Behavior and its role on reproductive performance under a life-history perspective

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Agraïments

Gràcies a tots els que heu contribuït d'una manera o altra a la realització d'aquesta tesi.

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Abstract

Behavior allows animals to confront adverse environmental conditions, enabling individuals to anticipate and respond to a wide array of risks. Thus, behavioral decisions are widely-held to enhance fitness under uncertain conditions. Less often recognized is that variation in behavioral responses across organisms is contingent to their life history strategy. For example, it is easy to imagine that the costs and benefits of behaving in a certain way are not the same for species that live a few years than for those that live many years. Life history may also affect behavioral responses by imposing developmental constrains, which may influence body size and limit cognitive capabilities. This thesis explores the behavioral mechanisms used by organisms to maximize their reproductive performance under a life-history perspective. Using birds as the subject of study, this over-arching question is explored from two different perspectives.

First, in **chapter 2**, the behavioral mechanisms leading to breeding site selection are explored. Animals must deal with environmental variability to select an appropriate place to reproduce, mostly through acquiring information form two putative sources: personal and social. However, the reasons favoring the different use of such information sources remain largely unexplored. This question is addressed by monitoring breeding habitat selection in the Eurasian Jackdaw (*Corvus monedula*). The results show that breeding site selection is greatly influenced by previously personally acquired knowledge of the breeding area and limited by structural features, suggesting that colonial breeding might be a by-product of a lack of suitable nesting sites. Ecological plasticity in the exploitation of resources and long-lived strategies in jackdaws may make individuals less dependent upon particular resources, allowing individuals to make breeding habitat decisions based on their own personal experiences and perception of risk.

In **chapter 3** behavioral mechanisms through which large organisms respond to offspring predation risk are addressed. While there is evidence that large body sizes confer substantial benefits, the potential costs of being big in terms of offspring predation risk remain greatly unexplored. This relationship is examined by means of phylogenetic-based comparative analyses based on an extensive nest predation dataset of passerine bird species distributed across the world. The results show that larger species suffer lower

nest predation rates than smaller species. Although nest predation rates were phylogenetically conserved and showed substantial geographic variation, the observed pattern remained consistent to the effect of these factors. Moreover, larger species attack a wider array of predators of different sizes, potentially explaining their lower offspring predation rates.

Taken together, this thesis reinforces the importance of behavior as a mechanism to cope with challenges influencing reproductive performance and remarks the crucial role of life history in determining it.

Resum

El comportament permet als animals afrontar condicions ambientals adverses, permetent als individus anticipar-se i respondre a una amplia varietat de riscos. Per tant, el rol de les decisions comportamentals per a la millora de l'aptitud (*fitness*) en condicions incertes és àmpliament acceptat. Menys freqüentment reconegut és el fet que la variació de les respostes comportamentals dels organismes està subjecte a les estratègies vitals. Per exemple, és fàcil imaginar que els costos i els beneficis de comportar-se d'una determinada manera no són els mateixos per a les espècies que viuen pocs anys que per les que viuen molts anys. Les estratègies vitals també poden afectar les respostes comportamentals imposant restriccions en el desenvolupament, que poden influir en la mida del cos i limitar les capacitats cognitives. En aquesta tesi s'hi exploren els mecanismes comportamentals que els organismes utilitzen per maximitzar el seu èxit reproductiu, tenint en compte el context d'estratègia vital. Utilitzant les aus com a model d'estudi, la qüestió s'adreça a través de dues perspectives diferents.

En primer lloc, al **capítol 2** s'hi exploren els mecanismes comportamentals que contribueixen al procés de selecció del lloc de cria. Els animals han d'enfrontar-se a la variabilitat ambiental per seleccionar un lloc apropiat on criar, majoritàriament a través de l'adquisició d'informació de dues potencials fonts: personals i socials. Tot i així, les causes que afavoreixen l'ús d'una o altra font d'informació romanen poc conegudes. Aquesta qüestió s'aborda per mitjà del monitoratge de la selecció del lloc de nidificació en la gralla (*Corvus monedula*). Els resultats mostren que la selecció del lloc de nidificació està marcada per coneixements personals sobre la zona adquirits amb anterioritat i limitada per característiques estructurals, suggerint que la formació de colònies en aquesta espècie podria ser conseqüència de l'escassetat de llocs de nidificació apropiats. La plasticitat ecològica en l'explotació dels recursos i la longevitat en les gralles poden explicar l'ús d'informació en la selecció de lloc de nidificació, remarcant així la importància del context d'estratègia vital en els processos de presa de decisions.

Al **capítol 3** s'hi estudien els mecanismes comportamentals d'espècies de mida gran per respondre al risc de predació de la descendència. Tot i l'existència d'evidències mostrant els múltiples avantatges que comporta una mida corporal gran, els seus costos respecte el risc de predació de la descendència romanen en gran part poc coneguts. Aquesta relació

és estudiada a través de mètodes filogenètics comparatius basats en una extensa base de dades sobre predació al niu en aus passeriformes distribuïdes arreu del món. Els resultats mostren que les espècies de mida gran pateixen menys predació al niu que espècies de mida petita. Tot i que les taxes de predació es troben filogenèticament conservades i mostren una variació geogràfica destacable, cap d'aquests factors altera el resultat obtingut. A més, les espècies de mida gran ataquen un rang més ampli de depredadors de mides corporals diferents, el què potencialment contribueix a menors taxes de depredació de la descendència.

En conjunt, aquesta tesi reafirma la importància del comportament com a mecanisme per afrontar diversos factors que amenacen l'èxit reproductiu dels organismes i destaca el rol essencial de les estratègies vitals en determinar-lo.

Chapter 1

General introduction

Introduction

Organisms must face a wide sort of challenges influencing their reproductive success, and as a consequence, their fitness. These challenges include different sources of offspring mortality such as predation, starvation or weather-induced mortality (Ricklefs 1969; Martin 1992a), as well as a variety of environmental and biotic stressors influencing parents' behavior (Fontaine and Martin 2006). Because the challenges animals face can greatly vary across space and time, the decision of where and when to reproduce is expected to highly influence their breeding performance. Thus, exploring how organisms anticipate and respond to challenges affecting their reproduction is crucial to better understand variation in fitness and its consequences for population dynamics and evolution.

Behavioral responses provide animals a fast way to cope with adverse conditions, as they allow for a degree of plasticity rarely found in other phenotypic traits (Ghalambor et al. 2010). Individuals may, for instance, improve reproductive success by choosing the habitats that best fit their phenotype, a process known as matching habitat choice (Davis and Stamps 2004; reviewed in Sol and Maspons 2016). Animals can further enhance reproductive performance through additional behavioral mechanisms, such as anti-predatory responses or parental care behaviors to respond to predation risk (Montgomerie and Weatherhead 1988; Fontaine and Martin 2006; LaManna and Martin 2016). These choices and behavioral responses can express activational plasticity, that is, an innate response to environmental cues (Snell-Rood 2013; reviewed in Sol et al. 2013; reviewed in Sol and Maspons 2016), but can also be modified through learning (Dukas 1998; reviewed in Sol et al. 2013; reviewed in Sol and Maspons 2016). The process of learning allows to guide behavioral plasticity on the basis of previous experience, improving thus decision-making processes (Eliassen et al. 2007). Altogether, activational plasticity and learning abilities help organisms to deal with the spatial and temporal variability of conditions threatening their reproduction.

Less often appreciated is the fact that the way animals respond to challenges largely depends on their life history (Maspons et al. 2019). Because time and energy are limiting for most organisms, individuals cannot simultaneously maximize their reproduction, growth and survival (Stearns 2000). Thus, the life history of an organism reflects the "optimal" combination of reproduction, growth and survival that maximize fitness in their environment (Stearns 2000). Much of the variation in life history can be described by the "fast-slow continuum", which reflects the trade-off between survival and fecundity (Stearns 1983; Bielby et al. 2007). At the fast extreme of the continuum we find short-lived species with high fecundity whereas at the slow extreme species we find slow-lived species with low fecundity. Because long-lived organisms have higher chances to breed in the future, they are expected to allocate resources toward their own survival, whereas short-lived species are expected to allocate resources toward reproduction (Stearns 2000). This variation in resource allocation leads to a different perception of risks and their associated costs across species (Martin et al. 2000; Maspons et al. 2019). Moreover, the delayed maturity in long lived species allows for longer development periods, which are required for the development of large body sizes and/or brains (Peters 1983; Iwaniuk and Nelson 2003; Barton and Capellini 2011). For this reason, in contrast to short-lived species, long-lived species have the potential for enhanced cognitive abilities (Dukas 1998; Sol and Maspons 2016; Maspons et al. 2019) and/or increased body sizes, which allow the development of behaviors such as exploration and learning, or more efficient anti-predatory responses.

Birds as study model

Because birds are easy to observe, they are one of the most studied group of organisms (Mayr 1984). Thus, high quality information regarding their behavior and ecology is currently available in literature. Large extent of this published information is gathered in several handbooks and encyclopedias (Del Hoyo et al. 2019; Rodewald 2019), facilitating the acquisition of data. Moreover, the availability of a global phylogeny of birds (Jetz et al. 2012) provides the necessary phylogenetic framework to use comparative approaches while accounting for the masking effects of common ancestry. These sets of properties are particularly advantageous for addressing experimental and comparative approaches, both necessary for understanding processes from different scales.

Main goals of the thesis

The aim of this thesis is to explore behavioral mechanisms used by organisms to maximize their reproductive performance, under a life-history perspective and using birds as the subject of study. The role of behavior is assessed from two different perspectives. First, we investigate how organisms anticipate reproductive costs through breeding site selection by means of long-term study in Eurasian jackdaws (*Corvus monedula*) (**Chapter 2**). Second, by means of a comparative approach based on passerine birds, we explore the behavioral mechanisms of response to the increased offspring predation risk in large species due to their extended development periods and conspicuous nests (**Chapter 3**). In the next sections, the state of art of these general issues is further described.

The use of information during breeding site selection

Selecting a wrong place for breeding can entail reproductive costs due to factors such as food scarcity, parasite load, predation risk or competition (Martin 1993; Turner and McCarty 1998). The acquisition of such information is crucial to reduce uncertainty and guide decisions to enhance fitness (Danchin et al. 2004; Dall et al. 2005). Animals can acquire information about the quality of a breeding site directly through interacting with the environment (personal information) or indirectly from cues provided by conspecifics and heterospecifics (social information) (Valone 1989; Danchin et al. 2004; Dall et al. 2005). The importance of personal and socially acquired information has received a great deal of attention in the past (Danchin et al. 1998; Doligez et al. 1999, 2002, 2004; Brown et al. 2000; Serrano et al. 2001, 2004; Suryan and Irons 2001; Calabuig et al. 2008). However, our current understanding of the reasons favoring the use of one or another source of information still remains poorly understood. Different factors can influence the use of information sources. First, information availability and the capacity of individuals to prospect can vary along time (Brewer and Harrison 1975; Cadiou et al. 1994; Reed et al. 1999; Clobert et al. 2001). Second, reliability on social information can be influenced by environmental predictability and the strength of social interactions with other individuals (Boulinier and Danchin 1997; Doligez et al. 2003). **Chapter 2** explores the use of information in breeding site selection and its underlying causes by monitoring the process of colony foundation and growth in the Eurasian Jackdaw (Corvus monedula), in the north-east of the Iberian Peninsula —a long-lived, highly social and semi-colonial bird passerine.

The risk of offspring predation in large species

Body size influences almost all the aspects of organism’s biology. While there is evidence that large body sizes confer a large extent of benefits (Watson 1949; Rensch 1959; Gould 1966; Schoener and Janzen 1968), the costs of being big still remain largely unexplored (Blanckenhorn 2000). A potential reproductive cost of larger body sizes is an increased offspring predation risk due to their extended development periods and more conspicuous nests (Snow 1978; Blanckenhorn 2000). However, empirical support for this hypothesis is contradictory (Ricklefs 1969; Murphy and Fleischer 1986; Møller 1990; Weidinger 2004; Biancucci and Martin 2010; Remeš et al. 2012; Mouton and Martin 2019). As a result, the influence of body size and associated nest size on nest predation rates still remains unresolved. One issue that may obscure the relationship between body size and nest predation is the substantial geographic variation that exhibits nest predation (Martin 1992b; Chalfoun et al. 2002; Thompson 2007; Martin et al. 2017). Thus, accounting for the environmental factors influencing nest predation at both broad and local scales (Skutch. 1949; Snow 1978; Skutch 1985; Chalfoun et al. 2002; Thompson et al. 2002; Thompson and Burhans 2003; Thompson 2007; Boyle 2008; Nana et al. 2015) is crucial to disentangle body size-nest predation relationship. Also, the relationship between body size and nest predation can be influenced by the potential of animals to respond to predation risk by a number of behavioral mechanisms (Hoogland and Sherman 1976; Montgomerie and Weatherhead 1988; Martin 1992b, 1993, 1995; Wiklund and Andersson 1994; Krams et al. 2009). **Chapter 3** examines the relationship between body size and nest predation and unravel the behavioral mechanisms underlying this relationship, by means of a phylogenetic-based comparative approach based on an extensive nest predation dataset of passerine bird species distributed across the world.

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Chapter 2

The role of personal and social information on breeding habitat selection during colony development of a long-lived bird

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In preparation

Abstract

In variable environments, the acquisition of information is crucial to deal with uncertainty and improve decision-making processes affecting fitness. Information may be acquired through both individual experience and cues derived from other individuals, but the circumstances under which individuals should use each strategy remain largely unexplored. Here, we investigate the importance of both sources of information and its underlying causes in the crucial decision of where to reproduce, using a 20 years monitoring of 23 artificial breeding colonies of Eurasian Jackdaws (*Corvus monedula*) in the north-east of the Iberian Peninsula. Our analyses revealed that jackdaws did not select their breeding sites on the basis of environmental cues or social information, despite evidence that individuals acquired information through exploration. We in fact found no evidence that breeding success co-vary with environmental variation. Instead, jackdaws selected those nesting sites conferring the best structural conditions to breed, suggesting that in this semi-colonial species, colonial breeding might be a by-product of a lack of suitable nesting sites. However, individuals also used personal experiences in habitat choice, relying on information acquired through exploration to make breeding site decisions and showing a tendency to reproduce in close and similar environments to those previously used. Although jackdaws live in highly heterogenous environments, their ecological plasticity in the exploitation of resources and life history may make individuals less dependent upon particular resources, allowing individuals to make breeding habitat decisions based on their own personal experiences and perception of risk.

Keywords: breeding habitat selection, conspecific attraction, *Corvus monedula*, dispersal, facultative coloniality, performance-based attraction, personal information, prospecting behavior, public information.

Introduction

All animals experience to a certain extent temporal and spatial variation in their environment. The acquisition of information can improve decision-making processes to cope with such uncertainty, being therefore key to survive and reproduce (Danchin et al. 2004; Dall et al. 2005). A particularly crucial decision all animals face is where to reproduce. Reproducing in a wrong place can entail important costs in terms of reduced food availability and higher exposure to risks (Martin 1993; Turner and McCarty 1998), but anticipating these costs is challenging because conditions at the time of habitat choice can largely differ from those found when rearing offspring. While there is ample evidence that habitat choice affects fitness (Hildén 1965; Clark and Shutler 1999; Mayor et al. 2009), what sources of information individuals use in such a decision-making is still not well understood.

Animals can acquire information about the quality of a site from two main sources (Valone 1989; Dall et al. 2005): by using personal information through directly interacting with the environment—including the use of environmental cues, philopatry and previous breeding experience (Marzluff 1988; Pärt 1991; Switzer 1993; Clark and Shutler 1999)— or by means of socially acquired information when is extracted from other individuals—including direct transmitted signals or cues provided inadvertently by other individuals (inadvertent social information) (Danchin et al. 2004; Dall et al. 2005). The assessment of inadvertent social information can encompass social cues, such as the presence of other individuals (social attraction) (Stamps 1988) or public information, involving available information about the quality of a resource, such as reproductive success (performance-based attraction) (Boulinier and Danchin 1997; Danchin et al. 1998). Researchers have expended considerable effort in analyzing the importance of personal and socially acquired information (Danchin et al. 1998; Doligez et al. 1999, 2002, 2004; Brown et al. 2000; Serrano et al. 2001, 2004; Suryan and Irons 2001; Calabuig et al. 2008), but the reasons favoring the different use one or another strategy remain largely unexplored (Doligez et al. 2003; Laland 2004).

A common assumption is that copying the decisions of others is a better strategy than using personal information because this source of information is considered more reliable (Danchin et al. 2004) and represents a shortcut to acquiring adaptive information

(Danchin and Wagner 1997; see Laland 2004). However, this ignores that the circumstances under which individuals should use each strategy can vary (Doligez et al. 2003). In colonial species, for instance, the sources of information are expected to vary during colony formation. While during colony foundation events first colonizers cannot rely on social cues from conspecifics, in the subsequent stages of colony growth this information is available to future breeders (Oro and Ruxton 2001; Calabuig et al. 2010; Payo-Payo et al. 2017). Therefore, it is likely that colonial species need to integrate both personal and social sources of information to assess breeding site quality.

The benefits of copying the decisions of others can also vary as a function on environmental predictability and interactions with other individuals (Boulinier and Danchin 1997; Doligez et al. 2003). Theoretical studies suggest that when habitat quality varies temporally in a predictable way, using public information is better than choosing at random, being philopatric or using the mere presence of conspecifics (Doligez et al. 2003). However, using public information is not always a better strategy than directly using intrinsic patch quality and both can theoretically coexist (Doligez et al. 2003). The benefits of copying the decisions of others can also be affected by density-dependent processes. Density-dependent processes can reduce fecundity for strategies that tend to aggregate individuals in space (McCallum et al. 2000; Rodenhouse et al. 2003; Carrete et al. 2006), resulting in mismatches between cues derived from the mere presence of conspecific and their breeding performance. However, the strategies based on public information may perform well under Allee effects leading to positive density dependence at low population sizes (Doligez et al. 2003).

Finally, decision-making rules can be influenced by learning (Dukas 1998; Eliassen et al. 2007; see Sol et al. 2013; see Sol and Maspons 2016). Individuals may for instance show a consistent preference to settle in familiar types of habitats, for example those containing stimuli comparable to the stimuli in their natal habitat, a process known as natal habitat preference induction (Davis and Stamps 2004). Breeding habitat choice can also be influenced by the personal information acquired during previous breeding experiences. Experience in a particular area can enhance the value of space through the acquired knowledge of important features such as the location, type or quality of resources, escape routes or nesting sites (Stamps 1995). Moreover, previous breeding experiences can also modify breeding habitat choice. A change in nest site choice is a well-documented response to a reproductive failure (Marzluff 1988; Lima 2009), and through learning may lead to change the cues used in subsequent choices (Dukas 1998; Eliassen et al. 2007; see Sol et al. 2013; see Sol and Maspons 2016).

Information of potential breeding sites is gathered through prospecting behavior. Because information varies with time (Brewer and Harrison 1975), the availability and reliability of information will be influenced by the timing of prospecting. Reproductive cues, for instance, are expected to be more informative at the end of the breeding season, that is when chicks are present (Boulinier et al. 1996; Reed et al. 1999). Thus, prospecting behavior is crucial to assess the quality of potential breeding sites and influence breeding habitat selection decisions determining fitness. Although investing time on gathering information during the breeding season may also entail reproductive costs for prospectors engaged in their breeding activities (Clobert et al. 2001), these costs should not condition exploration behavior in non-breeders, failed breeders and juvenile individuals (Cadiou et al. 1994; Reed et al. 1999; Clobert et al. 2001). However, in highly mobile species, assessing reproductive costs due to prospecting behavior is difficult, as information may be acquired while engaging other activities (Clobert et al. 2001; Doligez et al. 2003).

Disentangling which sources of information are used in breeding habitat selection is relevant to better understand the spatial distribution and population dynamics of social animals. If breeding site quality is assessed through environmental cues, aggregations should reflect local environmental variation (Danchin and Wagner 1997). However, under the social-attraction hypothesis, aggregations should differ from environmental variation (Danchin and Wagner 1997) and larger colonies should grow exponentially until the costs of colonial breeding override their benefits (Calabuig et al. 2008). Instead, under the performance-based attraction hypothesis, aggregations should fluctuate along time, reflecting the environmental variability affecting breeding success of individuals (Calabuig et al. 2008). In this scenario, individuals would gather to form more colonies but not necessarily of larger sizes (Calabuig et al. 2008). Finally, given that individuals may have differ in their natal and breeding experiences, learning can lead to differences in decision-making across individuals, masking general preferences.

Assessing the relative importance of personal and socially acquired information in habitat choice is challenging because the presence of conspecifics and their productivity are likely to be correlated with each other and with habitat quality. However, important insight can be gained by tracking changes in colony formation over time, where the selection process can be analyzed both in absence and presence of conspecific cues. Here, we investigate the use of information and its underlying causes during both foundation and growth stages of colony development in a long-lived, highly social species: the Eurasian Jackdaw (*Corvus monedula*). Our analyses are based on a long-term monitoring (20 years) of 23 colonies breeding in artificial structures (towers, hereafter), built along an environmental gradient from intensive dryland monocultures to mosaic landscapes of natural and agricultural habitats in the north-east of the Iberian Peninsula. Thus, our study system not only provides a rare opportunity to assess breeding habitat choice both in absence and presence of conspecific cues, but also to explore the critical issue of how these cues change over time.

Methods

Study species. The Eurasian Jackdaw is a 215.6 ± 16.1 grams (mean ± sd) corvid inhabiting open areas in the Palearctic. This omnivorous bird, is resident in most of its range and short-distance migrant in the northern and eastern regions of its distribution (Madge and de Juana 2019). Jackdaws are long-lived species, reaching sexual maturity after 2 years and with a maximum lifespan of 20.3 years recorded in the wild (Tacutu et al. 2018). They are monogamous, establish long-term pair-bonds (Röell 1978; Henderson et al. 2000) and breed semi-colonially, building their nests in cavities (Madge and de Juana 2019).

Study area. Our study was conducted in the Catalan Ebro basin (Lleida plain), north-east of the Iberian Peninsula. In this region dominated by an agricultural landscape, 23 towers were built between 1998 and 2014, covering an area of 1,428 km2 and offering new breeding opportunities for cavity nesting species (Supplementary Figure 1). Each tower had between 25 and 40 nest boxes located at three different heights. Both hole and nest box sizes varied across nests (big vs. small sizes). Thus, structural features of nest boxes varied within and across towers (detailed in Supplementary information) allowing the coexistence of different cavity nesting species breeding in the area: *Corvus monedula*, *Falco naumanni*, *Falco tinnunculus*, *Coracias garrulus*, *Athene noctua*, *Tyto alba*, *Columba oenas*, *Sturnus vulgaris* and *Passer domesticus*.

Data collection in the field. Towers were monitored during the breeding seasons between 1998 and 2018. During this period, all nest boxes were checked between 1 and 12 times (mean ± sd = 4.4 ± 2.92) from April to July to determine all the pairs breeding in the towers and assess their breeding performance. From 2015, fledglings and adults were captured and banded at their nests. Body mass of all the captured individuals was measured with a portable balance (Scout Pro 600g, Ohaus Corporation, New Jersey, USA). To allow the posterior identification of individuals without the need of recapturing, birds were banded with two different rings: i) PVC plastic rings with a three-character code, and ii) plastic rings with a transponder HITAG-S 76 inside (MC603 ring, TIPES, Höxter, Germany). Every breeding season, the detection of banded birds was done by reading PVC rings using telescopes and by installing RFID readers able to read animal HITAG-S (RFIDLOG and RFIDLOG-AUX, Priority 1 Design, Melbourne, Australia) both at nest box entrances (N=8 units installed during breeding season) and at tall perches located at the side some towers (N=3 units installed permanently). Mark-recapture data was used to estimate dispersal distances and prospecting behavior used in further analyses.

During 2015-2018 nestling periods (May-June), we monitored 10 adult jackdaws nesting in 7 different colonies with Gipsy-5 GPS-dataloggers (TechnoSmArt, Rome, Italy). GPS devices were attached using backpack harnesses formed by a 4 mm wide Teflon Ribbon (Falconry Electronics, West Yorkshire, United Kingdom). The total weight of the devices was 8.6 g, which did not exceed the 5% of the equipped individuals body mass (mean ± sd = 214.5 ± 14 g), being comfortable with the recommended limits for flying animals (Barron et al. 2010). We programmed GPS-dataloggers to acquire locations at 5 fixes/second for 10 minute intervals (N=6units), except for the devices used in 2015, which acquired locations at 10 fixes/second for 5 minute intervals (N=4 units). To download the data from GPS-dataloggers, jackdaws were recaptured at their nest boxes. In total, individuals were tracked during 7.7 ± 2.94 days (mean ± sd).

Determining space-use in jackdaws

Land-cover data. To assess the habitats present in the study area, we obtained land-cover maps from 2005 and 2009 in a raster format and a pixel size of 2m from the Land Cover Map of Catalonia (http://www.uab.creaf.es/mcsc). The initial 241 land-use categories of these land-cover maps were reclassified into 28 categories (detailed in Supplementary Information) using QGIS version 2.18 (QGIS Development Team 2016) and the “r.reclass” module in GRASS GIS (Neteler et al. 2012).

Processing GPS data. We assessed the quality of the tracking data through different approaches. First, to ensure a good accuracy of the records, we removed all the positions with a dilution of precision over 3 and less than 4 satellites (Lewis et al. 2007; Frair et al. 2010). Second, we checked for the presence of records located outside the study area (Urbano and Cagnacci 2014). Then, we calculated the mean coordinates and acquisition time of the last 5 fixes taken for each interval of time. Finally, using these mean records, we controlled for errors due to impossible acquisition times and for records that would imply impossible movements (Urbano and Cagnacci 2014). For this latter purpose, we estimated the maximum speed between locations, through calculating the geodesic distance between relocations and assuming that jackdaws can fly at the maximum speed of 60 km/h (Gyllin et al. 1977; Alerstam et al. 2007). Then, movements exceeding this speed limit were removed.

Utilization distribution estimation. We calculated the utilization distribution (UD) (Van Winkle 1975) for each tracked individual, using a Movement-based kernel density estimation approach (Benhamou and Cornélis 2010; Benhamou 2011), as implemented in the adehabitatHR R package v.0.4.15 (Calenge 2011a). This method considers the activity times spent between pairs of successive relocations, applying an advective-diffusive movement in the trajectory (i.e. a “drift” between successive relocations) (Benhamou 2011; Calenge 2011a). UDs were estimated based on the functions “BRB.D” and “BRB” (Calenge 2011a) (parameter settings: Tmax=40min, Lmin=20m, hmin=50m, habitat = land-cover raster from 2009), from which we extracted the 95% Volume Contours.

Environmental characterization of the region. The habitat surrounding each tower was characterized by analyzing 2005 and 2009 land-cover maps using the R package landscapemetrics (Hesselbarth et al. 2019). Within an area of 5 km2 around each tower (mean UD 95% area) we measured the area of each habitat type, the Shannon diversity index of habitats and the number of farms. Comparing land use cover data, we did not find substantial changes in land use patterns from 2005 and 2009 (Supplementary Figure

2A), except for farms (Supplementary Figure 2B). Thus, for further analyses, number of farms was extracted from the 2005 land cover map for the period between 1998-2007 and from the 2009 land cover map for the period between 2008-2018. Because jackdaws frequently concentrate in dumps to forage, we used information from the Waste Agency of Catalonia (http://residus.gencat.cat) to estimate the distance to the closest dump. Dumps operating in the area did not change along the study period. Finally, we used surveys from 2011 of the number of abandoned houses in the study area, and calculated the number of abandoned houses within a radius of 3865 meters (median breeding dispersal distance, N=14 adult breeders) to account for the fact that the establishment of new individuals in the towers could be influenced by the availability of breeding sites in the surroundings. An evaluation of the condition of abandoned houses in 2011 revealed that the 60% of them were in good conditions, the 10% had the roof damaged, the 11% had no roof and the remaining 19% only had damaged walls. The condition of most of these houses remained constant (73%) from 2011 to 2017, when a posterior survey was done (Supplementary Figure 3).

Habitat selection analysis. We first investigated whether habitat use within the UD 95% was consistent among tracked individuals by means of chi-square test. Then, we studied habitat selection using a desing III approach (Thomas and Taylor 1990), which accounts for different habitat availability across individuals and measures both habitat use and availability at individual level. To describe habitat selection, we used an Eigenanalysis of Selection Ratios (Calenge and Dufour 2006), which accounts for several habitat categories, using the R package adehabitatHS (Calenge 2011b). The Eigenanalysis of Selection Ratios generalizes the White and Garrot statistic (White and Garrott 1990) and Manly’s selection ratios (Manly et al. 2002) within the framework of eigenanalysis (Calenge and Dufour 2006). This approach can be considered an extension of principal component analysis, providing a graphical tool to explore habitat selection and identify whether different groups of individuals select their habitat in a similar way (Calenge and Dufour 2006).

Climatic data. Daily records of mean temperature and accumulated precipitation produced by the Meteorogical Service of Catalonia were obtained from the RuralCat website (https://ruralcat.gencat.cat/web/guest/agrometeo.estacions). For each colony, this climatic data was extracted from the closest weather station (mean distance between colonies and their respective closest station = 6 km) and for a period of time comprised between the 1rst of May (20 days prior to the mean hatching date) (Kruuk et al. 2015) and the 19th of June (mean fledging date). Then, for each year climatic variables were aggregated to obtain mean, variation (estimated as the coefficient of variation) and extreme values (estimated as the mean value of the 75%-95% Quantile) of daily mean temperature and accumulated precipitation.

Modeling breeding site selection and information cues. The role of environmental and social information cues on breeding site selection was explored by means of Bayesian generalized linear mixed models, using the “brm” function in the brms R-package (Bürkner 2017). Because we studied how colonies varied across space and time, observations were not totally independent from each other. Indeed, towers showed a clumped distribution and their construction along time varied with both space and habitat characteristics (Supplementary Figure 4). Thus, for each model, we first considered the inclusion of tower, year or nest box as random factors and then, tested the best random structure according to the Widely Applicable Information Criterion (waic). Finally, model residuals were examined for both spatial and temporal effects.

First, we investigated which information cues are used during the foundation of colonies. To better understand the colonization process, two different responses were modeled: i) colonization lag (binary response: 0 = colonization events occurring immediately after tower construction vs 1 = colonization events occurring later), and ii) group colonization (binary response: 0 = colonization events done by only one pair vs 1 = colonization events done by more than one pair). For each model we examined the effects of environmental cues, such as habitat features and number of abandoned houses around the towers, and structural features of towers (presence of big holes or big nest boxes). Predictors were tested separately to avoid collinearity effects. To know whether the presence of other species at the towers before jackdaw colonization could affect the colonization process, colonization lag was also tested across species. Species not consistently monitored along the study period, such as *Columba oenas, Sturnus vulgaris* and *Passer domesticus*, were excluded from the analyses addressing heterospecific effects to avoid spurious results. Structural nesting preferences were further explored by testing the influence of structural nest features (hole diameter, nest box sixe and nest height) on nest box occupation (binary response: 0 = non-occupied nest box vs 1 = occupied nest box). The relationship between adult body size and nest hole size was also tested to investigate whether structural nest features were equally available for all individuals.

Then, we explored whether information use changed during colony growth stages. Colony growth was defined as the period between tower colonization and the maximum number of pairs reached by each colony. Nest box occupation for first time (binary response: 0 = non-occupied nest box vs 1= nest box occupied for the first time) was modeled as a function of not only structural and environmental cues, but also social cues such as the number of conspecifics and heterospecifics breeding at the colony the year before and the mean fledging success of the conspecifics breeding at the colony the year before. Again, predictors were tested separately to avoid collinearity effects. The effect of the number of conspecifics on breeding site selection during colony growth was further investigated through exploring how the number of pairs breeding in a tower influenced colony growth rate (r), calculated by the formula $r\ = \log(\frac{N\ occupied\ nests\ t+1}{N\ occupied\ nests\ t})$, where t indicates year. To investigate how public information varied across space and time, we assessed fledging success variation across years and colonies by measuring its repeatability using the rptR R-package (Stoffel et al. 2017). Predictability of fledging success was also explored by modeling mean colony fledging success as a function of mean colony fledging success at both one and two year lags. Because the number of surveys done during the nestling period could influence fledging success estimations, the difference of number of surveys across years was included as a confounding factor. Finally, Allee effects were investigated by testing the relationship between fledging success and the number of conspecifics in the colony while controlling for the possible effects of climate and the number of surveys done.

Each model (all responses and predictors summarized in Supplementary information), was ran with two chains for 7,000 iterations each, discarding the first 1,000 iterations. To ensure the validity of our posterior samples, adapt_delta was set to 0.99. Model convergence was confirmed by examining traceplots and evaluating that Rhat values did not exceed 0.01 (Bürkner 2017).

