

Long-term stability of dominance hierarchies in a wild parrot with fission-fusion dynamics

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Data accessibility

All scripts used in this study can be found at https://github.com/JuliaPenndorf/stability_hierarchy. Upon acceptance, data and code will be made available at Edmond, the open access repository of the Max Planck Society.

Acknowledgements

We acknowledge the Gamaragal and Gadigal people as the Traditional Custodians of the Land on which this study was conducted. We thank two anonymous reviewers for their insightful comments. All procedures were approved by the ACEC (ACEC Project No. 19/2107), and were conducted under a NSW Scientific License (SL100107). This work was supported by the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract number MB22.00056. Part of the work was supported by funding from the Max Planck Society to JP and LMA. DRF was funded by an Eccellenza Professorship Grant of the Swiss National Science Foundation (Grant Number PCEFP3 187058) and the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No. 850859).

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Abstract

1 Dominance hierarchies are a common feature of stable groups, allowing animals to limit the costs of fighting
2 over access to resources. However, while the emergence of dominance is relatively well known from species
3 that form stable groups, less is known about whether hierarchies are maintained in societies with open group
4 membership. One challenge for species that live in an open social environment is that they have the possibility
5 of engaging in dominance interactions with a large number of conspecifics. To better understand how
6 animals navigate the complexities of interacting within a large, open society, we recorded social associations
7 and aggressive interactions in a highly social, communally roosting parrot, the sulphur-crested cockatoo
8 (*Cacatua galerita*). By following 515 individuals across three neighbouring communities and recording social
9 interactions during foraging, we show that sulphur-crested cockatoos form clear, linear hierarchies. We find
10 males rank higher than females and that adults rank higher than juveniles. Within sex, where individuals
11 may still have to compete with up to 100 individuals from the same age-sex class, body size did not affect
12 dominance rank. Finally, we find that, despite highly dynamic social associations (fission-fusion dynamics)
13 among individuals, hierarchies are stable, with dominance ranks being highly repeatable across at least three
14 years. This study demonstrates that closed group membership is not a pre-requisites for stable dominance
15 hierarchies to emerge.

16 Introduction

17 Contests over limited resources are a fact of life for most social species (Ward and Webster, 2016), and
18 can potentially be costly for the animals involved. As a result, many animals have evolved mechanisms to
19 assess competitors, allowing them to target a subset of potential competitors to engage with and decrease
20 overall level of aggression (Drews, 1993; Arnott and Elwood, 2009; Hobson and DeDeo, 2015; Hobson et al.,
21 2021; Dehnen, Papageorgiou, et al., 2022). Dominance hierarchies are one such mechanism, and dominance
22 rank is thought to give the most precise information on competitive ability (Parker, 1974). Accordingly, the
23 question of how animal groups form and maintain dominance hierarchies has received much attention over
24 the last century (Dehnen, Arbon, et al., 2022; Hobson, 2022).

25

26 Current research about the formation and maintenance of dominance hierarchies focuses around two
27 axes. The first considers how and when contests are determined by the intrinsic resource holding poten-
28 tials (RHP) of individuals. RHP is typically based on a combination of morphological (e.g., body-size or
29 colouration Arnott and Elwood, 2009) and behavioural traits (e.g. personality Briffa et al., 2015). Because
30 of their reliance on individual assessment, rather than memory of past interactions, RHP-based hierarchies
31 have been suggested to be particularly advantageous in open societies, where social interactions are drawn
32 from a potentially large pool of individuals, thus limiting (de Silva et al., 2017b)—or alleviating (Boehm,

33 1999) — the ability to form hierarchies based on memory. For example, in Mandrills (*Mandrillus sphinx*)
34 where groups can include up to 800 individuals, face colouration has been suggested to be a honest signal of
35 dominance rank (Setchell et al., 2008), with the intensity of red colouration changing with changing status
36 (Setchell & Dixson, 2001).

