# **Chapter 2: Sharing is caring - The evolution of communal roosting behavior in birds**

**Introduction**

Communal roosts are aggregations of unrelated individuals (either con- or heterospecific) that spend the resting period (either diurnal or nocturnal) together (Laughlin et al. 2014). This behavior is striking given the apparent little benefits of sharing space and resources with unrelated individuals. Yet, it is seen in species across many taxa, including fish (Clough and Ladle 1997), mammals (Kunz, 1982) and birds (Eiserer 1984). The frequency and diverse range of species in which communal roosting occurs suggest that it has evolved independently on numerous occasions, and that there should be an underlying mechanism, or set therefore, that support(s) this behavior.

It has been argued that these roosts are sites where naïve individuals can potentially exchange information with more experienced individuals on the location of food sources. This concept is formalized by Ward and Zahavi (1973) via the Information Center Hypothesis (ICH). Some prerequisites have been proposed by Mock (1988) to successfully test the ICH. First, *site fidelity*: individuals commute from specific roost sites to a recently detected carcass. Second, *differential success*: individuals differ in the information they have regarding food locations a given moment. In other words, there are informed and naïve individuals. Third, *signal transfer*: informed individuals may be identified by others through reliable physical (e.g., visual cues) or behavioral signals, either intentionally or inadvertently. This will allow for uninformed individuals to follow informed individuals. Fourth, *tolerance:* food resources are typically larger than the feeding capacity of a single individual, leading to satiation. Hence, information on location of food sources has little costs for the informed individual. Lastly, it is assumed that the cost of being a follower has an overall positive payoff than exploring for food individually. If the ICH holds true, individuals that exhibit communal roosting behavior are expected to have increased foraging efficiency than those who do not (e.g., Harel et al. 2017). Undoubtedly, this would be beneficial for scavengers given the high competition for their pulsed food resources (Van Overveld et al. 2022).

In an attempt to answer this question, the drivers for the communal roosting behavior in 201 bird species were tested by Beauchamp (1999), and his findings suggested that increased foraging efficiency was the most likely cause for communal roosting behavior. Other studies on specific species support this idea (Dermody et al. 2011). The conclusions on the aforementioned studies altogether open a new avenue for research to test this hypothesis in several other systems. Although the ICH has been well studied conceptually, these ideas have not been tested yet on a broader taxonomic scale after Beauchamp’s study, and a general understanding of the factors influencing avian communal roosting behaviour remain unknown. Using the comparative method, this chapter will focus on answering the following research question: what biological variables affect the prevalence of communal roosting behavior in landbirds?

**Methods**

*Communal roosting behavior*

To evaluate the relationship between biological variables and the evolution of communal roosting behavior in landbirds (Brusatte et al. 2015), I first collected data on communal roosting behavior. To do so, I gathered information on each species profile in Birds of the World, as it is the most comprehensive centralized database for birds’ natural history. When the information was not available for a given species, I used online databases and research papers using keywords like ‘*species name and communal roosting*’, ‘*species name and social roosting*’, and ‘*species name and social behavior*’. I then used the first five pages in google scholar to look for publications on the selected species. In parallel, I used Python's BeautifulSoup to web scrape Wikipedia for the number of literature references per species. The number of references where then clustered into three groups: not enough information (0-2 references), medium amount of information (3-5 references), and a lot of information (6-10). Clusters 1 and 2 where then used with web scraping tools to extract data from Wikipedia, OpenAlex, and Scopus. The manually collected data served as a benchmark to evaluate the accuracy of the web scraping results. The references in the output were then used to look for information on communal roosting behavior. This accelerated the search by dismissing species for which the number of references is negligible (cluster 1).

Communal roosting behavior will be classified as a discrete binary variable where 0 is non-roosting behavior, and 1 is evidence of communal roosting behavior. Species for which this behavior is not properly documented will be classified as data deficient, and excluded from the analysis.

*Phylogenetic data*

I used the comparative method to explore the evolutionary relationship between physiological and biological traits and the communal roosting behavior in landbirds (*sensu* Felsenstein 1985) comprising roughly 8373 species. To access phylogenetic data and relationships between species, I used Trees from <https://vertlife.org/>. For each species we generated 100 trees and the information was then used to construct a phylogenetic diagram using the phytools package.

*Biological variables*

To test for the biological variables driving the evolution of communal roosting behavior, I selected four main traits: body mass (kg) following Beauchamp (1999), Hand-wing index (HWI), trophic guild and residuals of body size to brain size ratio (as a proxy for memory). A rationale as to why these potential explanatory variables were selected follows:

* Trophic guild: Trophic guild follows a comparable pattern, where scavengers are expected to rely more on CRB given the unpredictable nature of their food sources (Harel et al. 2017). Data from Trophic guild will be obtained through AVONET, an online database for all bird species. Complementary information will be used to adjust for these categories where pertains.
* Hand-wing Index (HWI): Hand-wing index is a metric of dispersal ability in birds (Arango et al., 2022) and therefore it indicates the capacity of a species to scout looking for food sources. Where HWI is high, CRB may bring more benefits as they might access food location over broader areas that can be then accessed by others through information sharing (Buckley 1997). Hand-wing Index values will be obtained through AVONET.
* Memory: Memory was chosen as, for species to share information, memory on the location of the food source is required to be later passed on (G Hernández-Montero et al. 2020). Thus, I expect to see a positive relationship between memory and the prevalence of CRB. To test for this variable, residuals of relative brain size (absolute brain size in relation to body mass) were used following van Overbeld et al. (2022).
* Mass: Finally, mass was selected *a priori* from a larger pool of co-variates to reduce correlation between parameters. For instance, body mass, average lifespan and clutch size can potentially have an effect on communal roosting behavior given that larger, long-lived species tend to rely on information sharing to meet their greater energetic demands. Mass values will be obtained through AVONET.