Results and Discussion

Jackdaws varied in the extent they used artificial breeding towers (Figure 1). During colony foundation events, individuals cannot rely on socially acquired information from conspecifics to decide where to breed. If any, the decision must be based on environmental or heterospecific cues. However, the need to discriminate among habitats is only necessary if the environment is heterogenous. We characterized the environment around the towers by means of a factor analysis on the most well-represented habitats. The first component explained 46.8% of habitat variation across colonies, describing a gradient from intensive dryland monocultures to mosaic landscapes of natural and agricultural habitats (Supplementary Figure 5, Supplementary Table 1). The second component explained 25.9% of variation and described a gradient from irrigated crops to dryer habitats (Supplementary Figure 5, Supplementary Table 1). Other relevant anthropogenic factors also varied across space. Distance to dumps ($\chi2 = 31938$, df=22, $p<0.001$) and the number of farms present around colony ($\chi2 = 244$, df=22, $p<0.001$) largely differed between colonies. The abundance of old constructions around colonies also varied spatially ($\chi2 = 215.3$, df=21, $p<0.001$).

While the existence of environmental heterogeneity increases the need of being selective when deciding where to reproduce, what really matters is how individuals experience such variation. We therefore also investigated how jackdaws breeding in towers used this heterogeneous landscape by monitoring 10 individuals from 7 colonies with GPS. We focused on the nestling period, where the need to obtain food to provision offspring is more crucial. Because habitat preferences differed across individuals ($\chi2 = 8869.7$, df=135, $p<0.001$), habitat selection was described at individual level. An Eigenanalysis of selection ratios revealed that farms, shrublands and grasslands were used by some individuals more often than expected by their availability within their home range (Supplementary Figure 6). Manly selection ratios indicated that dumps were also frequently used when available within the individuals' utilization distribution (Supplementary Table 2). We also found evidence that jackdaws explore for breeding site opportunities both during and before the breeding season. From 2015 to 2018 we recorded 41 events in which individuals explored towers where they were not breeding, 39% (N=16) of which involved adults.

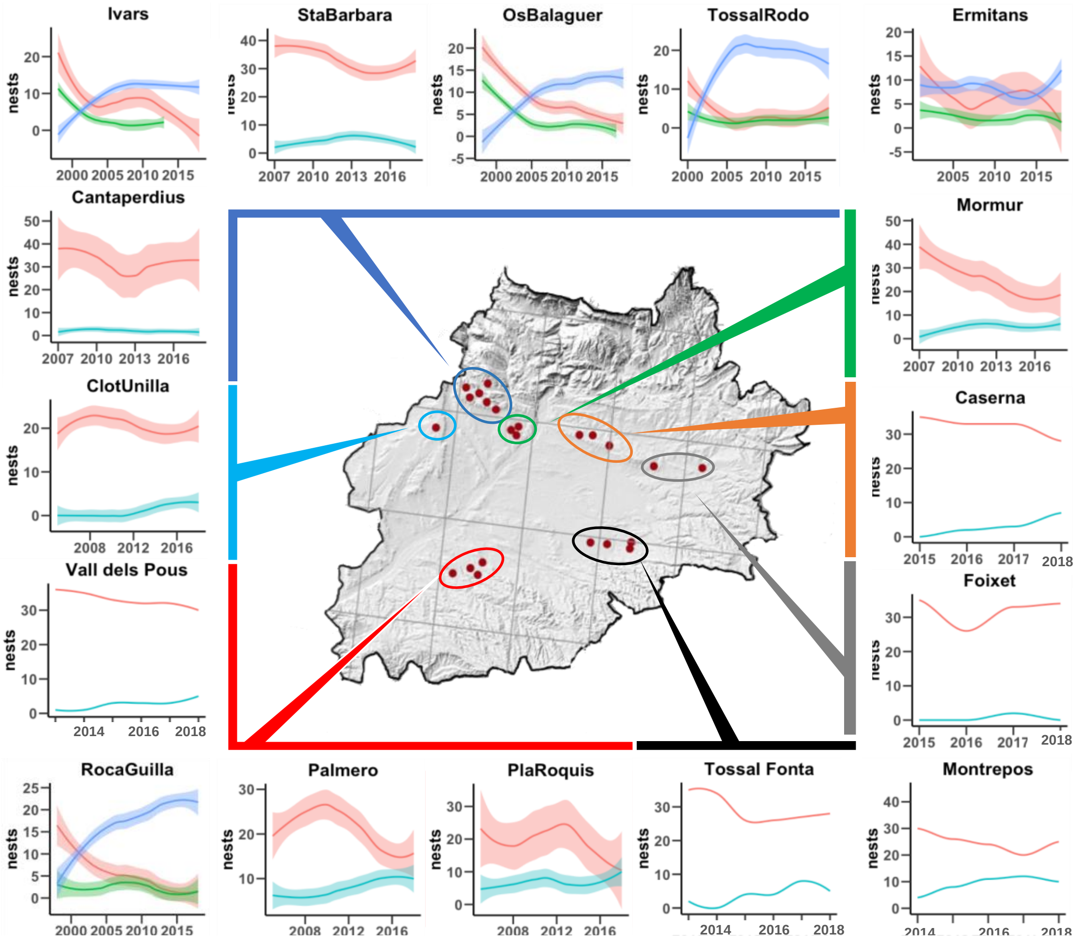

Figure 1. Change of nest box occupancy and availability over time. Occupied nests are represented in blue, with dark blue denoting towers having nests with both big and small hole entrances, and emerald blue denoting towers having only nests with small hole entrances. Available nests are represented in red when having big hole entrances and in green when their hole entrance is small. Lines and 95% confidence intervals are based on Loess regressions.

The existence of environmental heterogeneity and foraging habitat preferences suggests that individuals should consider the habitat surrounding artificial colonies in their nest-site choice. However, the fact that individuals varied in foraging habitat preferences may indicate that they can exploit a broad diversity of environments and hence do not need to be too selective when choosing a breeding habitat. To evaluate these alternatives, we investigated whether the decision to settle in a tower was influenced by the features of the environment surrounding them. We found little variation across towers in the lag between the year of construction of the tower and that of colonization. In fact, most towers (14 of 23) were occupied by jackdaws the same year of construction, highlighting the high demand of nest-site opportunities in the study area. Given the reduced variation, it is unsurprising that colonization lag was little influenced by environmental features (Supplementary Figure 7). However, we found some evidence that colonization lag decreased with both the proximity to dumps (Figure 2A) and the number of old constructions around the colony (Figure 2B). Thus, tower colonization was faster in places where food resources and nesting sites were already abundant, perhaps because the species was already common in these areas.

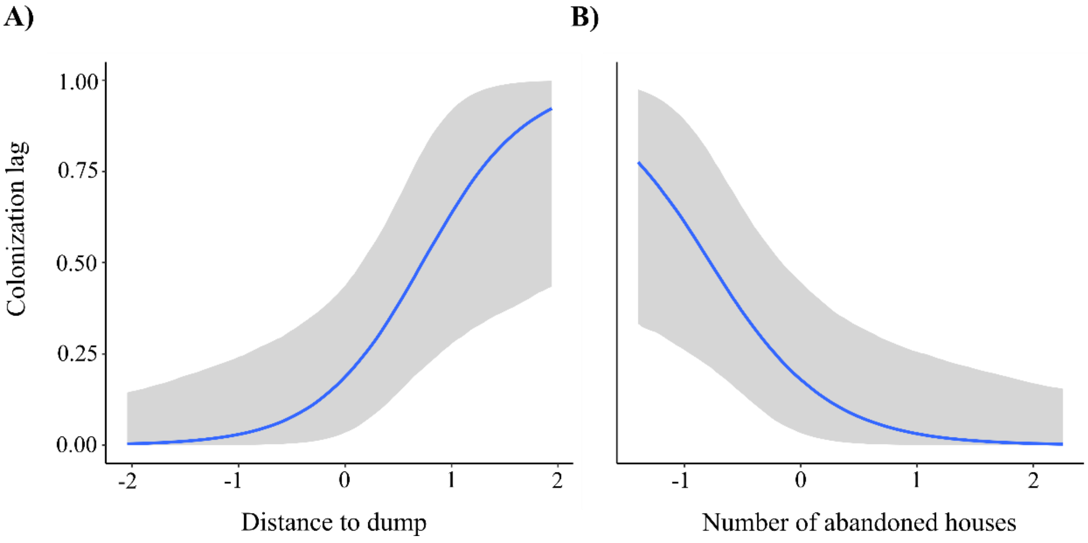

Figure 2. Effects of the distance to dump and the number of abandoned houses on colonization lag. Colonization lag increased with distance to dumps (standardized and log-transformed) (CI 95% = 0.48 – 4.54) (A) and decreased with the number of old constructions around the colony (standardized) (CI 95% = 0.48 – 4.54) (B). Solid lines and shaded areas show the mean predicted probabilities and 95% CI derived from univariant Bayesian generalized mixed models.

The demand of suitable nesting sites is also reflected in the observation that jackdaws often colonized the towers in group (range of 1-9 jackdaw pairs; mean ± sd = 2.81 ± 2.12). However, neither habitat nor the number of abandoned houses around the colony explained whether the settlement in a tower was in group or solitary (Supplementary Figure 8). Because there were other nest site opportunities surrounding the first occupied towers, it may be that individuals were looking for improved conditions to breed. Supporting this possibility, the probability to occupy a nest box increased with hole

(Figure 3A) and nest box sizes (Figure 3B), and was also higher if the nest box was localized on top of the tower (Figure 3C). Our analyses also revealed that colonization in group was influenced by the presence of big holes in the colonies (Figure 4A) but not by other structural features such as the presence of large nest boxes (Supplementary Figure 9). Colonization lag was neither influenced by structural features of nests (Supplementary Figure 10).

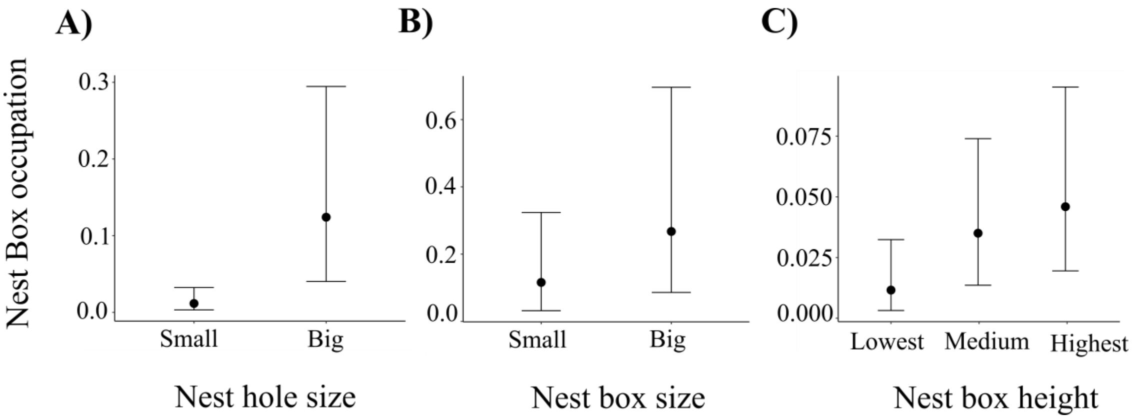

Figure 3. Effects of nest structural features on nest box occupation during colony foundation. The probability to occupy a nest box increased with hole size (CI 95% = 1.39 – 3.70) (A), nest box size (CI 95% = 0.12 – 1.66) (B) and nest height (CI 95% nests at middle row = 0.13 – 2.20; CI 95% nests at highest row = 0.47 – 2.46) (C). Large dots with error bars show mean predicted probabilities and 95% CI derived from a Bayesian generalized mixed model of nest box occupation as a function of hole size, nest box size and nest height and including colony as random factor.

The presence of other species did not affect the probability of tower colonization because the jackdaw was generally the first species to colonize the towers, together with Coracias garrulus (Supplementary Figure 11). The presence of Coracias garrulus at the colony the year before jackdaw colonization neither influenced the number colonizers (Supplementary Figure 12). Newer towers were not colonized faster than older towers, indicating that the observed patterns were not confounded by increased density of jackdaws in the region (Supplementary Figure 13).

Once some individuals became established in the towers, social information from conspecifics became available —together with heterospecific and environmental cues— to guide the decision of where to reproduce. However, structural nest preferences were maintained during the growth of colonies. Thus, after colonization, jackdaws continued selecting nests with big holes and nest boxes, although not those located highest (Supplementary Figure 14). Our analyses also revealed that hole size was an important factor influencing colony growth, as nest box occupation was higher in colonies with big holes (Figure 4B). This may indicate that small holes could be reducing the pool of potential recruitments. Supporting this possibility, we found evidence that largest members of pairs were constrained by hole size, as small holes were occupied by smaller individuals (Supplementary Figure 15A). However, this was not the case for smallest members, which did not show hole size limitation (Supplementary Figure 15B).

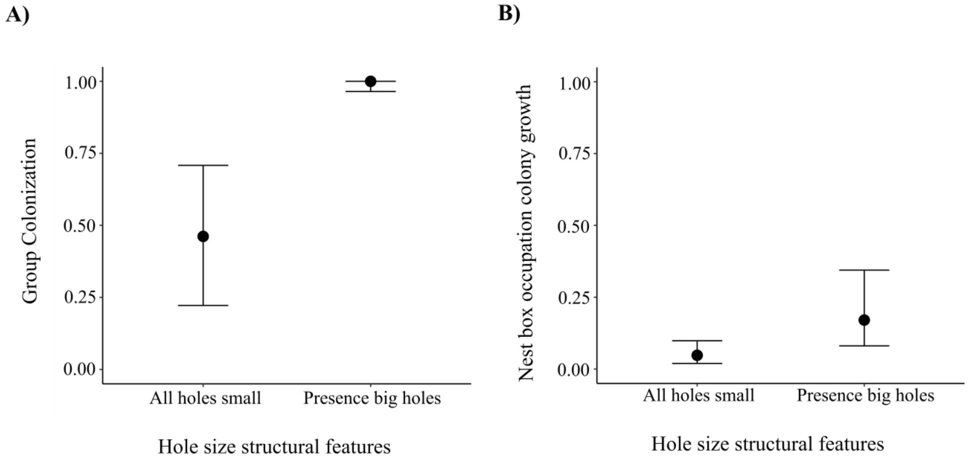

Figure 4. Effects of the presence of big holes in colonies on jackdaw occupation during colony foundation and growth. The presence of big holes in colonies influenced colonization in group (CI 95% = 3.35 – 159.95) (A) and the probability of nest box occupation during colony growth (CI 95% = 0.31 – 2.82) (B). Large dots with error bars show mean predicted probabilities and 95% CI derived from univariant Bayesian generalized mixed models. Nest box occupation during colony growth was modeled including colony, year and nest box as random factors.

Analyses of nest box occupation across nests with small hole sizes allowed us to examine whether other environmental or social cues were selected while controlling by structural effects. We did not find evidence that the probability to occupy a nest box during the growth stage was influenced by habitat nor the number of old constructions around the colony, when tower identity and year were included as random factors (Supplementary Figure 16). Likewise, other social cues, such as mean fledging success of the colony the year before (Supplementary Figure 17) or the number of heterospecifics breeding at the colony the year before (Supplementary Figure 18) had little effect on the likelihood that a nest box was occupied the next year, besides reducing nest site availability (Figure 1).

The lack of support for the performance-based attraction hypothesis is unsurprising, given that fledging success showed little variation across towers (repeatability for tower = 0.104, CI = 0.015-0.221) and no temporal correlation at both one year (Supplementary Table 3) and two years (Supplementary Table 4) lag. Moreover, while the strategies based on public information are expected to perform well under Allee effects (Doligez et al. 2003), we did not find evidence for such effects. Thus, our analyses revealed that fledging success was not influenced by the number of conspecifics in the colony during colony growth (Supplementary Figure 19), even when controlling for fluctuations in climatological conditions and the number of surveys done across years (Supplementary Table 5 and Table 6; supplementary Figure 20).

The probability to occupy a nest box was slightly influenced by the number of conspecifics breeding at the colony the year before (Supplementary Figure 21), but this could be a statistical artifact because each new nest occupied reduces the number of nests available next year. The social-attraction hypothesis however predicts that larger colonies should grow exponentially regardless of environmental variation (Danchin and Wagner 1997) until the costs of colonial breeding override their benefits (Calabuig et al. 2008). However, we did not find evidence that within towers the rate of colony growth increased with the number of pairs; rather, this rate often exhibited fluctuations over time and if any, the trend was toward decreasing with the number of pairs in the tower (Supplementary Figure 22). Although a negative density-dependence is to be expected when colonies approach saturation, it is worth noting that all towers still had vacant nest boxes when reaching their maximum.

Given that individuals seem to vary in the way they interact with the environment, we finally considered whether individuals use personal experience to choose a nesting site. Juvenile individuals showed little natal habitat preference, with over 88% of individuals (N=24) preferring to reproduce for first time in different towers than those where they were born. However, the median natal dispersal distance was generally low, with a median (±sd) of 4,730±12,167 meters (range 2,783-41,748 meters). Thus, the environment of the selected towers did not substantially differ from their natal site

(Supplementary Figure 23). Moreover, we also found evidence that some juveniles (N=4) settled in towers for which they had previous information, either acquired prospecting or because they returned to their natal site (Figure 5).

Unlike juveniles, adult jackdaws exhibited high breeding site fidelity from one season to the other, with 88.6% remaining in the same tower (N=44). Like juveniles, however, adults that changed tower showed a tendency to move to similar environmental features (Supplementary Figure 24). Thus, new breeding sites were generally chosen by proximity, with a median breeding dispersal distance of 3,865±12,032 meters (median ± sd, N=14 including movements across not consecutive years). We also found evidence that adult jackdaws (N=4) settled in towers explored before the breeding season.

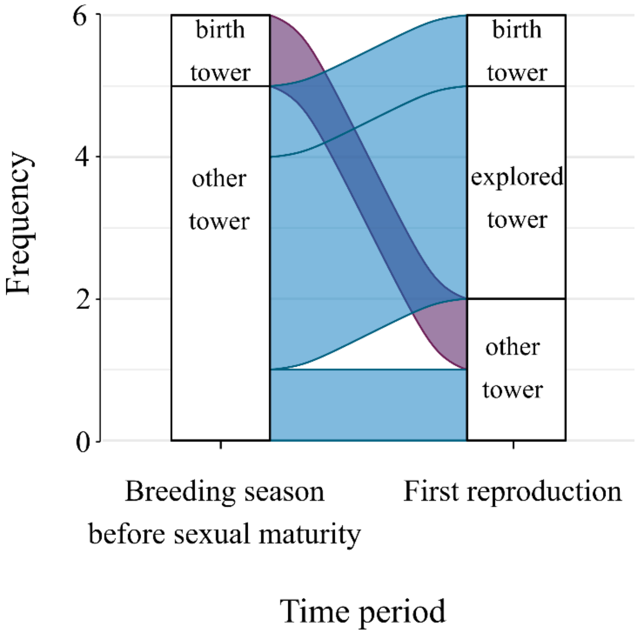

Figure 5. Exploration influence on breeding site selection. Alluvial diagram showing how some juveniles individuals (N=6) used previous information acquired through exploration to make settlement decisions.

Conclusions

Despite living in a highly heterogeneous environment, we found little evidence that jackdaws select their breeding habitats on the basis of environmental features. This may have to do with their behavioral plasticity and generalist diet, which makes individuals less dependent upon particular resources (Ghalambor et al. 2010). We in fact found no evidence that breeding success co-vary with environmental variation. The limitation of suitable nesting sites probably leads individuals to settle in the towers, regardless of their surrounding environment. Because there were other nest site opportunities surrounding the first towers occupied, it may be that individuals were looking for improved conditions to breed. When possible, individuals select nest boxes conferring the best conditions to breed, such as big entrance hole and size and low exposure. Long-lived species should be more risk-averse (Clark 1994; Wolf et al. 2007; Sol et al. 2018), thus, securing a good nesting site that poses little risks for adults may be particularly crucial. This is consistent with the striking risk-aversion behavior than exhibit individuals from the population to the presence of humans (Unzeta, pers. obs.).

Although colonial breeding has been often thought to confer advantages such as a reduction of predation risk (Wittenberger and Hunt 1985; Anderson and Hodum 1993; Clode 1993), we did not find evidence that jackdaws use socially acquired information to decide where to breed. Being highly sociable animals, we expected to find evidence for either social or performance-based attraction. But we did not. Social information based on breeding performance seems little reliable, considering that fledging success showed high heterogeneity within towers and little temporal correlation (Boulinier and Danchin 1997; Doligez et al. 2003). This is turn may make the density of pairs also unreliable, forcing individuals to rely more on personal information. We indeed found that many jackdaws prefer to reproduce in solitary nest boxes, even when could do so in a colony (Unzeta, pers. obs.). Coloniality in jackdaws could thus be a by-product of nesting sites limitations. Moreover, it could also be that individuals vary in their social personality, some preferring to breed in large groups while others not. Supporting this hypothesis, breeding success did not vary with the number of breeders.

Our results support the importance of personal experiences in influencing breeding habitat selection decisions in jackdaws. We found evidence that some individuals used the information acquired through exploration to make breeding site decisions. Moreover, mostly experienced and first breeders dispersed to close nesting sites showing similar environments, suggesting that for jackdaws, the acquisition of information of the breeding area is crucial for breeding site selection. The fact that juveniles prefer to settle in towers with similar features to those where they were born fits well with the natal habitat preference induction process (Davis and Stamps 2004). However, the short natal dispersal distances found could also reflect the importance of the acquired knowledge related to a site (Stamps 1995).

Regarding the exact mechanism, we suggest that to interpret our results we need to consider the importance of ecological plasticity in resource exploitation and life history in breeding habitat choice. Previous analyses contrasting the importance of personal and socially acquired information in breeding habitat choice of semi-colonial animals like jackdaws have focused on species with limited behavioral plasticity (Serrano et al. 2001, 2004). For these species, fitness is likely to be highly dependent on matching habitat choice, that is, choosing the habitats and resources that better match their phenotype (Davis and Stamps 2004; Edelaar et al. 2008; Sol and Maspons 2016; Maspons et al. 2019). Thus, in these species selection should favor decision-making mechanisms that facilitate linking the phenotype to the environment, both in terms of food availability, predation risk and parasite prevalence. These constrains may not be so important in species showing ecological plasticity in the exploitation of resources and long-lived strategies (Sol and Maspons 2016; Maspons et al. 2019), which may make individuals less dependent upon particular resources, allowing them to accommodate their decisions based on their own personal experiences and perception of risk.

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Supplementary material

Supplementary Information

Variation of structural nest features across towers

Structural nest features, such as nest box (χ^2 =192, df=19, p<0.001) and hole sizes (χ^2 =78.83, df=19, p<0.001) varied across artificial breeding colonies. Big nest boxes and holes were not equally present in all the towers: while 75 % of the towers had big nest boxes, only the 25% had big hole diameters. Despite nest boxes were located in different heights, the number of nests present in each height did not differ across colonies (χ^2 =13.37, df=38, p=0.999). In each colony, all these structural nest features remained constant from the construction of each colony until the last year of the present study (N hole diameters: χ^2 =2.13, df=19, p=1; N nest box sizes: χ^2 =10.04, df=38, p=1; N nest in each height: χ^2 =3.53, df=58, p=1).

Reclassified categories of land-cover maps

The 241 land-use categories of the Land Cover Map of Catalonia were reclassified into the following 28 categories: 1) forest; 2) shrubland; 3) reed bed; 4) wetland; 5) bog; 6) saline habitat; 7) grassland; 8) dune; 9) burned area; 10) rocky habitat; 11) bare soil; 12) beach; 13) glacier; 14) water body; 15) sea; 16) dry tree crops; 17) irrigated tree crops; 18) urban; 19) vineyard; 20) irrigated herbaceous crop; 21) dry herbaceous crop; 22) crops in transformation; 23) abandoned tree crops; 24) vegetable garden; 25) farm; 26) green infrastructure; 27) roads; 28) dumps.

Description of responses and predictors

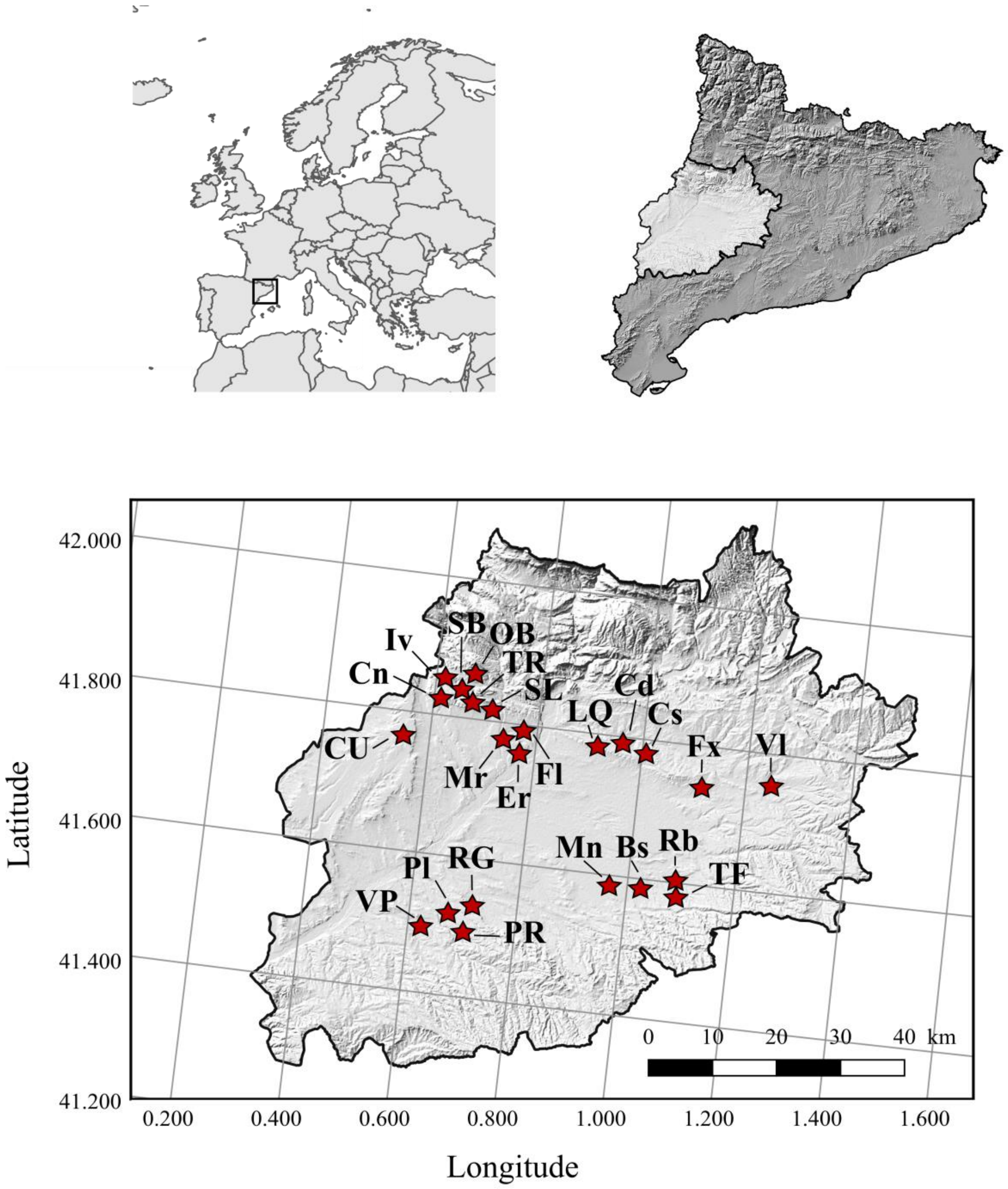
Response and explanatory variables used to investigate which environmental and social cues are used during colonization and colony growth stages of colony development.

Variables	Description
Response variables	
Colonization stage	
Colonization lag	Colonization occurring immediately after tower construction (0) or later (1)
Group colonization	Colonization done by 1 pair (0) or more (1)
Nest box occupation	Nest box occupied (1) or not (0)
Colony growth stage	
Nest box occupation for first time	Nest box occupied for first time (1) or not (0)
Colony growth rate	Number of new pairs from one year to the next
Environmental predictors	
Habitat heterogeneity	Habitat heterogeneity measured as Shannon diversity index
Land use intensification	Gradient from intensive dryland monocultures to mosaic landscapes (factor 1)
Irrigation	Gradient from irrigated crops to dryer habitats (factor 2)
Open natural habitat	Area of open natural habitats (grasslands and shrublands)
Grassland	Area of grassland
Shrubland	Area of shrubland
Farms	Number of farms
Dumps	Distance to the closest dump
Social predictors	
Number of conspecifics	Number of conspecifics breeding at the colony the year before
Number of heterospecifics	Number of heterospecifics breeding at the colony the year before
Fledging success	Mean fledging success of the cospecifics breeding at the colony the year before

Variables	Description
Structural predictors	
Hole size	Hole diameter size (big vs. small)
Nest box size	Nest box size (big vs. small)
Nest box height	Nest box height (highest row, middle row or lowest row)
Confouding variables	
Abandoned houses	Number of abandoned houses within a radius of 3865m (median breeding dispersal distance)
N surveys	Number of surveys done during the nestling period
Year	Year
Climatological conditions during breeding season	Gradient from wet to dry climatic conditions (factor 1)
	Gradient from hot and variable to colder and less variable temperatures (factor 2)

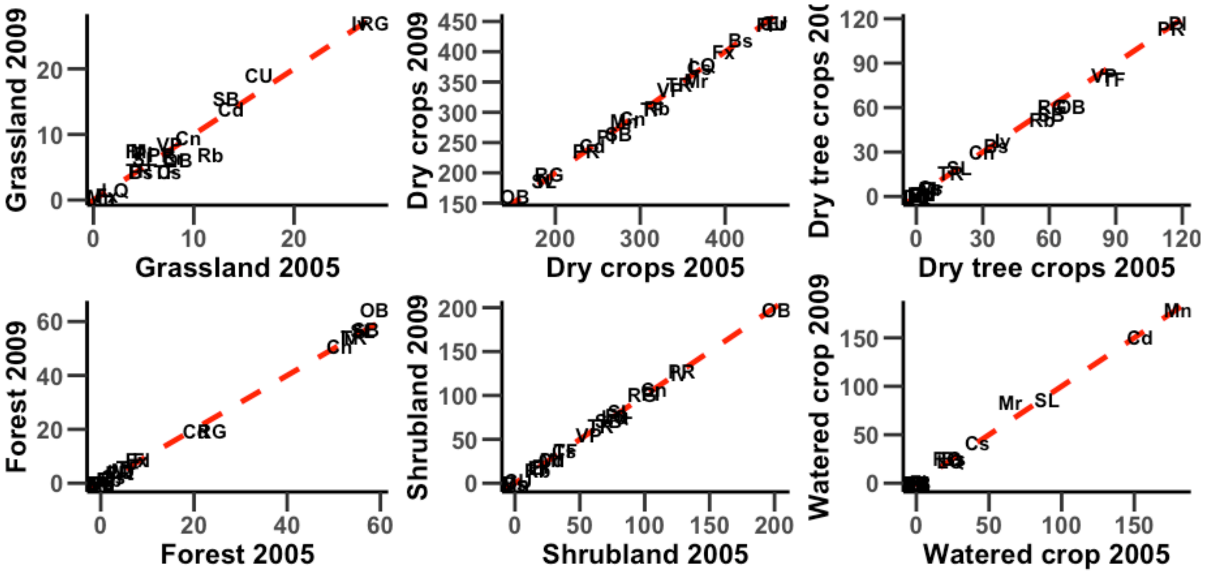
Supplementary Figures

Supplementary Figure 1. Spatial distribution of artificial breeding towers built in the Lleida plain (N=23). Find here the complete colony names corresponding to each abbreviation: CU (Clot Unilla), Cn (Cantaperdius), Iv (Ivars), SB (Santa Barbara), OB (Os de Balaguer), TR (Tossal Rodó), SL (Serra Llarga), Mr (Mormur), Er (Ermitans), Fl (Fuliola), LQ (Les Quadres), Cd (Cadolles), Cs (Caserna), Fx (Foixet), Vl (Vilassos), VP (Vall dels Pous), Pl (Palmero), RG (Roca la Guilla), PR (Pla de Roquís), Mn (Montrepòs), Bs (Biscarri), Rb (Rabinat), TF (Tossal de la Fonta).

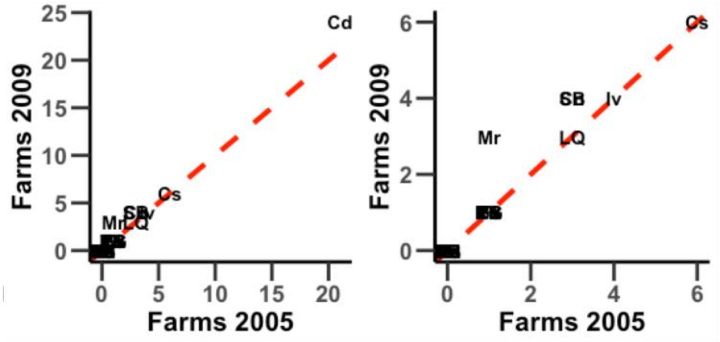


Supplementary Figure 2. Land cover data from 2005 and 2009 were used to evaluate changes in land-use over an area of 5 km^2 around each tower (mean UD 95% area). We did not find substantial changes between land-uses (A), but we did find changes in presence of farms (B).

