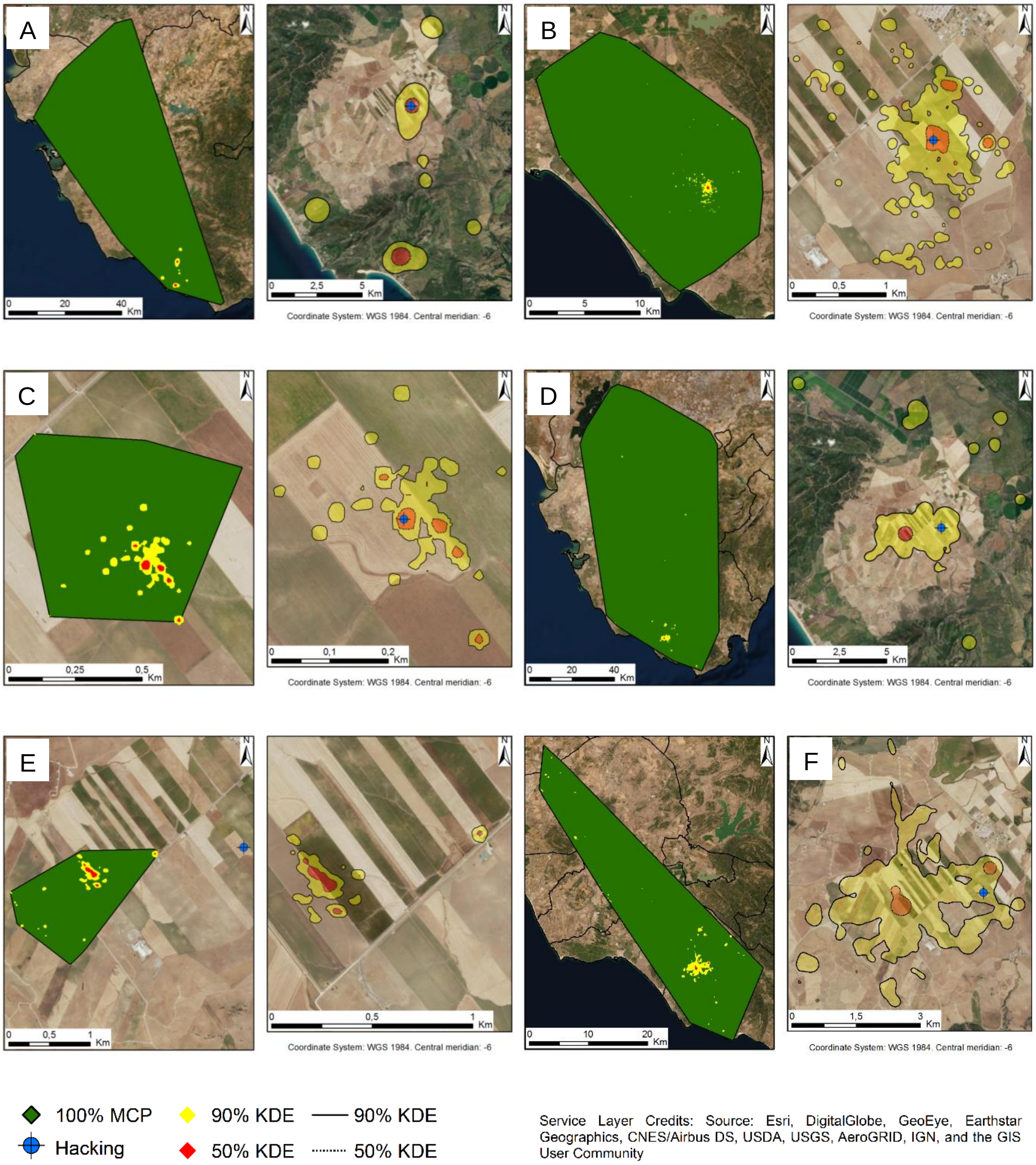


Figure 17. Representation of kernel density contours for each harrier in the breeding area, within the Minimum Convex Polygon. *A: Sacapuntas; B: Botellín; C: Compás; D: Jaramago; E: Tahivilla; F: Tahivilla JR. Green depicts the minimum area that contains 100% of the locations registered by the GPS transmitters. Yellow represents home range areas. Red stands for core areas of activity.*