Figure 2.1 below shows the anticipated relationships between avian communal roosting behavior and the variables tested.

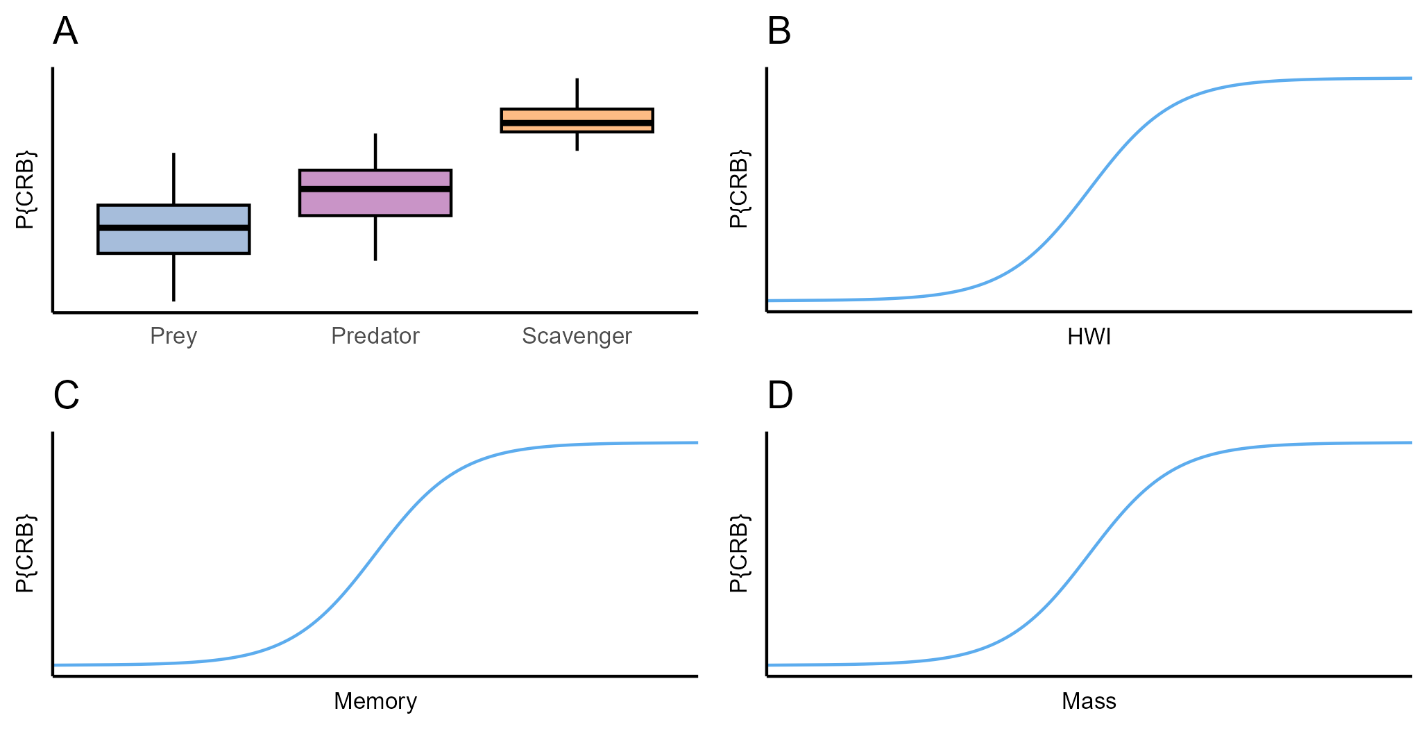


Figure 2.1. Anticipated relationships between the selected biological traits and the probability of Communal Roosting Behavior (p{CRB}). A) Trophic guild and Probability of Communal Roosting Behavior, where it will be considerably more probable in scavengers than in other trophic guilds. B-F show continuous biological variables and the expected relationship with P{CRB}.

*Statistical analyses*

The evolutionary relationship between communal roosting behavior (CRB) and was modelled using Equation 1.

Eq. 1

Where CRB is the Communal Roosting Behavior, and is the regression coefficient that determines the relationship between the variables. The model was fitted in R using the *brms* package as it allows for flexibility to handle binary data and includes phylogenetic structure as a random effect. I used a Bernoulli family distribution and the *loglink* function for the response variable as the probability of CRB should saturate at 1 despite increases in the predictors. The model was run with eight chains and 1000000 iterations. Given the large sample size in our model, we used default priors only so that the data informed the model without introducing biases.