37

38 The second axis of research considers that the formation of dominance hierarchies requires individual
39 recognition and memory of past interactions between individuals (Hobson, 2020). Dominance hierarchies
40 based on memory are generally thought to only emerge in animals that form stable groups with relatively
41 little turnover. This is because in more open societies, where social associations are drawn from a potentially
42 large pool of individuals, the cognitive challenge of keeping track of many individuals over extended periods
43 of time is thought to limit the ability for individuals to form hierarchies (de Silva et al., 2017a). In addition,
44 if dominance hierarchies are also informed by third party interactions, the opportunity to observe those
45 interactions may be more limited in open societies, further reducing the information available to individuals.
46 Finally, open societies may alleviate the need for individuals to form hierarchies entirely, as individuals may
47 be able to avoid repeated interactions by moving between groups (Boehm, 1999 — but see Chaine et al., 2011,
48 2018; Penndorf et al., 2023).

49

50 Assumptions about limits to dominance hierarchies in large or open groups have recently been chal-
51 lenged by growing evidence that animals can form and maintain differentiated social relationships and
52 complex multi-tiered social structures that can encompass tens or even hundreds of conspecifics (Papa-
53 georgiou et al., 2019; Papageorgiou & Farine, 2021; Camerlenghi et al., 2022). For example, in vulturine
54 guineafowl (*Acryllium vulturinum*) that form multi-level societies (where groups interact with other groups),
55 individuals maintain stable and steeply linear hierarchies in higher level social groupings that incorporate
56 multiple breeding units (Dehnen, Papageorgiou, et al., 2022; Nyaguthii et al., 2025). In corvids that express
57 fission-fusion dynamics, individuals have been shown to maintain long-term preferred social relationships
58 that are likely based on individual recognition (Izawa & Watanabe, 2008; Chiarati et al., 2010; Boeckle &
59 Bugnyar, 2012; Loretto et al., 2017; Boucherie et al., 2022). In this second case, it has been argued that such
60 memory based interactions are represent a high degree of social complexity, and may have led to selection
61 for social cognition (Bugnyar, 2013). However, the evidence remains limited to a relatively small number
62 of well studied taxa, and more studies are needed to test (i) whether animals living in societies containing
63 hundreds of potential social associates can form and maintain stable dominance hierarchies, and (ii) whether
64 in species with high social mobility, individuals can be simultaneously part of several dominance hierarchies.

65

66 Parrots represent an excellent taxa in which to investigate these questions. Many parrot species exhibit
67 strong pair bonds while also interacting within communal roosts and with individuals from the broader pop-
68 ulation. The outcome of this is that individuals may experience flock sizes ranging from several individuals
69 to aggregations of thousands (Hardy, 1965; Noske et al., 1982; Rowley, 1990; O’Hara et al., 2019). Given this
70 variable sociability, coupled with longevity (Wirthlin et al., 2018; Smeele et al., 2022) and complex cognition
71 (Olkowicz et al., 2016), parrots are often referenced in discussions on social complexity (e.g., Krashenin-

72 nikova et al., 2013; Hobson et al., 2014; Aplin et al., 2021). Yet studies of dominance patterns among wild
73 parrots remain rare (but see Diamond and Bond, 1999; Penndorf et al., 2022), and it has often been assumed
74 that parrot species which form large communal roosts cannot exhibit stable dominance hierarchies (Noske
75 et al., 1982).

76

77 Studies of social interactions in parrots in captivity are more common, but results are mixed. Some
78 species form linear or quasi-linear hierarchies (e.g., budgerigars, *Melopsittacus undulatus*: Soma and Hasegawa,
79 2004; cockatiels, *Nymphicus hollandicus*: Seibert and Crowell-Davis, 2001; Senegal parrot, *Poicephalus sene-*
80 *galus* : Lantermann, 1998) and others not (e.g., keas, *Nestor notabilis*: Tebbich et al., 1996, blue-fronted
81 amazons, *Amazona aestiva* : de Souza Matos et al., 2017). The most detailed examination of this question
82 comes from a series of captive studies on captive monk parakeets (*Myiopsitta monachus*), which revealed
83 that groups of 11-21 individuals form linear social hierarchies based on memory of past interactions (Hobson
84 et al., 2014; Hobson and DeDeo, 2015; Hobson et al., 2021; van der Marel et al., 2023). Furthermore,
85 dominant individuals removed from their social group for a period of 8 days could not regain their rank
86 immediately following reintroduction to the same group (van der Marel et al., 2023), providing further evi-
87 dence that dominance ranks were the outcome of past interactions and memory, rather than the expression of
88 intrinsic characteristics. However, because groups in captivity are necessarily much smaller and more stable
89 than those in the wild, and captivity has been shown to induce the formation of linear hierarchies even in
90 egalitarian species (Horová et al., 2015; but see Boucherie et al., 2022), questions remain about how these
91 results translate to natural conditions. Wild studies are therefore vital to our understanding of dominance
92 interactions in parrots and in open societies more generally.