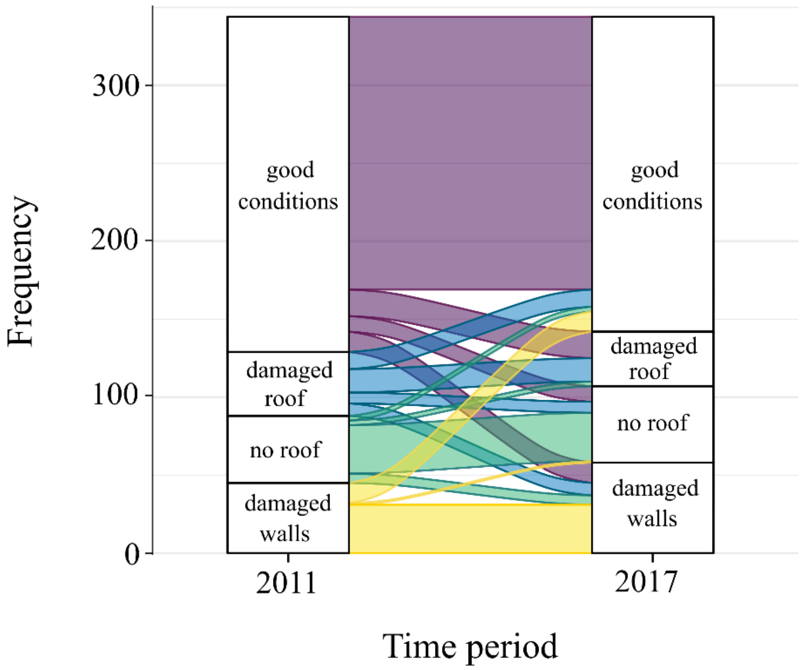
A)



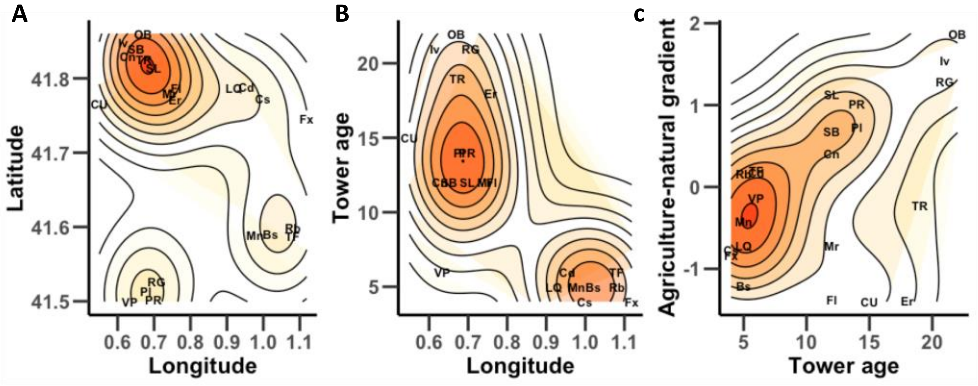
B)



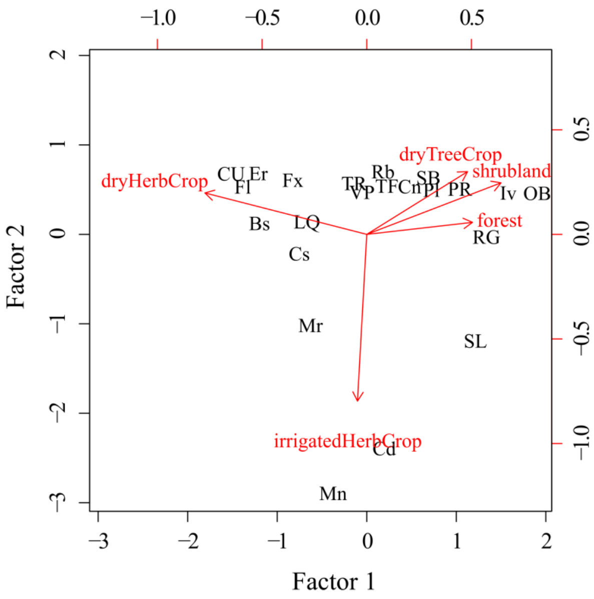
Supplementary Figure 3. Alluvial diagram showing how the condition of abandoned houses has changed during the period between 2011 and 2017.



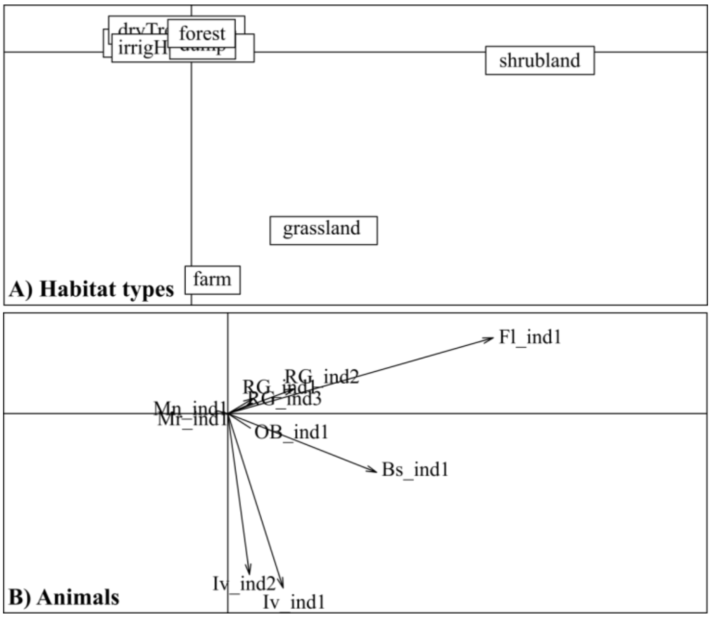
Supplementary Figure 4. Towers were concentrated in three main areas (A). They were built between 1998 and 2014, with the first towers being built in the west (B) and along the agriculture-natural gradient (C). Instead, newest towers were mostly built in the east and were located in areas of high agriculture intensification.



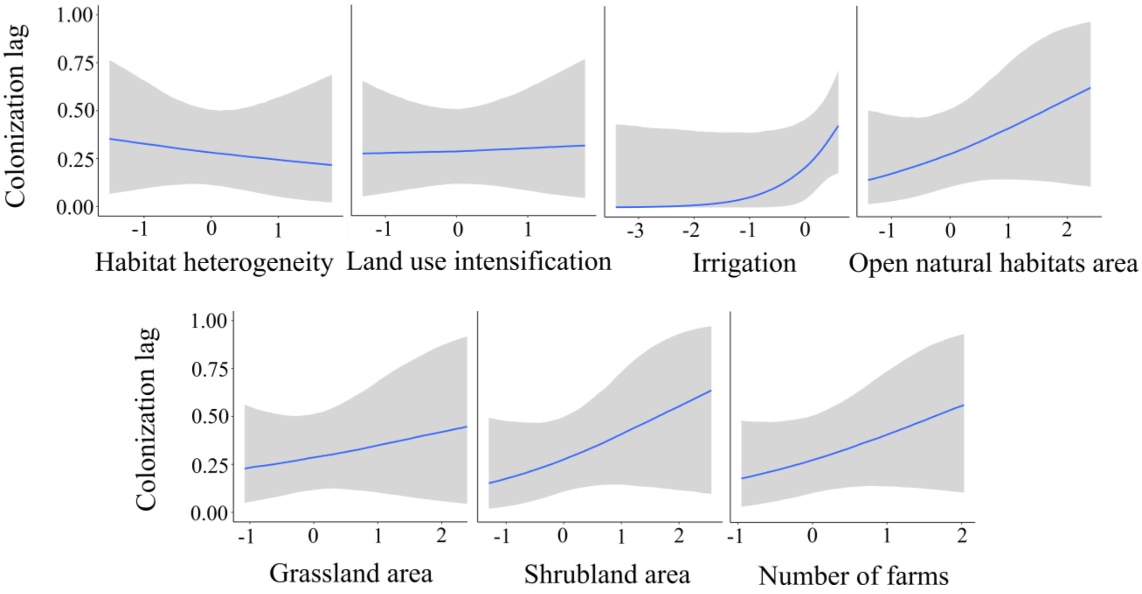
Supplementary Figure 5. Factor analysis of habitat variation with the most represented habitats around towers: dry herbaceous crops, dry tree crops, shrubland, forest and irrigated herbaceous crops. Top and right axes provide the loading values of the different habitats, while left and bottom axes provide the score values of towers.



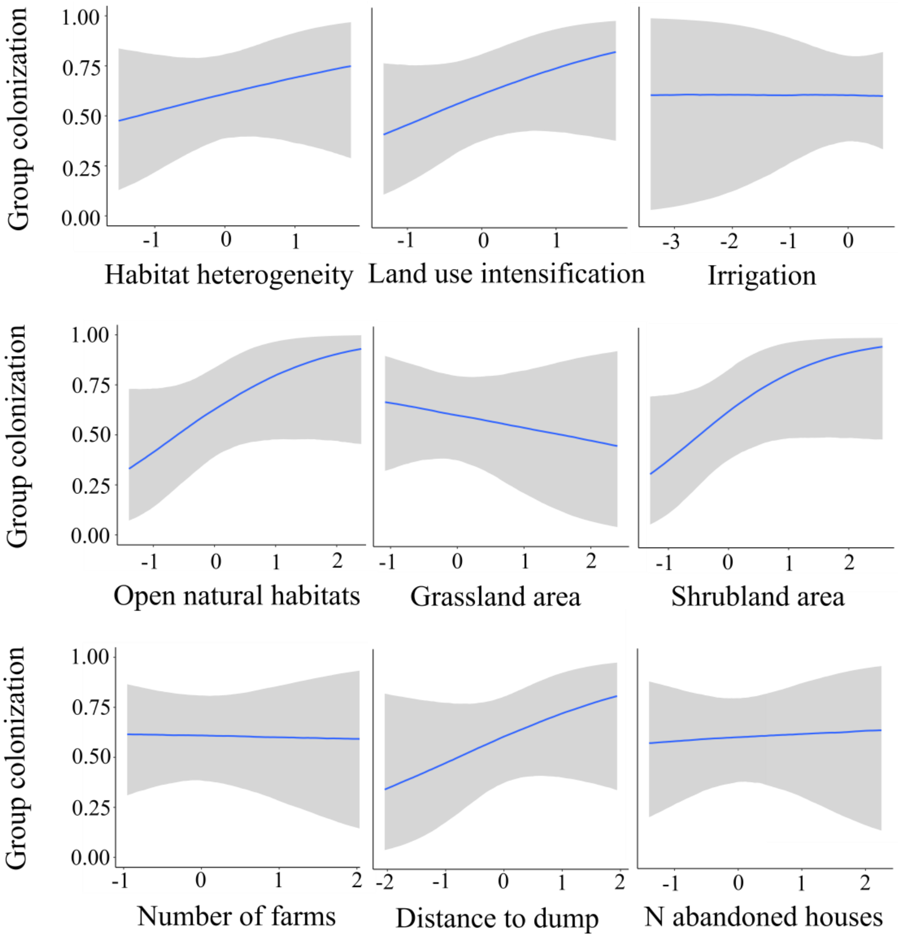
Supplementary Figure 6. Eigenanalysis of selection ratios at the 95% volume contour of the utilization distribution of each individual, showing the habitat loadings for the first two axes (A) and the scores for each tracked individual (B). Individual labels indicate the colony and the individual tracked. Habitats included are dry herbaceous crops, dry tree crops, forest, irrigated herbaceous crops, shrubland, grassland, farms and dumps.



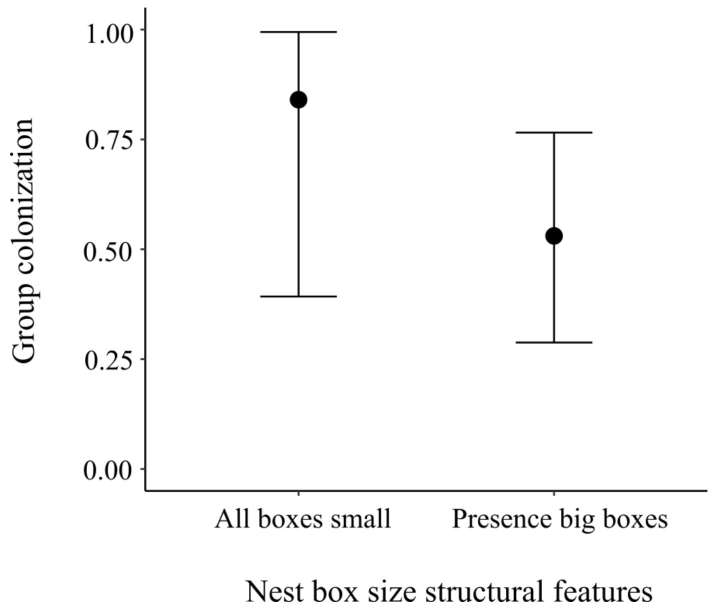
Supplementary Figure 7. Effects of environmental conditions (standardized) surrounding colonies on colonization lag. Solid lines and shaded areas show the mean predicted probabilities and 95% CI derived from univariant Bayesian generalized mixed models. In all cases, the CI 95% intervals of environmental predictors overlapped 0.



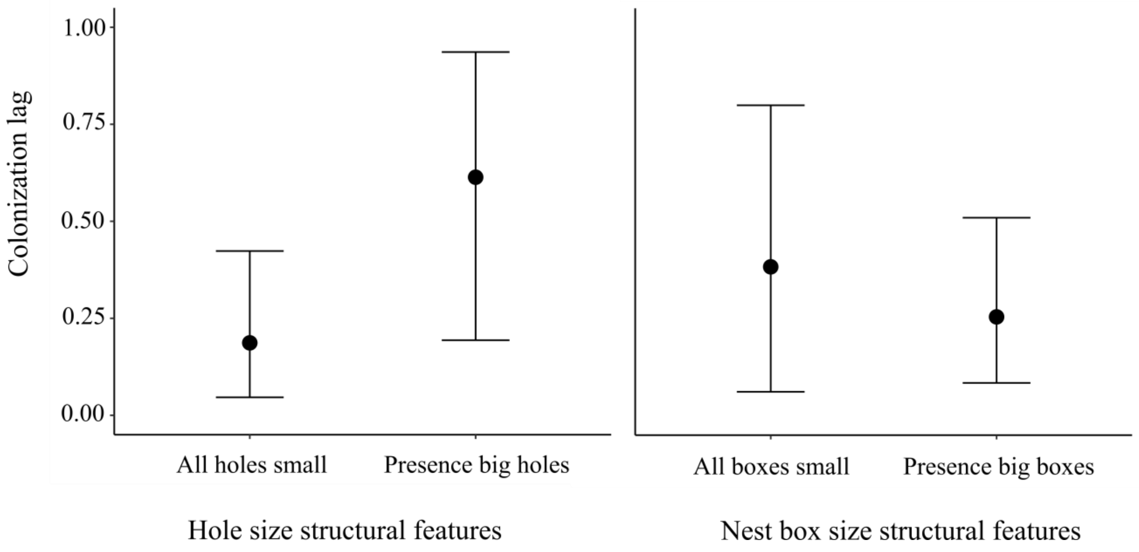
Supplementary Figure 8. Effects of environmental conditions (standardized) surrounding colonies on group colonization. Solid lines and shaded areas show the mean predicted probabilities and 95% CI derived from univariant Bayesian generalized mixed models. In all cases, the CI 95% intervals of environmental predictors overlapped 0.



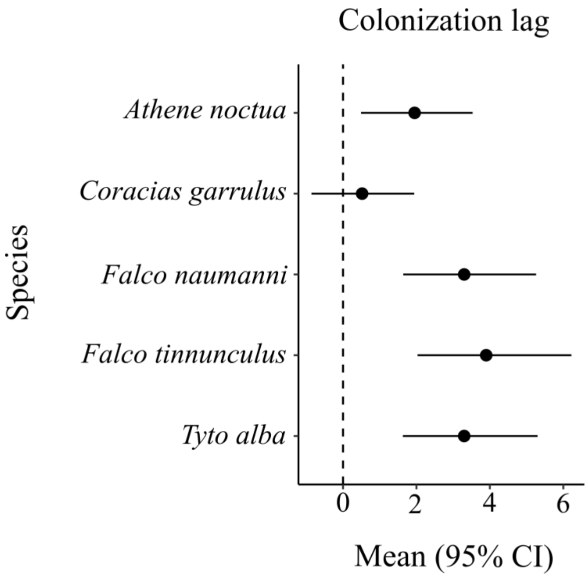
Supplementary Figure 9. Effect of nest box size on group colonization. Large dots with error bars show mean predicted probabilities and 95% CI derived from a univariant Bayesian generalized mixed model. The CI 95% interval of the predictor overlapped 0.



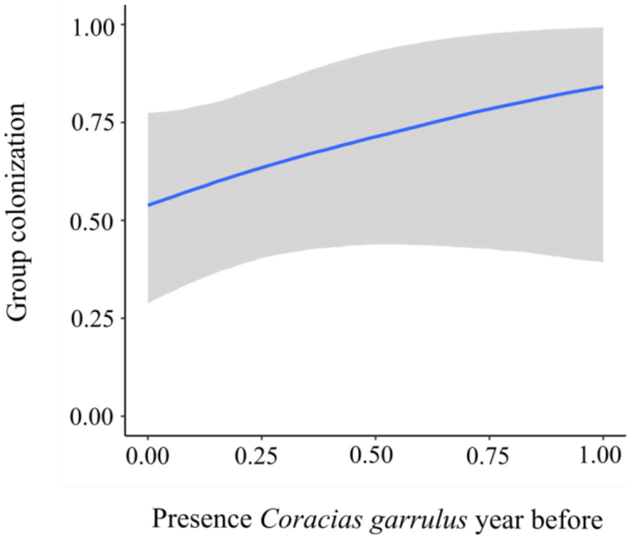
Supplementary Figure 10. Effect of nest box features on colonization lag. Large dots with error bars show mean predicted probabilities and 95% CI derived from univariant Bayesian generalized mixed models. The CI 95% intervals of predictors overlapped 0.



Supplementary Figure 11. Species effect on colonization lag. Posterior estimates and 95% CI derived from a Bayesian generalized mixed model of time lag as a function of species, including colony as random factor. For species variable, *Corvus monedula* is the reference level.

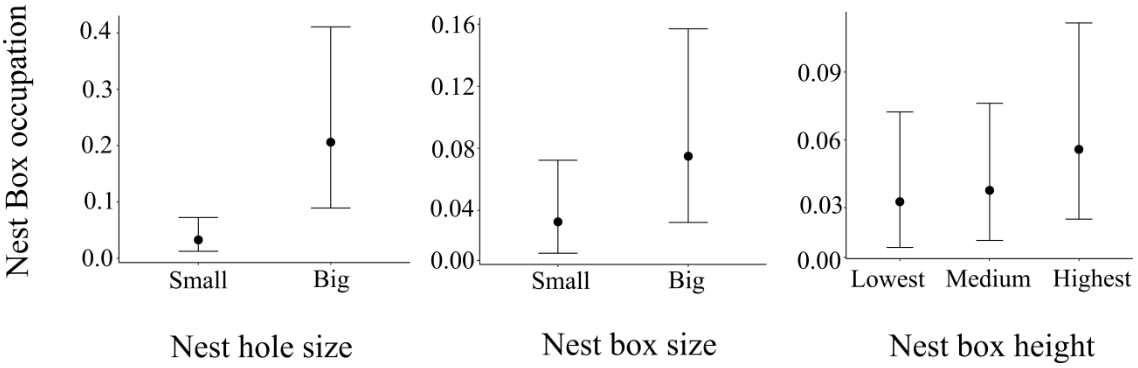


Supplementary Figure 12. Effect of the presence of *Coracias garrulus* in the colony the year before on group colonization. Solid line and shaded area show the mean predicted probability and 95% CI derived from a univariant Bayesian generalized mixed model. The CI 95% interval of the predictor overlapped 0.

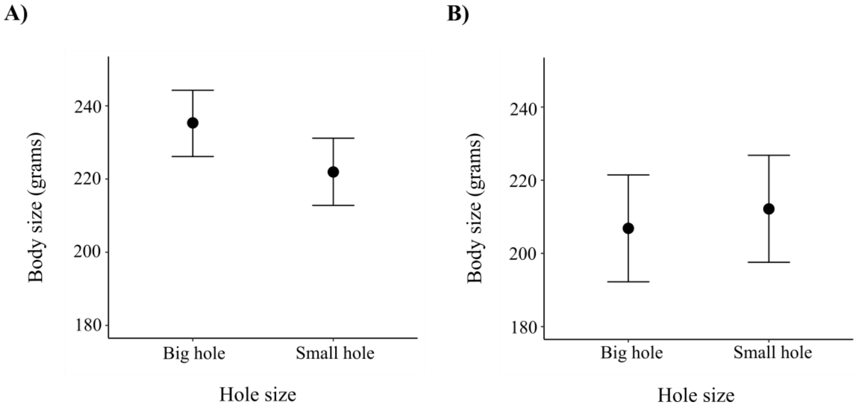


Supplementary Figure 13. Effect of colony antiquity on colonization lag. Solid line and shaded area show the mean predicted probability and 95% CI derived from a univariant Bayesian generalized mixed model. The CI 95% interval of the predictor overlapped 0.

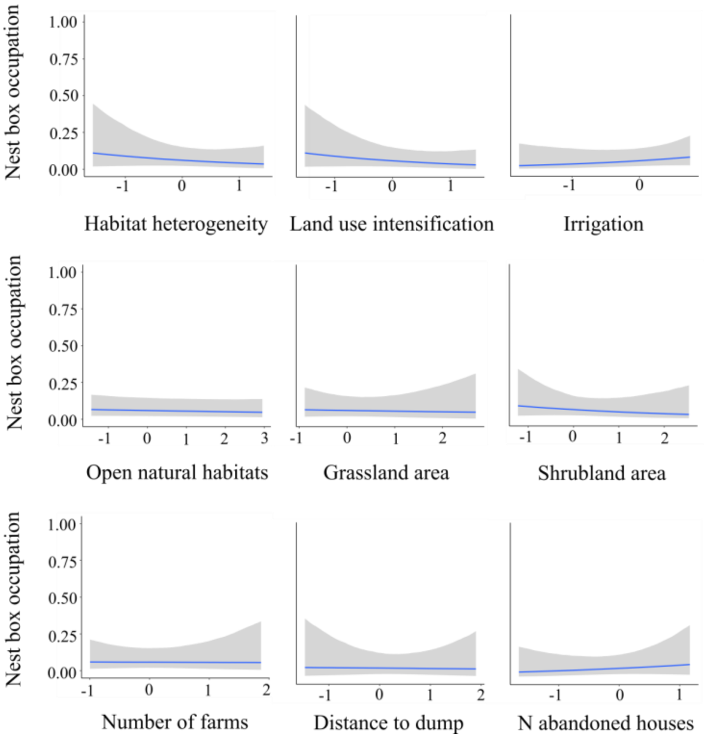
Supplementary Figure 14. Effects of nest structural features on nest box occupation during colony growth. The probability to occupy a nest box increased with hole size (CI 95% = 1.19 – 3.07) (A), nest box size (CI 95% = 0.40 – 1.45) (B) but not with nest height (CI 95% nests at middle row = -0.48 – 0.80; CI 95% nests at highest row = -0.05 – 1.23) (C). Large dots with error bars show mean predicted probabilities and 95% CI derived from a Bayesian generalized mixed model of nest box occupation as a function of hole size, nest box size and nest height and including colony, year and nest box as random factors.



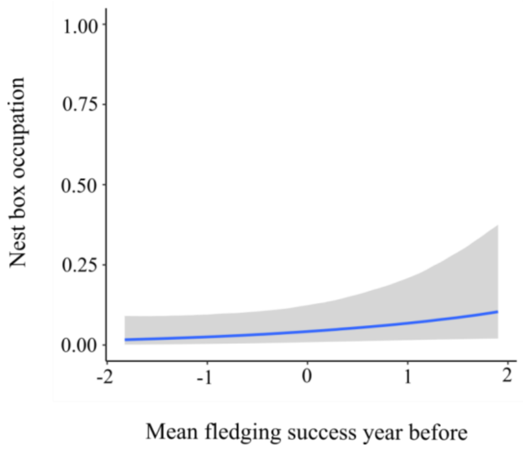
Supplementary Figure 15. Effects of hole size on nester body size. Small holes were occupied for small individuals in the largest members of a pair (CI 95% = -23.35 – -3.21) (A), but not in the smallest members of the pair (CI 95% = -12.11 – 22.84) (B). Large dots with error bars show mean predicted probabilities and 95% CI derived from univariant Bayesian generalized mixed models.



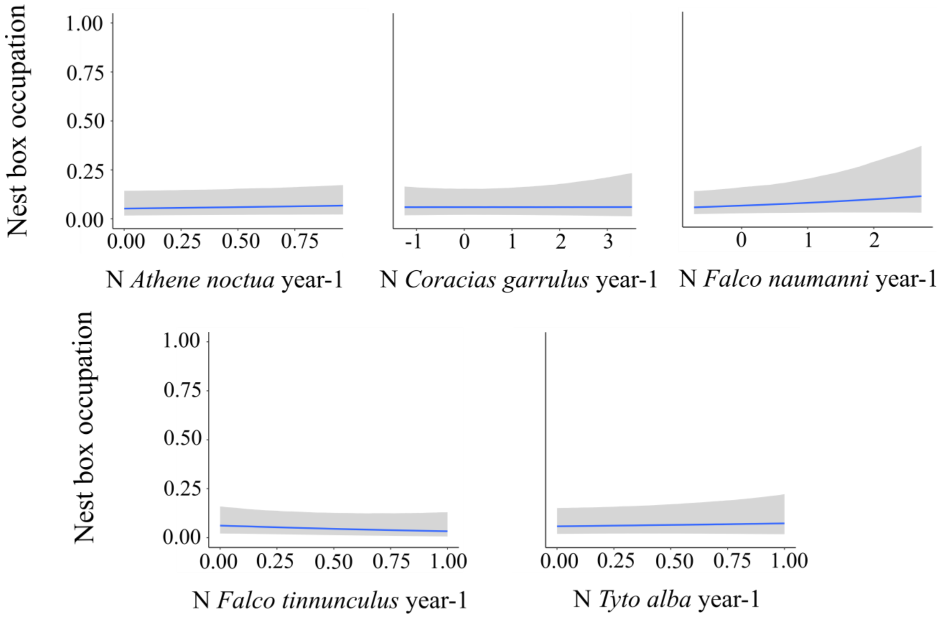
Supplementary Figure 16. Effects of environmental conditions (standardized) surrounding colonies on nest box occupation during colony growth. Solid lines and shaded areas show the mean predicted probabilities and 95% CI derived from univariant Bayesian generalized mixed models including colony, year and nest box as random factors. In all cases, the CI 95% intervals of environmental predictors overlapped 0.



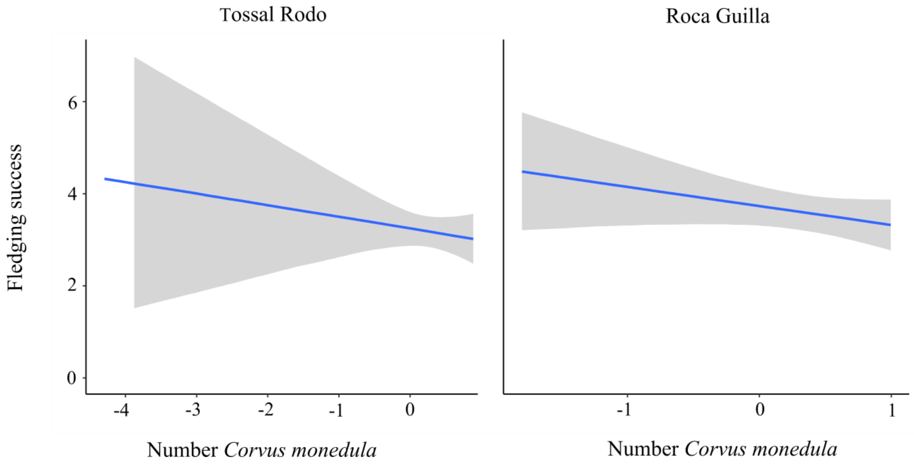
Supplementary Figure 17. Effects of mean fledging success during the year before on nest box occupation during colony growth. Solid line and shaded area show the mean predicted probability and 95% CI derived from a Bayesian generalized mixed model of nest box occupation as a function of mean fledging success of a colony the year before (standardized) and the mean number of surveys done during the nestling period the year before (standardized), including colony, year and nest box as random factors. The CI 95% intervals of predictors overlapped 0.



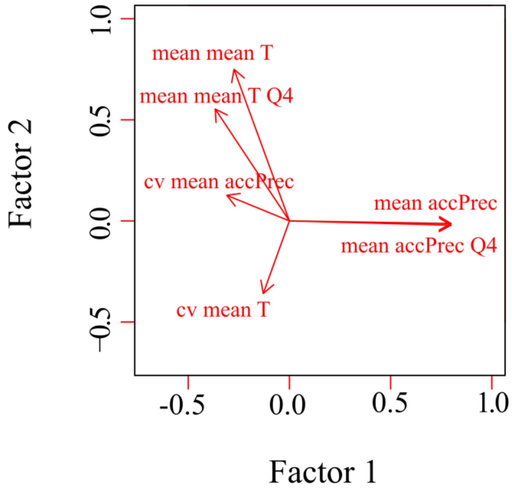
Supplementary Figure 18. Effects of the number of heterospecifics breeding in the colony the year before on nest box occupation during colony growth. Solid lines and shaded areas show the mean predicted probabilities and 95% CI derived from a Bayesian generalized mixed model including the presence of *Athene noctua*, *Coracias garrulus*, *Falco naumanni*, *Falco tinnunculus* and *Tyto alba* as predictors and colony, year and nest box as random factors. The CI 95% intervals of all predictors overlapped 0.



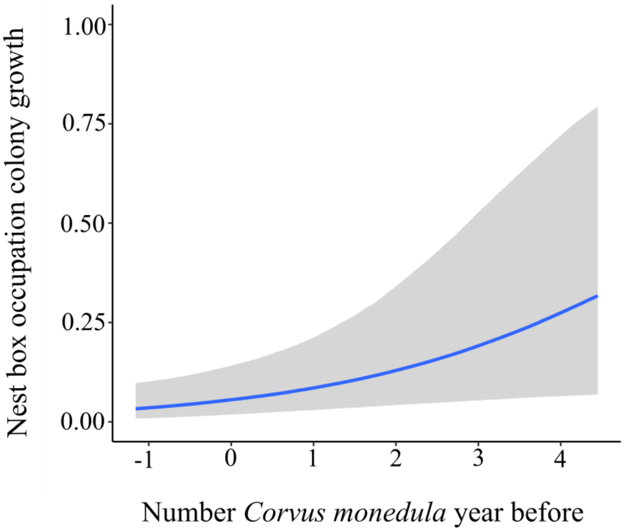
Supplementary Figure 19. Effects of the number of conspecifics on fledging success during colony growth in two of the colonies that experienced a greater occupation across time. Solid lines and shaded areas show the mean predicted probabilities and 95% CI derived from Bayesian generalized mixed models (each colony tested separately) of mean breeding success as a function of the number of conspecifics in the colony, the mean number of surveys done during the nestling period (standardized) and the first and second factors of climatic variation (standardized) as predictors, and including nest box as random factors. The CI 95% intervals of predictors overlapped 0.



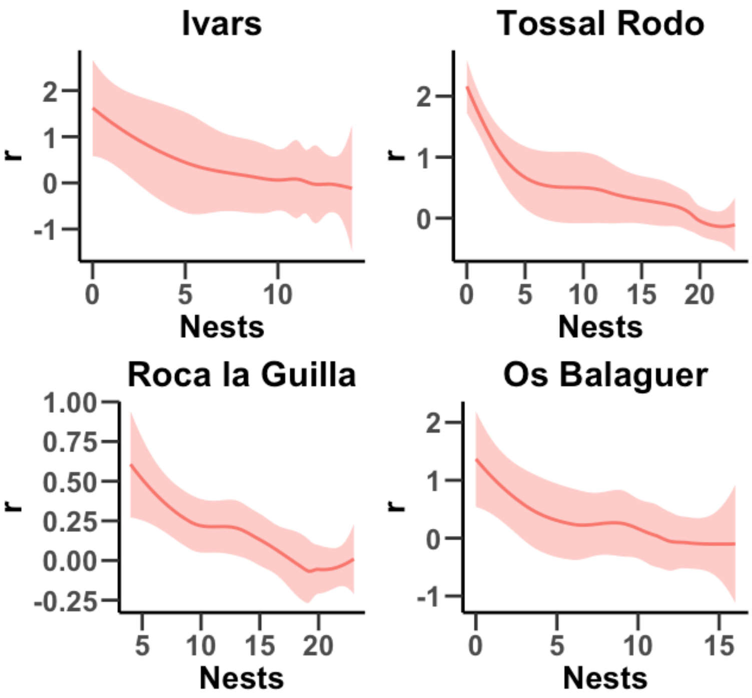
Supplementary Figure 20. Factor analysis of climatic variation showing the loadings of the first and second factors. Climatic variables measured the mean, variation (estimated as the coefficient of variation) and extreme values (estimated as the mean value of the 75%-95% Quantile) of daily mean Temperature and accumulated precipitation for each tower during the breeding season of the studied period.