*Model assumptions*

* The model assumes that the probability of CRB follows a binomial distribution (hence the Bernoulli family in the link function).
* HWI, mass and trophic guild are fixed effects and there are no changes in the slopes of each of these predictors (no interaction terms).
* There is no collinearity between the predictor variables – this has been tested and therefore validated.
* The only random effect in the data structure is phylogeny, and that the phylogenetic structure is properly modeled.
* The variables follow a linear function (e.g., not polynomial)
* Sample size is large enough that the data will converge without the need to inform the priors.

*Biological variables and CRB*

*Global model*

To test for the importance of biological variables on Communal Roosting Behavior, I tested five different models. The first set of models used all data available (946 species), and I compared the null hypothesis – in which CRB is only explained by phylogenetic relatedness, and the biological variables model (HWI, mass, trophic guild).

*Subset models*

The second set of models used only a subset of species (300), which include only the species for which we have brain size data. Brain size was obtained in volume (mm3) and mass (kg) from different sources. Because brain size and brain volume were highly correlated (0.9), brain volume was dropped to avoid collinearity. Brain mass was selected over brain volume as it had more raw data available. A linear model was fitted between both variables using the ‘lm’ function and used to predict brain mass for those species for which only brain volume was available. To correct for collinearity between brain mass and body mass, I fitted a linear model between the two variables. The residuals of the model were used as the predictor rather than brain mass itself (Van Overveld et al., 2022). The first model was the same model than before but only on a smaller sample size. The second model was ran adding the residuals of brain mass against body mass as a predictor variable. A third model was ran using an additional interaction term between brain mass and body mass instead of the residuals. Models were compared using DIC. (Table 1).

|  |  |  |
| --- | --- | --- |
| Model name | Predictor variables included | Number of species |
| Null\_model | phylogeny | 946 |
| Model\_1 | HWI, body mass, trophic guild, phylogeny | 946 |
| Model\_2 | HWI, body mass, trophic guild, phylogeny | 300 |
| Model\_3 | HWI, body mass, trophic guild, phylogeny, residuals brainmass/bodymass | 300 |
| Model\_4 | HWI, body mass, trophic guild, phylogeny, brain mass, brainmass:bodymass | 300 |

**Results**

*Web Scraping and Communal Roosting Behavior*

OpenAlex had approximately a 14% accuracy, compared to SCOPUS which had a 15% accuracy to the manually checked list of species.

*The distribution of Communal Roosting*

Of all 8373 bird species that were originally chosen for the analysis, I used a conservative approach and therefore only 946 species were used for the analysis since those were the ones for which enough information was available to confirm (1) or discard communal (0) roosting behavior. For the remaining 946 species for which Communal Roosting Behavior was classified, 42.1% showed 0 and 57.9% showed 1 which means my sample was fairly evenly distributed. Communal roosting was predominant in families Psittacidae, Accipitridae and Corvidae. Figure 2.2 shows the evolution of CRB in different taxonomic groups. These results highlight that the evolution of CRB evolved in several clades that do not share a direct common ancestor, suggesting convergence evolution of the trait.

