# Reproductive Science and Integrated Conservation

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# *Contents*

*List of contributors* [x]
*Foreword* [xiii]
RICHARD STONE

**Part I Introduction** [1]

1 Toward more effective reproductive science for conservation [2]
DAVID E. WILDT, SUSIE ELLIS, DONALD JANSSEN & JENNIFER BUFF

**Part II Reproduction and population viability** [21]

2 Behaviour and reproduction [24]
ALAN DIXSON, NANCY HARVEY, MARILYN PATTON & JOANNA SETCHELL

3 Nutrition and its interaction with reproductive processes [42]
TOM G. McEVOY & JOHN J. ROBINSON

4 Environmental chemicals and the threat to male fertility in mammals: evidence and perspective [57]
HELEN S. BAILLIE, ALLAN A. PACEY & HARRY D. M. MOORE

5 Assessing the consequences of inbreeding for population fitness: past challenges and future prospects [67]
ANDREA C. TAYLOR

6 Impacts of inbreeding on components of reproductive success [82]
KAREN KOENINGER RYAN, ROBERT C. LACY & SUSAN W. MARGULIS

7 The major histocompatibility complex (MHC) in declining populations: an example of adaptive variation [97]
PHILIP HEDRICK

8 When is the birth rate the key factor associated with population dynamics? [114]
TIM COULSON & ELODIE HUDSON

**Part III Reproductive techniques for conservation management** [129]

9 Reproductive and welfare monitoring for the management of *ex situ* populations [132]
AMANDA R. PICKARD

10 Non-invasive endocrine measures of reproduction and stress in wild populations [147]
STEVEN L. MONFORT

11 Ultrasound for analysis of reproductive function in wildlife species [166]
THOMAS B. HILDEBRANDT, JANINE L. BROWN, ROBERT HERMES & FRANK GÖRITZ

12 Role of embryo technologies in genetic management and conservation of wildlife [183]
NAIDA M. LOSKUTOFF

13 Application of nuclear transfer technology to wildlife species [195]
J. K. CRITSER, L. K. RILEY & R. S. PRATHER

**Part IV Integrated conservation management** [209]

14 Integrating reproductive sciences into recovery programmes for declining and extinct marsupial populations [211]
PETER D. TEMPLE-SMITH

15 Captive breeding and predator control: a successful strategy for conservation in Western Australia [232]
TERRY FLETCHER & KEITH MORRIS

16 Black-footed ferret: model for assisted reproductive technologies contributing to *in situ* conservation [249]
JoGAYLE HOWARD, PAUL E. MARINARI AND DAVID E. WILDT

17 Genetic resource banks for species conservation [267]
W. V. HOLT, TERESA ABAIGAR, P. F. WATSON & D. E. WILDT

18 Fertility control for wildlife [281]
JOHN C. RODGER

19 Contraceptive vaccine development [291]
KAREN E. MATE & LYN A. HINDS

20 Field applications of fertility control for wildlife management [305]
PHIL COWAN, ROGER PECH & PAUL CURTIS

**Part V Reproduction science in non-mammalian species** [319]

21 Reproductive technologies and challenges in avian conservation and management [321]
ANN M. DONOGHUE, JUAN MANUEL BLANCO, GEORGE F. GEE, YVONNE K. KIRBY & DAVID E. WILDT

22 Reptile reproduction and endocrinology [338]
VALENTINE A. LANCE

23 Reproductive research and the worldwide amphibian extinction crisis [359]
TERRI L. ROTH & AMY R. OBRINGER

24 Reproduction in fishes in relation to conservation [375]
GORDON McGREGOR REID & HEATHER HALL

**Part VI Conclusions** [395]

25 Postscript – sex, wildlife and vindication [396]
W. V. HOLT, A. R. PICKARD, J. C. RODGER & D. E. WILDT

*Index* [401]

1

# Toward more effective reproductive science for conservation

DAVID E. WILDT, SUSIE ELLIS, DONALD JANSSEN AND JENNIFER BUFF

## INTRODUCTION

Reproduction is the foundation on which a species survives, thrives or, failing this, becomes extinct. Therefore, the study of reproduction is fundamental to conserving species, populations and, indirectly, the vitality of entire ecosystems. Historically, reproductive biology research has been directed at easy-to-study domesticated livestock, laboratory animals and humans. The general approach has been one of scholarly, systematic studies that emphasised understanding mechanisms, sometimes seemingly arcane information that had (or did not have) practical application (e.g. making livestock more reproductively efficient or combating human infertility).