93

94 Here, we quantify dominance hierarchies in and across a population of wild sulphur-crested cockatoos
95 (SC-cockatoos; *Cacatua galerita*). SC-cockatoos are large, long-lived parrots that sleep in year-round com-
96 munal roosts of 50-1000 birds that are the basis of social communities (Aplin et al., 2021). As roosts are
97 located in areas that are also used for daily foraging, social interactions among individuals take place both at
98 the roost (including during the day) and in the surrounding landscape as birds fission into small to medium
99 foraging flocks (Noske et al., 1982; Styche, 2000; Aplin et al., 2021). Roost are open, and individuals can—
100 and do—also regularly engage in between-roost movements (Aplin et al., 2021; Penndorf et al., 2022). Yet,
101 despite these fission-fusion dynamics, SC-cockatoos maintain long-term social relationships beyond the pair
102 bond that are strongly suggestive of social recognition, including with kin and non-relatives, and with birds
103 from other roosts (Aplin et al., 2021; Penndorf et al., 2022).

104

105 In this study, we record social networks and aggressive interactions from 515 individuals across three
106 neighbouring roosts to address three aims. First, we test whether social communities of wild SC-cockatoos
107 that are centred on each roosting site form linear dominance hierarchies. Second, we identify individual
108 predictors of dominance rank, including age and sex, and a proxy for resource holding potential, body
109 weight. Third, we re-measure interactions across (i) two periods over two months (July and September
110 2019), and (ii) two periods over 3 years (2019-2022) to assess the short- and long-term stability of any

111 emergent hierarchies.

112 Methods

113 Study population

114 The study was conducted at three neighbouring roost sites in north Sydney, Australia (Table S1). At each
115 roost site, birds were habituated to the observer and then individually paint-marked with non-toxic dye
116 (Marabu Fashion Spray, MARABU GmbH) using methods detailed in Penndorf et al. (2022). In addition
117 to paint-marked birds, 144 birds were previously wing-tagged at the Royal Botanic Gardens as part of an
118 ongoing citizen science study *Big City Birds* (Davis et al., 2017; Aplin et al., 2021). The number of marked
119 birds at each roost varied from 42 - 165, depending on site and year (Table S1). Age (juveniles: <7 years,
120 adults: >7 years) and sex of birds were assessed by eye-colour (Berry, 1981). Additionally, feathers were
121 collected, from which DNA was extracted for molecular sexing and to match individuals across the two study
122 periods.

123

124 Once marked, birds were trained to jump on a flat scale that read at 1g accuracy in exchange for a food
125 reward (e.g. sunflower seed). This resulted in 214 birds being weighed across the three roost-sites in the first
126 study period. Within individuals, weight was highly repeatable (0.78, 95% CI=0.72-0.82, R-package *rptR*,
127 Stoffel et al., 2017, no. bootstraps=1000, *N*_{weightings per individual}:1-17) and ranged from 717g to 1054g.

128 Social data collection

129 Data on social associations and aggressive interactions were collected from all three sites in 2019 over two 10
130 day periods (July 8-20 and September 19 to October 2), resulting in a total of 165 observation hours. Data
131 were then collected at one site (Clifton Gardens) in 2022 over 12 days (July 7-20) for a further 36 observation
132 hours. During these periods, birds were attracted to forage on the ground by scattering small amounts of
133 seed over an approximate 385-500m² area of grass in parks close to the roost (300-680m distance). Forag-
134 ing flocks were then observed daily for 2.5 to 3 hours. During each daily sample, the identity of all birds
135 present—e.g. identifiable within the study area—was recorded every 10 minutes. Between presence scans,
136 aggressive interactions were recorded using all occurrence sampling (Altmann, 1974). For each interaction,
137 we recorded the time and the identities of winners and losers.

