Author for correspondence:
Eli D. Strauss
e-mails: estrauss@ab.mpg.de, straussed@gmail.com

THE ROYAL SOCIETY
PUBLISHING

DomArchive: a century of published dominance data

Eli D. Strauss[1,2,3], Alex R. DeCasien[4,5,6], Gabriela Galindo[4], Elizabeth A. Hobson[7], Daizaburo Shizuka[3] and James P. Curley[8]

[1]Department of Collective Behavior, Max Planck Institute of Animal Behavior, 78464 Konstanz, Germany
[2]Centre for the Advanced Study of Collective Behaviour, University of Konstanz, 78464 Konstanz, Germany
[3]School of Biological Sciences, University of Nebraska Lincoln, Lincoln, NE, 68588-0118 USA
[4]Department of Anthropology, New York University, New York, NY, USA
[5]New York Consortium in Evolutionary Primatology, New York, NY, USA
[6]Section on Developmental Neurogenomics, National Institute of Mental Health, Bethesda, MA, USA
[7]Department of Biological Sciences, University of Cincinnati, Cincinnati, OH, USA
[8]Department of Psychology, University of Texas at Austin, Austin, TX, USA

EDS, 0000-0003-3413-1642; ARD, 0000-0002-6205-5408; EAH, 0000-0003-1523-6967; DS, 0000-0002-0478-6309; JPC, 0000-0001-5546-007X

Dominance behaviours have been collected for many groups of animals since 1922 and serve as a foundation for research on social behaviour and social structure. Despite a wealth of data from the last century of research on dominance hierarchies, these data are only rarely used for comparative insight. Here, we aim to facilitate comparative studies of the structure and function of dominance hierarchies by compiling published dominance interaction datasets from the last 100 years of work. This compiled archive includes 436 datasets from 190 studies of 367 unique groups (mean group size 13.8, s.d. = 13.4) of 135 different species, totalling over 243 000 interactions. These data are presented in an R package alongside relevant metadata and a tool for subsetting the archive based on biological or methodological criteria. In this paper, we explain how to use the archive, discuss potential limitations of the data, and reflect on best practices in publishing dominance data based on our experience in assembling this dataset. This archive will serve as an important resource for future comparative studies and will promote the development of general unifying theories of dominance in behavioural ecology that can be grounded in testing with empirical data.

This article is part of the theme issue 'The centennial of the pecking order: current state and future prospects for the study of dominance hierarchies'.

1. Introduction

Dominance is a pervasive feature of animal societies that can have dramatic effects on individual fitness. As a result, agonistic interactions—the individual aggressive and submissive signalling behaviours that underlie dominance hierarchies—are some of the most commonly collected behaviours across studies of animal [1–190]. These interactions are typically used to understand how within-group competition structures animal societies [191,192]. In most social species, individuals form dominance relationships, where agonistic interactions between any pair of individuals follow a predictable asymmetric pattern, where one member of the dyad typically yields to the other [193]. The dominance hierarchy is the group-level social structure that emerges from the network of dominance relationships, and various ranking methods have been developed to infer individual position in the dominance hierarchy based on the outcomes of observed agonistic interactions [194–196]. Individual position in the hierarchy
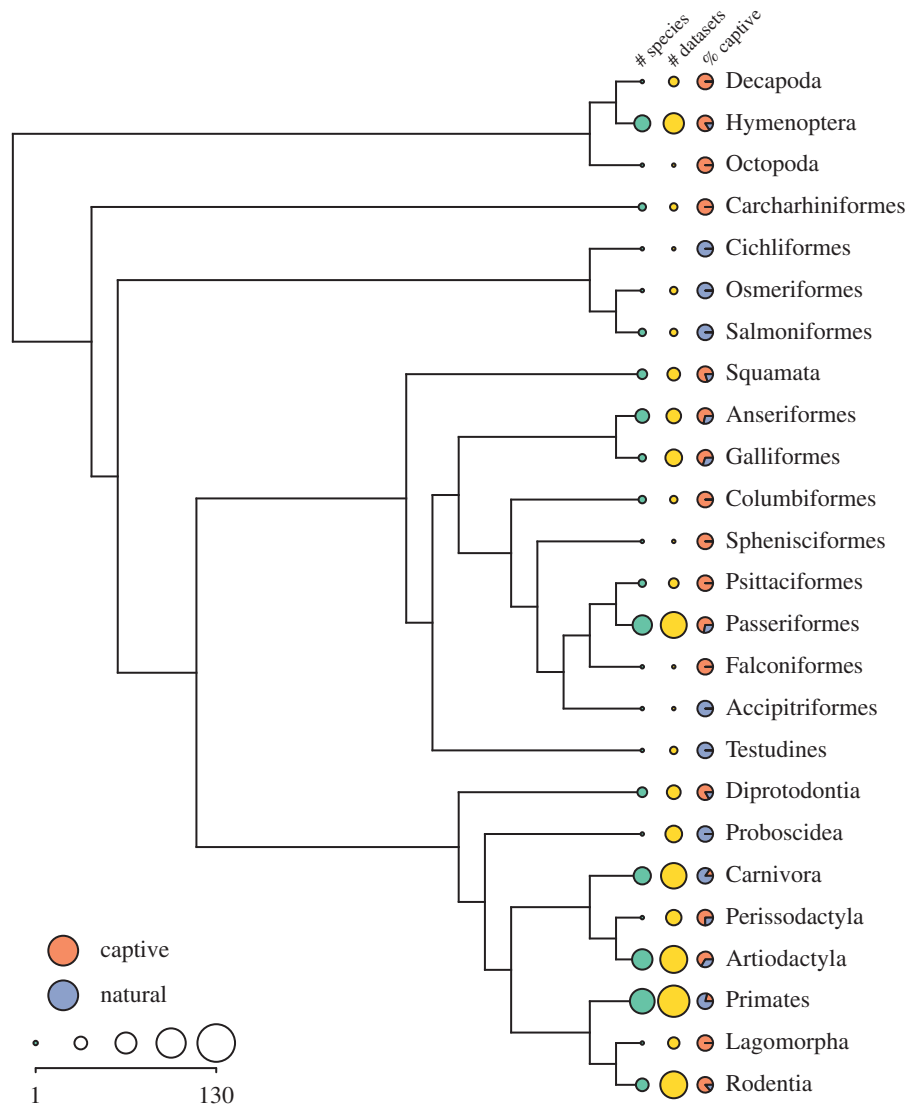
Figure 1. A phylogeny of taxonomic orders included in the archive, with counts of unique species and datasets in each order (dot sizes are $\log_{10}$ scaled, legend shows the corresponding untransformed sample sizes), and the percentage of datasets from captive versus wild populations. Phylogeny is from the Open Tree of Life [218]. Data for one order (Perciformes: 2 species, 3 datasets) are not included here due to paraphyly. (Online version in colour.)

is correlated with behaviour, physiology, gene expression, reproduction and longevity in many species (this issue: [197–205]). Higher-order patterns, such as the degree of linearity or transitivity of dominance relationships [206–208], or the amount of inequality in the outcomes of agonistic interactions [110] can reveal the overall structure of the dominance hierarchy in different societies [209]. Agonistic interactions sampled over time can be used to understand canonical patterns in sequences of interactions [210] or to infer the dynamics of social hierarchies [211–213].

Although agonistic interaction datasets are typically collected to address questions about the behaviour of a specific species, these datasets also have strong potential for comparative insight about the evolution of sociality in the face of competition. However, these data have only rarely been applied in a comparative framework to address evolutionary questions about competition and hierarchy structure (but see [206,207,214–217]).

Here, we aim to facilitate comparative study into dominance interactions and emergent aspects of hierarchical structure by assembling a comprehensive database of published agonistic interactions dating back to the first published 'peck-orders' in Schjelderup-Ebbe's research into dominance among

domestic hens in 1922 [39]. The data are presented in an R package alongside metadata and tools for filtering the archive by its associated metadata (see electronic supplementary material for an instructional vignette).

2. The dominance archive dataset

The archive contains 436 agonistic interaction datasets from 190 studies [1–190] of 135 unique species (figure 1), totalling over 243 000 interactions. Because some animal social groups were sampled multiple times within a single study or over multiple studies, the archive includes data from 365 unique social groups (mean group size = 13.8, s.d. = 13.4). The last century has seen notable shifts in the ways researchers approach the study of dominance (Hobson [219]), the analytical approaches to measuring dominance [110,195,206,220], and the customs governing data storage and sharing [221]. This variation is reflected in the archive and is captured by metadata and summary statistics associated with each dataset (table 1; electronic supplementary material, data S1).