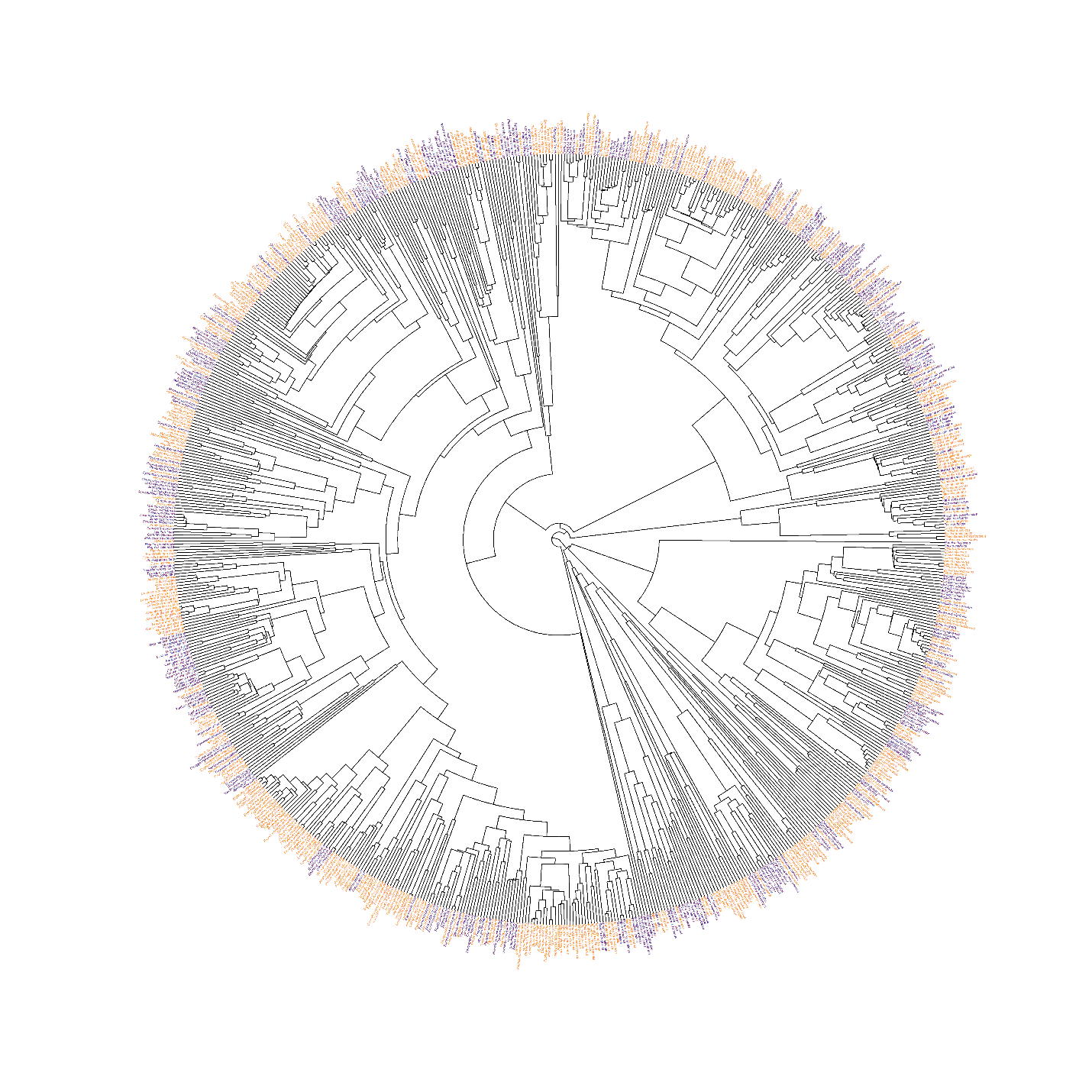


Figure 2.2. Evolution of Communal Roosting Behavior in Core Land Birds

*Biological variables and CRB*

The first set of models favored the model with biological variables over the null model (259.5 Model\_1 over null model, Figure 2.3). These suggests that overall, phylogeny alone cannot explain the evolution of this behavior. However, Rhat values in my model are currently greater than 1(Figure 2.4), which suggest the model has not converged properly so results of the model should be cautiously interpreted.