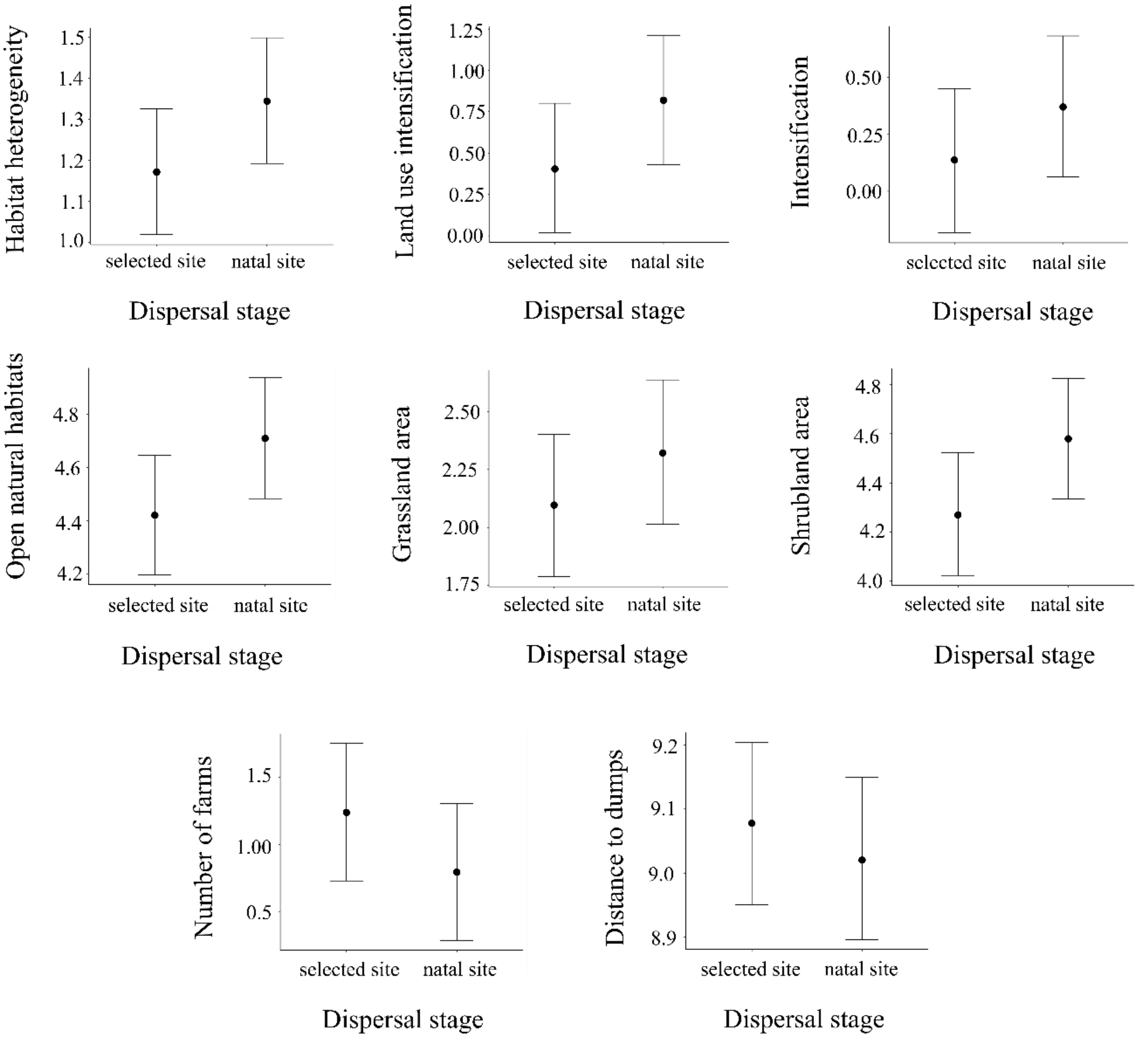
Supplementary Figure 21. Effects of the number of conspecifics during the year before on nest box occupation during colony growth. Solid line and shaded area show the mean predicted probability and 95% CI derived from a univariant Bayesian generalized mixed model including colony, year and nest box as random factors. The CI 95% interval of the predictor was 0.09 – 0.94.



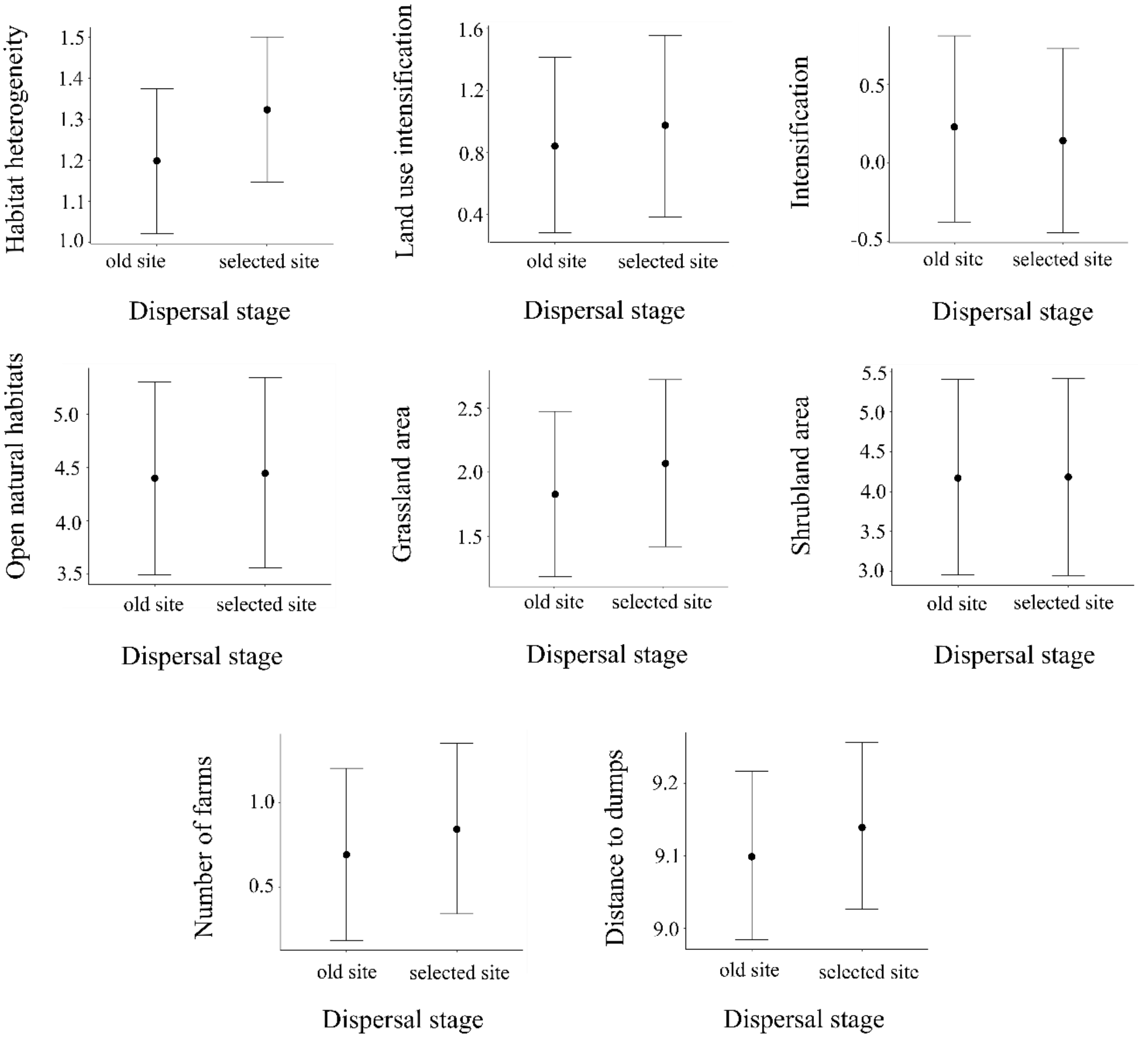
Supplementary Figure 22. Relationship between population growth rate and number of nests occupied for the four oldest towers. Population growth rate (r) is expressed as finite rate of increase, that is, the log of the equation $Nests_{t+1}/Nests_t$. Lines and 95% confidence intervals are based on Loess regressions.



Supplementary Figure 23. Effects of early experience on selected environmental conditions (log and square-root transformed). Large dots with error bars show mean predicted probabilities and 95% CI derived from univariant Bayesian generalized mixed pairwise models testing environmental conditions as a function of natal dispersal stage (natal site vs. selected site for first breeding), including individual as a random factor. In all models, the CI 95% intervals of predictors overlapped 0.



Supplementary Figure 24. Effects of adult experience on selected environmental conditions (log and square-root transformed). Large dots with error bars show mean predicted probabilities and 95% CI derived from univariant Bayesian generalized mixed pairwise models testing environmental conditions as a function of breeding dispersal stage (old breeding site vs. selected breeding site), including individual as a random factor. In all models, the CI 95% intervals of predictors overlapped 0.



Supplementary Tables

Supplementary Table 1. Loadings and explained variance of the first two axis of a factor analysis done with the most represented habitats around towers.

	PC1	**PC2**
Area dryland herbaceous crops	-0.966	0.247
Area dryland tree crops	0.602	0.375
Area forest	0.631	0
Area shrubland	0.801	0.308
Area irrigated herbaceous crops	0	-0.996
Proportion of Variance (%)	46.8 %	25.9 %

Supplementary Table 2. Manly's selection ratios at the 95% volume contour of the utilization distribution of each tracked individual. Selection ratios approaching 1 indicate that habitat use is in proportion to its availability. Thus, selection ratio values smaller than 1 indicate avoided habitats whereas selection ratios larger than 1 indicate selected habitats.

	RG	RG	RG	Mn	Iv	Iv	Mr	Bs	Fl	OS
	Ind 1	Ind 2	Ind 3	Ind 1	Ind 1	Ind 2	Ind 1	Ind 1	Ind 1	Ind 1
Dry herbaceous crops	0.98	0.72	0.80	1.59	0.30	0.55	1.00	0.81	0.14	0.84
Dry tree crops	0.14	0.19	0.65	NA	0.04	0.06	NA	0.36	NA	0.67
Forest	1.03	0.11	6.78	NA	0.37	0.56	0	NA	NA	1.85
Irrigated herbaceous crops	0.33	NA	1.07	0.65	NA	NA	NA	0.37	NA	0.14
Shrubland	1.38	2.58	1.84	0	0.58	0.79	0	16.97	12.36	1.60
Grassland	0.46	0.11	0.72	NA	8.95	3.40	NA	11.77	NA	2.28
Farms	0	NA	3.11	NA	2.90	30.94	NA	0.09	NA	3.04
Dumps	2.85	NA	5.90	NA	NA	NA	NA	NA	NA	NA

Supplementary Table 3. Bayesian generalized mixed model of the mean breeding success at year t+1, measured as the number of fledglings per nest, as a function of the number of Jackdaw pairs at year t (standardized) and the difference of the number of surveys done across years t+1 and t (standardized). Colony and year were included as random factors.

(N=47)	**Estimate**	**Est. error**	**l 95% CI**	**u 95% CI**	**Eff. sample**	**Rhat**
Fixed factors						
Intercept	2.98	0.32	2.37	3.68	2375	1.00
Mean breeding success year t	0.25	0.25	-0.25	0.74	4191	1.00
Difference number surveys across years t+1 and t	-0.21	0.22	-0.64	0.23	4359	1.00
Random factors						
Year	0.65	0.33	0.07	1.40	1325	1.00
Colony	0.38	0.29	0.02	1.09	2237	1.00

Supplementary Table 4. Bayesian generalized mixed model of the mean breeding success at year t+2, measured as the number of fledglings per nest, as a function of the number of Jackdaw pairs at year t (standardized) and the difference of the number of surveys done across years t+2 and t (standardized). Colony and year were included as random factors.

(N=39)	**Estimate**	**Est. error**	**l 95% CI**	**u 95% CI**	**Eff. sample**	**Rhat**
Fixed factors						
Intercept	2.89	0.27	2.36	3.43	3308	1.00
Mean breeding success year t	0.36	0.20	-0.03	0.77	4412	1.00
Difference number surveys across years t+2 and t	-0.08	0.21	-0.48	0.33	3845	1.00
Random factors						
Year	0.50	0.32	0.02	1.23	1295	1.00
Colony	0.29	0.24	0.01	0.89	2344	1.00

Supplementary Table 5. Pearson's correlation coefficients of a correlation matrix for the variables (standardized) describing climatic variation.

	Standardized Mean daily mean T 4Q	Standardized Mean daily accPrec 4Q	Standardized cv daily mean T	Standardized cv daily accPrec	Standardized Mean daily mean T
Mean daily accPrec	-0.48	1	-0.16	-0.40	-0.37
Mean daily mean T	0.81	-0.36	-0.37	0.28	-
cv daily accPrec	0.28	-0.38	-0.05	-	
cv daily mean T	0.20	-0.14	-		
Mean daily accPrec 4Q	-0.46	-			

Supplementary Table 6. Loadings and explained variance of the first two axis of a factor analysis describing climatic variation.

	PC1	**PC2**
Mean daily accPrec	0.998	0
Mean daily mean T	-0.342	0.937
cv daily accPrec	-0.387	0.158
cv daily mean T	-0.162	-0.448
Mean daily accPrec 4Q	0.998	0
Mean daily mean T 4Q	-0.458	0.692
Proportion of Variance	41.6%	26.4%

Chapter 3

Body size and nest predation in passerine birds

Unzeta, M., Martin, T.E. and Sol, D.

Under submission

Abstract

Despite widespread interest in the observed trend of organisms to increase in size over evolutionary time (Cope's rule), little effort has been spent in examining the costs of being larger. Larger species have extended development periods, which are thought to increase risk of offspring predation, potentially selecting against larger size. In birds, this source of selection can be important because predation is the main source of offspring mortality and predators should be more able to detect larger nest structures associated with larger body sizes. Here, we present a broad comparative analysis of 511 populations of 321 passerine species to assess the relationship between body size and nest predation rates. We found that, counter to expectations, larger species suffered lower nest predation rates than smaller species. Nest predation rates were phylogenetically conserved and showed substantial geographic variation, but none of these factors occluded the pattern of lower predation among larger species. We provide evidence that parents of larger species behaviorally attack a wider array of predator body sizes, potentially explaining their lower offspring predation rates. These results highlight the importance of behavior as a mechanism that can alter selection pressures, and provide a new explanation contributing to Cope's rule.

Keywords: body size evolution, nest predation, anti-predator behavior, life history, passerines.

Introduction

Body size subsumes much of an organism's biology, influencing almost all aspects of their ecology (Blueweiss et al. 1978; Peters 1983; Calder 1984; Saether 1989). Consequently, understanding how body size evolves has long been considered a central issue in evolutionary biology. Past theoretical and empirical work has largely focused on the benefits of larger bodies, perhaps influenced by the observed trend of organisms to increase in size over evolutionary time (Cope's rule). While the benefits of being large are beyond doubt (Watson 1949; Rensch 1959; Gould 1966; Schoener and Janzen 1968), the costs have been more rarely explored (Blanckenhorn 2000).

A potential cost of larger bodies is the need to extend the development period, which makes offspring more exposed to predation, parasitism and starvation (Blanckenhorn 2000). In birds, this cost can be particularly relevant for two reasons. First, predation is one of the most important sources of offspring mortality and longer exposure time from longer development times can increase risk of predation (Ricklefs 1969; Martin 1992a). Second, larger species need to construct larger nests that are more conspicuous and more likely to be detected by predators (Snow 1978; Slagsvold 1989; Biancucci and Martin 2010). Some studies of relatively small numbers of species found that larger species and nests experience higher nest predation rates (Murphy and Fleischer 1986; Møller 1990; Biancucci and Martin 2010; Mouton and Martin 2019), but other studies found lower predation rates (Ricklefs 1969; Weidinger 2004; Remeš et al. 2012a). Thus, the influence of body size and associated nest size on nest predation rates remains unclear.

One issue that may have hindered progress in disentangling the relationship between body size and nest predation rates is the existence of substantial geographic variation in nest predation (Martin 1992b; Chalfoun et al. 2002; Thompson et al. 2002; Thompson 2007; Martin et al. 2017). At broad geographic scales, latitudinal and elevational differences in predator diversity and abundance (Fischer 1960; Brown 2001) may lead to substantial variation in nest predation pressures (Skutch. 1949; Snow 1978; Skutch 1985; Thompson et al. 2002; Thompson 2007; Boyle 2008; Nana et al. 2015). At local scales, habitat type and configuration can also affect nest predation (Chalfoun et al. 2002; Thompson and Burhans 2003). Such variation in the exposure to predators may obscure a body size–nest predation relationship, highlighting the need for broad tests across a large array of species, habitats, and geographic locations.

Another possible influence on a body size–nest predation relationship is the potential of animals to proactively reduce predation risk through behavioral responses (Montgomerie and Weatherhead 1988; Martin 1992b). Birds for instance commonly respond to predators through a variety of active defense behaviors (e.g. direct attacks, distraction and defensive displays, alarm calls), which are chosen according to the risk that a predator entails (Gochfeld 1984). Evidence suggests that larger species engage in more vigorous defense against intruders (Ricklefs 1977; Weidinger 2002), although other strategies are also possible such as harassing predators by joining larger groups (Hoogland and Sherman 1976; Wiklund and Andersson 1994; Krams et al. 2009). Birds can also reduce nest predation by selecting less exposed nest locations (Martin 1993; Martin and Joron 2003; Colombelli-Négrel and Kleindorfer 2009) or by building more protected nests (Nice 1957; Snow 1978; Oniki 1985; Martin 1995; but see Martin et al. 2017). The link of these latter mechanisms to body size is less obvious, but they have the potential to obscure the relationship between body size and nest predation.

Here, we examine possible relationships between body size and nest predation rates by means of phylogenetic-based comparative analyses. We focus on passerine birds, a group that exhibits substantial body size variation (4 - 1135 g) while sharing a similar altricial development. Our analyses are based on a nest predation dataset of unusually large spatial extent and taxonomic diversity, comprising 510 populations of 321 species distributed across the world. A multi-scale analysis of this large dataset allowed us to rigorously test the relationship between body size and nest predation, and investigate the extent to which this relationship is explained by spatial variation and/or behavioral mechanisms that confer protection against predators.

Methods

Data collection on nest predation. We used nest predation data on passerine birds based on our personal field studies in five sites, and from studies reported in the literature (Supplementary Figure 1). Our personal field studies included nest predation data from five intensively studied field sites: i) a mixed conifer forest (at 2300 m elevation) in Arizona (34ºN) studied for 28 years, ii) a rain forest (between 1400-2000 m elevation) in Yacambu National Park, Venezuela (9ºN) studied for 7 years, iii) a rain forest (between 1450-1950 m elevation) in Kinabalu Park, Malaysian Borneo (6ºN) studied for 9 years, iv) a semi-evergreen subtropical montane forest, which forms part of the Andean tropical forest types (between 1000-2000 m elevation) in El Rey National Park, Argentina (24ºS) studied for 3 years and v) a mediterranean dwarf shrubland (between 0-60 m elevation) in Koeberg Nature Reserve, Western Cape Province, South Africa(33ºS) studied for 7 years. In each field site, nest predation rates were obtained from a large number of nests monitored following standardized long-term protocols (Martin 1993; Martin et al. 2017). Nests were checked every 2-4 days to determine their status and predation events, but were checked daily or twice daily during egg laying, near hatching and near fledging to obtain exact durations of developmental periods. Nest predation was assumed when all eggs or nestlings disappeared more than 2 days prior to average fledging age, and parents could not be found in the area feeding fledglings (Martin et al. 2017).

To further generalize the results, we added information on nest predation rates extracted from the literature, including both primary (detailed in Supplementary Data) and secondary sources (Martin 1993, 1995; Martin and Clobert 1996; Robinson et al. 2000; Remeš and Martin 2002; Remeš 2007; Matysioková et al. 2011; Remeš et al. 2012a, 2012b). Hole nesters were not considered in our analyses because they exhibit low nest predation rates (i.e., Lack 1954; Nice 1957; Martin 1995), that can obscure any body size relationships in more exposed nest types.

Data collection on body size. Body size of species was characterized in terms of adult body mass. For the species in the intensively studied field sites, body mass was measured with GemPro 250 portable electronic scales (MyWeigh, Phoenix, AZ, USA) in birds captured by mist nets (Martin 2015). For species where nest predation data were obtained from published sources, adult body mass was obtained from Dunning Jr. (2007).

Processing data on nest predation. Because not all nests were found at the beginning of the nesting cycle, nest predation was estimated as daily nest predation rates (Mayfield 1961). For the species from the intensively studied field sites, we estimated daily predation rates using the logistic exposure method (Shaffer 2004; Martin et al. 2017). However, most of the original sources for literature data provided nest predation estimates as the percentage of depredated nests. Following Ricklefs (1969), we transformed percentage of depredated nests to daily nest predation rates (DPR) by the formula $DPR = \frac{-[\ln(1-PR)]}{T}$, where PR is the proportion of depredated nests and T is the duration of nest cycle. The method of Ricklefs (1969) assumes that all nests are found at the beginning of the nesting cycle, but estimates using this method correlate well with those calculated by an alternative method (i.e., Beintema 1996) that varied T for simulated nests found at the middle stage of the nesting cycle (Matysioková et al. 2011; Remeš et al. 2012a). Following Remeš et al. (2012a), we estimated the duration of the nesting cycle by summing clutch size (assuming one egg laid per day), incubation period and nestling period. The information on these life history traits was collected from the Handbook of the Birds of the World Alive (Del Hoyo et al. 2018), the Birds of North America (Rodewald 2018) and original sources. Finally, we estimated nest predation rates during the entire development period (hereafter, total nest predation rates) by the formula $\mathrm{TotalPred} = 1 - \mathrm{DSR}^{\mathrm{time}}$ (Mayfield 1961), where time is the duration of nesting cycle.

Data collection on nest size. Measures of the outer height and diameter of nests were collected from The Birds of North America (Rodewald 2018), The Handbook of Australian, New Zealand and Antarctic Birds Vol. 5, 6 and 7 (Higgins et al. 2001, 2006; Higgins and Peter 2002) and the Handbook of the Birds of the World Alive (Del Hoyo et al. 2018). These measures were then used to estimate both nest side surface area as the half of an ellipse area (for open nests) and as the whole ellipse area (for domed nests) and nest top surface area as the area of a circle. Nest side surface area and nest top surface area were highly correlated, so we used the latter to maximize sample size.

Data collection for behavioral response to predators. A good surrogate of the anti-predatory potential of a species is to assess the body size of the predators that parents of the prey species can successfully attack. Consequently, we scored defense behavior as the body mass (range and maximum) of the bird and mammal predators that parents of the prey species has been reported to attack. The information on species agonistic behaviors was obtained from The Birds of North America (Rodewald 2018) and The Handbook of Australian, New Zealand and Antarctic Birds Vol. 5, 6 and 7 (Higgins et al. 2001, 2006; Higgins and Peter 2002), while the information on predator body mass was collected from the Animal Ageing and Longevity Database (Tacutu et al. 2018). We considered predators those species that were cited as nest or adult predators in The Birds of North America (Rodewald 2018) and The Handbook of Australian, New Zealand and Antarctic Birds Vol. 5, 6 and 7 (Higgins et al. 2001, 2006; Higgins and Peter 2002). The type of predator (bird or mammal) did not affect the relationship between body mass and maximum body size of predators, so they were pooled together in the final analyses. Data on body sizes of predators that the prey species can successfully attack are provided in the Supplementary Data.

Data collection on covariates. For each species in our data set, we extracted information on several factors that could affect the relationship between body size and nest predation: i) nest structure (open vs. domed), 2) nest location (ground, shrub or canopy), 3) habitat of the study site (open vs. forested) and 4) social organization (solitary vs. group breeders, the latter including cooperative breeding and colonial species). Information was obtained from original sources, the Handbook of the Birds of the World Alive (Del Hoyo et al. 2018), the Birds of North America (Rodewald 2018) and Cockburn (2006). We also collected data on the mean latitude, longitude and elevation of the study sites. Whenever the original articles did not provide coordinates or elevation of the study sites, we extracted the information based on the reported localities using Google Earth software (Google Inc. 2019). Finally, we used research effort estimates from Ducatez and Lefebvre (2014) to account for the fact that detection of agonistic behaviors can be increased in species that are more commonly studied. Research effort was based on the number of papers published for each species from 1978 to 2008 in the Zoological Record database.

Phylogeny. Phylogenetic trees were obtained from the global phylogeny of birds, available at www.birdtree.org (Jetz et al. 2012). To account for phylogenetic uncertainty, we built a maximum clade credibility tree (summary tree) for the first chunk of 1000 phylogenetic trees for each backbone, using Ericson et al. (2006) backbone and TreeAnnotator (a program included in the software BEAST v.1.8.0) (Drummond et al. 2012).

Modeling body size and daily nest predation. To investigate the relationship between body size and daily nest predation, we used Bayesian phylogenetic mixed models (BPMMs) with Gaussian error structures, as implemented in the MCMCglmm *R* package v2.20 (Hadfield 2010). We first used BPMMs to test the association between body size and daily nest predation. Nest predation rate measures were not totally independent from each other because of shared inheritance among species, and because several species and study sites accounted for multiple records. Thus, we included of phylogeny, species and study sites as random effects in the BPMMs, which proved to be the best random structure according to the Deviance Information Criterion (DIC). The proportion of daily nest predation variance explained for each random factor was assessed by means of intra-class correlation coefficients (ICC) (Nakagawa and Schielzeth 2010). Variation in the mean sqrt of daily predation rates across species was illustrated with a phylogenetic reconstruction based on the function “contMap” from Phytools R-package (Revell 2012).

Daily nest predation rates and body size estimates were, respectively, square-root and log-transformed prior to analyses to improve normality. We explored the possible contributing effects of nest location, habitat type, nest structure, latitude and elevation by including these variables as fixed effects (Z-transformed) in the model. We analyzed interactions between fixed factors and also examined whether nest predation relationships with elevation and latitude were better described by a polynomial than a linear model. To assess which predictors better explained daily nest predation variation, we performed a model selection approach based on phylogenetically informed DIC, in which a set of models containing all combination of traits were analyzed and compared. We also investigated the relationship between nest size and daily nest predation rates after accounting for body size effects. To avoid collinearity between nest size and body size, we estimated residual nest size as the residual from a BPMM of nest size (log-transformed) against body size (log-transformed). Using non-informative priors, each model was run for 3,100,000 iterations with a 100,000 burn-in and a thinning interval of 2000 to allow convergence. Model convergence was confirmed by ensuring that sample autocorrelation was < 0.1 and the number of iterations to obtain samples were at least 1000.

To ensure that the results were not affected by heteroscedasticity, the models were re-examined through a quantile regression approach. Current approaches to conduct quantile regression assume phylogenetic independence in the data. However, this assumption proved to be false (see Results). To tackle this limitation, we split our response variable (daily nest predation) into different quantiles along the values of the explanatory variable of interest (body size) and we then fitted a different BPMM for each quantile.

We also used BPMMs within a path analysis framework to test how social organization, the ability to attack large predators and nest size directly and/or indirectly influenced the relationship between body size and daily nest predation. Because the maximum predator size and the range of predator body sizes that species are able to attack were highly correlated, we used the former in this analysis to maximize sample size. The R package dSep (available at https://github.com/jmaspons/dSep) was used to test the fit of the causal models using the d-separation method (von Hardenberg and Gonzalez-Voyer 2013). All numerical variables were Z-transformed (mean centered with standard deviation=1) to allow assessment of the relative importance of each path. We used the Fisher's *C* statistic to test whether the predicted basis set of conditional independencies was fulfilled in the observational data (Shipley 2000, 2004; von Hardenberg and Gonzalez-Voyer 2013). The *C* statistic Information Criterion [CICc], an information criterion modified for small sample sizes and adapted to path analysis, was used to perform a model selection procedure (von Hardenberg and Gonzalez-Voyer 2013). The standardized path coefficients of the best fitted models (ΔCICc<2) were averaged following the conditional average method, where path coefficients of those paths not occurring in all models were averaged only between the models including that path (von Hardenberg and Gonzalez-Voyer 2013).

Results

Daily nest predation rates showed variation across geographic locations (ICC mode=0.26, CI=0.17-0.35). Predation rates increased towards the equator (Figure 1A; pMCMC latitude=0.026; pMCMC latitude^2=0.013; Supplementary Table 1) at similar rates in both north and southern hemispheres (pMCMC=0.106; Supplementary Table 2) but did not vary with elevation even after accounting for latitude (pMCMC=0.848; Supplementary Table 1). Ultimately, daily nest predation rates showed substantial variation across species (ICC species=0.40). Much of this variation was explained by the phylogeny (ICC phylogeny=0.33, CI=0.20-0.52; Supplementary Figure 2), indicating that differences were stronger between distantly-related species.

After accounting for regional and phylogenetic effects, we found a consistent decrease in daily nest predation rates with increasing body size (Figure 1B; pMCMC=0.004; Supplementary Table 3). The lower daily nest predation rates in larger species was statistically robust, as indicated by a regression by quantiles (Supplementary Figure 3), and the association remained strong after controlling for a number of potential confounding factors such as latitude, elevation, nest structure, habitat and nest location (Supplementary Table 1). In a model selection approach, body size and latitude emerged as the only predictors in the best model (pMCMC body size=0.002; pMCMC latitude=0.017; pMCMC latitude^2=0.001; Supplementary Table 4).

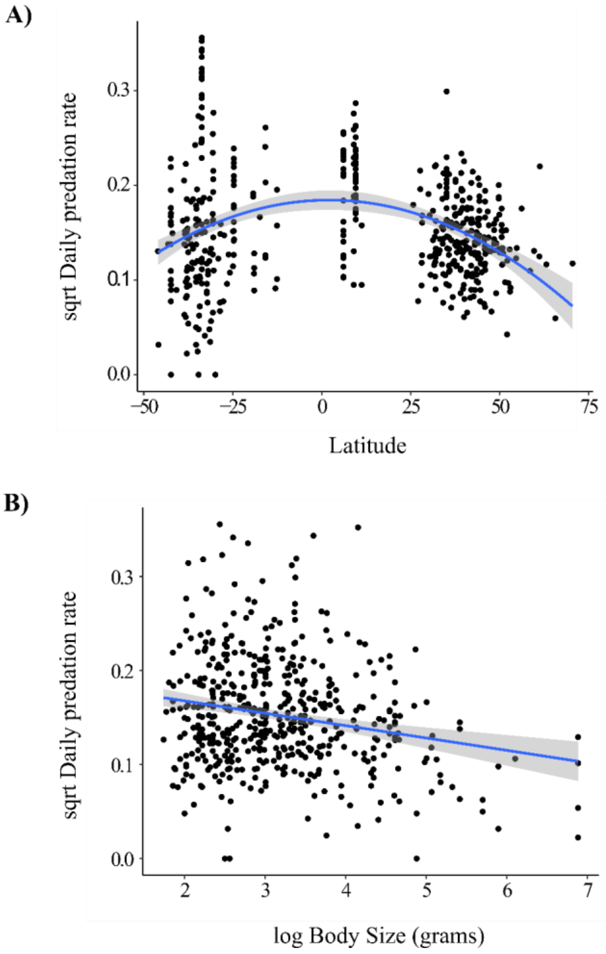


Figure 1. (A) Relationship between daily nest predation and latitude (N species = 270, N populations = 495) **(B)** Relationship between daily nest predation and body size across species (N species = 270, N populations = 422).

As expected, larger species had larger nests (Figure 2; pMCMC<0.001; Supplementary Table 5), which suffered lower daily predation rates (pMCMC=0.018; Supplementary Table 6). Nest size did not explain any additional variation in nest predation rates (pMCMC=0.156) after accounting for body size and latitude (Supplementary Table 7).

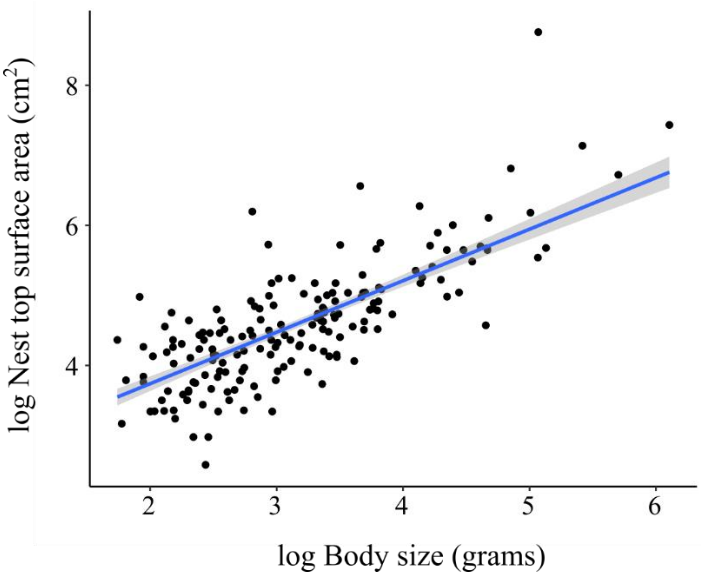


Figure 2. Nest top surface area of the nest increased with body size (N species = 176).