Most ($n = 418$) datasets are in the form of a sociomatrix, a square matrix documenting the outcomes of agonistic

Table 1. Metadata and summary statistics associated with each dataset in the archive.

metadata column	meaning	potential values
fileid	unique identifier for data	
order	order (taxonomic rank)	
species	species name	
common_name	common name	
study_site	nation where study was conducted	
captivity	captive or free-ranging animals?	'captive', 'natural'
sex	males, females, or both?	'M', 'F', 'MF'
age	what age classes?	'adult', 'non-adult', 'mixed'
measure	what behaviour was measured?	
data_location	where is data in reference (e.g. Tb1)?	
countbinary	are data raw counts or binary? (edgelists are counts)	'count', 'binary'
repeat_group	are there multiple datasets for this group?	'yes', 'no'
groupid	unique identifier for social group	
matrix_edgelist	are data in matrix or edgelist format?	'matrix', 'edgelist'
edgelist_time_meaning	for edgelist data, what is the meaning (units) of the 'time' column	
note	miscellaneous notes	
full_citation	source for the data	
number_individuals	number of individuals in the dataset	
number_interactions	number of interactions in the dataset	
interactions_per_individual	number of interactions per individual	
proportion_unknown	proportion of relationships for which there are no observations (matrix data only)	

interactions over the study period (figure 1). During the last century, sociomatrix notation became the standard for presenting data on dominance interactions. In these matrices, the identities of winners of interactions—the individuals who elicit submission or avoidance in their opponents—are listed in the rows, and losers of interactions—exhibitors of submission or avoidance—are listed in the columns. The entries in the matrix correspond to the numbers of times the row individual was observed to dominate the column individual. In rare cases, these data were published in binary format, such that cells in the matrix are either 1 if the row individual was observed to dominate the column individual more often than vice versa and 0 otherwise. These 'binary' matrices are noted in the metadata (table 1). In all cases, the diagonal of the matrix is 'NA' because individuals cannot dominate themselves. Because sociomatrices tabulate interactions over the duration of some observation period, these datasets contain no information about the order in which interactions occurred.

Some ($n = 18$) datasets in the archive are in edgelist format, which presents dominance interactions listing the winner, the loser, the sequence in which the interactions occurred, and (in some cases) information on the timing of the interactions. This data format has become increasingly common in the last decade as ranking methods that incorporate sequence information (e.g. [220,222]) are becoming more popular, and as raw data is increasingly supplied in digital supplements rather than appearing directly in print. Because of this extra temporal information, these datasets are crucial for addressing questions about the dynamics of dominance [223], which occur over both short [224] and long [57] timescales.

In addition to these data-format metadata, the archive also includes biological and methodological metadata about the study. These metadata include demographic information about the animal social group (age-class and sex composition), taxonomic information about the study organism (species, order), behavioural information about the agonistic interaction (interaction type), whether the study was conducted in captivity or on wild animals, the country in which the study was conducted, and whether the group was sampled repeatedly. For age-class and sex composition, it is important to note that these often reflect the study design rather than the biology of the organism—for instance, many datasets were collected from mixed-age social groups, but only data on interactions among adults were recorded. Groups are denoted as mixed-sex if at least one male and one female was included in the dataset. Groups were considered 'captive' if they were housed in an enclosure for any part of the collection of dominance interaction data; this therefore includes zoo and laboratory studies as well as studies where wild animals were captured and temporarily observed in an enclosure. Interaction type describes the specific agonistic behaviours (e.g. threats, chasing, displacement, submission) that are represented in the dataset, as laid out by the original authors. Finally, social groups were considered 'repeated' if the same set of individuals were observed multiple times in close succession or if multiple behaviours and corresponding datasets were collected from the same set of individuals. Importantly, groups sampled over longer time-frames during which demographic processes occur (e.g. long-term observational studies) and groups where membership was fluid (and

Table 2. Hierarchy structure measures associated with each matrix dataset in the archive.

measure (column name in metadata)	range	description	dataset criteria	source
directional consistency index (dci)	0–1	the average directional asymmetry in wins across dyads. 1 = all dyads have one individual who wins every interaction, 0 = all dyads are ties.	matrix_edgelist = 'matrix' countbinary = count	[145]
triangle transitivity index (ttri)	mostly 0–1, rarely <0	the proportion of triads in the network of dominance relationships that are transitive, scaled so that 0 = expected triangle transitivity under random interactions and 1 = perfectly transitive. Rarely, negative values can occur if dominance relationships are less transitive than expected under random interactions.	matrix_edgelist = 'matrix'	[206]
modified Landau's h' measure of linearity (modified_landaus_h)	0–1	a measure of the linearity of dominance relationships, or the degree to which dominance relationships show transitive properties. 0 = completely cyclical hierarchy, 1 = completely linear hierarchy. This value is biased downward with increasing proportions of unknown relationships [225]; triangle transitivity is recommended as an alternative measure [206].	matrix_edgelist = 'matrix' countbinary = count	[226]
hierarchy steepness (ds_steepness)	0–1	a measure of the differentiation in winning ability among individuals, calculated as the absolute value of the slope of a line fitted through the normalized David's Scores of all contestants. David's Scores measure an individual's winning tendency. 0 = all individuals have the same score, 1 = all individuals are maximally differentiated in their scores. This value is biased downward with increasing proportions of unknown relationships [225].	matrix_edgelist = 'matrix' countbinary = count	[110]

thus some individuals appear in multiple groups) were not considered 'repeat' groups.

Finally, the archive includes dataset summary statistics alongside these metadata. The number of individuals, number of interactions, and proportion of unknown relationships describe the sampling coverage of each dataset. Additionally, the archive includes calculated measures of the structure of dominance relationships for each dataset (table 2): directional consistency [145], triangle transitivity [206], linearity [226] and steepness [110]. These summary statistics are useful for comparative insight into the ecological and evolutionary determinants of hierarchy structure [206,207,217,227,228].

3. Dataset assembly

The following search criteria were used to identify potential datasets for the archive. First, we searched Google Scholar and PubMed for any papers, book chapters or theses that: (1) had cited key papers used to measure various hierarchy metrics [110,195,196,206,220,226,229,230]; (2) had used software to calculate hierarchy matrices including all versions of SOCPROG [231], MatMan [232] and the compete [233] and

aniDom R packages [234]; or (3) had included the keyword phrases 'linear dominance' and/or 'social hierarchy' but had not cited the above papers or software. We also identified older papers (pre 1983) by opportunistically examining the references of already identified papers. Finally, we included data from two previous papers that had collated several sociomatrices [206,214].

Individual papers, book chapters and theses and any supplementary information or data repositories associated with papers were then searched for the presence of a sociomatrix, edgelist or some other data format (e.g. pecking order) that could be converted to a sociomatrix. To be included in the archive, we applied the following inclusion criteria: (1) We only included datasets that contained interactions among individuals, so datasets reporting on agonistic interactions among groups or species were not included (e.g. [235,236]). (2) The group needed to contain at least six individuals, because this is the minimum number of individuals for calculating some measures of hierarchy structure [226]. (3) All individuals in the study had to be free to interact with any other member of the group—that is, this archive does not include 'tournament' style studies where individuals are repeatedly paired for dyadic competition where the outcomes

are treated as reflecting an underlying hierarchy linking all individuals. These studies were excluded from the dataset because evidence from the latter half of this century of research suggests that social context (e.g. bystander effects, winner-loser effects) is a fundamental feature of dominance hierarchies [126,237,238]. (4) We excluded matrices where physiological manipulations had been used to examine their effects on the hierarchy structure (e.g. [116]).

4. Using the package

Users can install the latest version of the DomArchive R package using the command 'devtools::install_github('DomArchive/ DomArchive', build_vignettes = TRUE)' (installation requires the devtools package). The datasets are accompanied by 'subset_archive()', a flexible function for selecting data from the archive based on the metadata. This function accepts either a list of dataset identifiers, or subsetting can be achieved by providing a list of metadata column names and a list of values corresponding to those columns (see electronic supplementary material, Supplemental Data for plain-text copy of the metadata). A simple vignette accompanying the R package provides a tutorial for how to do this. The vignette (electronic supplementary material) can be accessed after installing the package by running 'vignette('introduction', package = 'DomArchive')'. Users wishing to report issues, suggest additions to the archive, or inquire about data sources can contact the authors or submit an Issue at https://github.com/DomArchive/DomArchive.

Users of the dominance archive should be aware of some limitations to these data. First of all, most data are in sociomatrix format, which does not capture the order in which interaction occurred, making these data not suitable for analyses that require interaction order (e.g. Elo-rating). For data sources that are in edgelist format, information on the order of interactions is preserved, but the timings of the interactions are still uncertain. Two adjacent observations could have occurred immediately one after the other, or could have been days or weeks apart. We include time data when available, but the temporal resolution of this data is variable among studies. Another limitation of note for these data is that the datasets varied considerably in the timespan over which the data were collected and the frequency of observation during the study. For instance, some data were collected during uninterrupted observation within a single day (e.g. [121]), whereas other datasets were collected over multiple years of non-continuous observation (e.g. [43]). When group membership was fluid (e.g. [121]) or when multiple studies focused on a social group over long periods with demographic turnover (e.g. [51,143]), groups with different group ids in the archive contain overlapping individuals. Finally, users of the data for comparative analyses should exercise caution when only one or a few datasets are available for a given species. In assembling these data, we found that authors often included only a subset of their total data in the manuscript (e.g. an example matrix from one of many study groups). The decision process for selecting which example dataset to include was not always evident from the paper, but sometimes authors would publish a particular example for some notable characteristics of that data. For instance, in a study of 31 flocks of willow tits, over 90% of flocks were found to have linear hierarchies, but the examples included in the publication were the flocks with non-linear hierarchies, because those exceptions were the focus of

the study [163]. In such cases, we included this information in the 'note' column of the archive, but it was often the case that no reason was given for which example data were shared in the publication. In comparative studies, users of the data should inspect the original sources of datasets for species with limited available data to ensure that characteristics inferred for that species reflect the typical behaviour and are not biased by the research focus of the original source.