Reproductive biologists involved with wildlife also conduct scholarly research, often in a challenging environment. These explorers are hampered by limited resources and the practical difficulties of accessing rare, intractable and sometimes dangerous study specimens. Nonetheless, there has been progress in the study of the reproductive biology of wildlife, including endangered species. Perhaps the most important lesson learned during the past quarter-century has been that species vary remarkably – and wondrously – in precisely how they reproduce. The mechanisms that regulate reproductive success in the cow are quite different from those that control reproduction in the elephant, dolphin, snake, shark, parrot or frog. This reproductive machinery varies significantly even within families, species positioned in the same branches of the evolutionary tree (Wildt *et al.*, 1992, 1995). Therefore, for example, mechanisms controlling reproduction in the cheetah are likely to be different from those of a lion or snow leopard.

Understanding these species-specific strategies has become a top priority. The resulting discoveries provide intellectual capital that has practical value for monitoring, enhancing or controlling reproduction.

There is a perception problem about reproductive biology – the discipline is poorly understood by colleagues in the wildlife community. Reproduction is not even listed under 'topics of interest' in major journals devoted to biodiversity conservation (see, for example, publication guidelines for the journals *Conservation Biology* and *Animal Conservation*). One reason for such benign disregard is that reproductive scientists are often seen as enamoured with using 'high-tech' assisted breeding methods (artificial insemination, *in vitro* fertilisation, embryo transfer and even cloning). Conservation biologists traditionally have eschewed techno-fixes, fearing that reproductive technologies could divert funds from protecting habitat while giving a false sense of security that species on the brink of extinction could be easily resurrected (Wildt & Wemmer, 1999). We have presented alternative arguments in other venues showing how assisted breeding has contributed to species conservation, including *in situ* (Howard *et al.*, Chapter 16; Wildt *et al.*, 1997; Wildt & Wemmer, 1999).

The point remains – there is a need to change the way that reproductive biology is perceived so that the discipline provides more mainstream contributions to conserving threatened species. A commonsense first step is redefining 'reproductive biology' under the umbrella 'reproductive sciences'. This more inclusive and accurate descriptor embraces any and all skills required to address priorities for understanding, monitoring, enhancing or controlling reproduction. Historically, reproductive biologists have been sub-disciplinarians within animal behaviour, physiology and endocrinology. But ecologists, population biologists, geneticists, nutritionists, veterinarians and animal scientists have long studied reproductive patterns, performance and fitness. It is logical to develop a way of thinking that merges related disciplines to understand more clearly the factors that regulate reproductive success, a cornerstone of species management.

However, semantic change is a small step compared to the need to leap into larger and more coordinated research efforts for all threatened wildlife species. The general aim of this chapter is to discuss how the reproductive sciences can play a more valued role in conservation. We begin by introducing and advocating integrative research, cooperative multidisciplinary studies that can more efficiently address wildlife management problems. Our second objective is to provide evidence on the woeful amount of reproductive research accorded virtually all wildlife species on earth. The chapter concludes by exploring how the essence of the discipline, sex, is a provocative subject that gives rise to public curiosity. This inherent interest is not being exploited, and we cite our experience in using reproductive science stories to inspire and educate children, the next generation of conservationists.

## REPRODUCTIVE SCIENCES IN AN INTEGRATIVE APPROACH

### Uni-disciplinary to multidisciplinary

Scientists are highly trained specialists, many being experts in a defined sub-field (e.g. dominance behaviour, sperm function, ovarian–endocrine relationships) who focus on a single species (Figure 1.1*a*). This approach is the hallmark of academic research, inevitably resulting in fundamental knowledge. However, this 'uni-disciplinary' strategy applied to wildlife can have minimal practical impact on conservation. This is because conservation can be likened to a complex jigsaw puzzle where the puzzle pieces are issues, stakeholders or scientific disciplines themselves (Figure 1.2). It is unlikely that any single discipline (e.g. reproductive physiology, genetics, nutrition) could be the sole key to solving a particular conservation puzzle. However, assembling additional pieces (more disciplines to generate more knowledge) substantially increases the chances of solving the puzzle. Thus, a more 'conservation-effective' model can be represented by the scientist with specific tools and skills focused on a given species, but now in parallel and partnership with others (Figure 1.1*b*). These partners represent diverse stakeholders in the life sciences, as well as sociologists, economists, demographers and wildlife/habitat managers themselves. Multidisciplinary partnerships will be key to more efficient problem solving in conservation.