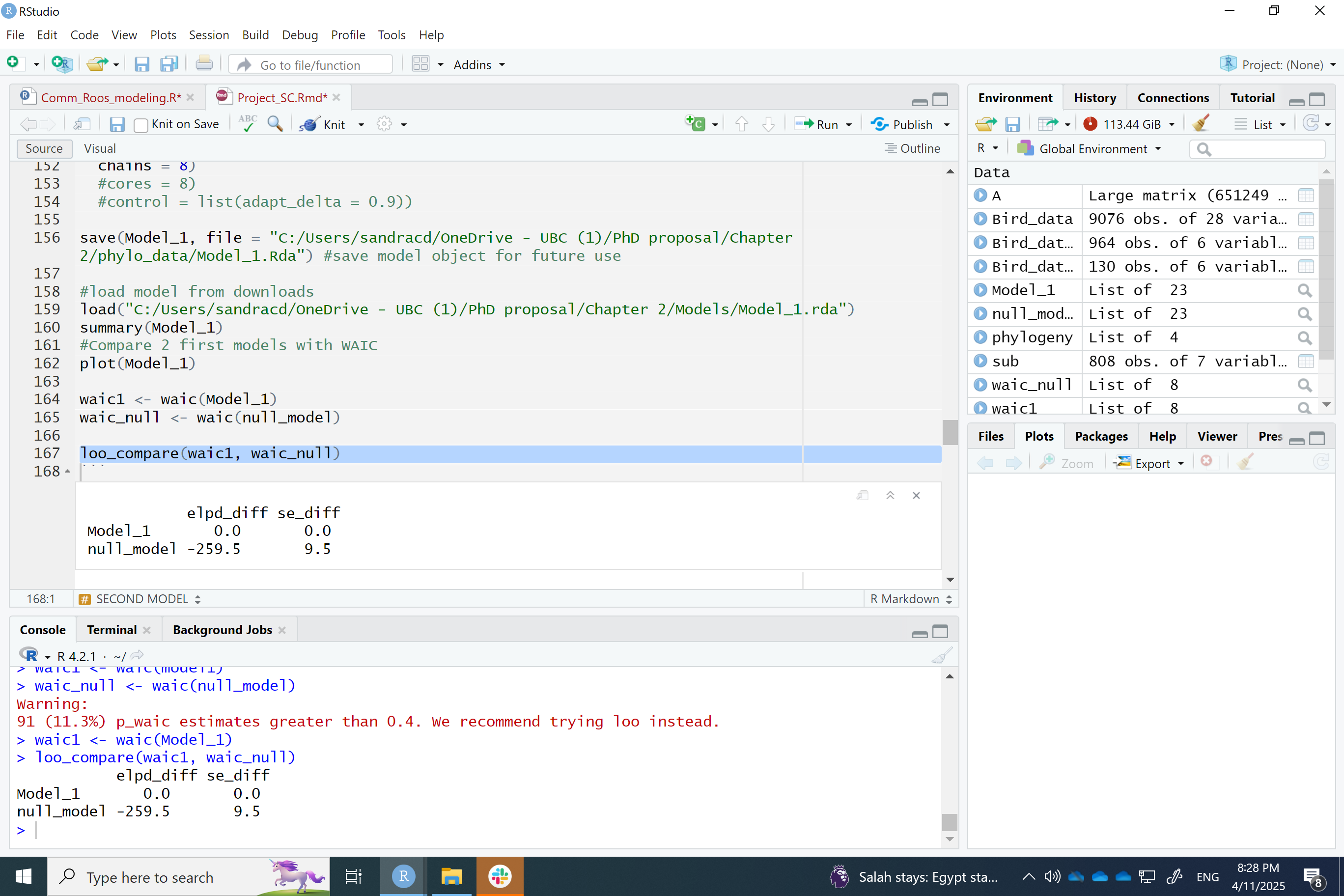


Figure 2.3 Model comparison between global (all data model) and null model.

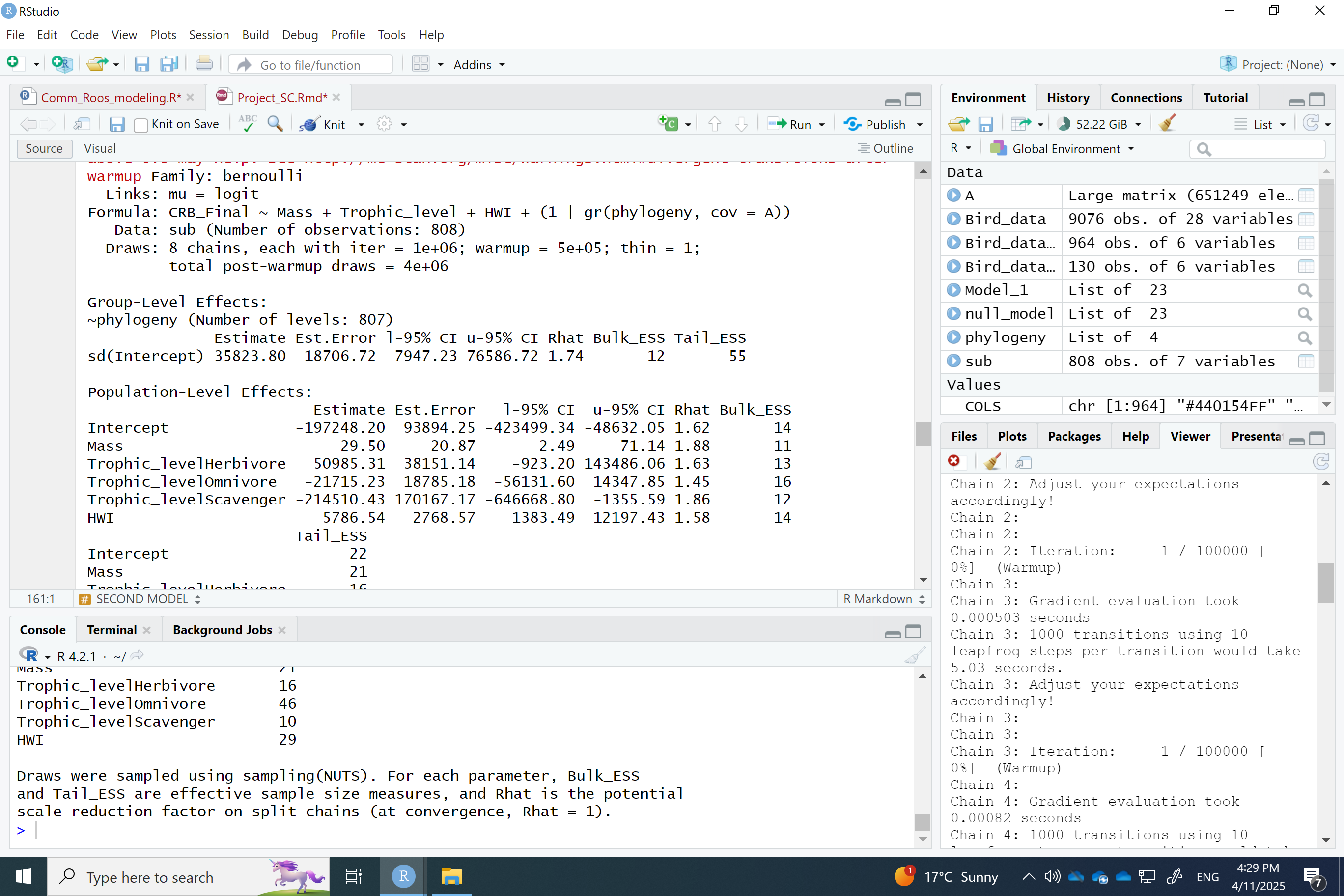


Figure 2.4. Summary of global model.