5. Recommendations for publishing future dominance data

In collecting data for this archive, we noticed a culture shift in the way dominance data are used and published that merits discussion. In the twentieth century, it was common to publish sociomatrices of (at least some of) the interaction data used in dominance analyses (e.g. [86]). However, more recently, the practice of publishing the raw dominance interaction data in the manuscript has become less frequent, with much of this information either not appearing in the paper at all or appearing only in electronic supplementary material. The movement of this data to online supplements has the potential to greatly improve data availability because of the relaxation of constraints imposed by journal page limits, but it has been accompanied by new emerging challenges that stifle this potential. In particular, there has been a troubling trend towards sharing processed data rather than raw interaction data. In many papers, data that accompany the paper include calculated ranks or ratings associated with individuals in the study, but the raw interactions used to infer those ratings are omitted. Recent steps towards reproducibility and open science have emphasized publishing the analysis code and raw data to reproduce all steps of the analysis [221,239]—here, we echo this call, and highlight that for analyses including rank as a covariate, this entails sharing the raw interaction data used to infer those ranks. Finally, the increasing use of the Elo-rating method has led to a shift away from sociomatrices and towards data structures that include information about the sequence of interactions. This change has led to exciting new research into dominance and its dynamics [220,223], but has also led to new challenges for data sharing. Whereas sociomatrices are standardized data structures, the edgelist datasets we assembled were much more variable in their structure, and the metadata associated with the data were often incomplete or difficult to interpret. These issues are likely in part driven by the reduced scrutiny during peer review paid to data and electronic supplementary material compared to the sociomatrices that used to appear in the main text of the paper. To facilitate data sharing and comparative research, we recommend that researchers publishing edgelist data include columns for the group identifier, the sequence number of the interaction, the identity of the winner, the identity of the loser, and a date or time column giving as precise a measure of the timing of the interaction as possible.

6. Conclusion

Dominance interaction data are widely collected and used to gain insight into the structure of animal societies. Here, we compile previously published data to encourage comparative

insight into animal social hierarchies—insight which has been surprisingly sparse despite the potential of existing data. We look forward to building on this insight and expanding this archive in the years to come.

References

1. Adcock SJJ, Martin GM, Walsh CJ. 2015 The stress response and exploratory behaviour in Yucatan minipigs (*Sus scrofa*): relations to sex and social rank. *Physiol. Behav.* **152**, 194–202. (doi:10.1016/j.physbeh.2015.09.033)

2. Alados CL, Escós JM. 1992 The determinants of social status and the effect of female rank on reproductive success in Dama and Cuvier's gazelles. *Ethol. Ecol. Evol.* **4**, 151–164. (doi:10.1080/08927014.1992.9525336)

3. Berman CM, Ionica CS, Li J. 2004 *Dominance style among Macaca thibetana* on Mt. Huangshan, China. *Int. J. Primatol.* **25**, 1283–1312. (doi:10.1023/B:IJOP.0000043963.77801.c3)

4. Nakano S. 1994 Variation in agonistic encounters in a dominance hierarchy of freely interacting red-spotted masu salmon (*Oncorhynchus masou ishikawai*). *Ecol. Freshw. Fish* **3**, 153–158. (doi:10.1111/j.1600-0633.1994.tb00017.x)

5. Nakano S. 1995 Competitive interactions for foraging microhabitats in a size-structured interspecific dominance hierarchy of two sympatric stream salmonids in a natural habitat. *Can. J. Zool.* **73**, 1845–1854. (doi:10.1139/z95-217)

6. Natoli E, De Vito E. 1991 Agonistic behaviour, dominance rank and copulatory success in a large multi-male feral cat, *Felis catus* L., colony in central Rome. *Anim. Behav.* **42**, 227–241. (doi:10.1016/S0003-3472(05)80554-8)

7. Nelissen MHJ. 1985 Structure of the dominance hierarchy and dominance determining 'group factors' in *Melanochromis auratus* (Pisces, Cichlidae). *Behaviour* **94**, 85–107. (doi:10.1163/156853985X00280)

8. Newton-Fisher NE. 2004 Hierarchy and social status in *Budongo* chimpanzees. *Primates* **45**, 81–87. (doi:10.1007/s10329-003-0064-6)

9. Norscia I, Palagi E. 2015 The socio-matrix reloaded: from hierarchy to dominance profile in wild lemurs. *PeerJ* **3**, 729. (doi:10.7717/peerj.729)

10. O'Shea TJ. 1976 Home range, social behavior, and dominance relationships in the African unstriped ground squirrel, *Xerus rutilus*. *J. Mammal.* **57**, 450–460. (doi:10.2307/1379295)

11. Ortius D, Heinze J. 1995 Dynamics and consequences of hierarchy formation in the ant *Leptothorax* sp. A. *Ethology* **99**, 223–233. (doi:10.1111/j.1439-0310.1995.tb00896.x)

12. Owens D, Owens M. 1996 Social dominance and reproductive patterns in brown hyaenas, *Hyaena brunnea*, of the central Kalahari desert. *Anim. Behav.* **51**, 535–551. (doi:10.1006/anbe.1996.0058)

13. Painter M. 2018 Social relationships and selfdirected behavior in hamadryas baboons (*Papio hamadryas hamadryas*). Masters thesis, Bucknell University, PA, USA. See https://digitalcommons.bucknell.edu/masters_theses/200.

14. Blatrix R, Herbers JM. 2004 Intracolonial conflict in the slave-making ant *Protomognathus americanus*: dominance hierarchies and individual reproductive success. *Insectes Soc.* **51**, 131–138. (doi:10.1007/s00040-003-0710-4)

15. Paoli T, Palagi E, Tarli SMB. 2006 Reevaluation of dominance hierarchy in bonobos (*Pan paniscus*). *Am. J. Phys. Anthropol.* **130**, 116–122. (doi:10.1002/ajpa.20345)

16. Pardi L. 1948 Dominance order in *Polistes* wasps. *Physiol. Zool.* **21**, 1–13. (doi:10.1086/physzool.21.1.30151976)

17. Parsons J, Baptista L. 1980 Crown color and dominance in the white-crowned sparrow. *Auk* **97**, 807–815. (doi:10.1093/auk/97.4.807)

18. Patterson IJ. 1977 Aggression and dominance in winter flocks of shelduck *Tadorna tadorna* (L.). *Anim. Behav.* **25**, 447–459. (doi:10.1016/0003-3472(77)90019-7)

19. Payne HFP, Lawes MJ, Henzi SP. 2003 Competition and the exchange of grooming among female samango monkeys (*Cercopithecus mitis erythrarchus*). *Behaviour* **140**, 453–471. (doi:10.1163/156853903322127931)

20. Poisbleau M, Fritz H, Guillemain M, Lacroix A. 2005 Testosterone and linear social dominance status in captive male dabbling ducks in winter. *Ethology* **111**, 493–509. (doi:10.1111/j.1439-0310.2005.01092.x)

21. Poisbleau M, Jenouvrier S, Fritz H. 2006 Assessing the reliability of dominance scores for assigning individual ranks in a hierarchy. *Anim. Behav.* **72**, 835–842. (doi:10.1016/j.anbehav.2006.01.024)

22. Post W. 1992 Dominance and mating success in male boat-tailed grackles. *Anim. Behav.* **44**, 917–929. (doi:10.1016/S0003-3472(05)80587-1)

23. Prieto AA, Ryan MJ. 1978 Some observations of the social behavior of the Arizona chuckwalla, *Sauromalus obesus tumidus* (Reptilia, Lacertilia, Iguanidae). *J. Herpetol.* **12**, 327. (doi:10.2307/1563613)

24. Reason RC, Laird EW. 1988 Determinants of dominance in captive female Addax (*Addax nasomaculatus*). *J. Mammal.* **69**, 375–377. (doi:10.2307/1381391)

25. Bonanni R, Cafazzo S, Abis A, Barillari E, Valsecchi P, Natoli E. 2017 Age-graded dominance hierarchies and social tolerance in packs of free-ranging dogs. *Behav. Ecol.* **28**, 1004–1020. (doi:10.1093/beheco/arx059)

26. Richter C, Mevis L, Malaivijitnond S, Schülke O, Ostner J. 2009 Social relationships in free-ranging male *Macaca arctoides*. *Int. J. Primatol.* **30**, 625–642. (doi:10.1007/s10764-009-9364-z)

27. Rizaldi, Kunio W. 2010 Early development of peer dominance relationships in a captive group of Japanese macaques. *Curr. Zool.* **56**, 190–197. (doi:10.1093/czoolo/56.2.190)

28. Robbins MM. 2008 Feeding competition and agonistic relationships among Bwindi *Gorilla beringei*. *Int. J. Primatol.* **29**, 999–1018. (doi:10.1007/s10764-008-9275-4)

29. Röell A. 2008 Social behaviour of the jackdaw, *Corvus monedula*, in relation to its niche. *Behaviour* **64**, 1–122. (doi:10.1163/156853978×00459)

30. Rossler C. 2017 Comparing food sharing and social tolerance in jackdaws (*Corvus monedula*) under daily life conditions and in experimental settings. Masters thesis, University of Vienna, Austria.