### An integrative case study, the giant panda

The giant panda, a carnivore that eats bamboo, has been the object of fascination for centuries. An early descendant from the line leading to more modern ursids, the giant panda once thrived in nature. However, due to habitat erosion, there are now fewer than 1200 wild giant pandas restricted to the mountainous bamboo forests of the Sichuan, Gansu and Shaanxi provinces of China. The wild population also is compromised by its scattered demography among 32 fragmented reserves with no corridors to allow genetic exchange. The national protection programme is under-funded, and there are enormous needs for community development, education, reserve

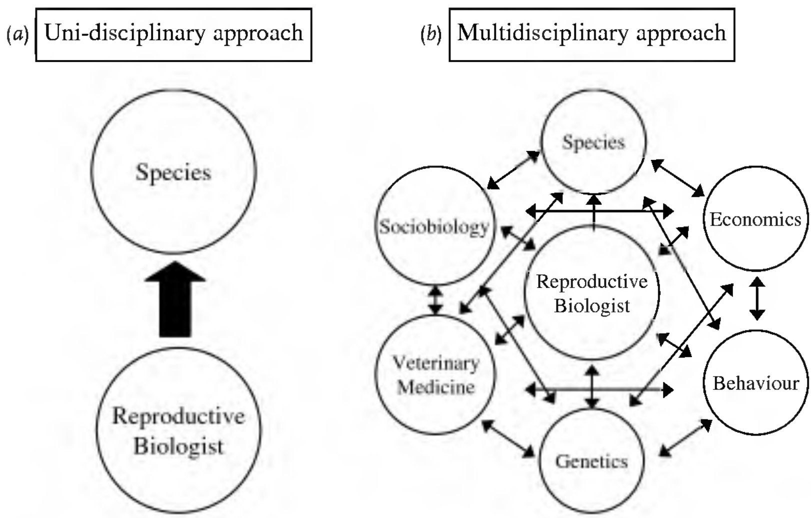


Figure 1.1 The 'uni-disciplinary' (*a*) versus the 'multidisciplinary' (*b*) model of conducting wildlife research for conservation.

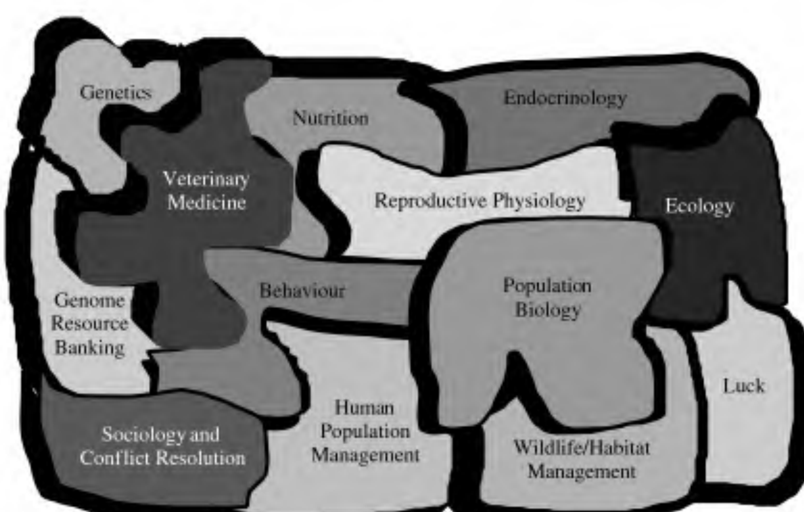


Figure 1.2 Conservation as a jigsaw puzzle where there are many 'pieces' including scientific disciplines, management, social processes and luck.

infrastructure (roads and buildings) and skilled staff to monitor habitat and prevent poaching.

The unstable status of wild giant pandas has provoked special interest in the *ex situ* management programme within China. Giant pandas in captivity provide some assurance that there is a hedge against potential extinction. This population also is a valuable source of new biological information from research and for educating the public about the precarious status of wild counterparts.