- Comparison of home ranges

Figure 18 represents the extension of the 50% isopleths in the breeding grounds for each harrier, in square kilometres. The core areas of Sacapuntas had an extension of 1’32 km^2. On the other hand, Botellín only used 0’08 km^2. Jaramago used around 0’46 km^2 and Tahivilla JR around 0’29 km^2. **Figure 19** shows the extension of the home range areas in which harriers spent the summer. In this case, Jaramago used 15’60 km^2, followed by Sacapuntas (11’80 km^2) and Tahivilla JR (10’13 km^2). Again, Botellín devoted much less surface, 1’45 km^2. For both isopleths, Compás and Tahivilla used the least surfaces.

Figure 20 represents the total surface of the Minimum Convex Polygons calculated with the movements of the harriers in the breeding areas. Jaramago used the bigger extension, 6688 km^2. Sacapuntas covered half of this area, 3104 km^2. Tahivilla JR and Botellín explored considerably smaller areas (590 km^2 and 291 km^2 respectively). Compás and Tahivilla did not use more than 1’5 km^2.

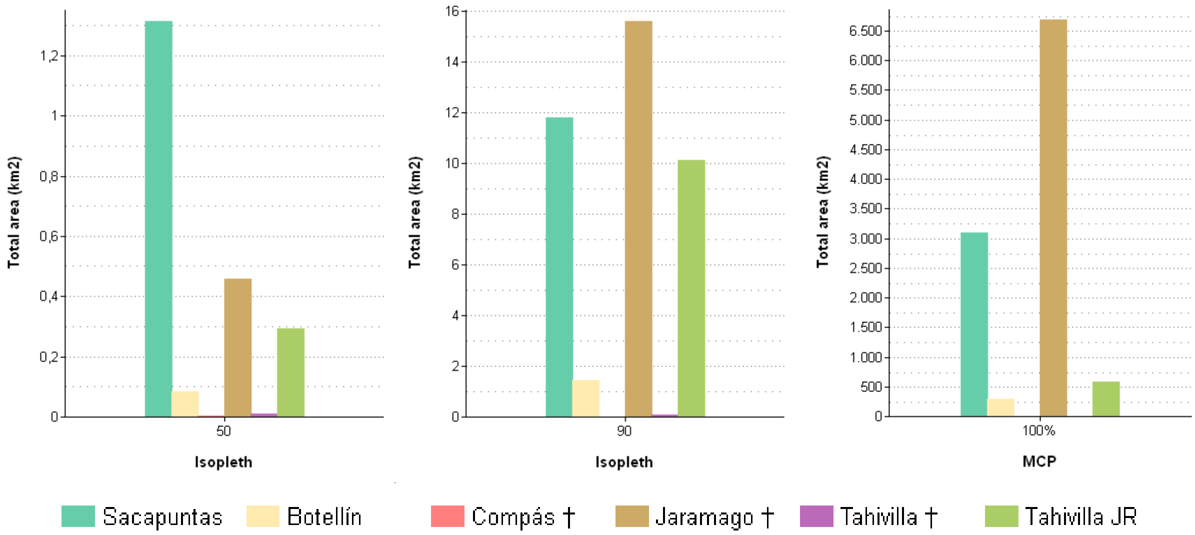


Figure 18. surface of the 50% KDE for each harrier in the breeding areas.

Figure 19. surface of the 90% KDE for each harrier in the breeding areas.

Figure 20. surface of the 100% MCP for each harrier in the breeding areas.

3.4 Land use in wintering grounds

Home range estimations were calculated for the winter period for Sacapuntas and Botellín following the kernel density approach. These estimations are represented within the Minimum Convex Polygons. As **Figure 21** shows, Sacapuntas used four main areas during its first winter and had three core activity areas in the whole period. It spent September in one of these areas, and moved to the second area in October, where it spent part of the month. Later, it flew to the most south area, where it stayed until January. Finally, it explored the last area, where it spent the last two months before starting the spring migration on the 1st of April 2020.