31. Rovero F, Lebboroni M, Chelazzi G. 1999 Aggressive interactions and mating in wild populations of the European pond turtle *Emys orbicularis*. *J. Herpetol.* **33**, 258–263. (doi:10.2307/1565723)

6

royalsocietypublishing.org/journal/rstb *Phil. Trans. R. Soc. B* **377**: 20200436

32. Russell EM. 1970 Agonistic interactions in the red kangaroo (*Megaleia rufa*). *J. Mammal.* **51**, 80–88. (doi:10.2307/1378534)

33. Rutberg A. 1986 Dominance and its fitness consequences in American bison cows. *Behaviour* **96**, 62–91. (doi:10.1163/156853986X00225)

34. Samuels A, Silk JB, Altmann J. 1987 Continuity and change in dominance relations among female baboons. *Anim. Behav.* **35**, 785–793. (doi:10.1016/S0003-3472(87)80115-X)

35. Sandel AA, Reddy RB, Mitani JC. 2017 Adolescent male chimpanzees do not form a dominance hierarchy with their peers. *Primates* **58**, 39–49. (doi:10.1007/s10329-016-0553-z)

36. Bonanni R, Cafazzo S, Fantini C, Pontier D, Natoli E. 2007 Feeding-order in an urban feral domestic cat colony: relationship to dominance rank, sex and age. *Anim. Behav.* **74**, 1369–1379. (doi:10.1016/j.anbehav.2007.02.029)

37. Satoh A, Ohkawara K. 2008 Dominance hierarchies and aggressive behavior among queens of the inquiline ant *Vollenhovia nipponica*. *Insectes Soc.* **55**, 200–206. (doi:10.1007/s00040-008-0989-2)

38. Schein MW, Fohrman MH. 1955 Social dominance relationships in a herd of dairy cattle. *Br. J. Anim. Behav.* **3**, 45–55. (doi:10.1016/S0950-5601(55)80012-3)

39. Schjelderup-Ebbe T. 1922 Beitrage zur sozialpsychologie des haushuhns. *Z. Psychol. Physiol. Sinnesorgane* **88**, 225–252.

40. Scott J, Lockard JS. 1999 Female dominance relationships among captive western lowland gorillas: comparisons with the wild. *Behaviour* **136**, 1283–1310. (doi:10.1163/156853999500721)

41. Seibert LM, Crowell-Davis SL. 2001 Gender effects on aggression, dominance rank, and affiliative behaviors in a flock of captive adult cockatiels (*Nymphicus hollandicus*). *Appl. Anim. Behav. Sci.* **71**, 155–170. (doi:10.1016/S0168-1591(00)00172-6)

42. Setchell JM, Wickings EJ. 2005 Dominance, status signals and coloration in male mandrills (*Mandrillus sphinx*). *Ethology* **111**, 25–50. (doi:10.1111/j.1439-0310.2004.01054.x)

43. Setia TM, Van Schaik CP. 2007 The response of adult orang-utans to flanged male long calls: inferences about their function. *Folia Primatol.* **78**, 215–226. (doi:10.1159/000102317)

44. Seyfarth RM. 1976 Social relationships among adult female baboons. *Anim. Behav.* **24**, 917–938. (doi:10.1016/S0003-3472(76)80022-X)

45. Sharpe LL, Hill A, Cherry MI. 2013 Individual recognition in a wild cooperative mammal using contact calls. *Anim. Behav.* **86**, 893–900. (doi:10.1016/j.anbehav.2013.07.023)

46. Shimoji H, Abe MS, Tsuji K, Masuda N. 2014 Global network structure of dominance hierarchy of ant workers. *J. R. Soc. Interface* **11**, 20140599. (doi:10.1098/rsif.2014.0599)

47. Bromley PT. 1991 Manifestations of social dominance in pronghorn bucks. *Appl. Anim. Behav. Sci.* **29**, 147–164. (doi:10.1016/0168-1591(91)90243-Q)

48. Shoemaker HH. 1939 Social hierarchy in flocks of the canary. *Auk* **56**, 381–406. (doi:10.2307/4078790)

49. Silk MJ, Cant MA, Cafazzo S, Natoli E, McDonald RA. 2019 Elevated aggression is associated with uncertainty in a network of dog dominance interactions. *Proc. R. Soc. B* **286**, 20190536. (doi:10.1098/rspb.2019.0536)

50. Slotow R, Alcock J, Rothstein SI. 1993 Social status signalling in white-crowned sparrows: an experimental test of the social control hypothesis. *Anim. Behav.* **46**, 977–989. (doi:10.1006/anbe.1993.1279)

51. Smith JE, Powning KS, Dawes SE, Estrada JR, Hopper AL, Piotrowski SL, Holekamp KE. 2011 Greetings promote cooperation and reinforce social bonds among spotted hyaenas. *Anim. Behav.* **81**, 401–415. (doi:10.1016/j.anbehav.2010.11.007)

52. Smith S. 1976 Ecological aspects of dominance hierarchies in black-capped chickadees. *Auk* **93**, 95–107. (doi:10.1093/auk/93.1.95)

53. Solberg EJ, Ringsby TH. 1997 Does male badge size signal status in small island populations of house sparrows, *Passer domesticus*? *Ethology* **103**, 177–186. (doi:10.1111/j.1439-0310.1997.tb00114.x)

54. Somers MJ, Nel JAJ. 1998 Dominance and population structure of freshwater crabs (*Potamonautes perlatus* Milne Edwards). *African Zool.* **33**, 31–36. (doi:10.1080/02541858.1998.11448450)

55. Stamps JA. 2008 A field study of the ontogeny of social behavior in the lizard *Anolis aeneus*. *Behaviour* **66**, 1–30. (doi:10.1163/156853978×00396)

56. Sterck EHM, Steenbeek R. 1997 Female dominance relationships and food competition in the sympatric Thomas langur and long-tailed macaque. *Behaviour* **134**, 749–774. (doi:10.1163/156853997×00052)

57. Strauss ED, Holekamp KE. 2019 Social alliances improve rank and fitness in convention-based societies. *Proc. Natl Acad. Sci. USA* **116**, 8919–8924. (doi:10.1073/pnas.1810384116)

58. Cafazzo S, Valsecchi P, Bonanni R, Natoli E. 2010 Dominance in relation to age, sex, and competitive contexts in a group of free-ranging domestic dogs. *Behav. Ecol.* **21**, 443–455. (doi:10.1093/beheco/arq001)

59. Strayer FF, Cummins MS. 1980 Aggressive and competitive social structures in captive monkey groups. In *Dominance relations: an ethological view of human conflict and social interaction* (eds DR Omark, FF Strayer, DG Freedman). New York, NY: Garland STPM Press.

60. Struhsaker TT. 1968 Social structure among vervet monkeys (*Cercopithecus aethiops*). *Behaviour* **29**, 83–121. (doi:10.1163/156853967X00073)

61. Sullivan RM. 1982 Agonistic behavior and dominance relationships in the harbor seal, *Phoca vitulina*. *J. Mammal.* **63**, 554–569. (doi:10.2307/1380260)

62. Surbeck M, Hohmann GG. 2013 Intersexual dominance relationships and the influence of leverage on the outcome of conflicts in wild bonobos (*Pan paniscus*). *Behav. Ecol. Sociobiol.* **67**, 1767–1780. (doi:10.1007/s00265-013-1584-8)

63. Surbeck M, Mundry R, Hohmann G. 2011 Mothers matter! Maternal support, dominance status and mating success in male bonobos (*Pan paniscus*). *Proc. R. Soc. B* **278**, 590–598. (doi:10.1098/rspb.2010.1572)

64. Tamm S. 1977 Social dominance in captive jackdaws (*Corvus monedula*). *Behav. Processes* **2**, 293–299. (doi:10.1016/0376-6357(77)90032-8)

65. Tamura N, Hayashi F, Miyashita K. 1988 Dominance hierarchy and mating behavior of the Formosan squirrel, *Callosciurus erythraeus thaiwanensis*. *J. Mammal.* **69**, 320–331. (doi:10.2307/1381382)

66. Tarvin KA, Woolfenden GE. 1997 Patterns of dominance and aggressive behavior in blue jays at a feeder. *Condor* **99**, 434–444. (doi:10.2307/1369950)

67. Thompson KV. 1993 Aggressive behavior and dominance hierarchies in female sable antelope, *Hippotragus niger*: implications for captive management. *Zoo Biol.* **12**, 189–202. (doi:10.1002/zoo.1430120205)

68. Thompson WL. 1960 Agonistic behavior in the house finch. Part I: annual cycle and display patterns. *Condor* **62**, 245–271. (doi:10.2307/1365516)

69. Cheney DL. 1977 The acquisition of rank and the development of reciprocal alliances among free-ranging immature baboons. *Behav. Ecol. Sociobiol.* **2**, 303–318. (doi:10.1007/BF00299742)

70. Tilson RL, Hamilton WJ. 1984 Social dominance and feeding patterns of spotted hyaenas. *Anim. Behav.* **32**, 715–724. (doi:10.1016/S0003-3472(84)80147-5)

71. Tong X, Shen C, Chen R, Gao S, Liu X, Schinckel AP, Zhou B. 2020 Reestablishment of social hierarchies in weaned pigs after mixing. *Animals* **10**, 36. (doi:10.3390/ani10010036)

72. Torr GA, Shine R. 1996 Patterns of dominance in the small scincid lizard *Lampropholis guichenoti*. *J. Herpetol.* **30**, 230–237. (doi:10.2307/1565514)

73. Trebouet FA. 2019 Male reproductive strategies in wild northern pig-tailed macaques (*Macaca leonina*): testing the priority-of-access model. PhD dissertation, Southern Illinois University Carbondale, IL, USA.