138

139 Presence scans were collated and used to construct social networks using a gambit-of-the-group approach
140 and a simple ratio to weight edges between 0 (never observed in the same scan) and 1 (always observed in
141 the same scan) (Cairns & Schwager, 1987; Farine & Whitehead, 2015; Hoppitt & Farine, 2018). We then
142 identified social network communities using the fast-and-greedy algorithm included in the *igraph* package
143 (Csardi, Nepusz, et al., 2006). These social network communities clearly mapped onto the roosting sites, and
144 so we assigned the roost membership (residency) of each bird according to which social network community
145 they were assigned to (Figure a).

146 Dominance hierarchies

147 We calculated a separate dominance hierarchy for each of the three sites and observation periods. In order to
148 obtain reliable dominance hierarchies, we only included individuals with seven or more agonistic interactions
149 at a given roost-site (BA: $N_{ind}=144$; CG: $N_{ind_{2019}}=103$, $N_{ind_{2022}}=68$; ; NB: $N_{ind}=82$; Sánchez-Tójar et al.,
150 2018—for more details about the choice of threshold used see Section S1.2, Figures S3, S4, S5). Hierarchies
151 were calculated using randomized Elo-ratings (R-package *aniDom*, Sánchez-Tójar et al., 2018; sigma: 1/300,
152 K: 200, randomisations: 10,000). We measured the robustness of the hierarchy by using the functions ‘*re-*
153 *peatability by splitting*’ and ‘*repeatability by randomisation*’. Furthermore, we assessed the transitivity of the
154 hierarchy following McDonald and Shizuka 2013 and Shizuka and McDonald 2015 (see Section S1.1).

155

156 To test whether dominance rank was predicted by age, sex, or body weight, we ran a Bayesian regression
157 model using the R-package *brms* (beta-family, 4 chains, 4000 iterations, Bürkner, 2017a, 2017b, 2018). Since
158 individuals could appear in the hierarchies of several sites (see Table S5) and across years, we included social
159 community (BA, CG 2019, CG 2022, NB) and individual ID as random variables.

160

161 To assess the stability of dominance hierarchies over time, we calculated the hierarchy at each roost loca-
162 tion separately for each observation period (July and September 2019 for short-term stability; 2019 and 2022
163 at Clifton Gardens for long-term stability). Using the *DynaRankR*-package (Strauss and Holekamp, 2019),
164 we tested dyadic similarity between hierarchies between each time period at each site and each randomisa-
165 tion of the Elo-Rating (randomisation = 10,000). To calculate the random expectation, we created 10,000
166 hierarchies for each site and time period by randomly assigning dominance ranks to all individuals, before
167 calculating the dyadic similarity obtained through random sampling. The resulting dyadic similarity score
168 calculated by the *DynaRankR*-package takes into account the number of individuals within each hierarchy.

169

170 All analysis were conducted in R v 4.3.0 (R Core Team, 2023).

171 Ethical Note

172 As the birds are never caught as part of our study, all participation is voluntary. While food provisioning
173 may cause temporary changes in the cockatoos’ diet / behaviour, feeding is limited in time (only part of the
174 day, for a maximum of 3 months a year), and is therefore not likely to induce a reliance on provisioning,
175 or changes in their natural feeding behaviour given the longevity of the study species. Once the birds were
176 habituated (hereafter defined as birds moving freely and without any signs of distress in close proximity to
177 the observer), finger sponges (used to apply makeup) dipped in water-based, non-toxic, paint (MARABU
178 Fashion Dye) were used to mark birds feeding within arms-reach. This method has been used previously
179 (Klump et al., 2021; Penndorf et al., 2022), and has not been observed to elicit negative responses, as after
180 marking: (i) birds stayed within close proximity of the observer, or—if startled by the touch/ movement—
181 were back within seconds. (ii) birds did not change their behaviour (i.e. preening/ investigation of the
182 paint-marks was not observed).

183

184 Once birds were marked, we opportunistically plucked 1-3 feathers per individual from the lower back,
185 while individuals forage freely within arm-length of the observer. These feathers are used for genetic iden-
186 tification of individuals across years. This method has previously been employed in the species (Penndorf
187 et al., 2022), and individuals (i) remained in proximity of the observer, and (ii) did not lose habituation as
188 a result, suggesting that the impact was relatively low.