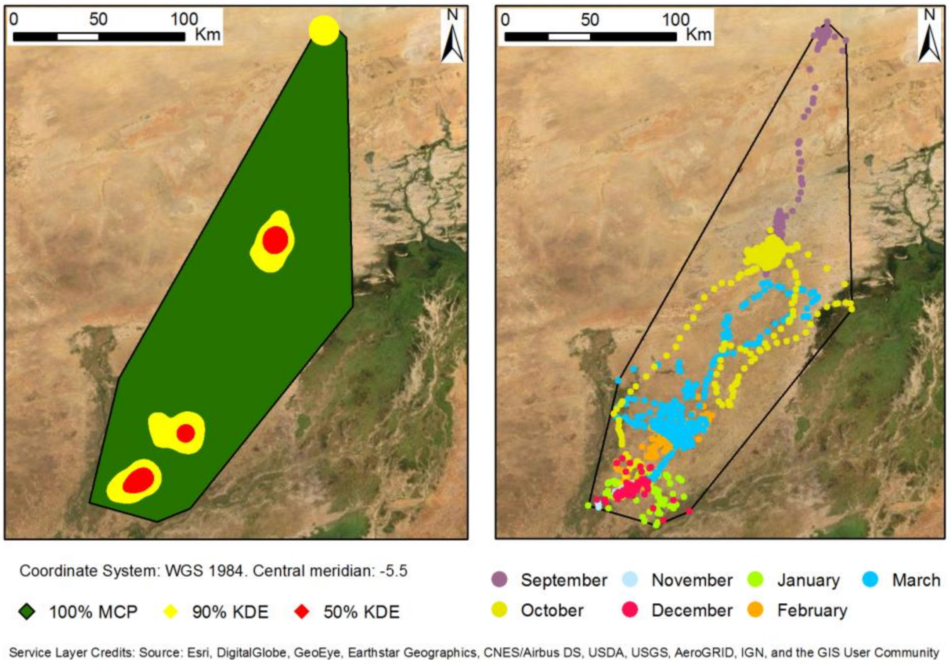


Figure 21. Representation of kernel density contours for Sacapuntas and registered movements in the wintering grounds, within the Minimum Convex Polygon. *Green depicts the minimum area that contains 100% of the locations registered by the GPS transmitters. Yellow represents home range areas. Red stands for core activity areas. Each of the seven months its migration lasted are represented in different colours.*

As **Figure 22** shows, Botellín spent its first winter in multiple areas and only had one core activity area. In general, it did not spend more than one month in the same home area. It spent September and part of October in the most north areas, then moved to the next area and stayed until part of November. At the end of the month, it switched area again. In December, it explored the remaining areas, and finally stayed in the core activity area until its GPS transmitter stopped emitting on the 8th April 2020.