We found evidence that body size effects on nest predation rates reflected nest defense. Parents of bird species with larger body sizes attacked larger predators (Figure 3A; pMCMC=0.001; Supplementary Table 8) and a wider range of predator body sizes (Figure 3B; pMCMC=0.005; Supplementary Table 8). These anti-predatory abilities were in turn associated with lower daily nest predation rates (Figure 3C, 3D; pMCMC<0.002; Supplementary Table 9). Although species with abilities to respond toward larger and more diverse body sizes of predators often built nests that are larger than expected by their body size (pMCMC<0.006; Supplementary Table 10), larger nests still did not have significant added explanatory power for daily predation rates (pMCMC=0.282; Supplementary Table 11).

The range of predators that a species can defend against was also influenced by sociality. In particular, the maximum size of attacked predators was bigger in social breeders than in solitary breeders (pMCMC=0.001; Supplementary Table 12). Social breeders also exhibited a marginally significant tendency to be able to attack a broader range of predators (pMCMC=0.057; Supplementary Table 13). Sociality thus contributed to reduced daily predation rates (pMCMC=0.001; Supplementary Table 14). However, sociality was not related to body size, and hence did not explain the link between body size and daily predation rates (pMCMC=0.688; Supplementary Table 15).

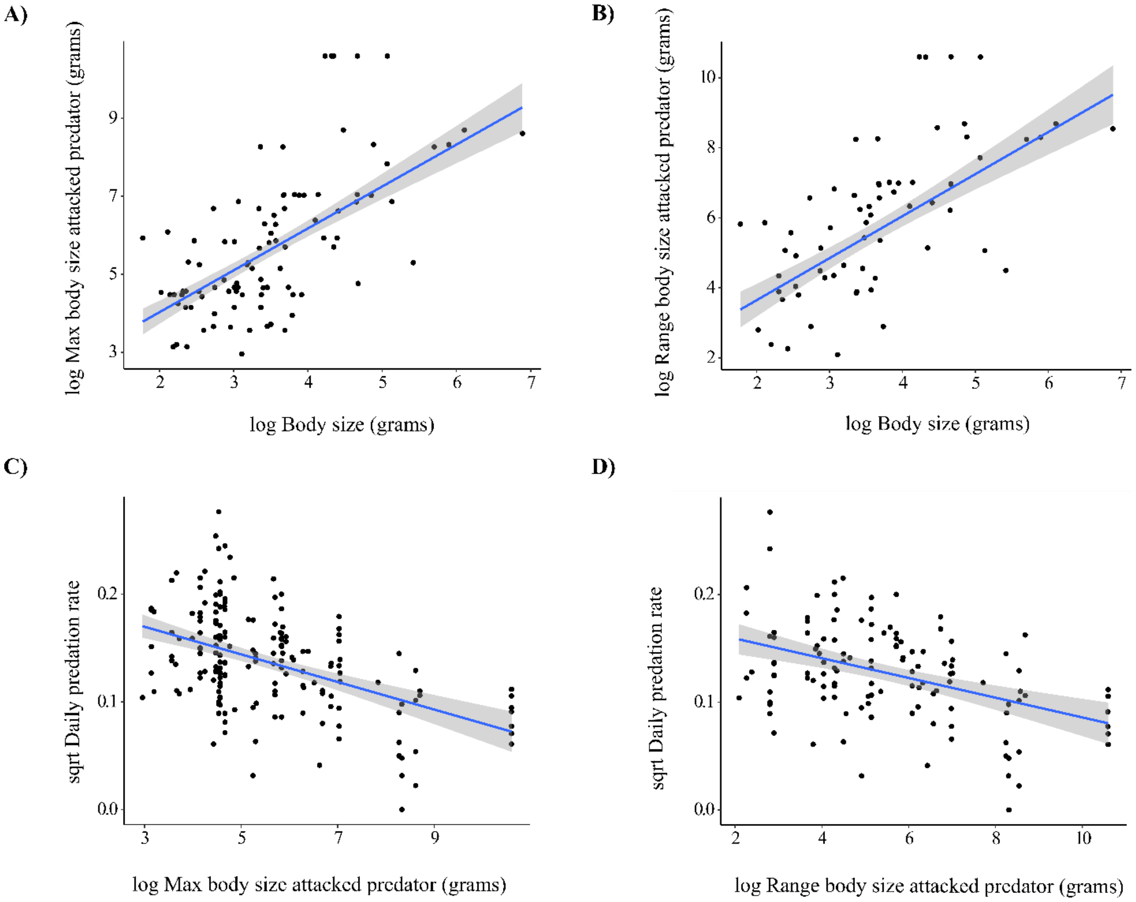


Figure 3. Species ability to respond towards bird and mammal predators and is related with body size and daily nest predation rates. Larger species were able to attack **(A)** larger (N species = 96) and **(B)** a wider range (N species = 65) of predator body sizes. Daily nest predation rates decreased with the ability to attack **(C)** larger (N species = 79, N populations = 152) and **(D)** a wider range (N species = 52, N populations = 98) of predator body sizes.

A phylogenetic path analysis further clarified direct and indirect effects of anti-predatory behavior, nest size and group breeding on the relationship between body size and nest predation (Supplementary Figure 4). The best supported models (Figure 4) indicated that social factors contribute to reduce daily nest predation rates indirectly by favoring anti-predatory behavior (path coefficient=1.02, pMCMC=0.002). However, group breeding was only slightly related to body size (path coefficient=0.12, pMCMC=0.042), and hence did explain the relationship between body size and daily nest predation. Instead, the relationship was better explained by the larger and more diverse array of predators that parents of larger species were able to deter. Thus, the best supported causal scenarios suggested that larger species show enhanced anti-predator behaviors (path coefficient=0.67, pMCMC<0.001) that are associated with reduced daily nest predation rates (path coefficient=-0.45, pMCMC<0.001) despite having larger, more conspicuous nests (path coefficient=0.90, pMCMC<0.001) that did not contribute to nest predation rates.

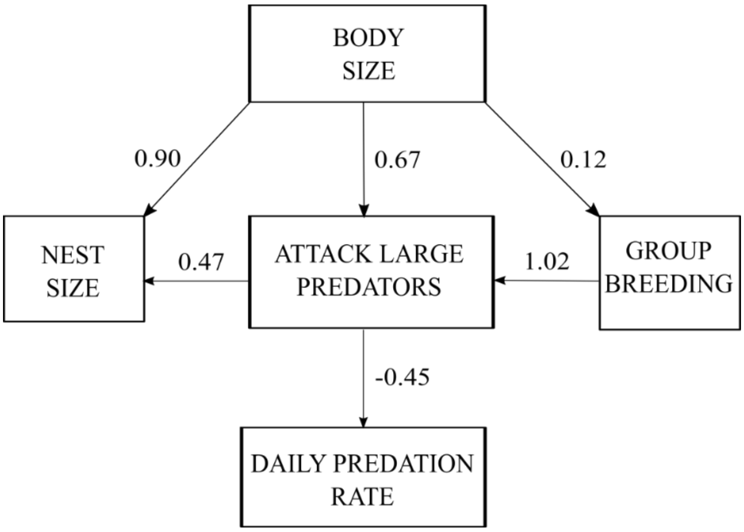


Figure 4. Path coefficients averaged among the best fitted models (ΔCICc<2) of a phylogenetic path analysis approach to test direct and indirect effects influencing the body size and daily nest predation relationship (n = 62 species, 116 populations).

The above analyses were based on daily predation rates, which may underestimate total predation pressure over the entire nesting cycle because the duration of the development period tends to be longer in larger species (Figure 5A; pMCMC<0.001; Supplementary Table 16). However, we found that larger species exhibited slightly reduced nest predation rates over the entire development period compared with smaller species (Figure

5B; pMCMC=0.026; Supplementary Table 17). This latter result indicates that the reduction in daily nest predation rates is sufficiently large as to compensate for the extended development time of larger species.

Discussion

The possible role of offspring predation risk as an influence on the broadly observed increase in body size over evolutionary time, Cope's rule, has received little consideration. Yet, we found that body size played an important role in explaining variation in nest predation rates among species beyond effects of phylogeny and spatial variation. Given the importance of reduced offspring predation to fitness (Ricklefs 1969; Martin 1992a; Thompson 2007; Remeš et al. 2012b), the reduction in nest predation among larger species could be an important contributor to the evolution of larger body size.

Our results of reduced predation in larger species are counter to long-standing arguments that their larger nests should cause higher nest predation (Snow 1978; Murphy and Fleischer 1986; Slagsvold 1989; Møller 1990; Biancucci and Martin 2010; Mouton and Martin 2019). Moreover, their daily nest predation rates were sufficiently reduced so as to compensate for the increase in development periods of larger species to yield lower predation rates over the entire nesting cycle. We show that this reduction may in part be achieved by anti-predator behavioral mechanisms that reduce the risk of predation. A larger body size provides physical advantages when confronting a wide array of predators (Rensch 1959; Borgmann and Conway 2015), which may reduce exposure risks (Montgomerie and Weatherhead 1988), allowing larger species to defend the nest against a larger number of potential predators (Werner and Gilliam 1984). We found evidence that a larger body allows parents of songbird species to deter a wider array of large and small predators (Werner and Gilliam 1984). These results align with previous studies reporting more aggressive nest defense behaviors in larger species (Larsen et al. 1996). Ultimately, we found that the ability to attack larger and more types of predators accounts for part of the negative co-variation between body size and nest predation rates.

The importance of defense to nest predation rates was further demonstrated by the effect of group breeding on increasing the ability to deter predators (Hoogland and Sherman 1976; Wiklund and Andersson 1994; Krams et al. 2009). Nonetheless, group breeding effects did not obscure the role of anti-predatory behavioral responses in mediating the relationship between body size and nest predation. Thus, our broad results from across the world confirm and generalize previous suggestions that enhanced anti-predatory defense capabilities of larger birds can substantially reduce the risk of nest predation (Ricklefs 1977; Weidinger 2002).

Body size relationships could be obfuscated to some extent by variation in other factors influencing nest predation risk. For example, predation pressures may vary geographically as a function of the diversity and abundance of local predators (Fischer 1960). Nest predation has long been argued to be greater in the tropics than north temperate zones (Skutch. 1949; Ricklefs 1969; Snow 1978), whereas the change with latitude in the southern hemisphere has been less clear (Martin 1996). Our extended dataset confirmed the existence of substantial geographic variation in daily nest predation rates with clear latitudinal patterns in both the north and southern hemispheres.

Our geographically-broader analyses did not detect systematic differences in daily nest predation rates across habitats or nest locations, in contrast to previous studies within North America (Martin 1993). This finding was not obscured by other factors thought to affect nest predation, such as the geographic context or nest structure. Indeed, enclosed structures have been proposed to confer protection benefits against predators (Nice 1957; Snow 1978; Oniki 1985), but not all studies support this expectation (Martin et al. 2017; Mouton and Martin 2019; present study). Moreover, enclosed nests were more common in small than large species (Martin et al. 2017), demonstrating that it cannot contribute to the lower predation rates observed for larger species. Additional conditions such as landscape configuration, predator assemblage or vegetation structure can have greater effects on nest predation than the habitat or nest site (Donovan et al. 1997; Martin and Joron 2003; Colombelli-Négrel and Kleindorfer 2009). Given the lack of support for differences in nest predation pressures across habitats and nest locations, nest structure and site choice does not seem to be an explanation for lower nest predation pressures in larger species.

Our results highlight the importance of anti-predatory responses in explaining why larger birds suffer lower nest mortality despite their extended development periods and more conspicuous nests. However, the existence of substantial unexplained variation suggests that other mechanisms can also play a role. Additional parental behaviors, such as nest attentiveness or visitation rates (Fontaine and Martin 2006; LaManna and Martin 2016), and the role of learning aimed at improving selection for safer nest sites (Burhans and Thompson 1998; Chalfoun and Martin 2010) deserve particular attention in the future (Cresswell 1997; Weidinger 2002). For example, a reproductive failure can cause parents to modify nest site choices and parental behaviors in subsequent breeding attempts (Chalfoun and Martin 2010). These responses are expected to be linked to life history — and hence to body size— because a slow strategy increases the probability of future reproduction and provides more opportunities to learn and benefit from learned behaviors (LaManna and Martin 2016; Sol et al. 2016; Maspons et al. 2019). Understanding how behavior varies as a function of life history strategies seems a crucial next step to further understand the mechanisms behind the selective forces driving the evolution of body size.

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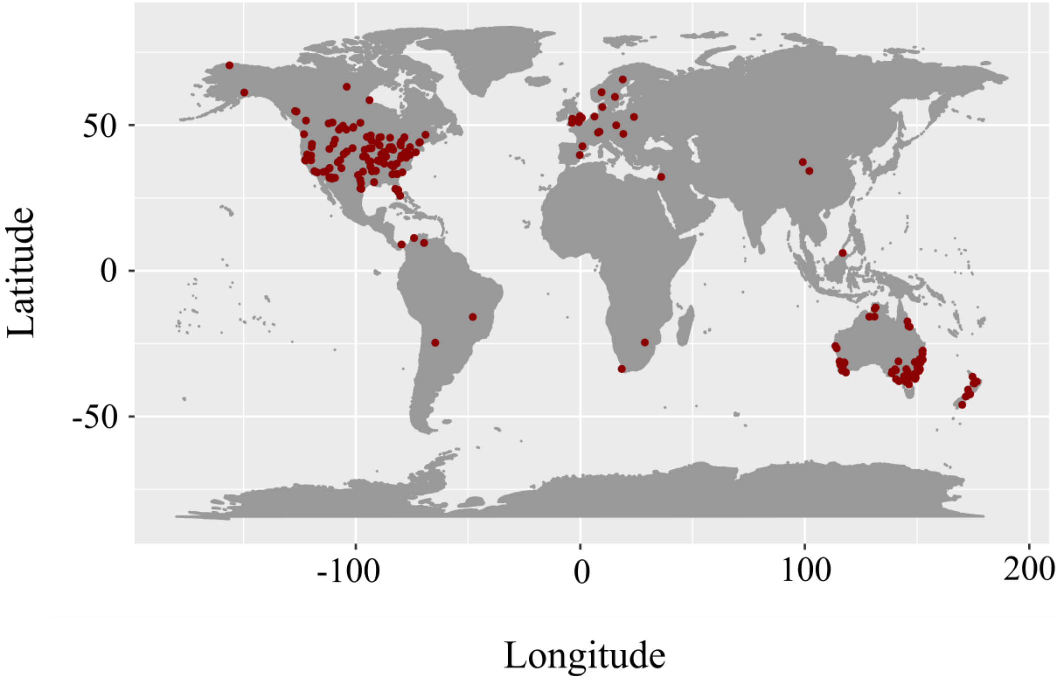
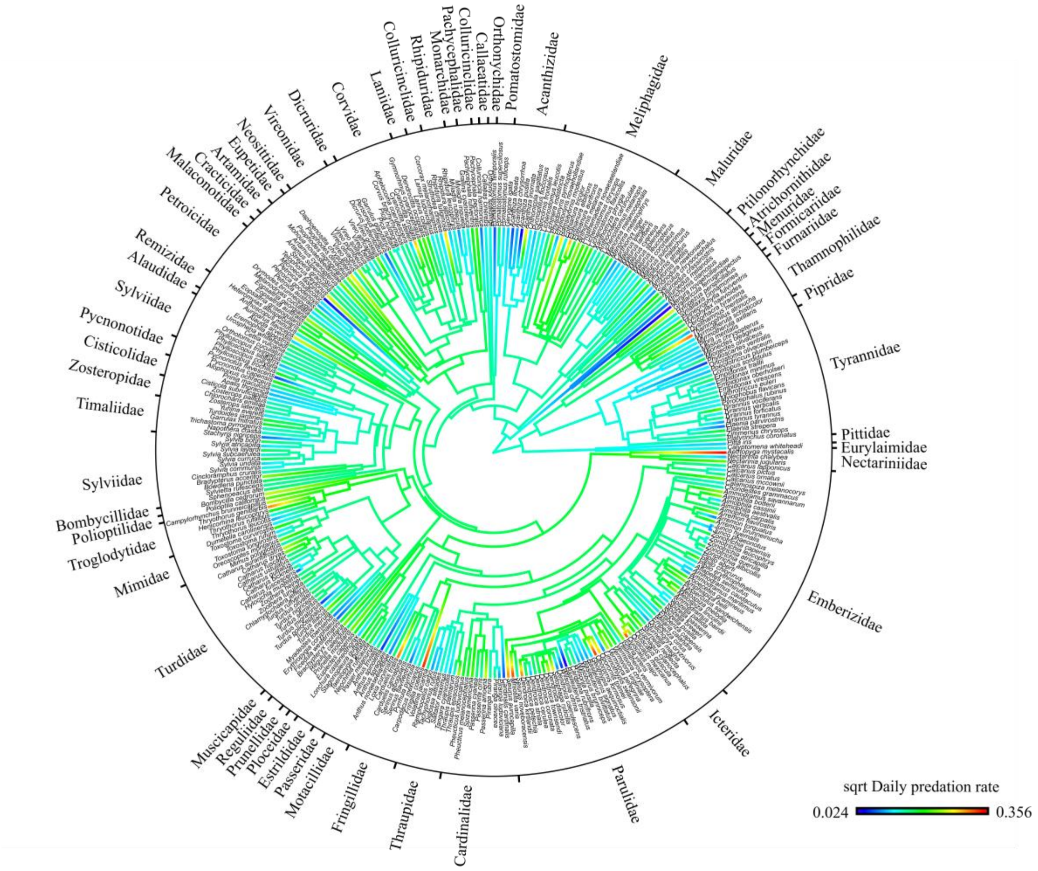
Supplementary material

Supplementary Figures

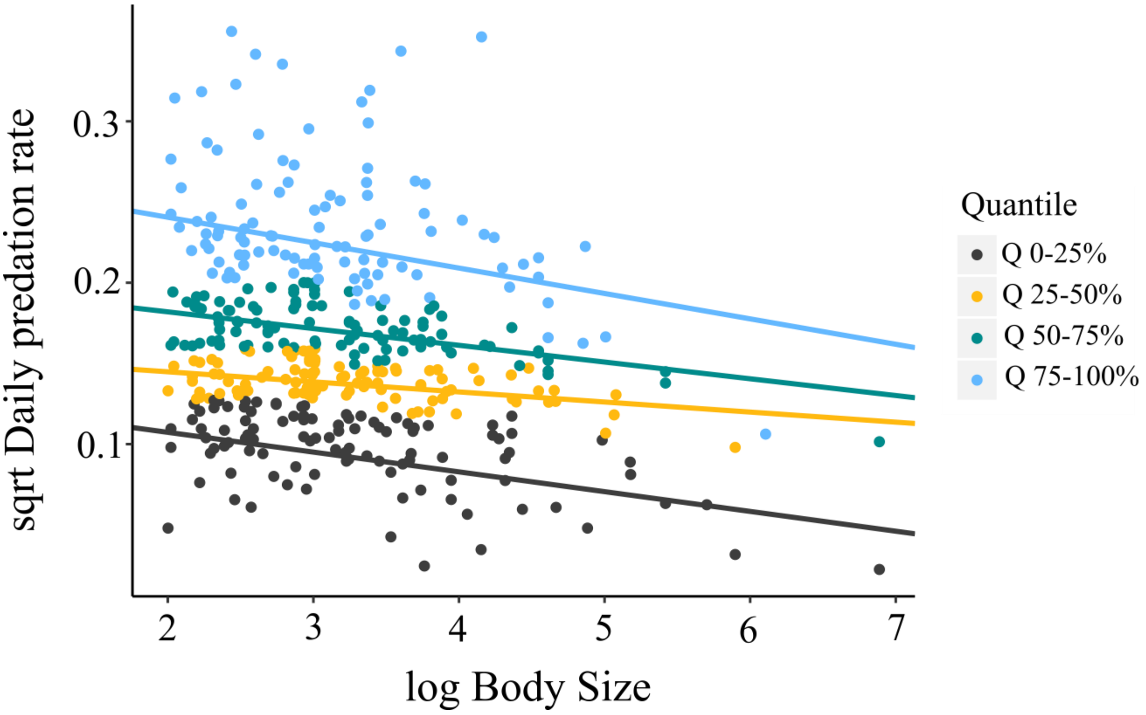
Supplementary Figure 1. Distribution of the study sites used in the analyses (N study sites = 211).



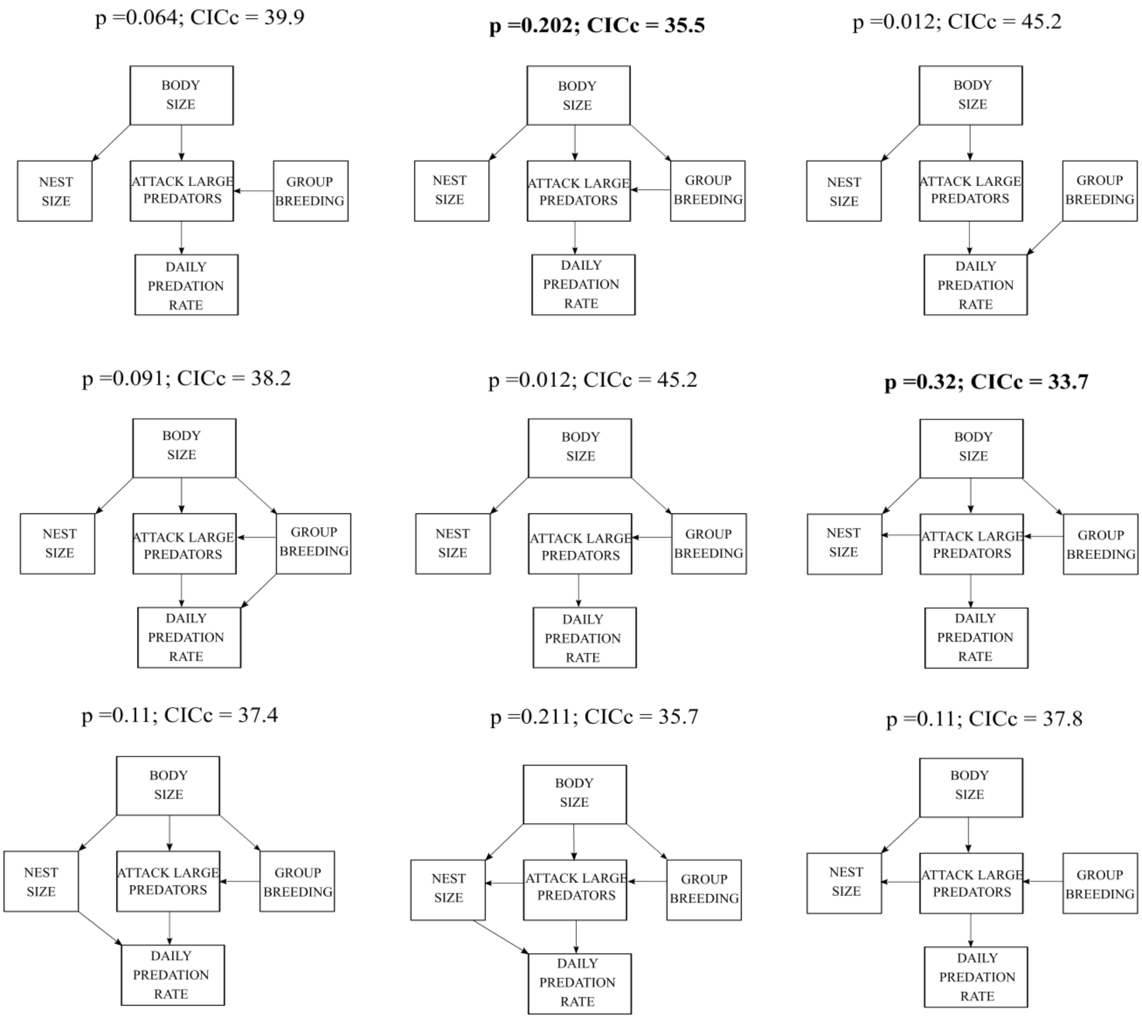
Supplementary Figure 2. Variation in mean daily predation rates (square-root transformed) across species (N = 321), with their corresponding taxonomic families.



Supplementary Figure 3. BPMM models conducted by quantiles (N species = 270, N populations = 422). The negative relationship between body size and daily predation risk was significant in all first (BPMM: pMCMC<7e-04), second (BPMM: pMCMC=0.036), third (BPMM: pMCMC<7e-04) and fourth (BPMM: pMCMC=0.0026) quantiles. The fitted line in the figure is derived from the raw data.



Supplementary Figure 4. Alternative models tested through a phylogenetic path analysis approach to investigate direct and indirect effects influencing body size and daily nest predation relationship (n = 62 species, 116 populations). The best fitted models (highlighted in bold) show non-significance and a ΔCICc<2.



p =0.064; CICc = 39.9

p =0.202; CICc = 35.5

p =0.012; CICc = 45.2

p =0.091; CICc = 38.2

p =0.012; CICc = 45.2

p =0.32; CICc = 33.7

p =0.11; CICc = 37.4

p =0.211; CICc = 35.7

p =0.11; CICc = 37.8

Supplementary Tables

Supplementary Table 1. BPMM of daily nest predation rate (square-root transformed) as a function of body size (standardized and log-transformed), latitude (standardized), elevation (standardized and square-root -transformed), nest structure, habitat and nest location. For nest structure, habitat and nest site, domed nests, open habitats and ground nest sites are respectively the reference levels. This full model has a DIC=-1479.495.

(N species=256, N populations=398)	post Mean	l 95% CI	u 95% CI	eff. sample	pMCMC
Fixed factors					
Intercept	0.1242	0.0917	0.1569	1500	< 7e-04 ***
Body size	-0.0120	-0.0194	-0.0047	1500	< 7e-04 ***
Latitude	-0.2384	-0.4420	-0.0551	1500	0.0267 *
Latitude ^{2}	-0.1959	-0.3556	-0.0488	1500	0.0133 *
Elevation	0.0007	-0.0057	0.0075	1500	0.8480
Nest structure open	0.0119	-0.0037	0.02625	1500	0.1280
Nest location canopy	-0.0051	-0.0361	0.0297	1500	0.7680
Nest location shrub	-0.0030	-0.0245	0.0162	1500	0.7320
Habitat forest	-0.0030	-0.0276	0.0225	1500	0.7933
Nest location canopy : Habitat forest	0.0086	-0.0295	0.0468	1500	0.6507
Nest location shrub : Habitat forest	0.0160	-0.0115	0.4482	1500	0.2880
Random factors					
Phylogeny	0.0011	0.0004	0.0018	1500	
Species	0.0003	0.0001	0.0005	1500	
Study Site	0.0007	0.0004	0.001	1500	
Units	0.0009	0.0006	0.0011	1500	

Supplementary Table 2. BPMM of daily nest predation rate (square-root transformed) as a function of latitude (standardized absolute latitude) and Hemisphere. For Hemisphere, southern hemisphere is the reference level.

(N species=270, N populations=422)	post Mean	l 95% CI	u 95% CI	eff. sample	pMCMC
Fixed factors					
Intercept	0.1661	0.1236	0.2065	1500	<7e-04 ***
Absolute Latitude	-0.0009	-0.0018	-0.0001	2025	0.0293 **
Hemisphere north	-0.0197	-0.0450	0.0028	1500	0.1067
Random factors					
Phylogeny	0.0013	0.0004	0.0022	1500	
Species	0.0003	0.0001	0.0005	1500	
Study site	0.0007	0.0004	0.0010	1500	
Units	0.0009	0.0006	0.0011	1500	

Supplementary Table 3. BPMM of daily nest predation rate (square-root transformed) as a function of body size (log-transformed).

(N species=270, N populations=422)	post Mean	l 95% CI	u 95% CI	eff. sample	pMCMC
Fixed factors					
Intercept	0.1757	0.1338	0.2126	1500	<7e-04 ***
Body size	-0.0127	-0.0201	-0.0048	1500	0.004 **
Random factors					
Phylogeny	0.0012	0.0005	0.0020	1500	
Species	0.0002	0.0001	0.0004	1278	
Study site	0.0008	0.0005	0.0011	1500	
Units	0.0009	0.0006	0.0011	1271	

Supplementary Table 4. Best BPMM selected after a model selection approach. Daily nest predation rate (square-root transformed) in relation to body size (standardized and log-transformed) and latitude (standardized). This model has a DIC=-1482.631.

(N species=256, N populations=398)	post Mean	l 95% CI	u 95% CI	eff. sample	pMCMC
Fixed factors					
Intercept	0.1331	0.1052	0.1631	1500	< 7e-04 ***
Body size	-0.0115	-0.0194	-0.0047	1500	0.0026 **
Latitude	-0.2351	-0.4195	-0.0350	1660	0.0173 *
Latitude^2	-0.2091	-0.3390	0.0636	1500	0.0013 **
Random factors					
Phylogeny	0.0013	0.0005	0.002	1361	
Species	0.0002	0.0001	0.0004	1612	
Study site	0.0007	0.0004	0.001	1500	
Units	0.0009	0.0006	0.0011	1500	

Supplementary Table 5. BPMM of nest size measured as nest top surface area (log-transformed) as a function of body size (log-transformed).

(N species=130)	post Mean	l 95% CI	u 95% CI	eff. sample	pMCMC
Fixed factors					
Intercept	2.0121	1.2592	2.7688	1500	<7e-04 ***
Body size	0.8555	0.7194	1.0020	1920	<7e-04 ***
Random factors					
Phylogeny	0.6705	0.3887	0.9716	1500	
Units	0.0587	0.0167	0.1124	1500	

Supplementary Table 6. BPMM of daily nest predation rate (square-root transformed) as a function of nest size measured as nest top surface area (log-transformed).

(N species=151, N populations=269)	post Mean	l 95% CI	u 95% CI	eff. sample	pMCMC
Fixed factors					
Intercept	0.1872	0.1424	0.2355	1391	<7e-04 ***
Nest size	-0.0103	-0.0193	-0.0022	1500	0.0187 *
Random factors					
Phylogeny	0.0008	0.0001	0.0015	1500	
Species	0.0003	0.0001	0.0005	1592	
Locality	0.0010	0.0006	0.0015	1500	
Units	0.0006	0.0004	0.0009	1663	

Supplementary Table 7. BPMM of daily nest predation rate (square-root transformed) as a function of body size (standardized and log-transformed), latitude (standardized) and nest size measured as nest top surface area (standardized and log-transformed).

(N species=151, N populations=269)	post Mean	l 95% CI	u 95% CI	eff. sample	pMCMC
Fixed factors					
Intercept	0.1342	0.1003	0.1594	1500	<7e-04 ***
Body size	-0.0017	-0.0129	0.0104	1256	0.792
Latitude	-0.2096	-0.4231	-0.0315	1500	0.032 *
Latitude^2	-0.1528	-0.2802	-0.0282	1500	0.020 *
Nest size	-0.0074	-0.0178	0.0030	1500	0.156
Random factors					
Phylogeny	0.0010	0.0002	0.0019	1500	
Species	0.0003	0.0001	0.0005	1630	
Locality	0.0009	0.0005	0.0012	1156	
Units	0.0006	0.0004	0.0008	1500	

Supplementary Table 8. BPMM of body size (log-transformed) as a function of the maximum body size of predators that a species is able to attack (standardized and log-transformed) and research effort (standardized and sqrt-transformed) (**Model 1**) or as a function of the range of predator body sizes that a species is able to attack (standardized and log-transformed) and research effort (standardized and sqrt-transformed) (**Model 2**).

	post Mean	l 95% CI	u 95% CI	eff. sample	pMCMC
MODEL 1 (N species=96)					
Fixed factors					
Intercept	3.7822	2.8235	4.8357	1500	<7e-04 ***
Body size attacked predators	0.2236	0.0994	0.3605	1743	0.0013 **
Research effort	0.0029	-0.1322	0.1383	1500	0.9586
Random factors					
Phylogeny	1.395	1.025	1.823	1500	
Units	0.0026	0.0001	0.0082	1500	
MODEL 2 (N species=65)					
Fixed factors					
Intercept	3.8279	2.6978	4.9289	1500	<7e-04 ***
Body size attacked predators	0.3228	0.1303	0.5420	1500	0.0053 **
Research effort	-0.0004	-0.1980	0.1767	1500	0.9893
Random factors					
Phylogeny	1.698	1.031	2.519	1330	
Units	0.0274	0.0001	0.1117	1500	

Supplementary Table 9. BPMM of daily nest predation rate (square-root transformed) as a function of the maximum body size of predators that a species is able to attack (standardized and log-transformed), research effort (standardized and sqrt-transformed) and latitude (standardized) (**Model 1**) or as a function of the range of predator body sizes that a species is able to attack (standardized and log-transformed), research effort (standardized and sqrt-transformed) and latitude (standardized) (**Model 2**).

	post Mean	l 95% CI	u 95% CI	eff. sample	pMCMC
MODEL 1 (N species=79, N populations=152)					
Fixed factors					
Intercept	0.1334	0.1101	0.1578	1500	<7e-04 ***
Latitude	-0.0333	-0.1931	0.1274	1500	0.664
Latitude^2	-0.0880	-0.1954	0.0154	1500	0.096 .
Body size attacked predators	-0.0215	-0.0309	-0.0126	1500	<7e-04 ***
Research effort	0.0010	-0.0099	0.01185	1500	0.835
Random factors					
Phylogeny	0.0005	0.0001	0.001	1500	
Species	0.0003	0.0001	0.0006	1500	
Locality	0.0005	0.0002	0.0009	1500	
Units	0.0009	0.0006	0.0013	1500	
MODEL 2 (N species=52, N populations=98)					
Fixed factors					
Intercept	0.1271	0.0973	0.1509	1632	<7e-04 ***
Latitude	0.0211	-0.1295	0.1850	1500	0.8120
Latitude^2	-0.0669	-0.1764	0.0359	1500	0.2386
Body size attacked predators	-0.0209	-0.0329	-0.0092	1500	0.0013 **
Research effort	0.0005	-0.0128	0.0161	1613	0.9533
Random factors					
Phylogeny	0.0006	0.0001	0.0013	1627	
Species	0.0004	0.0001	0.0008	1507	
Locality	0.0005	0.0001	0.001	1500	
Units	0.0009	0.0005	0.0014	1500	

Supplementary Table 10. BPMM of residual nest size as a function of the maximum body size of predators that a species is able to attack (standardized and log-transformed) and research effort (standardized and square-root transformed) (**Model 1**) or as a function of the range of predator body sizes that a species is able to attack (standardized and log-transformed) and research effort (standardized and sqrt-transformed) (**Model 2**). Residual nest size was estimated as the residual from a BPMM of nest size (log-transformed), measured as nest top surface area, against body size (log-transformed).

	post Mean	l 95% CI	u 95% CI	eff. sample	pMCMC
MODEL 1 (N species=75)					
Fixed factors					
Intercept	-0.0019	-0.4869	0.3851	1644	0.9893
Body size attacked predators	0.4331	0.1828	0.6979	1500	0.0053 **
Research effort	-0.1124	-0.3528	0.1636	1500	0.3626
Random factors					
Phylogeny	0.1793	0.0002	0.8718	1232	
Units	1.034	0.6067	1.603	1012	
MODEL 2 (N species=49)					
Fixed factors					
Intercept	0.1001	-0.4529	0.5424	1500	0.5586
Body size attacked predators	0.4789	0.1909	0.7806	1500	0.0013 **
Research effort	-0.1249	-0.4267	1500	0.3920	
Random factors					
Phylogeny	0.1741	0.0002	0.8096	1500	
Units	0.974	0.4694	1.447	1500	

Supplementary Table 11. BPMM of daily nest predation rate (square-root transformed) as a function of latitude (standardized) and residual nest size (standardized). Residual nest size was estimated as the residual from a BPMM of nest size (log-transformed), measured as nest top surface area, against body size (log-transformed).

