

Table 1. Examples of ecological and evolutionary data registries^a, institutional repositories^b and topical repositories^{c,d}

	Data sets	URL
Registries^a		
Global Biodiversity Information Facility portal	343 ^e	http://www.gbif.net
National Biological Information Infrastructure	17 000	http://www.nbi.gov
Knowledge Network for Biocomplexity	1500 ^f	http://knb.ecoinformatics.org/index.jsp
Institutional or journal repositories^b		
NCEAS	72	http://knb.ecoinformatics.org/knb/style/skins/nceas/
Ecological Archives data papers (ESA journals)	6	http://www.esapubs.org/archive/archive_D.htm
Topical repositories^c		
Interaction Web Database	74 webs	http://www.nceas.ucsb.edu/interactionweb
TreeBase	2869 phylogenetic trees	http://www.treebase.org
Global population dynamics database	5000 time series	NERC Centre for Population Biology http://cpbnts1.bio.ic.ac.uk/gpdd/
VegBank	19 000 plots	http://vegbank.org/

^aProviding access to metadata and pointers to data stored elsewhere.

^bArchived data sets.

^cSpecific kinds of archived data sets in standardized file formats.

^dIncludes only sources with online access to machine-readable data and metadata; data sets are counted or self-reported as of 23 February 2005. Data sets in repositories can also be represented in registries.

^eData sets are typically museum collections; the total number of records now exceeds 45 million.

^fIncludes Long-term Studies Section Data Registry (of ESA); for example: 567 data sets from the Long Term Ecological Research (LTER), 434 from the University of California Natural Reserve System and 193 from the Organization of Biological Field Stations.

researchers at NCEAS and the new National Evolutionary Synthesis Center (NESCent) and the National Ecological Observatory Network (NEON) are forging ahead with research that relies on shared data. Data shared as benchmark data sets (e.g. [10]) can kick-start innovation by providing well defined challenges to computer scientists and informatics experts. The resulting technology can speed progress by ecologists and evolutionary biologists.

With substantial benefits for individuals, scientific communities, and society as a whole, the time for data sharing has come. It is up to us as individuals to take advantage of the many opportunities to share data, to make use of that data, and to support the development of related tools and data manipulation techniques.

References

- 1 National Research Council (2003) *Sharing Publication-related Data and Materials: Responsibilities of Authorship in the Life Sciences*, The National Academies Press
- 2 Insel, T.R. *et al.* (2003) Neuroscience networks: data-sharing in an information age. *PLoS Biol.* 1, 9–11
- 3 Anderson, E. (1935) The irises of the Gaspé Peninsula. *Bull. Am. Iris Soc.* 59, 2–5

- 4 Fisher, R.A. (1936) The use of multiple measurements in taxonomic problems. *Ann. Eugen.* 7, 179–188
- 5 Palmer, M.A. *et al.* (2004) *Ecological Science and Sustainability for a Crowded Planet*, Ecological Society of America (<http://www.esa.org/ecovisions>)
- 6 Michener, W.K. (2003) Building SEEK: the Science Environment for Ecological Knowledge. *DataBits: Elect. Newslett. Inf. Manag.* 3 (<http://intranet.lternet.edu/archives/documents/Newsletters/DataBits/03spring/>)
- 7 Cotter, G. *et al.* (2004) Integrated science for environmental decisionmaking: the challenge for biodiversity and ecosystem informatics. *Data Sci. J.* 3, 38–59
- 8 Silver, S. (2004) Editorial: publishing for the digital age. *Front. Ecol. Environ.* 10, 507
- 9 Caragea, D. *et al.* (2004) Learning classifiers from semantically heterogeneous data. In *Proceedings of the Third International Conference on Ontologies, DataBases and Applications of Semantics for Large Scale Information Systems (ODBASE'04)* (Meersman, R. and Tari, Z., eds), pp. 963–980, Springer-Verlag
- 10 Plaisant, C. (2004) The challenge of information visualization evaluation. *Proc. Adv. Vis. Interf.* 2004, 320–327

0169-5347/\$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.tree.2005.04.023

A new eusocial vertebrate?

Kevin R. Foster^{1,2} and Francis L.W. Ratnieks^{2,3}

¹Department of Ecology and Evolutionary Biology, Rice University, MS 170, 6100 Main St, Houston, TX 77005, USA

²Current address: Wissenschaftskolleg zu Berlin, Institute for Advanced Study, Wallotstrasse 19, 14193, Berlin, Germany

³Laboratory of Apiculture and Social Insects, Department of Animal and Plant Sciences, University of Sheffield, UK, S10 2TN

Insect eusociality is well known and is characterized by individuals (workers) that forgo direct reproduction to

rear siblings. In most eusocial species, workers and reproductives (i.e. queens) are morphologically distinct and, in some species, such as the fire ant *Solenopsis invicta*, the workers are permanently sterile. In vertebrates, young naked mole rats *Heterocephalus glaber* are

Corresponding author: Foster, K.R. (krfoster@rice.edu).

Available online 17 May 2005

the workers and, later in life, some of the workers become breeders. In females, this switch involves a morphological change with elongation of lumbar vertebrae to enable enhanced fertility. Recent data show that distinct reproductive and helping strategies also occur in a more familiar vertebrate species, but in the reverse temporal sequence to mole rats. In mid-adult life, half the breeders become physiologically incapable of reproducing and help their close relatives. Uniquely for a vertebrate, the helpers are permanently sterile. What species is this? It is our own.