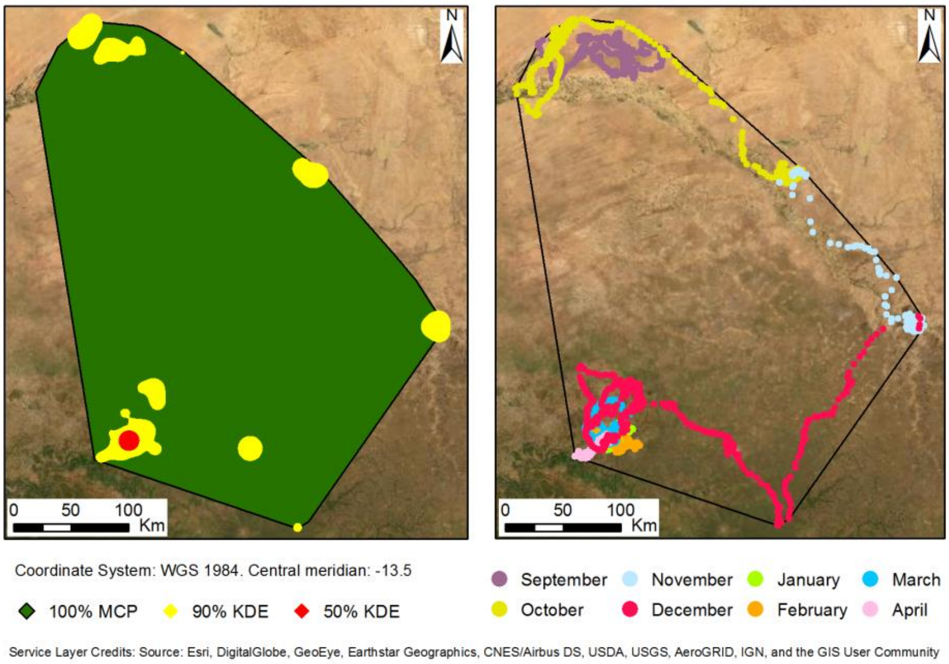


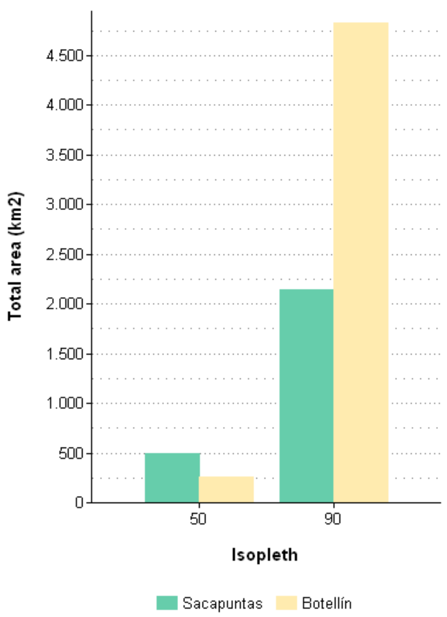
Figure 22. Representation of kernel density contours for Botellín and registered movements in the wintering grounds, within the Minimum Convex Polygon. *Green depicts the minimum area that contains 100% of the locations registered by the GPS transmitters. Yellow represents home range areas. Red stands for core activity areas. Each of the eight months its migration lasted are represented in different colours.*

In general, the movements of Botellín seem to be more dispersive than the displacements of Sacapuntas.

- Comparisons of home ranges

Figure 23 shows the extension of the 50% and 90% isopleths in wintering grounds in the Sahel for Sacapuntas and Botellín. Differences between surfaces of the core areas are smaller than differences between the total home range areas. The core areas of Sacapuntas extend to 493 km^2 while the ones of Botellin only covered 255 km^2. In the case of the total home range, Sacapuntas used 2147 km^2 and Botellín used 4830 km^2.

Figure 24 depicts the extension of the Minimum Convex Polygon for Sacapuntas and Botellín in the Sahel. Botellín explored a much bigger area, 98061 km^2, while Sacapuntas only examined about 1/5 of this extension (21610 km^2).



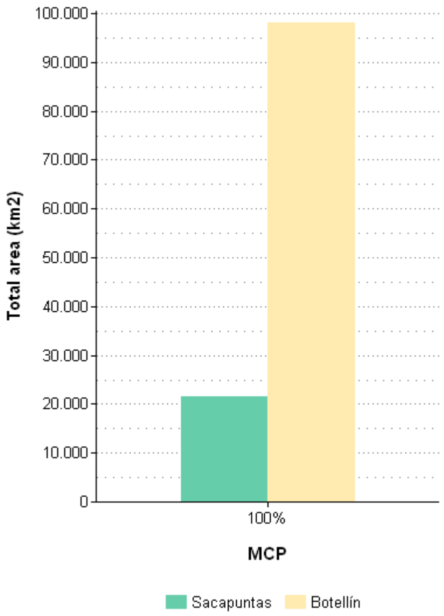


Figure 23. surface of the 50% and 90% KDE for each harrier in the wintering areas.

Figure 24. surface of the 100% MCP for each harrier in the wintering areas.

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4 DISCUSSION

First, studies analysing the behaviour of Montagu's harriers grown in natural conditions are compared with those birds analysed in this study, which have been born and bred in captivity, and later released to the natural environment. Then, the comparability of results obtained in different home range studies is assessed. Finally, the hacking methodology as a reintroduction methodology for raptors is evaluated.