74. Trunzer B, Heinze J, Hölldobler B. 1999 Social status and reproductive success in queenless ant colonies. *Behaviour* **136**, 1093–1105. (doi:10.1163/156853999501775)

75. Utt AC, Harvey NC, Hayes WK, Carter RL. 2008 The effects of rearing method on social behaviors of mentored, captive-reared juvenile California condors. *Zoo. Biol.* **27**, 1–18. (doi:10.1002/zoo.20151)

76. Val-Laillet D, Passillé AM de, Rushen J, von Keyserlingk MAG. 2008 The concept of social dominance and the social distribution of feeding-related displacements between cows. *Appl. Anim. Behav. Sci.* **111**, 158–172. (doi:10.1016/j.applanim.2007.06.001)

77. Van Dierendonck MC, De Vries H. 1994 An analysis of dominance, its behavioural parameters and possible determinants in a herd of Icelandic horses in captivity. *Netherlands J. Zool.* **45**, 362–385. (doi:10.1163/156854295X00366)

78. Varley M, Symmes D. 1966 The hierarchy of dominance in a group of macaques. *Behaviour* **27**, 54–74. (doi:10.1163/156853966X00100)

79. Vervaecke H, De Bonte L, Maertens L, Tuyttens F, Stevens JMG, Lips D. 2010 Development of hierarchy and rank effects in weaned growing rabbits (*Oryctolagus cuniculus*). *World Rabbit Sci.* **18**, 139–149. (doi:10.4995/wrs.2010.8229)

80. Clutton-Brock TH, Greenwood PJ, Powell RP. 2010 Ranks and relationships in highland ponies and highland cows. *Z. Tierpsychol.* **41**, 202–216. (doi:10.1111/j.1439-0310.1976.tb00477.x)

81. Vervaecke H, De Vries H, Van Elsacker L. 2000 Dominance and its behavioral measures in a captive group of bonobos (*Pan paniscus*). *Int. J. Primatol.* **21**, 47–68. (doi:10.1023/A:1005471512788)

82. Vilette C, Bonnell T, Henzi P, Barrett L. 2021 Comparing dominance hierarchy methods using a data-splitting approach with real-world data. *Behav. Ecol.* **31**, 1379–1390. (doi:10.1093/beheco/araa095)

83. Waterhouse M, Waterhouse H. 1976 The development of social organization in rhesus monkeys (*Macaca mulatta*) - an example of bimodal attention structure. In *The social structure of attention* (eds MRA Chance, RR Larsen), pp. 83–104. Hoboken, NJ: John Wiley & Sons.

84. Watson JR. 1970 Dominance-subordination in caged groups of house sparrows. *Wilson Bull.* **82**, 268–278.

85. Watt DJ. 1986 Relationship of plumage variability, size and sex to social dominance in Harris' sparrows. *Anim. Behav.* **34**, 16–27. (doi:10.1016/0003-3472(86)90002-3)

86. Watts DP. 1994 Agonistic relationships between female mountain gorillas (*Gorilla gorilla beringei*). *Behav. Ecol. Sociobiol.* **34**, 347–358. (doi:10.1007/BF00197005)

87. Watts DP. 1985 Relations between group size and composition and feeding competition in mountain gorilla groups. *Anim. Behav.* **33**, 72–85. (doi:10.1016/S0003-3472(85)80121-4)

88. Wells SM, von Goldschmidt-Rothschild B. 1979 Social behaviour and relationships in a herd of Camargue horses. *Z. Tierpsychol.* **49**, 363–380. (doi:10.1111/j.1439-0310.1979.tb00299.x)

89. West Eberhard MJ. 1986 Domination relations in *Polistes canadensis* a tropical wasp. *Monit. Zool. Ital.* **20**, 263–281.

90. White FJ, Wood KD. 2007 Female feeding priority in bonobos, *Pan paniscus*, and the question of female dominance. *Am. J. Primatol.* **69**, 837–850. (doi:10.1002/ajp.20387)

91. Collias NE. 1950 Some variations in grouping and dominance patterns among birds and mammals. *Zoologica* **35**, 97–119. (doi:10.5962/p.203494)

92. Wikberg EC, Sicotte P, Teichroeb JA, Bădescu I. 2013 Individualistic female dominance hierarchies with varying strength in a highly folivorous population of black-and-white colobus. *Behaviour* **150**, 295–320. (doi:10.1163/1568539X-00003050)

93. Williams WT, Kikkawa J, Morris DK. 1972 A numerical study of agonistic behaviour in the greybreasted silvereye (*Zosterops lateralis*). *Anim. Behav.* **20**, 155–165. (doi:10.1016/S0003-3472(72)80186-6)

94. Williamson CM, Franks B, Curley JP. 2016 Mouse social network dynamics and community structure are associated with plasticity-related brain gene expression. *Front. Behav. Neurosci.* **10**, 152. (doi:10.3389/fnbeh.2016.00152)

95. Williamson CM, Lee W, Curley JP. 2016 Temporal dynamics of social hierarchy formation and maintenance in male mice. *Anim. Behav.* **115**, 259–272. (doi:10.1016/j.anbehav.2016.03.004)

96. Williamson CM, Lee W, DeCasien AR, Lanham A, Romeo RD, Curley JP. 2019 Social hierarchy position in female mice is associated with plasma corticosterone levels and hypothalamic gene expression. *Sci. Rep.* **9**, 1–4. (doi:10.1038/s41598-019-43747-w)

97. Williamson CM, Lee W, Romeo RD, Curley JP. 2017 Social context-dependent relationships between mouse dominance rank and plasma hormone levels. *Physiol. Behav.* **171**, 110–119. (doi:10.1016/j.physbeh.2016.12.038)

98. Wittemyer G, Getz WM. 2007 Hierarchical dominance structure and social organization in African elephants, *Loxodonta africana*. *Anim. Behav.* **73**, 671–681. (doi:10.1016/j.anbehav.2006.10.008)

99. Wittig RM, Boesch C. 2003 Food competition and linear dominance hierarchy among female chimpanzees of the Taï National Park. *Int. J. Primatol.* **24**, 847–867. (doi:10.1023/A:1024632923180)

100. Yasukawa K, Bick EI. 1983 Dominance hierarchies in dark-eyed juncos (*Junco hyemalis*): a test of a game-theory model. *Anim. Behav.* **31**, 439–448. (doi:10.1016/S0003-3472(83)80064-5)

101. Zine MJ, Krausman PR. 2000 Behavior of captive mountain sheep in a Mojave desert environment. *Southwest. Nat.* **45**, 184–195. (doi:10.2307/3672460)

102. Collias NE, Taber RD. 1951 A field study of some grouping and dominance relations in ring-necked pheasants. *Condor* **53**, 265–275. (doi:10.2307/1364987)

103. Allee WC, Dickinson JC. 1954 Dominance and subordination in the smooth dogfish *Mustelus canis* (Mitchill). *Physiol. Zool.* **27**, 356–364. (doi:10.1086/physzool.27.4.30152372)

104. Correa LA, Zapata B, Samaniego H, Soto-Gamboa M. 2013 Social structure in a family group of Guanaco (*Lama guanicoe*, Ungulate): is female hierarchy based on 'prior attributes' or 'social dynamics'? *Behav. Processes* **98**, 92–97. (doi:10.1016/j.beproc.2013.05.003)

105. Côté SD. 2000 Dominance hierarchies in female mountain goats: stability, aggressiveness and determinants of rank. *Behaviour* **137**, 1541–1566. (doi:10.1163/156853900502718)

106. Cui LW, Sun QL, Li BG. 2014 Dominance hierarchy and social relationships in a group of captive black-and-white snub-nosed monkeys (*Rhinopithecus bieti*). *Dongwuxue. Yanjiu.* **35**, 204–213. (doi:10.11813/j.issn.0254-5853.2014.3.204)

107. David BO, Stoffels RJ. 2003 Spatial organisation and behavioural interaction of giant kokopu (*Galaxias argenteus*) in two stream pools differing in fish density. *New Zeal. J. Mar. Freshw. Res.* **37**, 315–322. (doi:10.1080/00288330.2003.9517169)

108. De la Fuente MF, Schiel N, Bicca-Marques JC, Caselli CB, Souto A, Garber PA. 2019 Balancing contest competition, scramble competition, and social tolerance at feeding sites in wild common marmosets (*Callithrix jacchus*). *Am. J. Primatol.* **81**, 22964. (doi:10.1002/ajp.22964)

109. De La O C, Fürtbauer I, King AJ, Valenzuela-Galván D. 2019 A resident-nepotistic-tolerant dominance style in wild white-nosed coatis (*Nasua narica*)? *Behaviour* **156**, 927–968. (doi:10.1163/1568539X-00003547)

110. de Vries H, Stevens JMGG, Vervaecke H. 2006 Measuring and testing the steepness of dominance hierarchies. *Anim. Behav.* **71**, 585–592. (doi:10.1016/j.anbehav.2005.05.015)

111. de Waal FBM. 1977 The organization of agonistic relations within two captive groups of Java-monkeys (*Macaca fascicularis*). *Z. Tierpsychol.* **44**, 225–282. (doi:10.1111/j.1439-0310.1977.tb00995.x)

112. de Waal FBM, Luttrell LM. 1985 The formal hierarchy of rhesus macaques: an investigation of the bared-teeth display. *Am. J. Primatol.* **9**, 73–85. (doi:10.1002/ajp.1350090202)

113. Dessel TVAN, Vervaecke H. 2018 Social behavior and welfare in horses (*Equus caballus*). BA thesis, Odisee University of Applied Sciences, Belgium.

114. Anderson E. 2016 The behaviour and welfare of zoo-housed Japanese macaques (*Macaca fuscata*). Masters thesis, Concordia University, Canada.