189
190 All procedures were approved by the ACEC (ACEC Project No. 19/2107), and were conducted under a
191 NSW Scientific License (SL100107).

192

193 **Results**

194 The number of birds included in the hierarchy at each site (i.e. ≥ 7 observed interactions) varied between 82
195 and 144 (Table S1). We recorded 6,402 (2019, 3 sites) and 2,087 (2022, 1 site) aggressive interactions across
196 all birds, of which 5,694 and 2,006 respectively were between individuals that were included in the same
197 dominance hierarchy (N_{ind} 2019 = 202, N_{ind} 2022 = 68). Most aggressive interactions between individuals of
198 known sex were between males (N_{males} 2019 = 72, $N_{interactions\ males}$ 2019 = 1,662, $N_{interactions\ known\ sex}$ 2019
199 = 3,776, N_{males} 2022 = 35, $N_{interactions\ males}$ 2022 = 633, $N_{interactions\ known\ sex}$ 2022 = 1,479).

200 **Cockatoos form clear dominance hierarchies**

201 We found that, within social communities, SC-cockatoos formed robust and highly transitive hierarchies
202 (robustness: Figures 2a,b, S2 a,c,e,g & Table S2; transitivity ≥ 0.80 —Table S4). Similar results were found
203 without thresholding (i.e., including all individuals that interacted at least once at a given location—S1.5.1,
204 robustness: Table S6; transitivity $geq 0.80$, Table S7).

205 **Predictors of dominance rank**

206 Sex and age were significant predictors of rank, with males ranked higher than females (se: 2.09, es: 0.24,
207 95%: [1.64, 2.57]—Figure S2 a,c,d,f), and adults ranked higher than juveniles (es: 0.82, se: 0.29, 95%CI:
208 [0.26, 1.41]). However, body weight did not predict dominance rank (es: -0.61, se: 1.99, 95%CI: [-4.46,
209 3.32]). We obtain similar results when including all individuals that interacted at least once at a given site
210 (i.e., no threshold, Section S1.5.2).

211

212 **Steepness of the hierarchy**

213 Given the sex-based segregation of the dominance hierarchies, and that most interactions occurred within
214 individuals of the same sex, we calculated the steepness of the hierarchies separately for each sex. In male
215 hierarchies, individuals typically had a chance of $>60\%$ to win an aggressive interaction against a male one
216 rank lower than themselves (Figure b-e). This probability increased relatively rapidly with increasing rank

217 difference, reaching 0.9 with a rank difference between 4 and 16 (Figure b-e). In females (hierarchy only
 218 possible at Clifton Gardens in 2019 and 2022), the probability of winning against an individual of one rank
 219 below or above was more variable (2019: 0.6, 2022: 0.85), and reached 0.9 for a rank difference of 8 and 3
 220 respectively (Figure S1a,b—for values of steepness without threshold, see S1.5.3).