Middle-aged women become sterile via the menopause. This regulated, rapid and irreversible physiological change is distinct from senescence, the gradual reduction in physical ability with age [1,2]. Two fitness-based hypotheses have been proposed to explain why women are not reproductive throughout adulthood [1–5]. The ‘mother effect’ hypothesizes that sterility increases direct reproduction by providing women with more time to rear younger offspring to independence [1,4]. Second, the ‘grandmother effect’ hypothesizes that sterility enables women to help their offspring reproduce more [2–4], thereby enhancing the grandmother’s inclusive fitness. Data from pastoral Taiwanese indicate that both might be important [4]. A recent study of two rural populations from 18–19th-century Finland and Canada provides convincing support for the grandmother effect [5]. In both countries, the presence of a grandmother was correlated with offspring who bred earlier, more frequently, and more successfully. Indeed, the grandmother effect alone appears sufficient to explain the menopause [5] although the two hypotheses are not mutually exclusive.

Helping by grandmothers has been compared with non-reproductive helpers in cooperatively breeding vertebrates, such as the Florida scrub jay *Aphelocoma coerulescens* [5]. We go further and ask, are humans eusocial? Eusociality is usually defined by three criteria: (i) reproductive division of labour; (ii) overlap of generations; and (iii) cooperative brood care [6]. It is epitomized by the eusocial Hymenoptera (ants, some bees and wasps), which is unsurprising, given that it is based on them. But humans also fit this definition. That grandmothers are sterile and enhance the reproduction of close relatives is telling because reproductive division of labour is considered to be the most important definitional criterion of eusociality, and has been the focus of attempts to define it more clearly. Sherman *et al.* broadened the definition by introducing a eusociality continuum based on variation among society members in direct reproduction [7]. Here, species with temporary helpers, such as cooperatively breeding birds, are eusocial. Crespi and Yanega narrowed the definition by requiring irreversibly distinct groups or castes with respect to sterility and/or other features [8]. Here, species that are traditionally considered to be eusocial, including some wasps and bees, and also the naked mole rat, are not eusocial.

The newer definitions centre upon the reproductive division of labour [7,8], which occurs in humans. Some aspects of human helping fit less well to the new

definitions, but this is largely because humans have intriguing idiosyncrasies, which have not previously been considered. One is that reproducing individuals become permanently sterile later in life, which would not fit Crespi and Yanega’s criterion of ‘becoming irreversibly distinct at some point prior to reproductive maturity’ [8]. But it is not clear that helping after reproducing should be disallowed. Similarly, both new definitions emphasize lifetime differences among individuals in reproductive success [7,8]. In humans, however, all women have the same lifetime reproductive strategy of breeding first and helping second. That is, the distinct classes of sterile helper and reproductive that occur in women occur within, rather than among, individuals.

A third idiosyncrasy is that human parents help offspring rear grandchildren, rather than offspring helping parents rear siblings. The former is less favourable from a relatedness perspective because relatedness to grand offspring is 0.25, whereas relatedness to full siblings is, on average, 0.5. This suggests that the benefits of grandmothers must greatly outweigh the decreased personal reproduction costs. What could cause such a large benefit:cost ratio? Older women have valuable experience that they can provide to many families headed by offspring. Interestingly, an age benefit of experience is also known in elephants, where older matriarchs are better at leading troops between food and water [9]. Grandmothers can also provide help at short-lived crucial points, such as at births. Such helping is facilitated by our ability to recognize sons and daughters, which enables a grandmother to help all grandchildren living nearby, even if they are not living together.

Human society has remarkable cultural sophistication. The grandmother effect shows that we still have much to learn about our biological nature and indicates that sterility in women occurs, at least in part, because of the beneficial effects on kin [5]. Human society, it seems, has reached a previously unrecognized level of sociality.

References

- 1 Williams, G.C. (1957) Pleiotropy, natural selection, and the evolution of senescence. *Evolution* 11, 398–411
- 2 Hamilton, W.D. (1966) The moulding of senescence by natural selection. *J. Theor. Biol.* 12, 12–45
- 3 Hawkes, K. *et al.* (1998) Grandmothering, menopause, and the evolution of human life histories. *Proc. Natl Acad. Sci. U. S. A.* 95, 1336–1339
- 4 Shanley, D.P. and Kirkwood, T.B.L. (2001) Evolution of the human menopause. *Bioessays* 23, 282–287
- 5 Lahdenperä, M. *et al.* (2004) Fitness benefits of prolonged post-reproductive lifespan in women. *Nature* 428, 178–181
- 6 Mitchener, C.D. (1969) Comparative social behavior of bees. *Annu. Rev. Entomol.* 14, 299–342
- 7 Sherman, P.W. *et al.* (1995) The eusociality continuum. *Behav. Ecol.* 6, 102–108
- 8 Crespi, B.J. and Yanega, D. (1995) The definition of eusociality. *Behav. Ecol.* 6, 109–115
- 9 McComb, K. *et al.* (2001) Matriarchs as repositories of social knowledge in African elephants. *Science* 292, 491–494