(N species=151, N populations=284)	post Mean	l 95% CI	u 95% CI	eff. sample	pMCMC
Fixed factors					
Intercept	0.1336	0.0980	0.1603	1500	<7e-04 ***
Latitude	-0.2275	-0.4238	-0.0217	1500	0.0173 *
Latitude^2	-0.1545	-0.2848	-0.0289	1500	0.0253 *
Residual nest size	-0.0036	-0.0103	0.0033	1500	0.2827
Random factors					
Phylogeny	0.0011	0.0003	0.0022	1500	
Species	0.0003	0.0001	0.0006	2062	
Study site	0.0009	0.0006	0.0014	1500	
Units	0.0005	0.0003	0.0007	1500	

Supplementary Table 12. BPMM of the maximum body size of predators that a species is able to attack (log-transformed) as a function of social organization and research effort (square-root transformed). For group breeding, solitary breeders are the reference level.

(N species=96)	post Mean	l 95% CI	u 95% CI	eff. sample	pMCMC
Fixed factors					
Intercept	5.0941	3.3807	6.6843	1500	<7e-04 ***
Social organization group	1.2568	0.5387	2.1138	1500	0.0013 **
Research effort	0.0764	0.0072	0.1488	1500	0.0280 *
Random factors					
Phylogeny	3.076	1.065	5.372	1500	
Units	1.109	0.4454	1.897	1500	

Supplementary Table 13. BPMM of the range of predator body sizes of predators that a species is able to attack (log-transformed) as a function of social organization and research effort (square-root transformed). For group breeding, solitary breeders are the reference level.

(N species=64)	post Mean	l 95% CI	u 95% CI	eff. sample	pMCMC
Fixed factors					
Intercept	5.2146	3.1398	7.0534	1500	<7e-04 ***
Social organization group	1.1209	-0.0371	2.3077	1620	0.0573 .
Research effort	0.0588	-0.0665	0.1923	1727	0.3867
Random factors					
Phylogeny	2.752	0.0003	7.055	1500	
Units	2.738	0.8489	4.83	1500	

Supplementary Table 14. BPMM of daily nest predation rate (square-root transformed) as a function of latitude (standardized) and social organization. For group breeding, solitary breeders are the reference level.

(N species=264, N populations=416)	post Mean	l 95% CI	u 95% CI	eff. sample	pMCMC
Fixed factors					
Intercept	0.1338	0.1051	0.1626	1553	<7e-04 ***
Latitude	-0.2412	-00.4223	-0.0280	1659	0.0213 *
Latitude^2	-0.2093	-0.3474	-0.0729	1500	0.0040 **
Social organization group	-0.0233	-0.0380	-0.0097	1500	0.0013 **
Random factors					
Phylogeny	0.0012	0.0005	0.0020	1500	
Species	0.0002	0.0001	0.0004	1307	
Study site	0.0007	0.0004	0.0010	1793	
Units	0.0008	0.0006	0.0010	1740	

Supplementary Table 15. BPMM of body size (log-transformed) as a function of social organization. For group breeding, solitary breeders are the reference level.

(N species=313)	post Mean	l 95% CI	u 95% CI	eff. sample	pMCMC
Fixed factors					
Intercept	3.6500	2.9441	4.3190	1500	<7e-04 ***
Social organization group	0.0314	-0.1157	0.1941	1500	0.688
Random factors					
Phylogeny	0.9758	0.8177	1.14	1500	
Units	0.0011	0.0002	0.0026	1500	

Supplementary Table 16. BPMM of body size (log-transformed) in relation to development period (log-transformed).

(N species=288)	post Mean	l 95% CI	u 95% CI	eff. sample	pMCMC
Fixed factors					
Intercept	-3.153	-4.912	-1.458	1500	<7e-04 ***
Development period	1.858	1.416	2.287	1500	<7e-04 ***
Random factors					
Phylogeny	0.784	0.6663	0.9338	1500	
Units	0.0030	0.0002	0.0080	1500	

Supplementary Table 17. BPMM of total nest predation rate (square-root transformed) in relation to body size (standardized and log-transformed) and latitude (standardized).

(N species=240, N populations=391)	post Mean	l 95% CI	u 95% CI	eff. sample	pMCMC
Fixed factors					
Intercept	0.6449	0.5829	0.7025	1500	<7e-04 ***
Body size	-0.0191	-0.0345	-0.0011	1500	0.0267 *
Latitude	-0.4148	-0.9015	0.0731	1500	0.0960 .
Latitude^2	-0.6547	-1.0893	-0.2430	1500	0.0040 **
Random factors					
Phylogeny	0.0051	0.0007	0.0103	1500	
Species	0.0009	0.0001	0.0020	1500	
Study site	0.0075	0.0044	0.0109	1916	
Units	0.0103	0.0080	0.0128	1630	

Chapter 4

General conclusions

Conclusions

The use of information during breeding site selection

I. In semi-colonial species showing strong breeding site limitations such as hole nesting species, colony formation can be greatly influenced by the availability of nests offering good structural conditions.

II. Ecological and behavioral plasticity reduce the dependence on choosing the habitats and resources that better match to the phenotype. So that, decision-making processes linked with breeding habitat selection in long-lived species such as jackdaws are less constrained by environmental conditions.

III. The acquisition of information of the breeding area is crucial for breeding site selection. Therefore, the previous acquired knowledge related to a site can influence dispersal decisions.

The risk of offspring predation in large species

IV. Counter to long-standing arguments that extended development periods and larger nests should increase nest predation, daily nest predation in large species are sufficiently reduced so as to compensate the increase in development periods, yielding lower predation rates over the entire nesting cycle.

V. Enhanced anti-predatory responses of larger birds can substantially reduce the risk of nest predation, compensating thus the potential costs of extended development periods and larger nests.

VI. Predation pressures experience substantial geographic variation, in large part explained by the latitudinal patterns of an increase of nest predation rates towards the equator.

Final conclusions

VII. Behavior decisions are crucial to cope with challenges associated with reproduction, and hence may have important fitness consequences.

VIII. The costs and benefits of behavioral responses are contingent to the life history of the species.

IX. Further understanding on the relationship between behavior and life-history is crucial to understand how animals cope with new environmental challenges, and hence it is expected to be an important avenue for future research.

Appendix

Supplementary data

Supplementary data 1. Dataset of the information on daily nest predation rates (DPR) used in the analyses. Data includes information on the following covariates: Dev (development: duration of the nestling cycle days), Body size (adult body mass, grams), Elevation and Latitude (from the locality where nest predation was measured, m a.s.l), Nest location (G=ground; S=shrub; C=canopy), Nest structure (O=open nests; D=dommed nests), Habitat (O=open habitats; F=forested habitats); Max/Range body size attacked predators (maximum / range body mass of the bird and mammal predators that the prey species has been reported to attack, grams), Research effort (extracted from Ducatez and Lefebvre 2014), Social organization (S=soiltary breeders; G=group breeders) , nest top surface (cm2) and references (number of reference).

Species	Dev	DPR	Size	Elev	Lat	Loc.	Struct.	Hab.	Max size pred	Range size pred	Effort	Soc.	Nest top area	Ref
Acanthiza chrysorrhoa	39.50	0.026	9.20	217	-34.60	S	D	F	NA	NA	16	G	NA	1
Acanthiza chrysorrhoa	39.50	0.019	9.20	NA	-35.27	S	D	NA	NA	NA	16	G	NA	2
Acanthiza chrysorrhoa	39.50	0.006	9.20	25	-32.07	S	D	O	NA	NA	16	G	NA	3
Acanthiza inornata	40.50	0.011	7.00	NA	-31.93	C	D	F	NA	NA	8	G	46.57	4
Acanthiza lineata	36.00	0.026	7.00	920	-30.53	C	D	F	NA	NA	15	G	43.01	5
Acanthiza pusilla	37.00	0.027	7.70	920	-30.53	S	D	F	NA	NA	28	S	NA	6
Acanthiza pusilla	37.00	0.022	7.70	645	-35.27	S	D	F	NA	NA	28	S	NA	7
Aethopyga mystacalis	35.16	0.034	6.44	1700	6.11	NA	D	F	NA	NA	2	S	NA	8
Ailuroedus crassirostris	46.50	0.006	205.50	NA	-28.58	C	O	F	NA	NA	11	S	NA	9
Ailuroedus melanotis	43.50	0.008	177.00	947	-18.96	C	O	F	NA	NA	8	S	NA	10
Aimophila aestivalis	26.00	0.024	19.60	139	34.13	G	O	F	NA	NA	0	S	128.68	11
Aimophila botterii	25.80	0.013	19.90	1467	31.60	G	O	O	NA	NA	1	S	70.88	12

Species	Dev	DPR	Size	Elev	Lat	Loc.	Struct.	Hab.	Max size pred	Range size pred	Effort	Soc.	Nest top area	Ref
Aimophila carpalis	23.56	0.048	15.30	1399	31.76	G	O	O	38.90	NA	0	S	82.52	13
Aimophila cassinii	24.00	0.015	18.90	890	32.02	G	O	O	NA	NA	0	S	89.92	14
Alauda arvensis	33.00	0.025	37.10	95	46.96	G	O	O	NA	NA	481	S	58.09	15
Alauda arvensis	33.00	0.004	37.10	435	47.70	G	O	O	NA	NA	481	S	58.09	16
Alauda arvensis	33.00	0.029	37.10	370	49.91	G	O	O	NA	NA	481	S	58.09	17
Alauda arvensis	33.00	0.008	37.10	15	52.91	G	O	O	NA	NA	481	S	58.09	18
Alophoixus ochraceus	30.01	0.020	48.65	1700	6.11	S	O	F	NA	NA	0	S	NA	19
Ammodramus bairdii	28.50	0.019	17.80	750	48.40	G	O	O	342.50	169.80	52	S	NA	20
Ammodramus bairdii	28.50	0.035	17.80	719	49.75	G	O	O	342.50	169.80	52	S	NA	21
Ammodramus bairdii	28.50	0.025	17.80	760	50.55	G	O	O	342.50	169.80	52	S	NA	22
Ammodramus bairdii	28.50	0.017	17.80	446	49.32	G	O	O	342.50	169.80	52	S	NA	23
Ammodramus bairdii	28.50	0.007	17.80	800	49.01	G	O	O	342.50	169.80	52	S	NA	24
Ammodramus caudacutus	24.70	0.018	19.25	2	40.64	G	O	NA	38.20	NA	49	G	78.54	25
Ammodramus maritimus	26.00	0.011	22.40	2	40.64	G	O	NA	19.25	8.10	62	S	78.54	26
Ammodramus savannarum	24.90	0.038	17.55	363	45.91	G	D	O	NA	NA	143	G	122.72	27
Ammodramus savannarum	24.90	0.017	17.55	750	48.40	G	D	O	NA	NA	143	G	122.72	28
Ammodramus savannarum	24.90	0.014	17.55	166	36.74	G	D	O	NA	NA	143	G	122.72	29
Ammodramus savannarum	24.90	0.034	17.55	580	39.57	G	D	O	NA	NA	143	G	122.72	30
Ammodramus savannarum	24.90	0.026	17.55	437	43.89	G	D	O	NA	NA	143	G	122.72	31
Ammodramus savannarum	24.90	0.038	17.55	19	27.70	G	D	O	NA	NA	143	G	122.72	32

Ammodramus savannarum	24.90	0.042	17.55	293	37.59	G	D	O	NA	NA	143	G	122.72	33
Amphispiza belli	26.50	0.021	17.70	1013	43.52	S	O	O	NA	NA	66	S	104.77	34
Amytornis striatus	30.50	0.010	19.65	77	-34.16	G	D	O	NA	NA	9	G	NA	35
Amytornis textilis	30.00	0.014	23.05	NA	-32.27	S	D	O	NA	NA	11	G	NA	36
Anthochaera carunculata	40.50	0.004	106.35	96	-38.17	C	O	O	40000.00	39983.60	55	G	283.53	37
Anthornis melanura	33.75	0.038	27.15	105	-42.36	C	O	F	NA	NA	52	S	176.71	38
Anthornis melanura	33.75	0.029	27.15	236	-42.33	C	O	F	NA	NA	52	S	176.71	39
Anthornis melanura	33.75	0.019	27.15	900	-43.15	C	O	F	NA	NA	52	S	176.71	40
Anthoscopus minutus	41.17	0.009	6.51	21	-33.68	S	D	O	NA	NA	4	G	NA	41
Anthus novaeseelandiae	30.50	0.013	23.85	1950	-36.51	G	O	O	NA	NA	102	S	NA	42
Anthus spinoletta	34.70	0.012	23.90	3200	44.98	G	O	O	NA	NA	212	S	NA	43
Anthus spragueii	29.20	0.014	25.50	NA	50.80	G	O	O	NA	NA	52	S	NA	44
Anthus trivialis	29.75	0.009	23.40	24	52.46	G	O	F	NA	NA	141	S	NA	45
Anthus trivialis	29.75	0.017	23.40	NA	NA	G	O	NA	NA	NA	141	S	NA	46
Apalis thoracica	32.75	0.104	11.79	21	-33.68	S	D	O	NA	NA	11	S	NA	47
Aphelocoma coerulescens	38.90	0.009	77.15	70	39.90	S	O	F	40000.00	NA	204	G	283.53	48
Arremon brunneinucha	32.69	0.054	45.09	1700	9.56	S	O	F	NA	NA	3	S	165.81	49
Arremon flavirostris	NA	0.026	24.35	1500	-24.69	G	D	F	NA	NA	2	S	NA	50
Arremon torquatus	30.50	0.042	40.90	1500	-24.69	S	O	F	NA	NA	0	NA	NA	51
Artamus cyanopterus	35.00	0.014	34.60	NA	-35.65	C	O	F	674.50	556.50	16	G	NA	52
Artamus superciliosus	29.50	0.021	35.50	934	-37.12	C	O	F	351.00	51.50	16	G	NA	53
Atlapetes semirufus	27.64	0.069	28.94	1700	9.56	S	O	F	NA	NA	1	S	124.49	54

Species	Dev	DPR	Size	Elev	Lat	Loc.	Struct.	Hab.	Max size pred	Range size pred	Effort	Soc.	Nest top area	Ref
Atrichornis clamosus	64.00	0.001	43.05	42	-34.85	S	D	O	NA	NA	39	S	122.72	55
Auriparus flaviceps	37.50	0.006	6.80	847	34.12	S	D	O	NA	NA	24	S	145.27	56
Basileuterus bivittatus	29.50	0.020	14.10	1500	-24.69	G	D	F	NA	NA	1	S	NA	57
Basileuterus signatus	NA	0.031	11.90	1500	-24.69	G	D	F	NA	NA	1	S	NA	58
Basileuterus tristriatus	28.05	0.041	11.72	1700	9.56	G	D	F	NA	NA	4	S	NA	59
Bombycilla cedrorum	31.70	0.008	31.60	272	43.05	C	O	F	106.10	95.15	118	G	112.53	60
Bowdleria punctata	34.50	0.014	25.20	0	-36.36	S	O	O	NA	NA	19	S	NA	61
Bowdleria punctata	34.50	0.008	25.20	17	-40.77	S	O	O	NA	NA	19	S	NA	62
Bowdleria punctata	34.50	0.017	25.20	0	-45.98	S	O	O	NA	NA	19	S	NA	63
Brachypteryx montana	36.97	0.044	20.61	1700	6.11	S	D	F	NA	NA	1	S	NA	64
Bradypterus accentor	NA	0.015	18.55	3250	6.11	NA	O	F	NA	NA	1	NA	NA	65
Calamospiza melanocorys	25.00	0.031	37.60	1556	40.91	G	O	O	172.70	72.00	70	G	NA	66
Calcarius lapponicus	28.40	0.014	27.85	23	70.47	G	O	O	NA	NA	0	S	139.98	67
Calcarius mccownii	27.50	0.018	25.70	1556	40.91	G	O	O	172.70	NA	151	S	NA	68
Calcarius ornatus	25.80	0.025	20.30	750	48.40	G	O	O	342.50	303.35	67	S	NA	69
Calcarius ornatus	25.80	0.040	20.30	719	49.75	G	O	O	342.50	303.35	67	S	NA	70
Calcarius ornatus	25.80	0.023	20.30	631	48.42	G	O	O	342.50	303.35	67	S	NA	71
Calcarius ornatus	25.80	0.027	20.30	800	49.01	G	O	O	342.50	303.35	67	S	NA	72
Calcarius ornatus	25.80	0.023	20.30	662	50.84	G	O	O	342.50	303.35	67	S	NA	73
Calcarius pictus	23.90	0.012	26.70	16	58.53	G	O	O	NA	NA	48	G	70.14	74

Callaeas cinereus	74.50	0.021	225.50	256	-37.98	NA	O	F	200.00	89.70	1	S	1256.64	75
Callaeas cinereus	74.50	0.019	225.50	430	-38.56	NA	O	F	200.00	89.70	1	S	1256.64	76
Callaeas cinereus	74.50	0.004	225.50	430	-38.56	NA	O	F	200.00	89.70	1	S	1256.64	77
Calyptomena whiteheadi	47.08	0.011	146.00	1700	6.11	C	D	F	NA	NA	1	S	NA	78
Campylorhynchus brunneicapillus	41.45	0.008	38.90	975	32.00	S	D	O	3900.00	3848.25	31	S	706.86	79
Cardellina rubrifrons	28.50	0.049	9.48	2550	32.07	G	O	F	70.00	NA	11	S	74.20	80
Cardellina rubrifrons	28.50	0.016	9.48	2550	32.07	G	O	F	70.00	NA	11	S	74.20	81
Cardellina rubrifrons	28.50	0.037	9.48	2350	35.10	G	O	F	70.00	NA	11	S	74.20	82
Cardinalis cardinalis	25.44	0.031	44.65	318	42.00	S	O	NA	88.00	NA	218	S	91.61	83
Cardinalis cardinalis	25.44	0.034	44.65	351	44.29	S	O	F	88.00	NA	218	S	91.61	84
Cardinalis cardinalis	25.44	0.030	44.65	414	31.27	S	O	O	88.00	NA	218	S	91.61	85
Cardinalis cardinalis	25.44	0.036	44.65	176	30.00	S	O	F	88.00	NA	218	S	91.61	86
Cardinalis cardinalis	25.44	0.021	44.65	1736	31.78	S	O	O	88.00	NA	218	S	91.61	87
Carduelis cannabina	31.75	0.031	19.55	57	56.16	S	O	F	NA	NA	93	G	NA	88
Carduelis cannabina	31.75	0.023	19.55	688	32.19	S	O	F	NA	NA	93	G	NA	89
Carduelis cannabina	31.75	0.017	19.55	NA	NA	S	O	NA	NA	NA	93	G	NA	90
Carduelis cannabina	31.75	0.023	19.55	62	51.79	S	O	O	NA	NA	93	G	NA	91
Carduelis tristis	30.75	0.018	12.80	194	41.50	S	O	O	NA	NA	148	G	50.27	92
Carduelis tristis	30.75	0.039	12.80	175	39.26	S	O	O	NA	NA	148	G	50.27	93
Carduelis tristis	30.75	0.011	12.80	326	43.54	S	O	O	NA	NA	148	G	50.27	94
Carpodacus mexicanus	33.11	0.018	21.40	23	38.27	C	O	O	958.50	919.60	437	G	84.13	95
Catharus aurantiirostris	32.80	0.042	28.55	1700	9.56	S	O	F	NA	NA	6	S	103.33	96

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Catharus bicknelli	27.10	0.043	27.50	NA	44.00	S	O	F	NA	NA	43	G	107.97	97
Catharus dryas	NA	0.044	36.90	1500	-24.69	S	O	F	NA	NA	1	S	NA	98
Catharus fuscater	32.03	0.056	31.80	1700	9.56	S	O	F	NA	NA	0	S	107.51	99
Catharus fuscescens	26.25	0.030	31.90	NA	40.90	S	O	F	NA	NA	75	S	NA	100
Catharus guttatus	28.66	0.089	29.27	2350	35.10	S	O	F	NA	NA	97	S	116.13	101
Catharus ustulatus	28.60	0.015	30.30	NA	44.60	S	O	F	NA	NA	137	S	88.25	102
Cercomacra tyrannina	30.70	0.076	16.30	44	9.02	S	D	F	NA	NA	14	S	NA	103
Certhionyx niger	32.50	0.009	9.90	52	-37.16	S	O	O	NA	NA	15	G	33.18	104
Cettia vulcania	35.50	0.054	10.48	1700	6.11	G	D	F	NA	NA	3	S	NA	105
Chlamydochaera jefferyi	34.52	0.026	65.06	1700	6.11	C	O	F	NA	NA	5	S	NA	106
Chlorocharis emiliae	NA	0.013	16.28	3250	6.11	C	O	F	NA	NA	1	NA	NA	107
Chondestes grammacus	25.60	0.019	29.00	264	34.03	G	O	O	NA	NA	43	S	102.07	108
Chthonicola sagittatus	38.50	0.011	13.30	709	-35.27	G	D	F	NA	NA	2	S	91.61	109
Cincloramphus cruralis	27.00	0.014	53.60	107	-33.73	G	O	O	NA	NA	1	S	NA	110
Cisticola subruficapilla	31.56	0.080	10.37	21	-33.68	S	D	O	NA	NA	1	S	NA	111
Colluricincla harmonica	37.50	0.001	63.55	800	-31.33	S	O	F	NA	NA	26	S	191.13	112
Contopus sordidulus	33.00	0.004	13.10	1850	40.00	C	O	F	83.75	44.60	36	S	56.75	113
Contopus sordidulus	33.00	0.014	13.10	2316	37.23	C	O	F	83.75	44.60	36	S	56.75	114
Corcorax melanorhamphos	50.50	0.001	364.00	709	-35.27	C	O	F	4132.00	4025.22	41	G	NA	115
Corcorax melanorhamphos	50.50	0.010	364.00	709	-35.27	C	O	F	4132.00	4025.22	41	G	NA	116

Corvus brachyrhynchos	54.00	0.011	448.50	212	34.18	C	O	F	6000.00	5912.00	306	G	1690.93	117
Cyanocitta cristata	40.00	0.012	88.00	NA	36.00	C	O	F	6000.00	5283.50	236	S	283.53	118
Cyanocitta stelleri	NA	0.026	128.00	2350	35.10	C	O	F	1126.00	5912.00	65	S	907.92	119
Daphoenositta chrysoptera	41.10	0.004	11.70	961	-30.56	C	O	F	NA	NA	7	G	19.63	120
Dendrocitta occipitalis	NA	0.016	101.10	1700	6.11	C	O	F	NA	NA	0	NA	NA	121
Dendroica caerulescens	25.70	0.021	10.15	550	43.94	S	O	F	96.00	NA	129	S	60.82	122
Dendroica caerulescens	25.70	0.009	10.15	600	43.94	S	O	F	96.00	NA	129	S	60.82	123
Dendroica caerulescens	25.70	0.016	10.15	525	43.94	S	O	F	96.00	NA	129	S	60.82	124
Dendroica caerulescens	25.70	0.015	10.15	525	43.94	S	O	F	96.00	NA	129	S	60.82	125
Dendroica cerulea	26.00	0.006	9.05	NA	44.50	C	O	F	NA	NA	79	S	NA	126
Dendroica coronata	27.96	0.044	12.44	2350	35.10	C	O	F	NA	NA	158	S	62.77	127
Dendroica discolor	25.50	0.038	7.65	229	39.26	S	O	O	NA	NA	95	S	28.37	128
Dendroica kirtlandii	31.25	0.016	13.95	NA	44.00	G	O	F	NA	NA	121	S	78.54	129
Dendroica petechia	25.10	0.017	10.00	NA	50.00	S	O	O	88.00	77.05	212	S	38.21	130
Dendroica striata	25.50	0.008	11.85	NA	44.58	S	O	F	NA	NA	74	S	86.59	131
Dendroica townsendi	26.00	0.016	8.85	270	61.15	C	O	F	NA	NA	94	S	70.88	132
Dicrurus hottentottus	NA	0.011	71.84	1700	6.11	C	O	F	NA	NA	23	S	363.05	133
Diglossa sittoides	NA	0.082	9.68	1700	9.56	NA	O	F	NA	NA	1	S	NA	134
Dolichonyx oryzivorus	29.00	0.012	31.55	363	45.91	G	O	O	39.15	NA	133	S	NA	135
Drymodes brunneopygia	28.50	0.012	33.15	32	-25.80	G	O	O	41.20	NA	5	S	81.71	136
Drymodes brunneopygia	28.50	0.025	33.15	59	-33.76	G	O	O	41.20	NA	5	S	81.71	137
Dumetella carolinensis	28.53	0.022	35.30	351	44.29	S	O	F	533.00	437.00	136	S	153.94	138

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Dumetella carolinensis	28.53	0.016	35.30	318	42.00	S	O	NA	533.00	437.00	136	S	153.94	139
Dumetella carolinensis	28.53	0.008	35.30	NA	42.00	S	O	O	533.00	437.00	136	S	153.94	140
Dumetella carolinensis	28.53	0.013	35.30	NA	42.00	S	O	O	533.00	437.00	136	S	153.94	141
Dysithamnus mentalis	28.98	0.039	15.02	1700	9.56	S	O	F	NA	NA	9	S	44.06	142
Elaenia parvirostris	31.50	0.048	13.80	1500	-24.69	C	O	F	NA	NA	5	S	33.18	143
Elaenia strepera	NA	0.040	19.30	1500	-24.69	C	O	F	NA	NA	4	S	176.71	144
Emberiza capensis	27.99	0.087	19.46	21	-33.68	G	O	O	NA	NA	5	S	NA	145
Emberiza cirlus	27.50	0.013	25.60	230	50.70	S	O	O	NA	NA	118	S	NA	146
Emberiza cirlus	27.50	0.008	25.60	30	39.70	S	O	O	NA	NA	118	S	NA	147
Empidonax minimus	32.75	0.023	10.00	267	50.77	C	O	F	88.00	48.85	74	S	37.39	148
Empidonax oberholseri	35.80	0.023	10.40	2393	43.53	S	O	F	NA	NA	39	S	43.01	149
Empidonax traillii	30.50	0.019	13.40	NA	43.00	S	O	F	35.30	NA	156	S	49.64	150
Empidonax virescens	30.50	0.013	12.60	196	37.81	C	O	F	96.00	56.85	74	S	46.20	151
Empidonax virescens	30.50	0.019	12.60	195	37.52	C	O	F	96.00	56.85	74	S	46.20	152
Empidonax virescens	30.50	0.016	12.60	478	35.72	C	O	F	96.00	56.85	74	S	46.20	153
Empidonax virescens	30.50	0.025	12.60	46	34.35	C	O	F	96.00	56.85	74	S	46.20	154
Empidonax virescens	30.50	0.011	12.60	276	42.38	C	O	F	96.00	56.85	74	S	46.20	155
Eopsaltria australis	30.00	0.046	20.25	1015	-30.42	S	O	F	63.55	NA	28	G	50.27	156
Eopsaltria australis	30.00	0.023	20.25	96	-38.17	S	O	O	63.55	NA	28	G	50.27	157
Eopsaltria australis	30.00	0.021	20.25	1000	-30.46	S	O	F	63.55	NA	28	G	50.27	158

Eopsaltria georgiana	29.50	0.005	19.15	254	-34.27	S	O	F	NA	NA	5	G	63.62	159
Eopsaltria georgiana	29.50	0.005	19.15	NA	-34.23	S	O	O	NA	NA	5	G	63.62	160
Eopsaltria griseogularis	NA	0.017	19.40	353	-32.77	C	O	F	NA	NA	9	G	28.27	161
Epinecrophylla fulviventris	35.20	0.053	10.40	44	9.02	S	D	F	NA	NA	10	S	NA	162
Epthianura albifrons	29.00	0.034	13.30	6	-37.89	S	O	O	NA	NA	4	S	NA	163
Epthianura albifrons	29.00	0.012	13.30	6	-37.89	S	O	O	NA	NA	4	S	NA	164
Epthianura aurifrons	24.50	0.013	10.50	NA	-24.92	S	O	O	NA	NA	9	S	NA	165
Epthianura tricolor	25.00	0.023	10.70	NA	-24.92	S	O	O	23.15	NA	5	S	NA	166
Eremophila alpestris	28.50	0.045	32.30	3663	34.23	G	O	O	NA	NA	190	S	63.62	167
Eremophila alpestris	28.50	0.031	32.30	3386	37.28	G	O	O	NA	NA	190	S	63.62	168
Eremophila alpestris	28.50	0.015	32.30	1675	54.62	G	O	O	NA	NA	190	S	63.62	169
Eremophila alpestris	28.50	0.021	32.30	63	46.85	G	O	O	NA	NA	190	S	63.62	170
Erythropygia coryphaeus	32.24	0.061	21.79	21	-33.68	G	O	O	NA	NA	4	G	NA	171
Euphagus cyanocephalus	31.25	0.019	62.65	1676	39.59	S	O	F	1148.00	1108.85	50	G	176.71	172
Euplectes capensis	NA	0.073	29.15	21	-33.68	S	D	O	NA	NA	5	S	NA	173
Ficedula westermanni	NA	0.055	8.00	1700	6.11	C	O	F	NA	NA	4	S	NA	174
Fringilla coelebs	30.60	0.024	22.85	NA	NA	C	O	F	NA	NA	688	S	NA	175
Garrulax mitratus	NA	0.053	64.91	1700	6.11	C	O	F	NA	NA	2	S	NA	176
Garrulus glandarius	43.25	0.017	160.50	110	59.67	C	O	F	NA	NA	281	S	NA	177
Geothlypis aequinoctialis	NA	0.026	12.80	1500	-24.69	G	O	F	NA	NA	2	S	86.59	178
Gerygone igata	41.00	0.048	6.40	105	-42.37	C	D	F	NA	NA	24	S	NA	179
Gerygone igata	41.00	0.006	6.40	63	-42.38	C	D	F	NA	NA	24	S	NA	180
Gerygone igata	41.00	0.028	6.40	NA	-42.37	C	D	F	NA	NA	24	S	NA	181