4.1 Sacapuntas one-year cycle

Schlaich *et al*. (2017) studied annual migration cycles of 29 Montagu's harriers from France, the Netherlands and Denmark. The complete one-year cycle for the studied population ranged from between 35653 and 88049 km/year. The total distance for Sacapuntas is substantially less: 17122 km/year. The difference is too big in order to be related only to the geographical proximity of Spanish breeding areas to the African wintering areas. Another possible explanation for this difference could be found in the habitat quality and food availability in both breeding areas and wintering areas for the studied season (Schlaich *et al*., 2016; Trierweiler *et al*., 2014). It has already been stated that food was supplied for harriers in the hacking installations during all summer period, until the last harrier started its migration. As a species that forages on the wing (Clarke 1996), covered distances registered in stationary periods are expected to be longer than in species foraging on the ground. Considering that harriers did not have to invest any effort in searching for prey-rich areas nearby the hacking installations, this could have led to reduced total distances in the breeding grounds. The fact that during winter, its foraging area is much smaller than the one of Botellín could mean that Sacapuntas found prey-rich areas, and did not have the need of exploring further areas within the Sahel.

Moreover, part of this difference could be explained by the location storing interval of the GPS, which can also influence distance values (Rowcliffe *et al*., 2012; Dewhirst *et al*., 2016), and by the underestimated real flights product of creating straight lines between locations, which can be prevented by applying a correction factor (Pépin *et al*., 2004; Rowcliffe *et al*., 2012). Schlaich *et al*. (2017) compared their findings with other results obtained by tracks of lower frequency of location and did not corrected for straight lines, and estimated that their values were 28-35% higher when these considerations were taking into account.

4.2 Movements in breeding grounds

Minimum Convex Polygons and Kernel Density Estimations had been previously estimated for this species. In the case of the MCP, it was estimated by radio-tracking data by Guixé and Arroyo (2011) for 14 different adult males in Lleida (Spain), resulting in an extension of 130’2 (SD: ± 110’2) km^2. Krupiński *et al*. (2020) reported the 90% of the MCP with an extension of 90 km^2 for males and 7 km^2 for females, in a sample of 50 adults tagged with GPS loggers in Poland.

Although in both cases they studied movements of adults from their nests during the breeding season, the estimations made for this work for the four surviving harriers were much higher: 6688, 3104, 590 and 291 km^2 respectively, which differ far from their results. In the study from 2011, the data used was based on radio locations, which must be gathered visually and manually, by using an extensive track network. The focused effort in the breeding areas may overlooked any distancing movement to further areas and thus, underestimates the actual distribution of the bird. In the study from 2020, the 90% MCP excluded the most outer locations which corresponded with 10% of the dataset. In this way, biased due to outliers is also avoided. Still, these arguments cannot explain such difference. By resampling the GPS locations at one or several fixes per hour, part of the differences would have been reduced. The obtained 100% MCP cannot be understood as home ranges but can still be applied to detect behavioral differences in the use of space among individuals (Burt, 1943, Laver and Kelly, 2008).

Regarding kernel densities, Guixé and Arroyo (2011) reported 90% home ranges of adult males as 103’2 km^2 and 50% core areas as 16’9 km^2. Krupiński *et al*. (2020) estimated these same contours as 67’3 km^2 and 13 km^2 respectively, in the case of breeding males, and 4’9 km^2 and 0’7 km^2 in the case of breeding females. Other studies have deepened in this aspect as well. In a study from Germany, 95% KDE resulted in 11.5 km^2 for radio tagged males and 6 km^2 for females in the breeding period (Grajetzky and Nehls, 2017). Other study within the Netherlands, following a different approach, obtained home range estimations from 15 to 88 km^2 by analyzing GPS data of 14 breeding Montagu's harriers (Klaassen *et al*., 2019).

Since males are the ones providing the food during the nesting and breeding period, their home ranges are expected to be much bigger than those of females, but also than those of juveniles. The 90% KDEs reported in this study for the summer period varied from 15'60 to 1'45 km^2 for the four surviving harriers. For the 50% KDE, estimations varied from 1'32 to 0'29 km^2. None of the published results focused on juveniles, but it could be expected that, given the conditions of constant food availability in the hacking installations, these harriers would have a small home range, but still, bigger than the one of a breeding female that normally do not fly away from the nest. Given the results of the above-mentioned studies, the results from this work seem to fit this hypothesis, most clearly regarding to the two first studies. Conclusions cannot be drawn without direct comparisons with juvenile data. Moreover, methodologies among these studies are different in several aspects to be robustly comparable. However, estimated home ranges are within the logical behaviour a juvenile of Montagu's harrier with permanent food supply would have.