There are two independent *ex situ* panda populations within China, one under the authority of the State Forestry Administration (SFA, also responsible for pandas living in nature) and the other managed by the Chinese Association of Zoological Gardens (CAZG, under the Chinese Ministry of Construction or MoC). Because SFA and MoC have been placed in the position of competing for funding from the central government, communication and cooperation have been minimal. Nonetheless, both agencies have had serious concerns about the viability of the *ex situ* giant panda population. Substantial governmental funding has been allocated to zoos and breeding centres to develop a self-sustaining population that would eliminate the need ever to remove more pandas from nature. However, until recently, successful reproduction in giant pandas *ex situ* has been inconsistent.

In 1996, the CAZG requested advice from the Conservation Breeding Specialist Group (CBSG), a non-governmental organisation operating under the IUCN–World Conservation Union's Species Survival Commission. CBSG is renowned for its ability to assist in developing recovery plans for endangered species: as a neutral facilitator, it catalyses change, builds communication and encourages partnerships. Its effectiveness is amplified by a network of more than 800 members world-wide who volunteer expertise to assist in projects. As the result of the CAZG invitation, CBSG facilitated an *Ex Situ* Management Planning Workshop for Giant Pandas in Chengdu in 1996 attended by more than 50 Chinese specialists. CBSG's advisory team comprised five Western scientists. Working together, participants created a plan for managing the *ex situ* population (Zheng *et al.*, 1997). Action-based recommendations emerged during the week that would begin to address the observations of poor reproduction and health problems in all age classes. The most significant recommendation was for a Biomedical Survey of the extant population. The reasoning was simple: developing a self-sustaining population would require maximising the use of the healthy, reproductively fit individuals, which then could be intensively managed to retain existing genetic diversity. This could only be achieved if the health and reproductive status of the existing population was first known.

### Biomedical Survey of giant pandas

CBSG was invited to organise and implement the Survey. This facilitated stakeholder buy-in and cooperation because, under the authority of the IUCN–World Conservation Union, CBSG was seen as neutral with no agenda other than to ensure excellent science. The Survey was conducted during the pre-breeding/breeding season (February/March) in 1998, 1999 and 2000 (Zhang *et al.*, 2000). Over this interval, the CBSG–USA team consisted of 20 specialists from seven institutions who represented the disciplines of veterinary medicine, reproductive physiology, endocrinology, animal behaviour, genetics, nutrition and pathology. This group was complemented by more than 50 Chinese counterpart specialists from MoC and SFA organisations. There was strong political support from the Chinese government, and the USA zoo community provided funding with equipment donations from corporations.

The overall objective was to thoroughly examine as many pandas as possible in order to identify the factors that limited reproductive success. Remediation then would allow the population to become self-sustaining. Teams worked together to collect and interpret data. Sixty-one animals were anaesthetised and subjected to an intensive medical examination that included multiple procedures for massive data collection (Table 1.1). Each animal was categorised according to the teams' consensus on its value to the future of the *ex situ* population. Seventy-eight per cent of the population appeared healthy and reproductively sound whereas 22% were compromised, some severely (Figure 1.3).

### Limits to giant panda reproduction

Six factors were identified as limiting reproductive success: (1) behavioural incompatibility between males and females introduced for mating (primarily expressed by excessive male aggression); (2) many individuals with unknown paternity (following the common practice of natural mating with a single breeder male combined with simultaneous artificial insemination with sperm from a non-breeding, under-represented male); (3) genetic overrepresentation by certain individuals (reflected by a few individuals always producing offspring, causing disproportionately high distribution of 'common' genes); (4) suboptimal nutrition (a consequence of the feeding of a high protein, palatable concentrate that reduced bamboo and, thus, fibre intake; (5) stunted growth syndrome (whereby 9.8% of individuals were abnormally small in stature and experienced multiple medical complications), and (6) testicular hypoplasia or atrophy (as indicated by a unilateral small