*Transition to CRB -* Section on ancestry of the behavior

**Discussion**

Communal Roosting Behavior has been widely documented in different taxa with several explanations for this behavior. Our results suggest that the ICH is the most likely hypothesis to explain this behavior given its predominance on species across all taxa and that inhabit a wide array of environments with contrasting weather conditions (e.g., Mindt et al., 2024, Preston, 2005; Saldanha et al., 2019).

*Hand Wing Index and Communal Roosting Behavior*

Our results supported the idea of a positive relationship between HWI and pCRB. These findings support the hypothesis of dispersing ability to promote this form of behavior, which has been discussed by other authors. For example, a study done by (Caccamise & Morrison, 1986)) suggests that European starlings (*Sturnus vulgaris*) gather in aggregations near supplementary feeding areas (SFA) to reduce the energetic cost of traveling to food sources. The rationale is that even if the individuals can commute long distances to feed in distant areas, they may benefit from roosting near the SFA. Hence, it is plausible to suggest that species that have high dispersal ability used to find food sources have evolved communal roosting behavior to reduce the energetic cost of feeding. Indeed, the sole idea of having supplemental feeding areas rests on the assumption that species can and have to disperse further away from their territories. In this study, the authors propose that individuals are more faithful to roosts near SFA rather than a stable communal roost. Nevertheless, the benefits of roosting (regardless of which type of roost) are inherently the same (e.g., Sonerud et al. 2002) support this hypothesis. In a recent study, Weeks et al. (2022) reported a strong correlation in birds between species with aerial lifestyle and HWI, arguing that species that rely highly on aerial lifestyles (e.g., commuting between roosting sites and foraging areas) have developed more efficient flight. Although they suggest that aerial lifestyle and efficient flight coevolve, here I propose that efficient flight mode is the driver of aerial lifestyle (e.g., Reliance on CRB) and not vice versa.

*Mass and Communal Roosting Behavior*

Body mass has long been recognized to affect lifespan (Healy et al., 2014) and therefore metabolic rate (Kleiber 1932; Peters, 1983); Hudson et al., 2013; Nagy et al., 1999). A comprehensive literature review done by (Hudson et al., 2013) outlines the studies done on this matter, highlighting the idea that there is variation on how the relationship scales between clades (e.g., birds, mammals, amphibians). While the scale at which body mass and metabolic rate relate is still being debated, it is reasonable to say that the greater the body size, the higher metabolic rates needed to sustain that amount of mass (Gillooly et al., 2001). For instance, high metabolic rates has been correlated to behaviors like torpor in hummingbirds, and food hoarding in several birds and mammals (Day & Bartness, 2003). The results of this study show that communal roosting behavior is positively correlated to body mass, perhaps since by increasing foraging efficiency, communal roosting acts as a mechanism to reduce energetic costs (metabolic rate). There is evidence that suggests that communal roosting behavior is positively related to longevity in parrots (Munshi-South & Wilkinson, 2006). Likewise, longevity is positively related to body mass (Healy et al., 2014). Therefore, it is possible to extend these results to suggest communal roosting is positively correlated to body mass as shown by my results. An extension of this idea could be tested by measuring metabolic rate in particular, rather than body mass. Specifically, mass-specific metabolic rate (Suarez & Gass, 2002) could shed light into more accurate relationship. However, these measures are not available for the vast majority of species.

*Trophic level and Communal Roosting Behavior*

My model shows that trophic level scavenger has a significant effect on CRB (although not any of the other trophic levels). This is not surprising considering the vast number of scavengers that have been documented to exhibit communal roosting (e.g., ravens, vultures). Because communal roosting has been found to increase foraging efficiency, it is reasonable to suggest that species that rely on ephemeral and unpredictable spatial-temporal food sources are particularly prone to take advantage of communal roosting (Kohles et al., 2022). However, communal roosting has evolved in other trophic levels as well. For instance, several seed parrots also show communal roosting (Munshi-South & Wilkinson, 2006). This may be indeed to increase group-foraging efficiency, but additional benefits may arise from this behavior. A study conducted on starlings (*Sturnus vulgaris*) where access to food was manipulated showed that receivers (naïve individuals) reacted to senders (e.g., individuals with access to food) by changing their foraging effort, as well as their vigilant activity. Therefore, species that have natural predators also benefit from CRB (Fern�ndez-Juricic & Kacelnik, 2004).