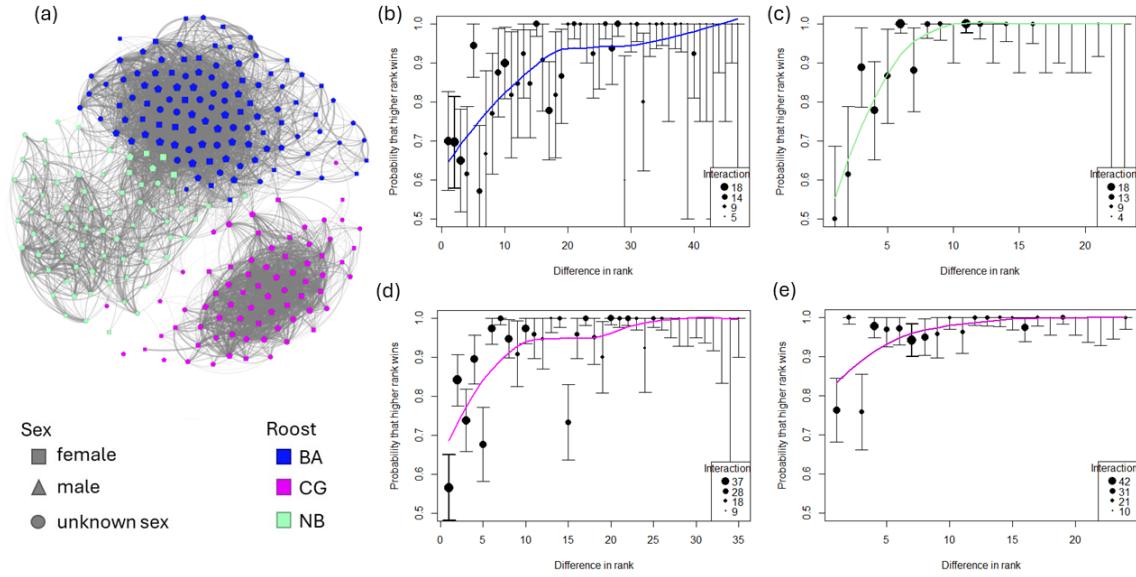


Figure 1: Social association network and steepness of dominance hierarchies. (a) Social network of sulphur-crested cockatoos in 2019. Node colour represents the three identified social communities identified using the "fast-and-greedy" algorithm

(blue: BA, pink: CG, green: NB). Node shape represents the sex of the individuals (square: female, triangle: males, circles: individuals of unknown sex). For visual clarity, only edges above 0.1 are represented. (b-e) The steepness of the male social hierarchy in three communities as identified in the social network (b: BA, c: NB, d-e: CG) across two years at CG (b-d: 2019, e: 2022). The error bars in b-d represent the standard deviation in elo-score for each individual across 10,000 randomisations.

221 Stability of dominance hierarchies over time

222 Within each social community, dominance ranks were highly repeatable over a period of two months (July-
 223 September 2019; dyadic similarity >0.77 , Table S4), which was significantly higher than expected by chance
 224 ($R \approx 0.5$, Table S4). Similar repeatability was found when repeating the analysis within each age (juve-
 225 nile/adult) and sex (males/females) class (Table S4), suggesting that this effect was not driven by predictable
 226 age and sex differences in dominance rank. In the CG social community measured again after a period of
 227 3 years, dominance ranks were very similar in their repeatability (2019-2022, similarity: 0.84 [0.81-0.87],
 228 random expectation: 0.50 [0.42-0.59], N=27, Figure 2c, Table S4). Similar values of dyadic similarity were
 229 found when not using any threshold (i.e., including all individuals that interacted at least once—Section
 230 S1.5.4 & Table S8).