115. Diniz P, Oliveira RS, Marini M, Duca C. 2019 Angry caciques: intrasexual aggression in a Neotropical colonial blackbird. *Ethol. Ecol. Evol.* **31**, 205–218. (doi:10.1080/03949370.2018.1544593)

116. Douglis MB. 1948 Social factors influencing the hierarchies of small flocks of the domestic hen: interactions between resident and part-time members of organized flocks. *Physiol. Zool.* **21**, 147–182. (doi:10.1086/physzool.21.2.30151991)

117. Duboscq J, Micheletta J, Agil M, Hodges K, Thierry B, Engelhardt A. 2013 Social tolerance in wild female crested macaques (*Macaca nigra*) in Tangkoko-Batuangus nature reserve, Sulawesi, Indonesia. *Am. J. Primatol.* **75**, 361–375. (doi:10.1002/ajp.22114)

118. Ellard ME, Crowell-Davis SL. 1989 Evaluating equine dominance in draft mares. *Appl. Anim. Behav. Sci.* **24**, 55–75. (doi:10.1016/0168-1591(89)90125-1)

119. Essler JL, Cafazzo S, Marshall-Pescini S, Virányi Z, Kotrschal K, Range F. 2016 Play behavior in wolves: using the '50:50' rule to test for egalitarian play styles. *PLoS ONE* **11**, 154150. (doi:10.1371/journal.pone.0154150)

120. Fairbanks WS. 1994 Dominance, age and aggression among female pronghorn, *Antilocapra americana* (Family: Antilocapridae). *Ethology* **97**, 278–293. (doi:10.1111/j.1439-0310.1994.tb01047.x)

121. Farentinos RC. 1972 Social dominance and mating activity in the tassel-eared squirrel (*Sciurus aberti ferreus*). *Anim. Behav.* **20**, 316–326. (doi:10.1016/S0003-3472(72)80053-8)

122. Foerster S, Franz M, Murray CM, Gilby IC, Feldblum JT, Walker KK, Pusey AE. 2016 Chimpanzee females queue but males compete for social status. *Sci. Rep.* **6**, 1–11. (doi:10.1038/srep35404)

123. Fournier F, Festa-Bianchet M. 1995 Social dominance in adult female mountain goats. *Anim. Behav.* **49**, 1449–1459. (doi:10.1016/0003-3472(95)90066-7)

124. Frank LG. 1986 Social organization of the spotted hyaena *Crocuta crocuta*. II. Dominance and reproduction. *Anim. Behav.* **34**, 1510–1527. (doi:10.1016/S0003-3472(86)80221-4)

125. Appleby MC. 1983 The probability of linearity in hierarchies. *Anim. Behav.* **31**, 600–608. (doi:10.1016/S0003-3472(83)80084-0)

126. Franz M, McLean E, Tung J, Altmann J, Alberts SC. 2015 Self-organizing dominance hierarchies in a wild primate population. *Proc. R. Soc. B* **282**, 20151512. (doi:10.1098/rspb.2015.1512)

127. Funkhouser JA, Mayhew JA, Sheeran LK, Mulcahy JB, Li JH. 2018 Comparative investigations of social context-dependent dominance in captive chimpanzees (*Pan troglodytes*) and wild Tibetan macaques (*Macaca thibetana*). *Sci. Rep.* **8**, 13909. (doi:10.1038/s41598-018-32243-2)

128. Harcourt AH. 1979 Social relationships among adult female mountain gorillas. *Anim. Behav.* **27**, 251–264. (doi:10.1016/0003-3472(79)90145-3)

129. Harcourt AH, Stewart KJ. 1989 Functions of alliances in contests within wild gorilla groups. *Behaviour* **109**, 176–190. (doi:10.1163/156853989×00213)

130. Hartzler JE. 1970 Winter dominance relationship in black-capped chickadees. *Wilson Bull.* **82**, 427–434.

131. Hass CC, Jenni DA. 1991 Structure and ontogeny of dominance relationships among bighorn rams. *Can. J. Zool.* **69**, 471–476. (doi:10.1139/z91-073)

132. Hausfater G. 1975 Dominance and reproduction in baboons (*Papio cynocephalus*). *Contrib. Primatol.* **7**, 1–150.

133. Hausfater G, Altmann J, Altmann S. 1982 Long-term consistency of dominance relations among female baboons (*Papio cynocephalus*). *Science* **217**, 752–755. (doi:10.1126/science.217.4561.752)

134. Hayaki H, Huffman MA, Nishida T. 1989 Dominance among male chimpanzees in the Mahale Mountains National Park, Tanzania: a preliminary study. *Primates* **30**, 187–197. (doi:10.1007/BF02381303)

135. Heitor F, do Mar Oom M, Vicente L. 2006 Social relationships in a herd of Sorraia horses. Part II. Factors affecting affiliative relationships and sexual behaviours. *Behav. Processes* **73**, 231–239. (doi:10.1016/j.beproc.2006.05.005)

136. Archie EA, Morrison TA, Foley CAH, Moss CJ, Alberts SC. 2006 Dominance rank relationships among wild female African elephants, *Loxodonta africana*. *Anim. Behav.* **71**, 117–127. (doi:10.1016/j.anbehav.2005.03.023)

137. Heitor F, Vicente L. 2010 Dominance relationships and patterns of aggression in a bachelor group of Sorraia horses (*Equus caballus*). *J. Ethol.* **28**, 35–44. (doi:10.1007/s10164-009-0152-1)

138. Hewitt SE, Macdonald DW, Dugdale HL. 2009 Context-dependent linear dominance hierarchies in social groups of European badgers, *Meles meles*. *Anim. Behav.* **77**, 161–169. (doi:10.1016/j.anbehav.2008.09.022)

139. Hirotani A. 1994 Dominance rank, copulatory behaviour and estimated reproductive success in male reindeer. *Anim. Behav.* **48**, 929–936. (doi:10.1006/anbe.1994.1318)

140. Hirsch BT. 2007 Spoiled brats: is extreme juvenile agonism in ring-tailed coatis (*Nasua nasua*) dominance or tolerated aggression? *Ethology* **113**, 446–456. (doi:10.1111/j.1439-0310.2007.01348.x)

141. Hirsch BT. 2011 Within-group spatial position in ring-tailed coatis: balancing predation, feeding competition, and social competition. *Behav. Ecol. Sociobiol.* **65**, 391–399. (doi:10.1007/s00265-010-1056-3)

142. Hobson EA, DeDeo S. 2015 Social feedback and the emergence of rank in animal society. *PLOS Comput. Biol.* **11**, e1004411. (doi:10.1371/journal.pcbi.1004411)

143. Holekamp KE, Smale L. 1993 Ontogeny of dominance in free-living spotted hyaenas: juvenile rank relations with other immature individuals. *Anim. Behav.* **46**, 451–466. (doi:10.1006/anbe.1993.1214)

144. Holekamp KE, Smale L. 1991 Dominance acquisition during mammalian social development: the 'inheritance' of maternal rank. *Am. Zool.* **31**, 306–317. (doi:10.1093/icb/31.2.306)

145. Hooff Van J, Wensing J. 1987 Dominance and its behavioral measures in a captive wolf pack. In *Man and wolf* (ed. H Frank), pp. 219–252. Dordrecht, The Netherlands: Springer.

146. Isbell LA, Pruetz JD. 1998 Differences between vervets (*Cercopithecus aethiops*) and patas monkeys (*Erythrocebus patas*) in agonistic interactions between adult females. *Int. J. Primatol.* **19**, 837–855. (doi:10.1023/A:1020393329574)

147. Arlet ME, Chapman CA, Isbell LA, Molleman F, Mänd R, Hõrak P, Carey JR. 2015 Social and ecological correlates of parasitic infections in adult male gray-cheeked mangabeys (*Lophocebus albigena*). *Int. J. Primatol.* **36**, 967–986. (doi:10.1007/s10764-015-9866-9)

148. Ito F. 1993 Functional monogyny and dominance hierarchy in the queenless ponerine ant *Pachycondyla* (=*Bothroponera*) sp. in West Java, Indonesia (Hymenoptera, Formicidae, Ponerinae). *Indones.* (Hymenoptera, Formicidae, Ponerinae). *Ethology* **95**, 126–140. (doi:10.1111/j.1439-0310.1993.tb00463.x)

149. Izar P, Ferreira RG, Sato T. 2006 Describing the organization of dominance relationships by dominance-directed tree method. *Am. J. Primatol.* **68**, 189–207. (doi:10.1002/ajp.20216)

150. Izawa EI, Watanabe S. 2008 Formation of linear dominance relationship in captive jungle crows (*Corvus macrorhynchos*): implications for individual recognition. *Behav. Processes* **78**, 44–52. (doi:10.1016/j.beproc.2007.12.010)

151. Jenks SM, Weldele ML, Frank LG, Glickman SE. 1995 Acquisition of matrilineal rank in captive spotted hyaenas: emergence of a natural social system in peer-reared animals and their offspring. *Anim. Behav.* **50**, 893–904. (doi:10.1016/0003-3472(95)80092-1)

152. Johnson AP. 2017 Strangers in a new land: the effects of ecology on female social relationships, *Macaca mulatta*, Ocala National Forest. Masters thesis, University of North Carolina at Charlotte, NC, USA.