*Brain size and Communal Roosting Behavior*

Social behaviors that rely on memory have been widely documented for birds (e.g., Boeckle & Bugnyar, 2012; Penndorf et al., 2023). The results of this study suggest that memory is positively correlated with Communal Roosting Behavior. Memory, in particular spatial memory, is important for individuals to be able to benefit from CRB efficiently since they require the capacity to remember the locations of food items, and return to those sits on subsequent foraging trips (Ward and Zahavi 1973, Dywer et al. 2018), as well as returning back to their communal roosts. A study conducted on bats showed that spatial memory together with social cues were key for individuals to track the resources efficiently (Lourie et al., 2024). Other study in bats showed how they relied on spatial memory to find their communal roosts (Hernández-Montero et al., 2020). Clearly, spatial memory has been well established as a mechanism for food finding in wildlife (Brodbeck, 1994; Marzluff, 2010; McGREGOR & Healy, 1999). Testing for this relationship requires a measure of memory that can be obtained and compared across a wide range of taxa. Unfortunately, direct measures of memory are challenging to obtain, and typically require some form of recall experiments (Brady et al. 2023) or data that might not be available for all species. For instance, it has been suggested that hippocampus volume is a good proxy for spatial memory in birds (Garamszegi and Ens 2004). However, data on hippocampus volume for all bird species are not readily available, which limits the scope of its application. Because lab experimentation was not feasible for the scope of this work, I used the residuals of the brain mass to body mass relationship as a proxy for memory. Residuals were chosen over brain size due to the strong correlation between brain size and body size (Smaers et al. 2021). Though not an explicit measure of memory, these residuals have been showed to correlate with individual cognitive capacity under experimental settings (Burns et al. 2008, Benson-Amram et al. 2016), and also relate to food caching in birds (Garamszegi and Ens 2004). Collectively, these lines of evidence support the use of the brain mass to body mass residuals as a robust proxy for memory in birds.

*Alternative predictors: Predictability of food sources and food abundance*

Access to regular food sources is a determinant factor on populations fitness. It is not surprising therefore that species that feed on ephemeral food sources tend to exhibit communal roosting behavior. This can be explained to the fact that their food source is limited and unpredictable, which makes it impossible for these species to defend a territory. Therefore, as proposed by the ICH, sharing information on food sources is especially beneficial for such species. This phenomenon has been observed in species with different feeding strategies. For instance, a study by (Farquhar et al., 2018) showed that the increase in probability in communal roosting (huddling) of Chimney swifts (*Chaetura pelagica*) was associated to higher temperatures, which was correlated to lower prey availability. Similarly, Brown & Brown (1996) showed that cliff swallows (*Petrochelidon pyrrhonota*) tend to form large aggregations near ephemeral but abundant insect patches. Predictability of food sources expands beyond the nature of the trophic guild itself and suggests that for example, for a given scavenger species, if their food source is predictable (e.g., dumpsites), the need to exhibit communal roosting might decrease. Yet, using opportunistic more reliable food sources has seldom evolved in geologic timescales. Thus, while some plasticity of CRB may be observed in recent years for some species, the origin of the behavior or lack thereof cannot be attributed to these human-induced scenarios.

Similarly, food abundance may have an effect on CRB. A wider amount of available food sources effectively means less need to defend a territory. From a cost-benefit perspective, greater abundance of food sources means there are more benefits of sharing location of food sources than defending a territory for a widely available resource (as long as all individuals can access the resource). For example, it has been documented that food availability may induce communal roosting behavior in highly territorial species (Great-Horned Owl). This is because high availability of food in a farm location makes it easy for everyone to access resources without the need to compete for it ((Robinson & Davis, 2014). One could argue that a greater amount of food resources may mean less need to communal roost since the food is available for everyone. This may hold true to some extent, in which case perhaps communal roosting is favored only after a threshold is reached in which every individual has enough access to the resource (e.g., Buckley, 1997), and in which case communal roosting may be bringing other benefits than information sharing (e.g., a quadratic relationship). A comprehensive review was done by Kohles et al. (2022) and they propose a framework in which social information benefits can be tested as a function of the type or abundance and predictability of resource that was tested on bats. This framework may be useful to test birds’ sociality in the same fashion to complement my research.

Noteworthy, ambient temperature seems to be an important predictor variable as well, where CRB might be beneficial during the winter in higher latitudes for temperature regulation. For instance, when there is food scarcity, communal roosting might be induced as a way to reduce heat loss (Lubbe et al., 2018). Hence, food availability may also be confounded with ambient temperature. While it is possible that in these scenarios, the evolution of CRB could be driven by environmental rather than biological factors, the likelihood is low given that habitats have been subject to dramatic climate variabilities in the last 10 000 years (Alley & Agustsdottir, 2005), so we cannot assume that current environmental conditions drove the evolution of CRB in species seen today.

Finally, while communal roosting has most likely evolved to increase foraging efficiency in flock-living birds (Sonerud et al., 2002), we cannot discard that the behavior has been maintained because it also may decrease predation risk (Gilbert et al., 2010), thermal stress (e.g., Wojciechowski et al., 2011), and the cost of mate assessment (Beauchamp 1999; Blanco and Tella 1999) as suggested by other alternative hypothesis.

*Limitations*

Although the aforementioned variables are suggested important drivers of CRB, other confounding variables may influence in the evolution of this behavior. For instance, while it is true that the ICH may hold true for several scavenger species, prey species may also benefit from this phenomenon to share information of potential predators. Similarly, a major challenge of memory as a predictor is that it could be correlated to trophic guild, another predictor variable that has been proposed for the model. In particular, several vultures and corvids have good memory and cognitive abilities for problem solving (Weir et al. 2002, Lefebvre et al. 2004, Van Overveld et al. 2022). Because all vultures and many corvids (e.g., ravens, crows, magpies) are also scavengers, the coincidence (or correlation) between trophic guild and cognitive abilities may hinder my capacity to link memory and communal roosting behavior.