4.3 Movement in wintering grounds

Schlaich (2019) analysed 129 wintering tracks belonging to 72 Montagu's harriers captured in different countries of Europe. The distribution of these wintering areas can be found in ANNEX 1. Both Sacapuntas and Botellín had a winter distribution within the same spatial range. The previous study reported an average of 3 different geographical sites per migratory track, ranging from 1 to 6. These were defined as places being 10 km apart or more, with no overlaps of track, in which birds spent at least three days. Following these criteria, 4 and 6 sites can be defined for Sacapuntas and Botellín, respectively.

For birds of Central Europe, the mean arrival date at the Sahel was 23 September ± 9 days, varying from 30 of August to 19 October between individuals (Schlaich, 2019). For Sacapuntas, last migration day was the 31st of August and for Botellín, the 19th of September. Mean date of departure from the winter area was 30 March ± 8 days in Schlaich study. In the case of Sacapuntas, spring migration started on 1st of April.

In Schlaich's sample, the wintering period had a length of 188 ± 12 days, ranging from 151 to 213 days, and harriers spent most of the time (3'5 months on average) in their last geographical site. As registered by their transmitters, Sacapuntas spent 212 days in the Sahel while Botellín spent 202 days, until its transmitter stopped working. Regarding the time spent in the last migration site, Sacapuntas stayed from 27^{th} of October to 31^{st} of March and Botellín stayed from 11^{th} of December 2019 to 8th of April, which means 156 and 119 days, respectively.

All temporal parameters analysed for Sacapuntas and Botellín fall within those reported by Schlaich (2019). Although arrival and departure dates at wintering grounds and duration of the winter period are not reported for south breeding harriers, Scapauntas and Botellín, bred under semi-natural conditions and with no parental contact, presented similar patterns, which may reflect genetically determined migratory behaviours.

In the present work, home range surfaces of the complete winter distribution were calculated as one, even if the winter distribution was patched. These corresponded to 2147 km^2 and 493 km^2 for Sacapuntas and 4830 km^2 and 255 km^2 for Botellín (90% KDE and 50% KDE respectively). Schlaich reported median size of a geographical site individually, as 35 km^2. On the other hand, Trierweiler *et al*. (2013) estimated home ranges of 200 km^2 which are more similar to the results of this report. Still, methodological differences are found within all results. Although values of MCP are not comparable, it can be noted that winter movements of Botellín were five times more spread than those of Scapauntas. This, together with the fact that in overall Botellín had more home range areas, could mean that it was settled in a drier area, with worse environmental conditions, and travelled longer daily distances (36 km/day for Sacapuntas and 41 km/day for Botellín during winter season) in order to ensure enough food supply.

4.4 Autumn and spring migrations

Schlaich *et al*. (2017) studied annual migration cycles of 29 Montagu's harriers from France, the Netherlands and Denmark. During autumn migration, they registered mean daily distances of 296 km/day and in spring migration the value was 252 km/day. Within this work, registered mean daily distances were 297 ± 118 and 302 ± 127 km/day in autumn (Sacapuntas and Botellín respectively), and 132 ± 144 km/day in spring for Sacapuntas. Daily distances of autumn migration fall close within the mean value Schlaich registered. An interesting thing to point out is that Botellín completed migration in only 9 days, while Sacapuntas took 12 days for arriving to the Sahel. Moreover, minimum and maximum distances covered by Botellín in this period were higher than those covered by Sacapuntas. These values reflect different migration strategies: Sacapuntas ended its migration on 31st of August, while Botellín stayed in the breeding area until the 11th of September. It was, indeed, the harrier which started migration latest (Sacapuntas, Jaramago and Tahivilla JR all started their migrations in mid-August). As Sacapuntas was arriving earlier compared with the range reported by Schlaich (2019), it devoted less daily effort to migration itself as conditions in the first wintering sites were still appropriate. It could also be, however, that Sacapuntas was conditioned to fly at slightly reduced speeds by any physiological reason.