153. Jones CB. 1980 The functions of status in the mantled howler monkey, *Alouatta palliata* Gray: intraspecific competition for group membership in a folivorous neotropical primate. *Primates* **21**, 389–405. (doi:10.1007/BF02390468)

154. Kaufmann JH. 1974 Social ethology of the shiptail wallaby, *Macropus parryi*, in northeastern New South Wales. *Anim. Behav.* **22**, 281–284. (doi:10.1016/S0003-3472(74)80032-1)

155. Kikkawa J. 1980 Weight changes in relation to social hierarchy in captive flocks of silvereyes, *Zosterops lateralis*. *Behaviour* **74**, 92–100. (doi:10.1163/156853980X00320)

156. Koenig A, Larney E, Lu A, Borries C. 2004 Agonistic behavior and dominance relationships in female Phayre's leaf monkeys - preliminary results. *Am. J. Primatol.* **64**, 351–357. (doi:10.1002/ajp.20084)

157. Kohda M. 1991 Intra and interspecific social organization among three herbivorous cichlid fishes in Lake Tanganyika. *Jpn. J. Ichthyol.* **38**, 147–163. (doi:10.11369/jji1950.38.147)

158. Barrette C, Vandal D. 1986 Social rank, dominance, antler size, and access to food in snow-bound wild woodland caribou. *Behaviour* **97**, 118–146. (doi:10.1163/156853986X00342)

159. Kolodziejczyk M, Kloskowski J, Krogulec J. 2005 Lack of social hierarchy in wintering white-tailed eagles (*Haliaeetus albicilla*) when scavenging. *Ethol. Ecol. Evol.* **17**, 181–188. (doi:10.1080/08927014.2005.9522607)

160. Korstjens AH, Sterck EHM, Noë R. 2002 How adaptive or phylogenetically inert is primate social behaviour? A test with two sympatric colobines. *Behaviour* **139**, 203–225. (doi:10.1163/156853902760102654)

161. Koutnik DL. 1981 Sex-related differences in the seasonality of agonistic behavior in mule deer. *J. Mammal.* **62**, 1–11. (doi:10.2307/1380472)

162. Kurvers RHJM, Eijkelenkamp B, van Oers K, van Lith B, van Wieren SE, Ydenberg RC, Prins HHT. 2009 Personality differences explain leadership in barnacle geese. *Anim. Behav.* **78**, 447–453. (doi:10.1016/j.anbehav.2009.06.002)

163. Lahti K, Koivula K, Orell M. 1994 Is the social hierarchy always linear in tits? *J. Avian Biol.* **25**, 347. (doi:10.2307/3677283)

164. Langbein J, Puppe B. 2004 Analysing dominance relationships by sociometric methods—a plea for a more standardised and precise approach in farm animals. *Appl. Anim. Behav. Sci.* **87**, 293–315. (doi:10.1016/j.applanim.2004.01.007)

165. Langley EJG, Van Horik JO, Whiteside MA, Madden JR. 2018 Group social rank is associated with performance on a spatial learning task. *R. Soc. Open Sci.* **5**, 171475. (doi:10.1098/rsos.171475)

166. Lee PC, Oliver JI. 1979 Competition, dominance and the acquisition of rank in juvenile yellow baboons (*Papio cynocephalus*). *Anim. Behav.* **27**, 576–585. (doi:10.1016/0003-3472(79)90193-3)

167. Lee W, Hiura LC, Yang E, Broekman KA, Ophir AG, Curley JP. 2019 Social status in mouse social hierarchies is associated with variation in oxytocin and vasopressin 1a receptor densities. *Horm. Behav.* **114**, 104551. (doi:10.1016/j.yhbeh.2019.06.015)

168. Lee W, Khan A, Curley JP. 2017 Major urinary protein levels are associated with social status and context in mouse social hierarchies. *Proc. R. Soc. B* **284**, 20171570. (doi:10.1098/rspb.2017.1570)

169. Bennett MA. 1939 The social hierarchy in ring doves. *Ecology* **20**, 337–357. (doi:10.2307/1930387)

170. Lee W, Yang E, Curley JP. 2018 Foraging dynamics are associated with social status and context in mouse social hierarchies. *PeerJ* **6**, e5617. (doi:10.7717/peerj.5617)

171. Lott DF, Galland JC. 1987 Body mass as a factor influencing dominance status in American bison cows. *J. Mammal.* **68**, 683–685. (doi:10.2307/1381605)

172. Lott DF. 1979 Dominance relations and breeding rate in mature male *American bison. Ethology* **49**, 418–432. (doi:10.1111/j.1439-0310.1979.tb00302.x)

173. Lu A, Koenig A, Borries C. 2008 Formal submission, tolerance and socioecological models: a test with female Hanuman langurs. *Anim. Behav.* **76**, 415–428. (doi:10.1016/j.anbehav.2008.04.006)

174. Malherbe GP, Bennett NC. 2007 An assessment of behavioural dominance in a social subterranean rodent, *Cryptomys hottentotus pretoriae*, using the cardinal dominance index method. *African Zool.* **42**, 187–198. (doi:10.3377/1562-7020(2007)42[187:AAOBDI]2.0.CO;2)

175. Marler P. 1955 Studies of fighting in chaffinches (1) behaviour in relation to the social hierarchy. *Br. J. Anim. Behav.* **3**, 111–117. (doi:10.1016/S0950-5601(55)80002-0)

176. Masure R., Allee WC. 1934 The social order in flocks of the common chicken and the pigeon. *Auk* **51**, 306–327. (doi:10.2307/4077659)

177. Mather JA. 1985 Behavioural interactions and activity of captive *Eledone moschata*: laboratory investigations of a 'social' octopus. *Anim. Behav.* **33**, 1138–1144. (doi:10.1016/S0003-3472(85)80173-1)

178. Matsuda I, Tuuga A, Bernard H, Furuichi T. 2012 Inter-individual relationships in proboscis monkeys: a preliminary comparison with other non-human primates. *Primates* **53**, 13–23. (doi:10.1007/s10329-011-0259-1)

179. McCune KB, Jablonski P, Lee SI, Ha RR. 2019 Captive jays exhibit reduced problem-solving performance compared to wild conspecifics. *R. Soc. Open Sci.* **6**, 181311. (doi:10.1098/rsos.181311)

180. Bergstrom ML, Fedigan LM. 2010 Dominance among female white-faced capuchin monkeys (*Cebus capucinus*): hierarchical linearity, nepotism, strength and stability. *Behaviour* **147**, 899–931. (doi:10.1163/000579510X497283)

181. McDougall P. 2010 An examination of social arousal and its implications for social cognition in the South African vervet monkey. MSc thesis, University of Lethbridge, Canada.

182. McMahan CA, Morris MD. 1984 Application of maximum likelihood paired comparison ranking to estimation of a linear dominance hierarchy in animal societies. *Anim. Behav.* **32**, 374–378. (doi:10.1016/S0003-3472(84)80271-7)

183. Miller EJ, Eldridge MDB, Cooper DW, Herbert CA. 2010 Dominance, body size and internal relatedness influence male reproductive success in eastern grey kangaroos (*Macropus giganteus*). *Reprod. Fertil. Dev.* **22**, 539–549. (doi:10.1071/RD09061)

184. Møller AP. 1987 Variation in badge size in male house sparrows *Passer domesticus*: evidence for status signalling. *Anim. Behav.* **35**, 1637–1644. (doi:10.1016/S0003-3472(87)80056-8)

185. Monnin T, Peeters C. 1999 Dominance hierarchy and reproductive conflicts among subordinates in a monogynous queenless ant. *Behav. Ecol.* **10**, 323–332. (doi:10.1093/beheco/10.3.323)

186. Moore J. 1978 *Dominance relations among free-ranging female baboons in Gombe National Park, Tanzania*. London, UK: Academic Press.

187. Murray CM. 2007 Method for assigning categorical rank in female *Pan troglodytes schweinfurthii* via the frequency of approaches. *Int. J. Primatol.* **28**, 853–864. (doi:10.1007/s10764-007-9164-2)

188. Mwamende KA. 2009 Social organisation, ecology and reproduction in the Sanje mangabey (*Cercocebus sanjei*) in the Udzungwa Mountains National Park, Tanzania. MSc thesis, Victoria University, New Zealand..

189. Myrberg AA. 1972 Social dominance and territoriality in the bicolor damselfish, *Eupomacentrus partitus* (Poey) (Pisces: Pomacentridae). *Behaviour* **41**, 207–230. (doi:10.1163/156853972X00013)

190. Myrberg AA, Gruber SH. 1974 The behavior of the bonnethead shark, *Sphyrna tiburo. Copeia* **1974**, 358. (doi:10.2307/1442530)

191. Dehnen T, Papageorgiou D, Nyaguthii B, Cherono W, Penndorf J, Boogert N, Farine D. 2021 Costs dictate strategic investment in dominance interactions. *Phil. Trans. R. Soc. B* **377**, 20200447. (doi:10.1098/rstb.2020.0447)

192. Hamilton I, Benincasa M. 2021 Emergence of size-structured dominance hierarchies through size-dependent feedback. *Phil. Trans. R. Soc. B* **377**, 20200449. (doi:10.1098/rstb.2020.0449)

193. Drews C. 1993 The concept and definition of dominance in animal behaviour. *Behaviour* **125**, 283–313. (doi:10.1163/156853993X00290)

194. Albers PCH, de Vries H. 2001 Elo-rating as a tool in the sequential estimation of dominance strengths. *Animal* **61**, 489–495. (doi:10.1006/anbe.2000.1571)

195. de Vries H. 1998 Finding a dominance order most consistent with a linear hierarchy: a new procedure and review. *Anim. Behav.* **55**, 827–843. (doi:10.1006/anbe.1997.0708)

196. Gammell MP, de Vries H, Jennings DJ, Carlin CM, Hayden TJ. 2003 David's score: a more appropriate dominance ranking method than Clutton-Brock *et al.*'s index. *Anim. Behav.* **66**, 601–605. (doi:10.1006/anbe.2003.2226)

197. Milewski T, Lee W, Champagne F, Curley J. 2021 Behavioral and physiological plasticity in social hierarchies. *Phil. Trans. R. Soc. B* **377**, 20200443. (doi:10.1098/rstb.2020.0443)

198. McCowan B, Beisner B, Vandeleest J, Balasubramaniam K, Nathman A, Hsieh F. 2021 Measuring dominance certainty and assessing its impact on individual and societal health in a nonhuman primate model: a network approach. *Phil. Trans. R. Soc. B* **377**, 20200438. (doi:10.1098/rstb.2020.0438)