Another limiting factor is the use of brain size residuals as a proxy for memory since these are also related to other aspects such as cognition (Biegler et al. 2001, Burns et al. 2008, Benson-Amram et al. 2016), intelligence (Dickie & Roth 2016) or other biological traits like life expectancy (Smeele et al. 2022). Thus, there is a risk that a relationship between brain size residuals and roosting behavior may be due to correlates with other variables other than memory *per se*. Alternatively, other patterns could obscure the relationship between the proposed variables. For instance, research has suggested that neuronal connections are more accurately related to cognitive abilities than is brain volume (Logan et al. 2018). Nonetheless, neuronal connections might not necessarily be positively correlated with brain mass to body mass residuals, which would limit the use of the latter as a proxy. Albeit, the density of neuronal connections is significantly more complicated to measure and it requires an invasive approach far beyond the scope of my research. Similarly, memory may lead to other behaviors that are not necessarily communal roosting under the foraging efficiency hypothesis. For instance, greater memory could lead to food hoarding (Clayton & Krebs 1995). Here, individuals do not rely on sociality to successfully access foraging sites, although they do rely on memory. Alternatively, memory (or intelligence) could increase the ability to rely on local enhancement (Everding & Jones, 2006), where individuals don’t exhibit communal roosting but rather loose aggregation that rely on visual cues of conspecifics to find food. Hence, greater memory might not necessarily correlate to communal roosting behavior alone. Further research should expand on this hypothesis using the data collected as part of this research.

Finally, there is a limitation in my ability to detect CRB. For instance, a study conducted in fish showed that their social cohesion varied depending on the state of hunger. Individuals that were food-deprived were less likely to join shoals, possibly to reduce competition with conspecifics (Killen et al., 2016). This suggests that the tendency to exhibit a social behavior state that increases foraging efficiency (e.g., communal roosting) may also be determined by the degree of urgency of feeding. A study conducted on American Robins found that the patterns of communal roosting behavior were consistent with food finding (more communal roosting by juveniles, more communal roosting later in the season, foraging areas used on consecutive days were farther apart after robins roosted communally, and home ranges were bigger for robins that used the communal roost more, Benson et al., 2012). It is worth noting that this condition does not suffice to drive the evolution of the behavior itself in a species, but instead affect the frequency of the behavior, which may hinder ability to detect it, which would ultimately impact the outcome of my model. In my model, CRB was classified as a binary response variable (0,1), however, as data becomes more available, it would be interesting to test biological (and ecological) variables against the frequency of CRB (as a percentage). Yet again, this information is not currently available for the vast majority of species.

*Future work*

One of the major limitations of this study is the available information on communal roosting for several bird species. A large volume of research is conducted on a handful few species only. Conducting more field observations on understudied species may help to bridge that information gap. Another approach to do so would be the use of weather radar data (e.g., Cheng et al., 2020), but this approach is limited to where weather radars are available.

Additionally, whilst the current research shed light on relevant drivers of CRB, further examination of the proposed variables should be tested to increase the accuracy of the predictions and better understand the biological processes behind the correlation. For instance, we acknowledge that the proxy used for memory is a limiting factor. Assessing the same correlation with other measures of memory (e.g., hippocampus size) may provide more accurate results. Furthermore, testing these models with empirical data from a random sample of species may also help to validate the models proposed. Significant work has been done on corvids and parrots, but other species remain underrepresented in the study of memory.

Testing the effects of ecological drivers (e.g., food abundance and predictability) is also a relevant task. Although terrestrial productivity at a global scale can be measured through NDVI and this measure can act as a proxy for abundance of food sources, that measure is seldom useful for the current research since several species exist on a vast geographic range with contrasting productivities. For instance, Peregrine falcons (*Falco peregrinus*) exist in every continent except Antarctica (Birdlife International, 2021). This makes it impossible to model their associated habitat productivity without oversimplifying the model. Thus, adopting a conservative approach, this variable was not considered here. However, doing a more detailed analysis at a local scale could take this into consideration. Moreover, coupled with weather, productivity of habitats has changed over time, often at geological scales. Hence, using current productivity might not be representable to determine the evolution of CRB. Even if we establish a correlation, causation could not be concluded.

Abundance of food sources has another challenge: number or resources and dietary breadth. A question arises of whether resource abundance of number of different items is more important. For instance, is it more important for Great-Horned Owls to have more mice or different prey sources despite low numbers of each? In addition, measuring dietary breadth poses its own challenges given that the level at which we group the diet items has a direct impact on the estimation of dietary breadth. Take, for example, a seed eater. Are seeds an item in the diet, or are each type of seed important? Although from a nutritional point of view these are important questions to consider, that is beyond the scope of the current research. From a conceptual and empirical point of view, this measurement is not feasible at a global scale.

Finally, testing the idea that species exhibiting communal roosting behavior are more efficient at finding food sources would provide valuable information to expand the current research. This can be feasibly done with movement data using ballistic length scales as a proxy for foraging efficiency, or experimental designs placing feeding stations in the landscape coupled with movement data.

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