4.5 Survival of first year individuals

Daily mortality rates for this species has been stablished based on data of 34 adults tracked with satellite transmitters (Klaassen *et al*., 2014; Trierweiler and Koks, 2009). It is the highest during autumn and spring migration (0.0023 and 0.0052 respectively). During the winter season, it has the lowest value (0.0006). For the breeding period, the value was stated as 0.0012. Based on field data, survival was estimated to vary between 57% and 75% for adults (Millon and Bretagnolle, 2008), and around 35%-65% for juveniles (Arroyo *et al*., 2002).

From this study, two of the harriers died in the breeding period early after their liberation, and one died during autumn migration. From the other three, two stopped emitting information: one when starting to cross the Strait of Gibraltar, and the other at the end of the winter period, maybe when starting its spring migration. Considering these are first year individuals, raised in captivity with no parental contact, there is an even higher possibility that the harriers that stopped emitting have died. However, conclusions cannot be drawn from this, since one of the harriers, Sacapuntas, did not emit any location data for a period of around seven months, and even if the harriers were dead, the GPS transmitter would be probably still working (as happened in the case of Jaramago, which died in Morocco). In order to draw conclusions, it would be necessary to increase our sample size and have data on birds raised in a natural way in our same population.

4.6 Limitations of used methodologies

- Soundness and reliability of home range methodologies

Although MCP is one of the oldest methodologies for estimating home ranges (Harris *et al*., 1990), it has shown high sensitivity to the number of locations being analysed (Harris *et al*., 1990; Seaman *et al*., 1999, Börger *et al*., 2006), the sampling strategy (Börger *et al*., 2006) and the sampling duration (Powell 2000) among others. Thus, several authors have stated MCP is not a robust estimator (Börger *et al*., 2006; Laver and Kelly, 2008), and recommended to avoid its use as a home range estimator. However, it can be still considered as a tool for identifying behavioural differences in the use of space with respect to the use of space in the actual home range (Burt, 1943, Laver and Kelly, 2008).

Regarding KDE, it is considered a much more consistent method. It is less sensitive to spatial resolution variations of data (Hansteen *et al*., 1997), it allows identifying multiple centres of animal activity (Powell, 2000) and has become a widely used method in movement ecology (e.g. López-López *et al.*, 2014; Rühmann *et al*., 2019).

- Comparability among different studies

Minimum Convex Polygon and Kernel Density Estimation have been the most used methodologies for estimating home ranges, mainly for facilitating comparison with previous studies. However, there exist multiple approaches to carry out these analyses and there is not any specific methodology stablished for movement ecology studies. Moreover, used methodologies are not always properly reported so reproducibility of analyses reduces (Laver and Kelly, 2008).

On the other hand, nature of the available data also influences the results. As the frequency for registering locations of the animal increases, so does the accuracy of the MCP and KDE (Seaman et al. 1999), and this can vary considerably in function of the tracking method used for monitoring the animal and the timespan of the data. Finally, there exist differences in the approaches that different softwares use to develop KDE analyses, which at the end prevents unification of methodologies among studies (Lawson and Rodgers 1997).

4.7 The hacking method as a conservation tool for Montagu's harrier

This study reported results of six Montagu's harriers bred and liberated following the hacking methodology (Sherrod *et al*., 1982). The procedure of breeding the birds in the most natural possible way is demanding, and it requires caretakers to respect natural timings of the species and while avoiding any direct human contact. Here, there can be variations depending the needs of the specific species, which makes it difficult to have an unique methodology among studies and to assess which factors may condition the results of the hacking process to a greater extent. Moreover, nestlings are raised without a parental model which offers guidance and protection during the first weeks of life, which may also have great influence in their development (Newton, 1979).

Dzialak, *et al*. (2006) evaluated the methodology of hacking for a raptor species. They tried to infer how could some variables influence the overall success of the hacking program. Among their conclusions, skewing sex by liberating more individuals of the more philopatric gender may not always be beneficial, since other variables, such as release time of the individuals, interact with this decision. Regarding provisioning of food, Dzialak, *et al*. reported that by alternating days in which food was provided, fledglings success increased (0.71 success for birds fed on alternate days and 0.43 for birds fed daily), and recommended a daily feeding for a specific period, as 14 days, and then changing frequency of food provisioning to a less predictable regime which at the end would allow emulating natural weaning, observed in Montagu's harrier adults (Kitowski, 2002). This would result in development of behaviours that fledglings usually acquire in this period.