199. Anderson J *et al.* 2021 Distinct gene regulatory signatures of dominance rank and social bond strength in wild baboons. *Phil. Trans. R. Soc. B* **377**, 20200141. (doi:10.1098/rstb.2020.0141)

200. Knoch S, Whiteside M, Madden J, Rose P, Fawcett T. 2021 Hot-headed peckers: thermographic changes during aggression among juvenile pheasants (*Phasianus colchicus*). *Phil. Trans. R. Soc. B* **377**, 20200442. (doi:10.1098/rstb.2020.0442)

201. Simons ND, Michopoulos V, Wilson M, Barreiro L, Tung J. 2021 Agonism and grooming behavior explain social status effects on physiology and gene regulation in rhesus macaques. *Phil. Trans. R. Soc. B* **377**, 20210132. (doi:10.1098/rstb.2021.0132)

202. Wallace K, Choudhary K, Kutty L, Le D, Lee M, Wu K, Hofmann H. 2021 Social ascent changes cognition, behavior, and physiology in a highly social cichlid fish. *Phil. Trans. R. Soc. B* **377**, 20200448. (doi:10.1098/rstb.2020.0448)

203. Ellis L. 1995 Dominance and reproductive success among nonhuman animals: a cross-species comparison. *Ethol. Sociobiol.* **16**, 257–333. (doi:10.1016/0162-3095(95)00050-U)

204. Zeng TC, Cheng J, Henrich J. 2021 Dominance in humans. *Phil. Trans. R. Soc. B* **377**, 20200451. (doi:10.1098/rstb.2020.0451)

205. Dwortz M, Curley J, Tye K, Padilla-Coreano N. 2021 Neural systems that facilitate the representation of social rank. *Phil. Trans. R. Soc. B* **377**, 20200444. (doi:10.1098/rstb.2020.0444)

206. Shizuka D, McDonald DB. 2012 A social network perspective on measurements of dominance hierarchies. *Anim. Behav.* **83**, 925–934. (doi:10.1016/j.anbehav.2012.01.011)

207. Shizuka D, McDonald DB. 2015 The network motif architecture of dominance hierarchies. *J. R. Soc. Interface* **12**, 20150080. (doi:10.1098/rsif.2015.0080)

208. Landau HG. 1951 On dominance relations and the structure of animal societies: I Effect of inherent characteristics. *Bull. Math. Biophys.* **15**, 143–148. (doi:10.1007/BF02476378)

209. Boucherie P, Gallego-Abenza M, Massen J, Bugnyar T. 2021 Dominance in a socially dynamic setting: hierarchical structure and conflict dynamics in ravens' foraging groups. *Phil. Trans. R. Soc. B* **377**, 20200446. (doi:10.1098/rstb.2020.0446)

210. Chase ID. 1985 The sequential analysis of aggressive acts during hierarchy formation: an application of the 'jigsaw puzzle' approach. *Anim. Behav.* **33**, 86–100. (doi:.1016/S0003-3472(85)80122-6)

211. Strauss ED, Holekamp KE. 2019 Inferring longitudinal hierarchies: framework and methods for studying the dynamics of dominance. *J. Anim. Ecol.* **88**, 521–536. (doi:10.1111/1365-2656.12951)

212. Strauss E, Shizuka D. 2021 The dynamics of dominance: open questions, challenges, and solutions. *Phil. Trans. R. Soc. B* **377**, 20200445. (doi:10.1098/rstb.2020.0445)

213. Tibbetts E, Pardo-Sanchez J, Weise C. 2021 The establishment and maintenance of dominance hierarchies. *Phil. Trans. R. Soc. B* **377**, 20200450. (doi:10.1098/rstb.2020.0450)

214. Douglas PH, Ngonga Ngomo AC, Hohmann G. 2017 A novel approach for dominance assessment in gregarious species: ADAGIO. *Anim. Behav.* **123**, 21–32. (doi:10.1016/j.anbehav.2016.10.014)

215. Hobson EA, Mønster D, DeDeo S. 2021 Aggression heuristics underlie animal dominance hierarchies and provide evidence of group-level social information. *Proc. Natl Acad. Sci. USA* **118**, 1–9. (doi:10.1073/pnas.2022912118)

216. Thierry B, Aureli F, Nunn CL, Petit O, Abegg C, de Waal FBM. 2008 A comparative study of conflict resolution in macaques: insights into the nature of trait covariation. *Anim. Behav.* **75**, 847–860. (doi:10.1016/j.anbehav.2007.07.006)

217. Balasubramaniam KN *et al*. 2012 Hierarchical steepness, counter-aggression, and macaque social style scale. *Am. J. Primatol.* **74**, 915–925. (doi:10.1002/ajp.22044)

218. Michonneau F, Brown JW, Winter DJ. 2016 rotl: an R package to interact with the open tree of life data. *Methods Ecol. Evol.* **7**, 1476–1481. (doi:10.1111/2041-210X.12593)

219. Hobson E. 2021 Quantifying the dynamics of nearly 100 years of dominance hierarchy research. *Phil. Trans. R. Soc. B* **377**, 20200433. (doi:10.1098/rstb.2020.0433)

220. Neumann C, Duboscq J, Dubuc C, Ginting A, Irwan AM, Agil M, Widdig A, Engelhardt A. 2011 Assessing dominance hierarchies: validation and advantages of progressive evaluation with Elo-rating. *Anim. Behav.* **82**, 911–921. (doi:10.1016/j.anbehav.2011.07.016)

221. Molloy JC. 2011 The Open Knowledge Foundation: open data means better science. *PLoS Biol.* **9**, 1–4. (doi:10.1371/journal.pbio.1001195)

222. Glickman ME. 1999 Parameter estimation in large dynamic paired comparison experiments. *J. R. Stat. Soc. C* **48**, 377–394. (doi:10.1111/1467-9876.00159)

223. Strauss E, DeCasien A, Galindo G, Hobson E, Shizuka D, Curley J. 2021 The dynamics of dominance: open questions, challenges, and solutions. *Phil. Trans. R. Soc. B* **377**, 20200445. (doi:10.1098/rstb.2020.0445)

224. Lee W, Fu J, Bouwman N, Farago P, Curley JP. 2019 Temporal microstructure of dyadic social behavior during relationship formation in mice. *PLoS ONE* **14**, 1–24. (doi:10.1371/journal.pone.0220596)

225. Klass K, Cords M. 2011 Effect of unknown relationships on linearity, steepness and rank ordering of dominance hierarchies: simulation studies based on data from wild monkeys. *Behav. Processes* **88**, 168–176. (doi:10.1016/j.beproc.2011.09.003)

226. de Vries H. 1995 An improved test of linearity in dominance hierarchies containing unknown or tied relationships. *Anim. Behav.* **50**, 1375–1389. (doi:10.1016/0003-3472(95)80053-0)

227. Balasubramaniam KN *et al*. 2012 Hierarchical steepness and phylogenetic models: phylogenetic signals in *Macaca*. *Anim. Behav.* **83**, 1207–1218. (doi:10.1016/j.anbehav.2012.02.012)

228. Shimoji H, Dobata S. 2021 The build-up of dominance hierarchies in eusocial insects. *Phil. Trans. R. Soc. B* **377**, 20200437. (doi:10.1098/rstb.2020.0437)

229. Schmid VS, de Vries H. 2013 Finding a dominance order most consistent with a linear hierarchy: an improved algorithm for the I&SI method. *Anim. Behav.* **83**, 1097–1105. (doi:10.1016/j.anbehav.2013.08.019)

230. Sánchez-Tójar A, Schroeder J, Farine DR. 2018 A practical guide for inferring reliable dominance hierarchies and estimating their uncertainty. *J. Anim. Ecol.* **87**, 594–608. (doi:10.1111/1365-2656.12776)

231. Whitehead H. 2009 SOCPROG programs: analysing animal social structures. *Behav. Ecol. Sociobiol.* **63**, 765–778. (doi:10.1007/s00265-008-0697-y)

232. Netto WJ, Hanegraaf PLH, de Vries H. 1993 Matman: a program for the analysis of sociometric matrices and behavioural transition matrices. *Behaviour* **125**, 157–175. (doi:10.1163/156853993X00218)

233. Curley JP. 2016 compete: analyzing social hierarchies. R package version 0.1.

234. Farine DR, Sanchez-Tojar A. 2019 aniDom: inferring dominance hierarchies and estimating uncertainty. R package version 0.1.2.

235. Cerný D, Lee K, Medal J, Blumstein DT. 2019 Applying Lanchester's laws to the interspecific competition of coral reef fish. *Behav. Ecol.* **30**, 426–433. (doi:10.1093/beheco/ary182)

236. Miller ET, Bonter DN, Eldermire C, Freeman BG, Greig EI, Harmon LJ, Lisle C, Hochachka WM. 2017 Fighting over food unites the birds of North America in a continental dominance hierarchy. *Behav. Ecol.* **28**, 1454–1463. (doi:10.1093/beheco/arx108)

237. Chase ID, Lindquist WB. 2016 The fragility of individual-based explanations of social hierarchies: a test using animal pecking orders. *PLoS ONE* **11**, 1–16. (doi:10.1371/journal.pone.0158900)

238. Hsu Y, Earley RL, Wolf LL. 2006 Modulation of aggressive behaviour by fighting experience: mechanisms and contest outcomes. *Biol. Rev. Camb. Phil. Soc.* **81**, 33–74. (doi:10.1017/S146479310500686X)

239. Hampton SE *et al*. 2015 The Tao of open science for ecology. *Ecosphere* **6**, art120. (doi:10.1890/es14-00402.1)