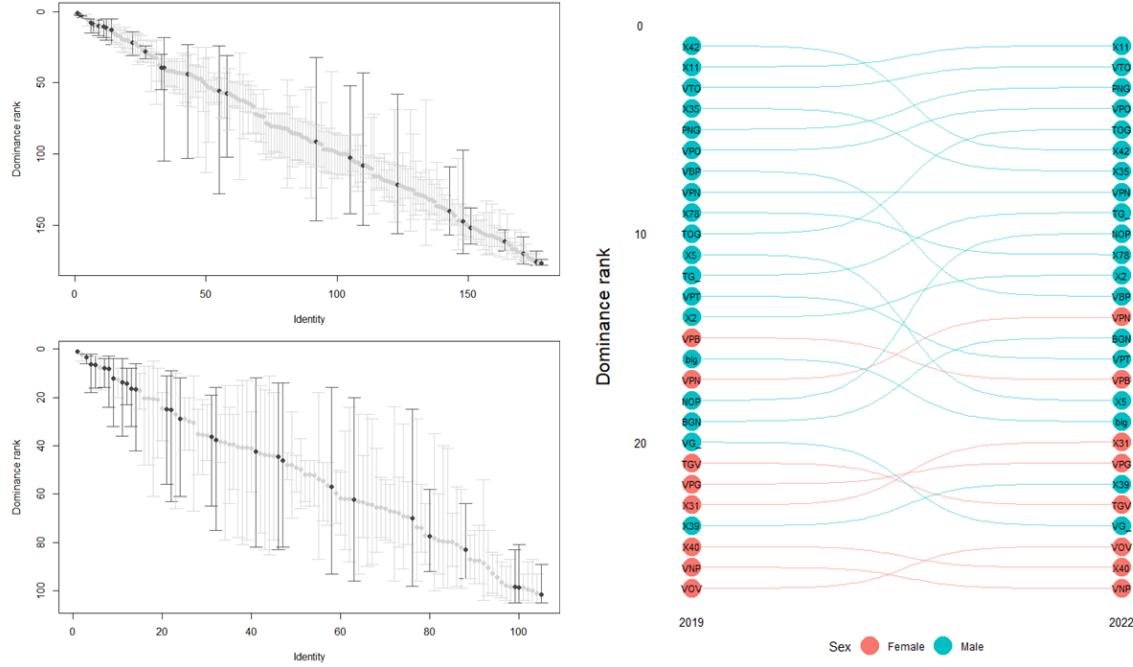


Figure 2: Mixed-sex dominance hierarchy at Clifton Gardens social community in (a) 2019 and (b) 2022. Individuals present in both study periods are shown in dark grey. Changes in their relative dominance rank across years is shown in (c). Males are represented in blue, and females in red.

231 Discussion

232 We found that, despite their largely open social structure and social communities of potentially hundred
 233 of individuals, SC-cockatoos formed clear linear dominance hierarchies. These hierarchies were structured
 234 by sex and age, with males and adults tending to be higher in the hierarchy than females and juveniles.
 235 However, while males tend to be larger than females, there was no evidence for an effect on body size on
 236 rank. Finally, SC-cockatoos were consistent in dominance across time: hierarchies were highly stable across
 237 periods of months to years.

238 RHP and the determination of dominance ranks in SC-cockatoos

239 Body weight—a measure of body size that is often linked to resource-holding potential (reviewed by Arnott
 240 and Elwood, 2009)—did not predict dominance ranks. Yet, SC-cockatoos maintain stable dominance hi-
 241 erarchies across months and years. This leads to several speculations about the mechanisms of hierarchy
 242 formation and maintenance in this species (reviewed by Dehnen, Arbon, et al., 2022; Tibbetts et al., 2022).
 243 First, hierarchies in this system could still be based on RHP. Body weight constitutes only one of the po-
 244 tential indicators of resource holding potential (Allen & Krofel, 2022), and we cannot exclude that there is
 245 another, undescribed status signal in this species. For example, colouration (Santos et al., 2011; Beltrao
 246 et al., 2021) is an indicator of dominance rank in many species, while crest-length (Dakin, 2011) is an indi-
 247 cator of dominance in Indian peafowl (*Pavo cristatus*). SC-cockatoos are almost entirely white except for
 248 their large yellow crests, which are used in signalling, for example at nest hollows. However, we believe it

249 to be unlikely that crest-colouration or length signal dominance in our study, as crest-displays were only
250 performed in 1 % of the dominance interactions that we recorded.

251

252 Second, in the absence of physical predictors of dominance ranks, it is possible that aggressive inter-
253 actions in this species are primarily based on social recognition and memory of past interactions. If the
254 formation and maintenance of dominance hierarchies in this species requires individuals to recognize and
255 remember all members of their social communities, SC-cockatoos in our population may need to remember
256 at least 68 individuals with high daily turnover, local hierarchies comprised between 68 and 144 individuals.
257 This would constitute a memory for conspecifics that is comparable to that of ravens (Boucherie et al., 2022),
258 elephants (McComb et al., 2000) and humans (Hill and Dunbar, 2003, but see Lindenfors et al., 2021). This
259 seems possible, even plausible, given that SC-cockatoos also share other life-history traits with these species,
260 including large relative brain-size and extended longevity (Smeele et al., 2022), and that this would be in line
261 with captive studies in monk parakeets (Hobson et al., 2014; Hobson & DeDeo, 2015; Hobson et al., 2021).
262 Further exploration will be needed to fully test the potential for reliance on memory of past interaction in
263 this system.