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Gerygone igata	41.00	0.025	6.40	NA	-42.33	C	D	F	NA	NA	24	S	NA	182
Grallaricula ferrugineipectus	32.54	0.069	16.89	1700	9.56	S	O	F	NA	NA	2	S	126.88	183
Grallina cyanoleuca	42.50	0.002	82.05	NA	-32.83	C	O	O	753.00	621.00	41	S	NA	184
Gymnorhinus cyanocephalus	40.5	0.009	105	NA	35	C	O	F	949.00	500.50	37	G	96.77	185
Gymnorhinus cyanocephalus	40.50	0.018	105.00	2358	35.28	C	O	F	949.00	500.50	37	G	96.77	186
Helmitheros vermivorum	27.20	0.009	14.20	NA	35.72	G	O	F	NA	NA	0	S	NA	187
Henicorhina leucophrys	39.09	0.030	15.39	1700	9.56	S	D	F	NA	NA	6	S	NA	188
Heteromyias albispecularis	NA	0.013	38.40	875	-18.96	S	O	F	NA	NA	2	S	NA	189
Hylocichla mustelina	29.05	0.026	50.15	130	39.76	C	O	F	88.00	NA	213	S	113.10	190
Hylocichla mustelina	29.05	0.018	50.15	NA	35.72	C	O	F	88.00	NA	213	S	113.10	191
Hylopezus perspicillatus	36.10	0.059	43.00	44	9.02	S	O	F	NA	NA	2	S	NA	192
Hylophylax naevioides	31.50	0.036	17.80	44	9.02	S	O	F	NA	NA	24	S	NA	193
Icteria virens	24.40	0.020	24.90	414	31.27	S	O	O	35.30	NA	66	S	151.75	194
Icteria virens	24.40	0.045	24.90	255	39.18	S	O	O	35.30	NA	66	S	151.75	195
Junco hyemalis	27.51	0.041	20.78	2350	35.10	G	O	F	96.00	NA	364	S	97.64	196
Junco phaeonotus	28.00	0.018	20.40	2550	32.07	G	O	F	NA	NA	31	S	188.69	197
Junco phaeonotus	28.00	0.026	20.40	2550	32.07	G	O	F	NA	NA	31	S	188.69	198
Junco phaeonotus	28.00	0.011	20.40	2560	31.88	G	O	F	NA	NA	31	S	188.69	199
Lanius collaris	33.63	0.068	43.27	21	-33.68	S	O	O	NA	NA	76	S	132.73	200
Lanius ludovicianus	39.25	0.006	51.75	11	27.08	S	O	O	1126.00	1081.80	256	S	NA	201

Lanius ludovicianus	39.25	0.018	51.75	709	50.82	S	O	O	1126.00	1081.80	256	S	NA	202
Lanius ludovicianus	39.25	0.024	51.75	169	38.95	S	O	O	1126.00	1081.80	256	S	NA	203
Lanius ludovicianus	39.25	0.004	51.75	1678	40.84	S	O	O	1126.00	1081.80	256	S	NA	204
Lathrotriccus euleri	NA	0.032	10.40	1500	-24.69	C	O	F	NA	NA	3	S	19.63	205
Lichenostomus chrysops	29.00	0.024	17.30	131	-37.68	S	O	F	NA	NA	21	S	34.73	206
Lichenostomus flavicollis	34.50	0.022	28.95	NA	-41.92	S	O	F	63.55	47.15	4	S	91.61	207
Lichenostomus leucotis	32.00	0.022	24.00	96	-38.17	S	O	O	190.00	NA	4	S	71.63	208
Lichenostomus melanops	29.00	0.027	32.35	100	-37.83	S	O	F	334.50	228.15	41	G	61.51	209
Lichmera indistincta	30.50	0.010	11.20	30	-12.57	S	O	F	NA	NA	36	S	31.17	210
Limnothlypis swainsonii	28.50	0.021	18.90	45	34.18	S	O	F	NA	NA	69	S	147.41	211
Limnothlypis swainsonii	28.50	0.014	18.90	13	33.78	S	O	F	NA	NA	69	S	147.41	212
Lonchura castaneothorax	36.00	0.016	13.60	50	-15.78	S	D	O	NA	NA	22	S	NA	213
Lonchura castaneothorax	36.00	0.068	13.60	50	-15.78	S	D	O	NA	NA	22	S	NA	214
Loxia curvirostra	36.85	0.007	34.20	1875	42.72	C	O	F	NA	NA	373	G	NA	215
Loxia curvirostra	36.85	0.002	34.20	408	52.10	C	O	F	NA	NA	373	G	NA	216
Malurus coronatus	26.50	0.041	11.10	49	-15.74	S	D	F	NA	NA	11	G	NA	217
Malurus cyaneus	29.00	0.027	10.50	645	-35.26	S	D	F	63.55	39.10	124	G	NA	218
Malurus cyaneus	29.00	0.016	10.50	1060	-30.57	S	D	F	63.55	39.10	124	G	NA	219
Malurus cyaneus	29.00	0.015	10.50	NA	-33.67	S	D	F	63.55	39.10	124	G	NA	220
Malurus cyaneus	29.00	0.031	10.50	157	-35.18	S	D	F	63.55	39.10	124	G	NA	221
Malurus cyaneus	29.00	0.032	10.50	NA	-35.27	S	D	F	63.55	39.10	124	G	NA	222
Malurus elegans	28.50	0.011	9.60	160	-34.27	S	D	F	NA	NA	9	G	NA	223

Species	Dev	DPR	Size	Elev	Lat	Loc.	Struct.	Hab.	Max size pred	Range size pred	Effort	Soc.	Nest top area	Ref
Malurus lamberti	29.00	0.012	8.10	NA	-33.67	S	D	O	NA	NA	23	G	NA	224
Malurus lamberti	29.00	0.008	8.10	NA	-32.27	S	D	O	NA	NA	23	G	NA	225
Malurus leucopterus	27.00	0.002	7.40	66	-31.55	S	D	O	NA	NA	28	G	28.27	226
Malurus leucopterus	27.00	0.018	7.40	70	-31.08	S	D	O	NA	NA	28	G	28.27	227
Malurus leucopterus	27.00	0.022	7.40	NA	-33.67	S	D	O	NA	NA	28	G	28.27	228
Malurus pulcherrimus	28.00	0.023	9.20	353	-32.77	S	D	F	NA	NA	10	G	NA	229
Malurus pulcherrimus	28.00	0.017	9.20	314	-31.39	S	D	F	NA	NA	10	G	NA	230
Malurus splendens	29.00	0.034	9.30	96	-34.37	S	D	O	24.45	NA	51	G	NA	231
Malurus splendens	29.00	0.012	9.30	218	-31.93	S	D	O	24.45	NA	51	G	NA	232
Manorina melanocephala	35.50	0.022	60.30	71	-27.38	C	O	F	593.50	563.05	59	G	211.24	233
Manorina melanophrys	29.50	0.013	30.45	131	-37.65	S	O	F	541.00	512.20	70	G	62.21	234
Masius chrysopterus	41.16	0.033	13.62	1700	9.56	S	O	F	NA	NA	4	S	37.39	235
Melanodryas cucullata	30.50	0.035	21.25	602	-31.48	C	O	F	106.35	77.55	12	G	53.46	236
Melospiza lincolnii	27.75	0.020	16.60	3250	37.95	G	O	O	NA	NA	19	S	83.32	237
Melospiza melodia	26.45	0.017	22.65	NA	40.00	S	O	O	NA	NA	332	S	189.91	238
Menura novaehollandiae	98.00	0.001	980.00	469	-37.88	S	D	F	5500.00	5149.00	56	S	NA	239
Menura novaehollandiae	98.00	0.010	980.00	454	-37.78	S	D	F	5500.00	5149.00	56	S	NA	240
Menura novaehollandiae	98.00	0.017	980.00	NA	-37.50	S	D	F	5500.00	5149.00	56	S	NA	241
Menura novaehollandiae	98.00	0.003	980.00	NA	-37.47	S	D	F	5500.00	5149.00	56	S	NA	242
Microeca fascinans	37.50	0.033	15.50	NA	-33.73	C	O	NA	53.95	NA	3	G	28.75	243

Microeca fascinans	37.50	0.025	15.50	NA	-28.37	C	O	NA	53.95	NA	3	G	28.75	244
Miliaria calandra	28.60	0.016	48.75	32	50.97	G	O	O	NA	NA	136	G	NA	245
Miliaria calandra	28.60	0.008	48.75	2	53.06	G	O	O	NA	NA	136	G	NA	246
Mimus polyglottos	28.70	0.028	48.50	10	30.32	S	O	O	1126.00	841.00	167	S	NA	247
Mimus polyglottos	28.70	0.028	48.50	34	28.22	S	O	O	1126.00	841.00	167	S	NA	248
Mimus polyglottos	28.70	0.032	48.50	3	25.72	S	O	O	1126.00	841.00	167	S	NA	249
Mionectes oleagineus	44.00	0.017	12.00	44	9.02	S	D	F	NA	NA	15	S	NA	250
Mionectes olivaceus	43.46	0.031	13.59	1700	9.56	S	D	F	NA	NA	5	S	NA	251
Mniotilta varia	25.90	0.012	10.90	NA	35.72	G	O	F	NA	NA	52	S	84.13	252
Mohoua novaeseelandiae	41.50	0.052	12.20	105	-42.37	C	O	F	NA	NA	1	G	63.62	253
Mohoua novaeseelandiae	41.50	0.012	12.20	NA	-42.37	C	O	F	NA	NA	1	G	63.62	254
Mohoua novaeseelandiae	41.50	0.026	12.20	NA	-42.37	C	O	F	NA	NA	1	G	63.62	255
Mohoua novaeseelandiae	41.50	0.000	12.20	NA	-42.33	C	O	F	NA	NA	1	G	63.62	256
Myadestes townsendi	27.00	0.020	33.20	NA	40.65	G	O	F	425.00	353.30	61	S	304.81	257
Myiagra inquieta	NA	0.055	20.90	1060	-30.57	S	O	F	118.00	NA	3	S	NA	258
Myiagra rubecula	30.50	0.029	11.80	1017	-30.58	C	O	F	351.00	263.25	19	S	NA	259
Myioborus brunniceps	NA	0.023	8.85	1500	-24.69	G	D	F	NA	NA	2	S	78.54	260
Myiophobus flavicans	39.50	0.027	10.00	1700	9.56	NA	O	F	NA	NA	0	S	NA	261
Myrmotherula axillaris	30.70	0.067	8.10	44	9.02	S	O	F	NA	NA	9	S	33.18	262
Myrmotherula schisticolor	27.88	0.050	9.58	1700	9.56	S	O	F	NA	NA	3	S	36.00	263
Napothera crassa	41.80	0.065	29.13	1700	6.11	S	O	F	NA	NA	0	S	NA	264
Nectarinia chalybea	31.69	0.099	7.75	21	-33.68	S	D	O	NA	NA	33	S	NA	265

Species	Dev	DPR	Size	Elev	Lat	Loc.	Struct.	Hab.	Max size pred	Range size pred	Effort	Soc.	Nest top area	Ref
Nectarinia jugularis	30.00	0.037	9.00	3	-19.22	S	D	F	NA	NA	21	S	NA	266
Neochmia ruficauda	39.00	0.015	11.15	50	-15.78	S	D	O	NA	NA	22	G	NA	267
Oncostoma olivaceum	37.60	0.009	6.60	44	9.02	S	D	F	NA	NA	1	S	NA	268
Oporornis formosus	26.75	0.013	14.00	NA	38.00	G	O	F	NA	NA	32	S	NA	269
Oporornis tolmiei	NA	0.042	10.03	2350	35.10	S	O	F	NA	NA	18	S	103.69	270
Oreoscoptes montanus	31.00	0.012	44.20	1013	43.52	G	O	O	51.75	NA	63	S	288.02	271
Orthonyx spaldingii	50.50	0.011	149.50	875	-19.00	S	D	F	NA	NA	12	S	483.05	272
Orthonyx spaldingii	50.50	0.028	149.50	820	-17.36	S	D	F	NA	NA	12	S	483.05	273
Orthotomus cuculatus	31.50	0.051	6.95	1700	6.11	C	D	F	NA	NA	2	S	NA	274
Pachycephala pectoralis	29.00	0.021	27.80	850	-37.51	C	O	F	NA	NA	44	S	114.04	275
Pachycephala rufiventris	28.00	0.065	22.55	1006	-30.57	C	O	F	87.75	NA	22	S	58.09	276
Passer melanurus	33.50	0.052	28.85	21	-33.68	C	D	O	NA	NA	32	G	NA	277
Passerculus sandwichensis	27.50	0.021	19.95	363	45.91	G	O	O	NA	NA	175	S	44.18	278
Passerculus sandwichensis	27.50	0.020	19.95	750	48.40	G	O	O	NA	NA	175	S	44.18	279
Passerculus sandwichensis	27.50	0.035	19.95	719	49.75	G	O	O	NA	NA	175	S	44.18	280
Passerculus sandwichensis	27.50	0.023	19.95	760	50.55	G	O	O	NA	NA	175	S	44.18	281
Passerculus sandwichensis	27.50	0.017	19.95	580	39.57	G	O	O	NA	NA	175	S	44.18	282
Passerina amoena	28.50	0.026	15.50	NA	42.00	S	O	O	NA	NA	72	S	67.20	283
Passerina ciris	27.75	0.016	15.55	414	31.27	S	O	O	106.10	18.10	72	S	52.81	284
Passerina ciris	27.75	0.016	15.55	9	30.42	S	O	O	106.10	18.10	72	S	52.81	285

Passerina cyanea	27.00	0.029	14.70	161	37.50	S	O	F	NA	NA	162	S	63.62	286
Passerina cyanea	27.00	0.026	14.70	318	42.00	S	O	NA	NA	NA	162	S	63.62	287
Passerina cyanea	27.00	0.029	14.70	196	37.81	S	O	F	NA	NA	162	S	63.62	288
Passerina cyanea	27.00	0.030	14.70	351	44.29	S	O	F	NA	NA	162	S	63.62	289
Passerina cyanea	27.00	0.021	14.70	478	35.72	S	O	F	NA	NA	162	S	63.62	290
Perisoreus infaustus	46.15	0.004	84.40	452	65.63	C	O	F	NA	NA	70	S	NA	291
Petroica australis	41.50	0.028	31.25	105	-42.37	C	O	F	NA	NA	86	S	153.94	292
Petroica australis	41.50	0.042	31.25	720	-38.67	C	O	F	NA	NA	86	S	153.94	293
Petroica australis	41.50	0.022	31.25	530	-38.37	C	O	F	NA	NA	86	S	153.94	294
Petroica australis	41.50	0.023	31.25	530	-38.37	C	O	F	NA	NA	86	S	153.94	295
Petroica australis	41.50	0.021	31.25	145	-37.95	C	O	F	NA	NA	86	S	153.94	296
Petroica australis	41.50	0.019	31.25	63	-42.38	C	O	F	NA	NA	86	S	153.94	297
Petroica australis	41.50	0.019	31.25	63	-42.38	C	O	F	NA	NA	86	S	153.94	298
Petroica goodenovii	30.50	0.035	8.90	380	-33.11	C	O	F	23.15	NA	25	S	28.75	299
Petroica goodenovii	30.50	0.016	8.90	NA	-26.17	C	O	F	23.15	NA	25	S	28.75	300
Petroica goodenovii	30.50	0.034	8.90	146	-36.14	C	O	F	23.15	NA	25	S	28.75	301
Petroica multicolor	NA	0.033	11.30	850	-36.71	C	O	F	63.55	9.60	33	S	78.54	302
Petroica multicolor	NA	0.015	11.30	NA	-29.03	C	O	F	63.55	9.60	33	S	78.54	303
Petroica multicolor	NA	0.043	11.30	1000	-30.46	C	O	F	63.55	9.60	33	S	78.54	304
Pheucticus ludovicianus	27.00	0.026	42.00	318	42.00	C	O	NA	106.10	18.10	65	S	120.96	305
Pheucticus ludovicianus	27.00	0.005	42.00	490	45.87	C	O	F	106.10	18.10	65	S	120.96	306
Pheucticus ludovicianus	27.00	0.019	42.00	210	43.00	C	O	F	106.10	18.10	65	S	120.96	307

Species	Dev	DPR	Size	Elev	Lat	Loc.	Struct.	Hab.	Max size pred	Range size pred	Effort	Soc.	Nest top area	Ref
Pheucticus ludovicianus	27.00	0.027	42.00	351	44.29	C	O	F	106.10	18.10	65	S	120.96	308
Pheucticus ludovicianus	27.00	0.018	42.00	429	45.83	C	O	F	106.10	18.10	65	S	120.96	309
Pheucticus melanocephalus	27.85	0.021	44.92	2100	35.20	C	O	F	NA	NA	80	S	136.23	310
Pheucticus melanocephalus	27.85	0.027	44.92	2350	35.10	C	O	F	NA	NA	80	S	136.23	311
Phylidonyris novaehollandiae	30.75	0.007	20.25	58	-38.14	S	O	O	106.35	NA	73	S	75.43	312
Phylidonyris novaehollandiae	30.75	0.037	20.25	1400	-30.50	S	O	O	106.35	NA	73	S	75.43	313
Phylidonyris novaehollandiae	30.75	0.038	20.25	171	-35.01	S	O	F	106.35	NA	73	S	75.43	314
Phylidonyris novaehollandiae	30.75	0.019	20.25	96	-38.17	S	O	O	106.35	NA	73	S	75.43	315
Phylidonyris novaehollandiae	30.75	0.060	20.25	80	-33.81	S	O	O	106.35	NA	73	S	75.43	316
Phylidonyris pyrrhopterus	28.20	0.026	16.40	507	-38.99	S	O	F	NA	NA	1	G	136.85	317
Phylloscartes ventralis	NA	0.026	8.30	1500	-24.69	C	D	F	NA	NA	4	S	95.03	318
Phylloscopus collybita	34.50	0.003	8.30	NA	NA	G	D	F	NA	NA	412	S	NA	319
Phylloscopus sibilatrix	32.00	0.014	9.20	410	52.15	G	D	F	NA	NA	154	S	NA	320
Phylloscopus sibilatrix	32.00	0.017	9.20	781	47.39	G	D	F	NA	NA	154	S	NA	321
Phylloscopus sibilatrix	32.00	0.017	9.20	164	52.77	G	D	F	NA	NA	154	S	NA	322
Phylloscopus trivirgatus	32.30	0.053	9.62	1700	6.11	G	D	F	NA	NA	1	S	NA	323
Phylloscopus trochilus	31.85	0.011	8.70	NA	NA	G	D	F	NA	NA	484	S	NA	324
Phylloscopus trochilus	31.85	0.048	8.70	1100	61.25	G	D	O	NA	NA	484	S	NA	325
Pica hudsonia	52.00	0.007	177.50	1535	41.78	C	D	O	NA	NA	1036	G	NA	326
Pica nuttalli	53.50	0.005	159.00	NA	36.38	C	D	O	40000.00	39916.25	19	G	6361.73	327

Pipilo aberti	29.50	0.034	45.95	95	33.91	S	O	O	NA	NA	0	S	161.73	328
Pipilo chlorurus	25.28	0.053	29.22	2350	35.10	S	O	F	NA	NA	38	S	121.54	329
Pipilo erythrophthalmus	27.05	0.027	40.05	412	40.78	G	O	O	35.30	NA	81	S	90.76	330
Pipra mentalis	35.40	0.053	15.00	44	9.02	S	O	F	NA	NA	18	S	NA	331
Piranga ludoviciana	27.11	0.036	29.90	2350	35.10	C	O	F	105.00	NA	73	S	148.49	332
Piranga olivacea	32.25	0.012	28.20	NA	39.00	C	O	F	800.00	764.70	61	S	NA	333
Piranga rubra	25.75	0.040	29.15	175	33.09	C	O	F	88.00	48.85	59	S	66.77	334
Pitta iris	31.50	0.038	62.20	NA	-12.55	S	D	F	NA	NA	3	S	530.93	335
Pitta iris	31.50	0.025	62.20	NA	-12.55	S	D	F	NA	NA	3	S	530.93	336
Platyrinchus coronatus	36.70	0.034	9.15	44	9.02	S	O	F	NA	NA	2	S	NA	337
Poecilotriccus plumbeiceps	NA	0.016	5.70	1500	-24.69	S	D	F	NA	NA	0	NA	78.54	338
Polioptila californica	32.00	0.024	5.90	485	33.74	S	O	O	376.00	337.10	62	S	23.76	339
Pomatostomus ruficeps	47.00	0.003	57.80	183	-31.09	C	D	O	NA	NA	6	G	NA	340
Pomatostomus superciliosus	39.00	0.026	41.20	NA	-32.27	S	D	NA	NA	NA	11	G	NA	341
Pomatostomus superciliosus	39.00	0.014	41.20	276	-31.58	S	D	O	NA	NA	11	G	NA	342
Pomatostomus temporalis	46.00	0.006	75.00	109	-27.61	C	D	F	40000.00	39713.50	37	G	NA	343
Pomatostomus temporalis	46.00	0.008	75.00	68	-13.00	C	D	O	40000.00	39713.50	37	G	NA	344
Pooecetes gramineus	25.25	0.031	25.70	580	39.57	G	O	O	NA	NA	63	S	49.64	345
Pooecetes gramineus	25.25	0.038	25.70	579	39.57	G	O	O	NA	NA	63	S	49.64	346
Pooecetes gramineus	25.25	0.031	25.70	760	50.55	G	O	O	NA	NA	63	S	49.64	347
Pooecetes gramineus	25.25	0.010	25.70	1063	51.51	G	O	O	NA	NA	63	S	49.64	348
Pooecetes gramineus	25.25	0.027	25.70	437	43.89	G	O	O	NA	NA	63	S	49.64	349

Species	Dev	DPR	Size	Elev	Lat	Loc.	Struct.	Hab.	Max size pred	Range size pred	Effort	Soc.	Nest top area	Ref
Prinia maculosa	30.36	0.101	9.32	21	-33.68	S	D	O	NA	NA	13	S	NA	350
Prionodura newtoniana	42.50	0.016	78.75	947	-18.96	S	O	F	NA	NA	13	S	NA	351
Prosthemadera	31.00	0.023	107.30	NA	-37.85	C	O	F	117.00	NA	39	S	448.63	352
Prunella modularis	29.15	0.006	20.25	NA	NA	S	O	O	NA	NA	238	G	NA	353
Psophodes nigrogularis	34.00	0.014	44.55	49	-34.93	S	O	O	NA	NA	6	S	119.79	354
Psophodes olivaceus	30.50	0.019	62.60	NA	-36.68	S	O	F	NA	NA	17	S	176.71	355
Pycnonotus capensis	27.24	0.118	36.65	21	-33.68	S	O	O	NA	NA	17	S	95.03	356
Pycnonotus flavescens	NA	0.023	32.85	3250	6.11	S	O	F	NA	NA	1	S	NA	357
Pycnoptilus floccosus	38.50	0.009	29.00	401	-37.83	S	D	F	130.00	NA	3	S	NA	358
Pyrocephalus rubinus	29.00	0.011	14.40	NA	34.73	C	O	O	NA	NA	69	S	38.48	359
Pyrrhula pyrrhula	32.70	0.018	24.40	NA	NA	S	O	F	NA	NA	246	S	NA	360
Quiscalus major	38.10	0.014	158.50	14	28.09	S	O	NA	2525.00	2240.00	58	G	254.47	361
Quiscalus mexicanus	33.50	0.011	169.00	NA	30.60	C	O	NA	958.50	158.50	95	G	291.95	362
Quiscalus quiscula	31.80	0.016	106.10	284	43.04	C	O	F	1148.00	1060.00	165	G	291.04	363
Ramphocelus carbo	25.79	0.063	24.13	1700	9.56	S	O	F	NA	NA	14	G	73.14	364
Ramsayornis modestus	30.50	0.035	12.10	3	-19.22	S	D	F	NA	NA	5	G	58.77	365
Regulus calendula	NA	0.035	6.10	2350	35.10	C	O	F	NA	NA	54	S	44.18	366
Rhipidura albicollis	30.14	0.047	12.53	1700	6.11	S	O	F	NA	NA	6	S	NA	367
Rhipidura fuliginosa	30.00	0.012	7.55	63	-42.38	C	O	F	93.40	16.45	50	S	62.21	368
Rhipidura fuliginosa	30.00	0.026	7.55	105	-42.37	C	O	F	93.40	16.45	50	S	62.21	369

Rhipidura fuliginosa	30.00	0.059	7.55	710	-35.56	C	O	F	93.40	16.45	50	S	62.21	370
Rhipidura fuliginosa	30.00	0.077	7.55	1190	-30.40	C	O	F	93.40	16.45	50	S	62.21	371
Rhipidura fuliginosa	30.00	0.010	7.55	NA	-42.37	C	O	F	93.40	16.45	50	S	62.21	372
Rhipidura fuliginosa	30.00	0.008	7.55	NA	-42.33	C	O	F	93.40	16.45	50	S	62.21	373
Rhipidura fuliginosa	30.00	0.010	7.55	96	-38.17	C	O	F	93.40	16.45	50	S	62.21	374
Rhipidura leucophrys	29.30	0.021	28.80	NA	NA	S	O	O	3900.00	3793.65	42	S	41.85	375
Saltator maximus	28.75	0.069	40.44	1700	9.56	S	O	F	NA	NA	8	S	154.60	376
Seiurus aurocapilla	25.45	0.013	18.80	478	35.72	G	D	F	96.00	73.00	37	S	306.35	377
Seiurus aurocapilla	25.45	0.045	18.80	255	35.75	G	D	F	96.00	73.00	37	S	306.35	378
Seiurus aurocapilla	25.45	0.011	18.80	299	41.82	G	D	F	96.00	73.00	37	S	306.35	379
Seiurus aurocapilla	25.45	0.025	18.80	315	44.14	G	D	F	96.00	73.00	37	S	306.35	380
Seiurus aurocapilla	25.45	0.014	18.80	490	45.87	G	D	F	96.00	73.00	37	S	306.35	381
Seiurus aurocapilla	25.45	0.040	18.80	351	44.29	G	D	F	96.00	73.00	37	S	306.35	382
Seiurus aurocapilla	25.45	0.017	18.80	399	46.46	G	D	F	96.00	73.00	37	S	306.35	383
Seiurus noveboracensis	25.30	0.027	16.30	NA	42.10	G	O	F	NA	NA	1	S	89.92	384
Sericornis frontalis	35.00	0.007	12.95	NA	-32.27	G	O	NA	NA	NA	52	G	103.87	385
Sericornis frontalis	35.00	0.025	12.95	645	-35.26	G	O	F	NA	NA	52	G	103.87	386
Sericornis frontalis	35.00	0.000	12.95	NA	-34.60	G	O	NA	NA	NA	52	G	103.87	387
Sericornis frontalis	35.00	0.009	12.95	68	-26.59	G	O	O	NA	NA	52	G	103.87	388
Sericornis frontalis	35.00	0.009	12.95	5	-32.25	G	O	O	NA	NA	52	G	103.87	389
Sericulus chrysocephalus	38.00	0.005	100.00	NA	-28.56	C	O	F	NA	NA	16	S	NA	390
Serinus albogularis	26.92	0.097	28.00	21	-33.68	G	O	O	NA	NA	6	S	NA	391

Species	Dev	DPR	Size	Elev	Lat	Loc.	Struct.	Hab.	Max size pred	Range size pred	Effort	Soc.	Nest top area	Ref
Serinus flaviventris	26.83	0.112	16.24	21	-33.68	S	O	O	NA	NA	16	S	NA	392
Setophaga ruticilla	24.50	0.019	8.25	NA	44.00	C	O	F	439.00	351.00	156	S	28.51	393
Sphenoeacus afer	33.33	0.102	29.59	21	-33.68	S	O	O	NA	NA	1	S	NA	394
Spiza americana	26.75	0.028	26.65	282	37.50	S	O	O	NA	NA	113	S	97.64	395
Spiza americana	26.75	0.030	26.65	400	39.19	S	O	O	NA	NA	113	S	97.64	396
Spiza americana	26.75	0.041	26.65	280	42.03	S	O	O	NA	NA	113	S	97.64	397
Spiza americana	26.75	0.024	26.65	166	36.74	S	O	O	NA	NA	113	S	97.64	398
Spiza americana	26.75	0.022	26.65	213	40.73	S	O	O	NA	NA	113	S	97.64	399
Spiza americana	26.75	0.035	26.65	317	41.52	S	O	O	NA	NA	113	S	97.64	400
Spizella breweri	23.50	0.010	10.90	1013	43.52	S	O	O	203.00	158.90	75	S	68.96	401
Spizella pallida	25.25	0.033	11.20	363	45.91	S	O	O	NA	NA	82	S	87.42	402
Spizella pallida	25.25	0.019	11.20	490	49.06	S	O	O	NA	NA	82	S	87.42	403
Spizella passerina	30.25	0.018	12.09	430	45.83	S	O	F	NA	NA	80	G	68.81	404
Spizella passerina	30.25	0.047	12.09	2350	35.10	S	O	F	NA	NA	80	G	68.81	405
Spizella pusilla	28.30	0.054	12.50	175	39.26	S	O	O	NA	NA	104	S	121.35	406
Spizella pusilla	28.30	0.015	12.50	580	39.57	S	O	O	NA	NA	104	S	121.35	407
Spizella pusilla	28.30	0.051	12.50	194	40.00	S	O	O	NA	NA	104	S	121.35	408
Spizella pusilla	28.30	0.026	12.50	272	42.42	S	O	O	NA	NA	104	S	121.35	409
Stachyris nigriceps	29.43	0.066	15.91	1700	6.11	G	D	F	NA	NA	5	S	NA	410
Stagonopleura guttata	40.50	0.075	17.60	217	-34.60	C	D	F	NA	NA	9	G	NA	411

Stipiturus malachurus	29.50	0.007	7.30	86	-37.88	S	D	O	NA	NA	20	G	NA	412
Strepera graculina	55.50	0.004	299.50	150	-34.42	C	O	F	3900.00	3793.65	67	S	829.58	413
Strepera graculina	55.50	0.003	299.50	NA	-35.27	C	O	F	3900.00	3793.65	67	S	829.58	414
Struthidea cinerea	42.50	0.002	132.00	117	-34.56	C	O	F	4132.00	4057.00	16	G	NA	415
Struthidea cinerea	42.50	0.000	132.00	NA	-29.88	C	O	NA	4132.00	4057.00	16	G	NA	416
Sturnella magna	29.25	0.024	94.30	125	37.74	G	O	O	NA	NA	89	S	240.53	417
Sturnella magna	29.25	0.025	94.30	166	36.74	G	O	O	NA	NA	89	S	240.53	418
Sturnella magna	29.25	0.018	94.30	167	38.92	G	O	O	NA	NA	89	S	240.53	419
Sturnella magna	29.25	0.020	94.30	NA	43.00	G	O	O	NA	NA	89	S	240.53	420
Sturnella magna	29.25	0.046	94.30	18	27.66	G	O	O	NA	NA	89	S	240.53	421
Sturnella magna	29.25	0.041	94.30	293	37.59	G	O	O	NA	NA	89	S	240.53	422
Sturnella neglecta	29.20	0.028	100.70	363	45.91	G	D	O	NA	NA	94	S	298.65	423
Sturnella neglecta	29.20	0.020	100.70	750	48.40	G	D	O	NA	NA	94	S	298.65	424
Sturnella neglecta	29.20	0.035	100.70	719	49.75	G	D	O	NA	NA	94	S	298.65	425
Sturnella neglecta	29.20	0.021	100.70	760	50.55	G	D	O	NA	NA	94	S	298.65	426
Sturnella neglecta	29.20	0.023	100.70	1136	42.07	G	D	O	NA	NA	94	S	298.65	427
Sturnella neglecta	29.20	0.017	100.70	NA	43.00	G	D	O	NA	NA	94	S	298.65	428
Sylvia atricapilla	27.30	0.009	17.70	NA	NA	S	O	F	NA	NA	646	S	NA	429
Sylvia borin	26.55	0.009	18.20	NA	NA	S	O	F	NA	NA	290	S	NA	430
Sylvia communis	26.75	0.009	15.10	NA	NA	S	O	O	NA	NA	227	S	NA	431
Sylvia curruca	28.85	0.011	11.45	NA	NA	S	O	O	NA	NA	178	S	NA	432
Sylvia layardi	28.33	0.117	13.50	21	-33.68	S	O	O	NA	NA	0	S	NA	433

Species	Dev	DPR	Size	Elev	Lat	Loc.	Struct.	Hab.	Max size pred	Range size pred	Effort	Soc.	Nest top area	Ref
Sylvia subcaerulea	29.75	0.085	13.78	21	-33.68	S	O	O	NA	NA	0	NA	NA	434
Sylvia undata	30.50	0.008	10.80	NA	NA	S	O	O	NA	NA	109	S	NA	435
Sylvietta rufescens	29.72	0.062	12.25	21	-33.68	S	D	O	NA	NA	8	S	NA	436
Synallaxis cinnamomea	NA	0.047	16.58	1700	9.56	S	D	F	NA	NA	0	S	490.87	437
Tachyphonus rufus	26.21	0.035	31.90	1700	9.56	C	O	F	NA	NA	8	S	136.43	438
Taeniopygia guttata	NA	0.018	11.90	111	-36.15	S	D	O	NA	NA	880	S	NA	439
Tangara cyanicollis	31.83	0.052	15.17	1700	9.56	C	O	F	NA	NA	4	S	NA	440
Telophorus zeylonus	37.13	0.124	63.74	21	-33.68	S	O	O	NA	NA	10	S	NA	441
Thamnophilus atrinucha	28.40	0.050	23.60	44	9.02	S	O	F	NA	NA	9	S	NA	442
Thraupis episcopus	30.82	0.036	32.79	1700	9.56	C	O	F	NA	NA	24	S	114.04	443
Thraupis palmarum	33.75	0.029	34.83	1700	9.56	C	O	F	NA	NA	18	S	NA	444
Thryothorus genibarbis	NA	0.049	25.00	1700	9.56	NA	D	F	NA	NA	2	S	NA	445
Thryothorus leucotis	31.70	0.025	19.50	200	11.24	S	D	F	NA	NA	14	S	NA	446
Thryothorus rufalbus	32.00	0.009	25.05	200	11.24	NA	D	F	NA	NA	14	S	NA	447
Toxostoma curvirostre	32.30	0.016	80.90	34	28.22	S	O	O	376.00	NA	44	S	404.71	448
Toxostoma longirostre	31.00	0.026	67.60	34	28.22	S	O	O	376.00	NA	11	S	301.72	449
Toxostoma rufum	29.00	0.012	68.80	339	39.00	S	O	O	40000.00	39964.70	81	S	223.52	450
Toxostoma rufum	29.00	0.011	68.80	318	42.00	S	O	NA	40000.00	39964.70	81	S	223.52	451
Trichastoma pyrrogenys	32.26	0.045	19.44	1700	6.11	G	O	F	NA	NA	0	NA	NA	452
Turdoides jardineii	37.85	0.020	78.20	1088	-24.60	C	O	O	NA	NA	20	G	NA	453