Although the sample population of this study is small, given the fact that one of the harriers survived the whole year cycle and came back to Tahivilla in an attempt to breed, it can be concluded that hacking is a potential methodology for restoring Montagu's harrier populations. By considering these variables when defining the hacking program and deepening in these recommendations, results of hacking methodology could be improved.

5 CONCLUSIONS

After analysing data of six Montagu's harriers bred and reintroduced by the hacking methodology in Tahivilla the conclusions of this study are the following:

1. Individuals of Montagu's harriers raised artificially, although emulating natural conditions, are able to survive once reintroduced, and Sacapuntas, one of our birds, is a good example of this.

2. Regarding the second research question, some of the analysed variables show behavioural similarities between "our artificially bred harriers" and those naturally bred by their parents, although a larger sample size would be needed to draw more meaningful conclusions. It would be necessary to better discern the effect and influences of methodological differences between home range estimations and data treatment among different studies.

3. Finally, regarding the hacking method as a technique for restoring a Montagu's harrier population, we can confirm that in our case it had preliminary positive results, yet these cannot be fully evaluated within the time span of the analysed data. Although it still has potential for being improved, it could be applicable to other populations and even could be considered a technique to be applied in future reintroduction programs for this threatened species.

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8 ANNEXES

ANNEX 1. Wintering sites belonging to 72 Montagu's harriers tracked between 2005 and 2018. Source: Schlaich, 2019

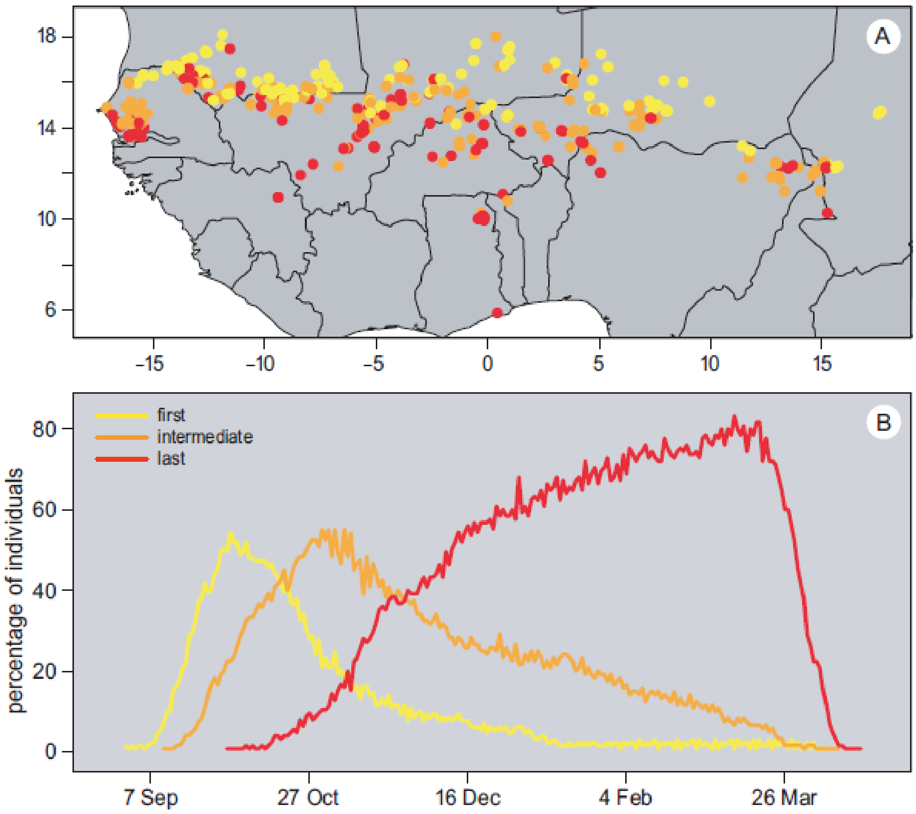

Figure 2.1. (A) Wintering sites of European GPS- and satellite-tracked Montagu's Harriers (n = 129 winters). (B) Percentage of individuals at first, intermediate and last sites during the wintering season.