264

265 The third possible mechanism to explain the existence of orderly hierarchies in such large groups is
266 that individual recognition and memory of a small subset of individuals (e.g., individuals of the same sex,
267 or frequent associates, see Chaine et al., 2011, 2018) is sufficient to maintain a stable, linear, dominance
268 hierarchy at the scale of social communities. We found that SC-cockatoos exhibit a sex- and age-segregated
269 hierarchy, with males above females and adults above juveniles. In this case, a categorisation of domi-
270 nance relationships (i.e. only remembering the exact dominance ranks of conspecifics of the same age class
271 and sex) would significantly reduce cognitive requirements that come with making social decisions in an
272 open society with significant fission-fusion dynamics (Aureli & Schino, 2019). In our study, this heuristic
273 would reduce the requirement for individual recognition substantially; for instance, individual adult males in
274 our population could encounter between 19 (1 site, NB) and 72 (all sites) other adult males on any given day.

275

276 It should also be noted that our roost sizes, while typical for our study population, are relatively small
277 for SC-cockatoos. Roost sizes in this species have been reported as reaching well over one thousand individ-
278 uals (Aplin et al., 2021), and in these cases, even a sex and age based categorisation would still result in
279 very large numbers of potential interaction partners. Further study is needed to determine what strategies
280 SC-cockatoos might use to reduce the cognitive demands of living in such enormous and dynamic societies,
281 and whether stability and/or linearity of hierarchies break down at larger social scales.

282

283 Stability in rank over space and time

284 Social communities were clearly differentiable in our social network, yet social communities were also con-
285 nected, with a subset of individuals exhibiting high social mobility (Penndorf et al., 2022). As a result, some
286 individuals in our study were present in two or three dominance hierarchies, and were likely to be familiar

287 with individuals across a much broader social landscape than just their own social community. Dominance
288 hierarchies in the three social communities measured were temporally stable when re-measured after a period
289 of two months. The dominance hierarchy was further re-measured in one social community after a period
290 three years, and showed a similarly level of repeatability. Together, this suggests that dominance hierarchies
291 are highly stable over at least three years, and perhaps even over longer periods of time

292

293 This social stability is consistent with some previous research—although higher than previously found in
294 birds. Common ravens, for example, form communal roosts with high fission-fusion dynamics similar to SC-
295 cockatoos, yet the social stability in the social group (3 % across 7 years—Boucherie et al., 2022, measured as
296 percentage of individuals present in both time periods) is around sixteen times lower than the one observed
297 in our study (30% across 3 years). However, stable dominance hierarchies have been shown in other open
298 systems with fission-fusion dynamics. For example, female mountain goats (*Oreamnos americanus*) form
299 linear hierarchies based on age, that are highly stable from one year to the next ($R^2 > 0.93$) (Côté, 2000), and
300 similar measures of stability in dominance ranks have been suggested for other ungulate species (Hirotani,
301 1990). Taken together, the social stability observed in SC-cockatoos is therefore remarkable, though not
302 unheard of in species with high fission-fusion dynamics. This is perhaps unsurprising; SC-cockatoos are
303 long-lived birds with an extended juvenile period of 7-years and adult lifespans of several decades (Smeele
304 et al., 2022). Previous research on SC-cockatoos found that birds tend to maintain differentiated social
305 relationships over periods of at least 18 months, with these relationships becoming more stable with age as
306 measured over 10 years (Aplin et al., 2021). Our study did not allow for a similar analysis of age, but
307 future research could ask how such increasing social stability influences dominance rank and relationships.

308 **Conclusion**

309 Wild SC-cockatoos can form stable long-term relationships (Aplin et al., 2021), and maintain some social
310 relationships even after movement into different social communities (Penndorf et al., 2022). Our results build
311 upon these findings by indicating that SC-cockatoos also form and maintain clear and stable dominance rela-
312 tionships with a large number of conspecifics, and retain their dominance rank over periods of at least three
313 years. Taken together, these studies provide ample evidence these long-lived parrots exhibit hidden social
314 stability within these extended and dynamic social networks. It adds to evidence from other large-brained
315 bird species that exhibit fission-fusion dynamics, such as common ravens (Boeckle and Bugnyar, 2012), that
316 such species possess social cognitive abilities that allow them to navigate a extended social landscape with
317 within- and between-community social interactions. Future studies should attempt to elucidate the cognitive
318 load of maintaining dominance hierarchies in such systems as well as the limits of such social structures,
319 contributing to ongoing debates about the evolution and ecology of socio-cognitive complexity.

320

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