Turdus iliacus	30.85	0.013	61.20	NA	NA	S	O	F	NA	NA	233	S	NA	454
Turdus merula	30.55	0.014	93.40	NA	NA	S	O	F	NA	NA	1055	S	NA	455
Turdus migratorius	31.50	0.014	77.30	270	44.68	C	O	O	299.00	171.00	339	S	145.69	456
Turdus migratorius	31.50	0.039	77.30	2350	35.10	C	O	F	299.00	171.00	339	S	145.69	457
Turdus migratorius	31.50	0.030	77.30	270	46.64	C	O	F	299.00	171.00	339	S	145.69	458
Turdus migratorius	31.50	0.007	77.30	NA	39.00	C	O	F	299.00	171.00	339	S	145.69	459
Turdus migratorius	31.50	0.011	77.30	451	42.42	C	O	F	299.00	171.00	339	S	145.69	460
Turdus nigriceps	28.50	0.057	55.85	1500	-24.69	C	O	F	NA	NA	2	S	NA	461
Turdus olivater	30.09	0.044	73.61	1700	9.56	S	O	F	NA	NA	1	S	185.54	462
Turdus poliocephalus	NA	0.022	88.09	3250	6.11	S	O	F	NA	NA	11	S	NA	463
Turdus rufiventris	30.50	0.052	69.50	1500	-24.69	C	O	F	NA	NA	27	S	NA	464
Turdus serranus	31.94	0.045	85.00	1700	9.56	S	O	F	NA	NA	2	S	154.60	465
Tyrannus forficatus	33.85	0.009	39.30	18	28.07	S	O	O	1126.00	1074.25	38	S	145.27	466
Tyrannus tyrannus	34.00	0.012	39.80	255	40.81	C	O	O	800.00	712.00	91	S	153.94	467
Tyrannus verticalis	33.30	0.014	39.60	1445	31.90	C	O	NA	1148.00	1036.00	68	S	198.56	468
Tyrannus vociferans	34.50	0.016	45.60	1445	31.90	C	O	NA	1148.00	1109.10	24	S	314.16	469
Urosphena whiteheadi	37.97	0.045	10.50	1700	6.11	S	O	F	NA	NA	0	NA	NA	470
Vermivora chrysoptera	24.75	0.013	8.75	482	45.71	G	O	F	NA	NA	119	S	115.94	471
Vermivora chrysoptera	24.75	0.020	8.75	580	36.42	G	O	F	NA	NA	119	S	115.94	472
Vermivora chrysoptera	24.75	0.019	8.75	1000	38.62	G	O	O	NA	NA	119	S	115.94	473
Vermivora chrysoptera	24.75	0.026	8.75	800	36.29	G	O	F	NA	NA	119	S	115.94	474
Vermivora peregrina	29.00	0.018	8.90	NA	49.80	G	O	F	NA	NA	16	S	56.08	475

Species	Dev	DPR	Size	Elev	Lat	Loc.	Struct.	Hab.	Max size pred	Range size pred	Effort	Soc.	Nest top area	Ref
Vermivora virginiae	26.61	0.035	8.42	2350	35.10	G	O	F	NA	NA	27	S	65.90	476
Vireo atricapilla	30.25	0.016	9.00	NA	32.85	S	O	O	88.00	10.85	22	S	25.52	477
Vireo belli	29.30	0.017	8.50	NA	32.00	S	O	O	88.00	NA	63	S	37.83	478
Vireo gilvus	30.15	0.031	11.97	2350	35.10	C	O	F	NA	NA	56	S	39.04	479
Vireo griseus	27.75	0.007	11.40	700	36.80	S	O	O	NA	NA	90	S	47.54	480
Vireo olivaceus	27.15	0.006	16.80	228	45.63	C	O	F	NA	NA	148	S	40.55	481
Vireo olivaceus	27.15	0.016	16.80	NA	46.00	C	O	F	NA	NA	148	S	40.55	482
Vireo olivaceus	27.15	0.025	16.80	NA	35.72	C	O	F	NA	NA	148	S	40.55	483
Vireo plumbeus	30.22	0.046	17.64	2350	35.10	S	O	F	128.00	88.85	12	S	69.25	484
Vireo solitarius	31.00	0.006	15.30	1960	40.08	C	O	F	800.00	712.00	59	S	50.27	485
Volatinia jacarina	21.75	0.058	9.95	1063	-15.86	S	O	O	NA	NA	34	S	NA	486
Wilsonia citrina	24.40	0.017	10.55	58	33.15	S	O	F	96.00	NA	126	S	42.43	487
Wilsonia citrina	24.40	0.021	10.55	81	33.24	S	O	F	96.00	NA	126	S	42.43	488
Wilsonia citrina	24.40	0.029	10.55	182	38.80	S	O	F	96.00	NA	126	S	42.43	489
Wilsonia citrina	24.40	0.026	10.55	478	35.72	S	O	F	96.00	NA	126	S	42.43	490
Wilsonia citrina	24.40	0.035	10.55	351	44.29	S	O	F	96.00	NA	126	S	42.43	491
Wilsonia pusilla	25.75	0.036	7.00	21	37.96	G	O	F	NA	NA	67	S	71.18	492
Wilsonia pusilla	25.75	0.017	7.00	NA	38.00	G	O	F	NA	NA	67	S	71.18	493
Xanthomyza phrygia	32.00	0.012	40.15	684	-30.33	C	O	F	299.50	211.75	49	G	102.07	494
Yuhina everetti	27.71	0.056	13.25	1700	6.11	S	O	F	NA	NA	1	G	NA	495

Zimmerius chrysops	37.88	0.057	9.03	1700	9.56	C	D	F	NA	NA	1	S	NA	496
Zonotrichia albicollis	26.75	0.020	24.40	470	45.61	G	O	NA	200.00	104.00	216	S	86.59	497
Zonotrichia atricapilla	25.80	0.018	32.00	636	54.80	G	O	O	NA	NA	57	S	176.71	498
Zonotrichia capensis	NA	0.050	20.30	1500	-24.69	S	O	F	NA	NA	105	S	NA	499
Zonotrichia leucophrys	25.30	0.025	28.40	211	37.79	S	O	O	290.00	NA	452	S	105.68	500
Zonotrichia leucophrys	25.30	0.018	28.40	3017	37.88	S	O	O	290.00	NA	452	S	105.68	501
Zonotrichia leucophrys	25.30	0.046	28.40	1860	42.43	S	O	O	290.00	NA	452	S	105.68	502
Zonotrichia leucophrys	25.30	0.021	28.40	470	45.61	S	O	NA	290.00	NA	452	S	105.68	503
Zonotrichia querula	26.35	0.014	35.55	200	63.12	G	O	O	NA	NA	54	S	NA	504
Zoothera heinei	NA	0.022	82.80	556	-28.46	C	O	F	NA	NA	0	S	NA	505
Zoothera lunulata	NA	0.050	130.00	96	-38.17	C	O	O	NA	NA	0	S	NA	506
Zosterops lateralis	24.50	0.001	12.65	NA	-45.87	C	O	NA	190.00	136.05	167	S	28.27	507
Zosterops lateralis	24.50	0.031	12.65	NA	-42.37	C	O	NA	190.00	136.05	167	S	28.27	508
Zosterops lateralis	24.50	0.009	12.65	NA	-42.33	C	O	NA	190.00	136.05	167	S	28.27	509
Zosterops pallidus	23.22	0.127	11.45	21	-33.68	C	O	O	NA	NA	17	S	13.20	510

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Supplementary data 2. Dataset of the information on behavioral response to predators used in the analyses. Data includes information of predators and their body mass that prey bird species have beed reported to attack. The information of these agonistic behaviors was obtained from The Birds of North America (Rodewald 2018) and The Handbook of Australian, New Zealand and Antarctic Birds Vol. 5, 6 and 7 (Higgins et al. 2001, 2006; Higgins and Peter 2002), while the information on predator body mass (grams) was collected from the Animal Ageing and Longevity Database (Tacutu et al. 2018). The type of predator (B=bird; M=mammal) is also specified.

Species	Predator type	Predator species	Predator mass
Aimophila carpalis	B	*Campylorhynchus brunneicapillus*	38.9
Rhipidura fuliginosa	B	*Philesturnus carunculatus*	76.95
Rhipidura fuliginosa	B	*Turdus merula*	93.4
Ammodramus bairdii	M	*Spermophilus tridecemlineatus*	172.7
Ammodramus bairdii	M	*Spermophilus richardsonii*	342.5
Ammodramus caudacutus	M	*Microtus pennsylvanicus*	38.2
Ammodramus maritimus	B	*Ammodramus caudacutus*	19.25
Ammodramus maritimus	B	*Cistothorus palustris*	11.15
Anthochaera carunculata	M	*Canis lupus*	40000
Anthochaera carunculata	M	*Felis catus*	3900
Anthochaera carunculata	B	*Dacelo novaeguineae*	334.5
Anthochaera carunculata	B	*Coracina novaehollandiae*	118
Anthochaera carunculata	B	*Oriolus sagittatus*	95.2
Anthochaera carunculata	B	*Cracticus torquatus*	87.75
Anthochaera carunculata	B	*Gymnorhina tibicen*	286.5
Anthochaera carunculata	B	*Strepera graculina*	299.5
Anthochaera carunculata	B	*Philemon corniculatus*	100.85
Anthochaera carunculata	B	*Phylidonyris pyrrhopterus*	16.4
Anthochaera carunculata	B	*Accipiter cirrocephalus*	172
Anthochaera carunculata	B	*Coracina novaehollandiae*	118
Anthochaera carunculata	B	*Oriolus sagittatus*	95.2
Anthochaera carunculata	B	*Gymnorhina tibicen*	286.5
Anthochaera carunculata	B	*Strepera graculina*	299.5
Anthochaera carunculata	B	*Corvus coronoides*	645

Species	Predator type	Predator species	Predator mass
Anthochaera carunculata	B	*Dacelo novaeguineae*	334.5
Anthochaera carunculata	B	*Cracticus torquatus*	87.75
Anthochaera carunculata	B	*Acridotheres tristis*	114
Anthochaera carunculata	B	*Strepera versicolor*	396.5
Phylidonyris novaehollandiae	B	*Anthochaera carunculata*	106.35
Pycnoptilus floccosus	M	*Rattus fuscipes*	130
Menura novaehollandiae	M	*Dasyurus maculatus*	5500
Menura novaehollandiae	B	*Accipiter fasciatus*	351
Manorina melanophrys	B	*Dacelo novaeguinea*	334.5
Manorina melanophrys	B	*Colluricincla harmonica*	63.55
Manorina melanophrys	B	*Rhipidura leucophrys*	28.8
Manorina melanophrys	B	*Anthochaera carunculata*	106.35
Manorina melanophrys	B	*Acridotheres tristis*	114
Manorina melanophrys	B	*Strepera graculina*	299.5
Manorina melanophrys	B	*Strepera versicolor*	396.5
Manorina melanophrys	B	*Corvus mellori*	541
Artamus superciliosus	B	*Dacelo novaeguineae*	334.5
Artamus superciliosus	B	*Accipiter fasciatus*	351
Artamus superciliosus	B	*Strepera graculina*	299.5
Petroica multicolor	B	*Colluricinsla harmonica*	63.55
Petroica multicolor	B	*Todiramphus sanctus*	53.95
Artamus cyanopterus	B	*Lophoictinia isura*	585.5
Artamus cyanopterus	B	*Aquila audax*	3466
Artamus cyanopterus	B	*Falco berigora*	593.5
Artamus cyanopterus	B	*Falco cenchroides*	167
Artamus cyanopterus	B	*Dacelo novaeguineae*	334.5
Artamus cyanopterus	B	*Coracina novaehollandiae*	118
Artamus cyanopterus	B	*Strepera versicolor*	396.5
Artamus cyanopterus	B	*Corvus coronoides*	645
Artamus cyanopterus	B	*Corvus tasmanicus*	674.5
Artamus cyanopterus	B	*Dacelo novaeguineae*	334.5
Malurus cyaneus	B	*Colluricincla harmonica*	63.55
Malurus cyaneus	B	*Chrysococcyx lucidus*	24.45
Calcarius ornatus	M	*Urocitellus richardsonii*	342.5
Calcarius ornatus	B	*Sturnella neglecta*	100.7

Species	Predator type	Predator species	Predator mass
Calcarius ornatus	B	*Molothrus ater*	39.15
Callaeas cinereus	M	*Rattus rattus*	200
Callaeas cinereus	M	*Mustela erminea*	110.3
Callaeas cinereus	B	*Eudynamys taitensis*	117
Campylorhynchus brunneicapillus	M	*Ammospermophilus harrisii*	126
Campylorhynchus brunneicapillus	M	*Spermophilus beecheyi*	509
Campylorhynchus brunneicapillus	M	*Felis catus*	3900
Campylorhynchus brunneicapillus	B	*Geococcyx californianus*	376
Campylorhynchus brunneicapillus	B	*Lanius ludovicianus*	51.75
Campylorhynchus brunneicapillus	B	*Melanerpes uropygialis*	64.85
Cardellina rubrifrons	M	*Tamias cinereicollis*	70
Cardinalis cardinalis	B	*Cyanocitta cristata*	88
Strepera graculina	M	*Felis catus*	3900
Strepera graculina	B	*Corvus coronoides*	645
Strepera graculina	B	*Corvus mellori*	541
Strepera graculina	B	*Accipiter fasciatus*	351
Strepera graculina	B	*Accipiter cirrocephalus*	172
Strepera graculina	B	*Scythrops novaehollandiae*	684
Strepera graculina	B	*Haliastur sphenurus*	753
Strepera graculina	B	*Falco longipennis*	253
Strepera graculina	B	*Gymnorhina tibicen*	286.5
Strepera graculina	B	*Dacelo novaeguineae*	334.5
Strepera graculina	B	*Anthochaera carunculata*	106.35
Strepera graculina	B	*Coracina novaehollandiae*	118
Strepera graculina	B	*Corvus coronoides*	645
Malurus splendens	B	*Chrysococcyx lucidus*	24.45
Carpodacus mexicanus	M	*Ammospermophilus harrisii*	126
Carpodacus mexicanus	B	*Campylorhynchus brunneicapillus*	38.9

Species	Predator type	Predator species	Predator mass
Carpodacus mexicanus	B	*Buteo swainsoni*	958.5
Petroica goodenovii	B	*Chrysococcyx basalis*	23.15
Contopus sordidulus	B	*Aphelocoma californica*	83.75
Contopus sordidulus	B	*Molothrus ater*	39.15
Corcorax melanorhamphos	M	*Vulpes vulpes*	4132
Corcorax melanorhamphos	M	*Felis catus*	3900
Corcorax melanorhamphos	B	*Gymnorhina tibicen*	286.5
Corcorax melanorhamphos	B	*Falco subniger*	785.5
Corcorax melanorhamphos	B	*Anthochaera spp.*	106.78
Corcorax melanorhamphos	B	*Cracticus nigrogularis*	128
Corcorax melanorhamphos	B	*Strepera graculina*	299.5
Corcorax melanorhamphos	B	*Corvus coronoides*	645
Corcorax melanorhamphos	B	*Struthidea cinerea*	132
Corcorax melanorhamphos	B	*Strepera graculina*	299.5
Corvus brachyrhynchos	M	*Procyon lotor*	6000
Corvus brachyrhynchos	M	*Sciurus carolinensis*	200
Corvus brachyrhynchos	M	*Sciurus niger*	800
Corvus brachyrhynchos	M	*Vulpes vulpes*	4132
Corvus brachyrhynchos	M	*Felis catus*	3900
Corvus brachyrhynchos	B	*Bubo virginianus*	1148
Corvus brachyrhynchos	B	*Tyto alba*	363.5
Corvus brachyrhynchos	B	*Buteo jamaicensis*	1126
Corvus brachyrhynchos	B	*Corvus corax*	941
Corvus brachyrhynchos	B	*Accipiter striatus*	137
Corvus brachyrhynchos	B	*Accipiter cooperii*	439
Corvus brachyrhynchos	B	*Haliaeetus leucocephalus*	4740
Corvus brachyrhynchos	B	*Caracara cheriway*	1035
Corvus brachyrhynchos	B	*Falco sparverius*	112
Corvus brachyrhynchos	B	*Cyanocitta cristata*	88
Cyanocitta cristata	M	*Procyon lotor*	6000
Cyanocitta cristata	M	*Felis catus*	3900
Cyanocitta cristata	M	*Sciurus niger*	800
Cyanocitta cristata	B	*Buteo jamaicensis*	1126
Cyanocitta cristata	B	*Bubo virginianus*	1148
Cyanocitta cristata	B	*Strix varia*	716.5

Species	Predator type	Predator species	Predator mass
Cyanocitta stelleri	M	*Sciurus carolinensis*	200
Cyanocitta stelleri	B	*Corvus corax*	941
Cyanocitta stelleri	B	*Buteo jamaicensis*	1126
Cyanocitta stelleri	B	*Accipiter cooperii*	439
Cyanocitta stelleri	B	*Accipiter gentilis*	949
Cyanocitta stelleri	B	*Cyanocitta cristata*	88
Dendroica caerulescens	M	*Tamias striatus*	96
Dendroica petechia	B	*Cyanocitta cristata*	88
Dendroica petechia	B	*Troglodytes aedon*	10.95
Dendroica petechia	B	*Agelaius phoeniceus*	52.4
Dendroica petechia	B	*Molothrus ater*	39.15
Dolichonyx oryzivorus	B	*Molothrus ater*	39.15
Drymodes brunneopygia	B	*Pomatostomus superciliosus*	41.2
Dumetella carolinensis	M	*Tamias striatus*	96
Dumetella carolinensis	M	*Sciurus carolinensis*	533
Dumetella carolinensis	M	*Tamiasciurus hudsonicus*	200
Empidonax minimus	B	*Cyanocitta cristata*	88
Empidonax minimus	B	*Molothrus ater*	39.15
Empidonax traillii	B	*Dumatella carolinensis*	35.3
Empidonax virescens	M	*Tamias striatus*	96
Empidonax virescens	B	*Molothrus ater*	39.15
Empidonax virescens	B	*Cyanocitta cristata*	88
Empidonax virescens	B	*Melanerpes carolinus*	72.5
Seiurus aurocapilla	M	*Peromyscus leucopus*	23
Seiurus aurocapilla	M	*Tamias striatus*	96
Eopsaltria australis	B	*Colluricincla harmonica*	63.55
Pachycephala rufiventris	B	*Cracticus torquatus*	87.75
Epthianura tricolor	B	*Chrysococcyx basalis*	23.15
Euphagus cyanocephalus	B	*Larus delawarensis*	518.5
Euphagus cyanocephalus	B	*Bubo virginianus*	1148
Euphagus cyanocephalus	B	*Molothrus ater*	39.15
Euphagus cyanocephalus	B	*Sturnella neglecta*	100.7
Grallina cyanoleuca	B	*Haliastur sphenurus*	753
Grallina cyanoleuca	B	*Gymnorhina tibicen*	286.5
Grallina cyanoleuca	B	*Corvus sp.*	554.1

Species	Predator type	Predator species	Predator mass
Grallina cyanoleuca	B	*Dacelo novaeguineae*	334.5
Grallina cyanoleuca	B	*Struthidea cinerea*	132
Gymnorhinus cyanocephalus	B	*Corvus brachyrhynchos*	448.5
Gymnorhinus cyanocephalus	B	*Corvus corax*	941
Gymnorhinus cyanocephalus	B	*Accipiter gentilis*	949
Hylocichla mustelina	B	*Cyanocitta cristata*	88
Lanius ludovicianus	B	*Pica pica*	219
Lanius ludovicianus	B	*Corvus brachyrhynchos*	448.5
Lanius ludovicianus	B	*Caracara cheriway*	1035
Lanius ludovicianus	B	*Circus cyaneus*	394.5
Lanius ludovicianus	B	*Falco columbarius*	190.5
Lanius ludovicianus	B	*Buteo swainsoni*	958.5
Lanius ludovicianus	B	*Buteo jamaicensis*	1126
Lanius ludovicianus	B	*Buteo lineatus*	607
Lanius ludovicianus	B	*Elanoides forficatus*	417
Lanius ludovicianus	B	*Sturnella neglecta*	100.7
Lanius ludovicianus	B	*Quiscalus major*	158.5
Lanius ludovicianus	B	*Oreoscoptes montanus*	44.2
Icteria virens	B	*Dumetella carolinensis*	35.3
Junco hyemalis	M	*Tamias striatus*	96
Tyrannus forficatus	B	*Buteo jamaicensis*	1126
Tyrannus forficatus	B	*Buteo swainsoni*	958.5
Tyrannus forficatus	B	*Quiscalus mexicanus*	169
Tyrannus forficatus	B	*Quiscalus quiscula*	106.1
Tyrannus forficatus	B	*Lanius ludovicianus*	51.75
Tyrannus forficatus	B	*Corvus brachyrhynchos*	448.5
Tyrannus forficatus	B	*Cyanocitta cristata*	88
Lichenostomus flavicollis	B	*Phylidonyris pyrrhopterus*	16.4
Lichenostomus flavicollis	B	*Colluricincla harmonica*	63.55
Lichenostomus leucotis	B	*Ninox novaeseelandiae*	190
Lichenostomus melanops	B	*Anthochaera carunculata*	106.35
Lichenostomus melanops	B	*Dacelo novaeguineae*	334.5
Piranga rubra	B	*Cyanocitta cristata*	88
Piranga rubra	B	*Molothrus ater*	39.15
Wilsonia citrina	M	*Tamias striatus*	96

Species	Predator type	Predator species	Predator mass
Manorina melanocephala	M	*Rattus rattus*	200
Manorina melanocephala	B	*Falco berigora*	593.5
Manorina melanocephala	B	*Todiramphus sanctus*	53.95
Manorina melanocephala	B	*Turdus merula*	93.4
Manorina melanocephala	B	*Egretta novaehollandiae*	560
Manorina melanocephala	B	*Manorina melanophrys*	30.45
Melanodryas cucullata	B	*Rhipidura leucophrys*	28.8
Melanodryas cucullata	B	*Rhipidura leucophrys*	28.8
Melanodryas cucullata	B	*Anthochaera carunculata*	106.35
Microeca fascinans	B	*Todiramphus sanctus*	53.95
Mimus polyglottos	M	*Sciurus sp.*	800
Mimus polyglottos	B	*Corvus ossifragus*	285
Mimus polyglottos	B	*Corvus brachyrhynchos*	448.5
Mimus polyglottos	B	*Buteo jamaicensis*	1126
Mimus polyglottos	B	*Buteo lineatus*	607
Zonotrichia leucophrys	M	*Spermophilus beldingi*	290
Myadestes townsendi	M	*Tamiasciurus douglasii*	200
Myadestes townsendi	M	*Spermophilus lateralis*	157.6
Myadestes townsendi	M	*Eutamias sp.*	71.7
Myadestes townsendi	M	*Sciurus griseus*	425
Myiagra inquieta	B	*Coracina novaehollandiae*	118
Myiagra rubecula	B	*Accipiter fasciatus*	351
Myiagra rubecula	B	*Dacelo novaeguinea*	334.5
Myiagra rubecula	B	*Strepera graculina*	299.5
Myiagra rubecula	B	*Cracticus torquatus*	87.75
Toxostoma rufum	M	*Canis familiaris*	40000
Toxostoma rufum	M	*Felis catus*	3900
Toxostoma rufum	B	*Dumetella carolinensis*	35.3
Toxostoma rufum	B	*Cyanocitta cristata*	88
Toxostoma rufum	M	*Felis catus*	3900
Toxostoma rufum	B	*Dumetella carolinensis*	35.3
Toxostoma rufum	B	*Cyanocitta cristata*	88
Passerina ciris	B	*Cyanocitta cristata*	88
Passerina ciris	B	*Quiscalus quiscula*	106.1
Pheucticus ludovicianus	B	*Cyanocitta cristata*	88

Species	Predator type	Predator species	Predator mass
Pheucticus ludovicianus	B	*Quiscalus quiscula*	106.1
Aphelocoma coerulescens	M	*Dasypus novemcinctus*	5500
Aphelocoma coerulescens	M	*Urocyon cinereoargenteus*	4750
Aphelocoma coerulescens	M	*Canis familiaris*	40000
Aphelocoma coerulescens	M	*Procyon lotor*	6000
Aphelocoma coerulescens	M	*Mustela frenata*	150.6
Aphelocoma coerulescens	M	*Lynx rufus*	8600
Aphelocoma coerulescens	M	*Felis catus*	3900
Aphelocoma coerulescens	B	*Bubo virginianus*	1148
Aphelocoma coerulescens	B	*Megascops asio*	180.5
Aphelocoma coerulescens	B	*Cyanocitta cristata*	88
Vireo solitarius	M	*Sciurus sp.*	800
Vireo solitarius	B	*Corvus brachyrhynchos*	448.5
Vireo solitarius	B	*Cyanocitta cristata*	88
Pica nuttalli	M	*Lynx rufus*	8600
Pica nuttalli	M	*Felis catus*	3900
Pica nuttalli	M	*Canis familiaris*	40000
Pica nuttalli	B	*Falco sparverius*	112
Pica nuttalli	B	*Accipiter striatus*	137
Pica nuttalli	B	*Accipiter cooperii*	439
Pica nuttalli	B	*Buteo jamaicensis*	1126
Pica nuttalli	B	*Buteo lineatus*	607
Pica nuttalli	B	*Bubo virginianus*	1148
Pica nuttalli	B	*Corvus brachyrhynchos*	448.5
Pica nuttalli	B	*Aphelocoma californica*	83.75
Pica nuttalli	B	*Accipiter striatus*	137
Pica nuttalli	B	*Falco sparverius*	112
Pipilo erythrophthalmus	B	*Dumetella carolinensis*	35.3
Calamospiza melanocorys	M	*Spermophilus tridecemlineatus*	172.7
Calamospiza melanocorys	B	*Sturnella neglecta*	100.7
Piranga ludoviciana	B	*Gymnorhinus cyanocephalus*	105
Piranga olivacea	M	*Sciurus niger*	800
Piranga olivacea	M	*Sciurus carolinensis*	533
Piranga olivacea	M	*Tamiasciurus budsonicus*	200
Piranga olivacea	M	*Tamias striatus*	96

Species	Predator type	Predator species	Predator mass
Piranga olivacea	B	*Colaptes auratus*	128
Piranga olivacea	B	*Dumetella carolinensis*	35.3
Piranga olivacea	B	*Molothrus ater*	39.15
Piranga olivacea	B	*Colaptes auratus*	128
Piranga olivacea	B	*Dumetella carolinensis*	35.3
Piranga olivacea	B	*Molothrus ater*	39.15
Piranga olivacea	B	*Cyanocitta cristata*	88
Calcarius mccownii	M	*Spermophilus tridecimlineatus*	172.7
Polioptila californica	B	*Campylorhynchus brunneicapillus*	38.9
Polioptila californica	B	*Geococcyx californianus*	376
Polioptila californica	B	*Aphelocoma californica*	83.75
Polioptila californica	B	*Sturnella neglecta*	100.7
Polioptila californica	B	*Campylorhynchus brunneicapillus*	38.9
Polioptila californica	B	*Sturnella neglecta*	100.7
Pomatostomus temporalis	M	*Felis catus*	3900
Pomatostomus temporalis	M	*Canis lupus*	40000
Pomatostomus temporalis	B	*Gymnorhina tibicen*	286.5
Pomatostomus temporalis	B	*Accipiter fasciatus*	351
Bombycilla cedrorum	B	*Quiscalus quiscula*	106.1
Bombycilla cedrorum	B	*Troglodytes aedon*	10.95
Bombycilla cedrorum	B	*Cyanocitta cristata*	88
Bombycilla cedrorum	B	*Dumetella carolinensis*	35.3
Bombycilla cedrorum	B	*Troglodytes aedon*	10.95
Prosthemadera novaeseelandiae	B	*Eudynamys taitensis*	117
Quiscalus quiscula	B	*Cyanocitta cristata*	88
Quiscalus quiscula	B	*Accipiter cooperii*	439
Quiscalus quiscula	B	*Buteo lineatus*	607
Quiscalus quiscula	B	*Tyto alba*	363.5
Quiscalus quiscula	B	*Bubo virginianus*	1148
Quiscalus quiscula	B	*Corvus brachyrhynchos*	448.5
Quiscalus major	B	*Ardea herodias*	2525
Quiscalus major	B	*Corvus ossifragus*	285
Quiscalus major	B	*Buteo lineatus*	607

Species	Predator type	Predator species	Predator mass
Quiscalus mexicanus	M	*Sciurus sp.*	800
Quiscalus mexicanus	B	*Buteo swainsoni*	958.5
Turdus migratorius	B	*Cyanocitta stelleri*	128
Turdus migratorius	B	*Asio otus*	299
Turdus migratorius	B	*Cyanocitta stelleri*	128
Rhipidura leucophrys	M	*Felis catus*	3900
Rhipidura leucophrys	B	*Dacelo novaeguineae*	334.5
Rhipidura leucophrys	B	*Gymnorhina tibicen*	286.5
Rhipidura leucophrys	B	*Coracina novaehollandiae*	118
Rhipidura leucophrys	B	*Anthochaera carunculata*	106.35
Rhipidura leucophrys	B	*Corvus coronoides*	645
Rhipidura leucophrys	B	*Haliastur sphenurus*	753
Rhipidura leucophrys	B	*Accipiter fasciatus*	351
Setophaga ruticilla	B	*Cyanocitta cristata*	88
Setophaga ruticilla	B	*Aegolius acadicus*	104.2
Setophaga ruticilla	B	*Quiscalus quiscula*	106.1
Setophaga ruticilla	B	*Accipiter cooperii*	439
Struthidea cinerea	M	*Felis catus*	3900
Struthidea cinerea	M	*Vulpes vulpes*	4132
Struthidea cinerea	B	*Pomatostomus temporalis*	75
Struthidea cinerea	B	*Gymnorhina tibicen*	286.5
Struthidea cinerea	B	*Struthidea cinerea*	132
Struthidea cinerea	B	*Strepera graculina*	299.5
Struthidea cinerea	B	*Gymnorhina tibicen*	286.5
Struthidea cinerea	B	*Dacelo novaeguineae*	334.5
Struthidea cinerea	B	*Accipiter fasciatus*	351
Toxostoma curvirostre	B	*Geococcyx californianus*	376
Toxostoma longirostre	B	*Geococcyx californianus*	376
Tyrannus verticalis	B	*Corvus brachyrhynchos*	448.5
Tyrannus verticalis	B	*Corvus cryptoleucus*	534
Tyrannus verticalis	B	*Falco sparverius*	112
Tyrannus verticalis	B	*Buteo jamaicensis*	1126
Tyrannus verticalis	B	*Accipiter cooperii*	439
Tyrannus verticalis	B	*Bubo virginianus*	1148
Tyrannus vociferans	B	*Buteo jamaicensis*	1126

Species	Predator type	Predator species	Predator mass
Tyrannus vociferans	B	*Bubo virginianus*	1148
Tyrannus vociferans	B	*Corvus corax*	941
Tyrannus vociferans	B	*Melanerpes formicivorus*	79.65
Tyrannus vociferans	B	*Aphelocoma ultramarina*	129
Tyrannus vociferans	B	*Campylorhynchus brunneicapillus*	38.9
Vireo atricapilla	B	*Cyanocitta cristata*	88
Vireo atricapilla	B	*Aphelocoma coerulescens*	77.15
Vireo bellii	B	*Molothrus ater*	39.15
Vireo bellii	B	*Cyanocitta cristata*	88
Vireo bellii	B	*Aphelocoma coerulescens*	77.15
Vireo plumbeus	B	*Aphelocoma californica*	83.75
Vireo plumbeus	B	*Cyanocitta stelleri*	128
Vireo plumbeus	B	*Molothrus ater*	39.15
Tyrannus tyrannus	M	*Sciurus sp.*	800
Tyrannus tyrannus	M	*Mustela frenata*	150.6
Tyrannus tyrannus	B	*Circus cyaneus*	394.5
Tyrannus tyrannus	B	*Corvus brachyrhynchos*	448.5
Tyrannus tyrannus	B	*Cyanocitta cristata*	88
Xanthomyza phrygia	B	*Strepera graculina*	299.5
Xanthomyza phrygia	B	*Cracticus torquatus*	87.75
Zonotrichia albicollis	M	*Tamiasciurus hudsonicus*	200
Zonotrichia albicollis	M	*Tamias striatus*	96
Oreoscoptes montanus	B	*Lanius ludovicianus*	51.75
Spizella breweri	M	*Mustela frenata*	150.6
Spizella breweri	M	*Tamias minimus*	44.1
Spizella breweri	M	*Spermophilus townsendii*	203
Zosterops lateralis	B	*Ninox novaeseelandiae*	190
Zosterops lateralis	B	*Todiramphus sanctus*	53.95