Table 1.1 *Technical procedures applied to giant pandas ($n = 61$) in the Biomedical Survey.*

| |
|---|
| Histories (breeding/behaviour/pedigree) |
| Anaesthesia/monitoring |
| Physical examination (including ultrasound) |
| Body morphometrics |
| Blood sampling/analysis |
| Tissue sampling |
| Transponder/tattoo |
| Urine analysis |
| Parasite check |
| Diet evaluation |
| Semen evaluation |
| Laparoscopy |

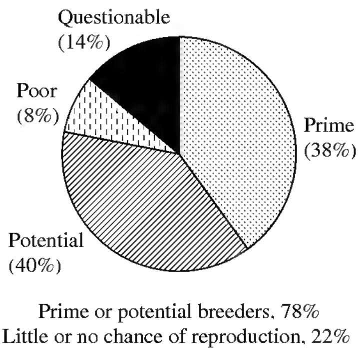


Figure 1.3 Giant pandas ($n = 61$) were objectively categorised as prime breeders, potential breeders (healthy, but prepubertal), questionable breeding prospects and poor breeding prospects.

testis). Isolated medical conditions were also identified, ranging from simple vaginal/cervical infections to untreatable squamous cell carcinoma.

Our multidisciplinary approach was key to revealing that no one variable was impeding reproductive fitness in giant pandas. Rather, failures appeared to be the culmination of multiple, linked factors (e.g. poor nutrition leading to compromised health that directly, or indirectly, decreased reproduction or offspring survivorship). Without the disciplinary collaboration, some causes and interactions would have gone undiscovered. In some cases, remediation was simple. Reproductive tract infections were treated with antibiotics that allowed some previously non-reproductive females to produce offspring. Others, such as modifying diet and sorting out paternities, were more complex and detailed systematic studies are in progress. Regardless, the point is that the Survey has provided the blueprint for continued action.

Another dividend of the project was the opportunity to conduct more basic research. For example, a by-product of male fertility evaluations was 'surplus' semen available for investigating the sensitivity of panda sperm to cooling and cryopreservation. New semen handling protocols emerged that have been useful for improving artificial insemination. One practical benefit was the production of a surviving cub from a wild-born, under-represented male with a lethal squamous cell carcinoma. Up to this time, such an individual would have died, its genes unrepresented in future generations. Artificial insemination will continue to be important for genetic management, including circumventing sexual incompatibility problems as well as moving genetic material among breeding centres and from *in situ* to *ex situ*.

### Other project benefits

Close partnerships that developed in the intensive working milieu (over anaesthetised animals) inspired trust between Chinese and American scientists. Chinese colleagues became comfortable with proposing the need for training courses. A veterinary workshop was held in Chengdu in 1999 that involved the training of 49 veterinarians from 27 Chinese institutions in veterinary diagnostics, anaesthesia, pathology and nutrition. Trainers included Western and Chinese specialists who had participated in the Biomedical Survey. Similar requests for capacity building have emanated from a CBSG facilitated workshop in 1999 on Conservation Assessment and Research Techniques conducted at the invitation of SFA (Yan *et al.*, 2000). The focus here was on the status of giant pandas in nature and research methods that could enhance the accurate monitoring of wild pandas while eventually linking *ex situ* and *in situ* populations. Again training emerged as a priority, especially in (1) remote sensing and geographical information systems (to assess habitat quality), (2) radiotelemetry (to track panda movements in nature) and (3) non-invasive DNA assessment (to identify individuals via molecular assessments of DNA extracted from faecal samples).

This project that began with a simple request from Chinese colleagues for information exchange has resulted in a remarkable cascade of (1) new biological data, (2) enhanced management practices and (3) capacity building. The project also illustrates the value of integrative, multidisciplinary research. Whether this is an 'ideal' model, to be touted for the future, is debatable. The charismatic giant panda is of inordinate interest so its high profile eased the way for the required approvals and funding. It may be more difficult to stimulate enthusiasm and to secure grants for less exciting species that may be as rare or even more ecologically important than the giant panda. Finally, there was widespread interest in participation by many USA specialists, thereby allowing the best scientists as well as those most likely to be team players to be selected. Not all multidisciplinary projects would have the luxury of unlimited numbers of eager scientists.

However, there were other project traits that should be considered in formulating similar studies in the future. Clearly, organising multiple institutions under a neutral entity like CBSG avoided the perception that any one organisation was empire building. Shunning a missionary mentality ('we are here to help') and focusing on developing personal relationships and knowledge-sharing inspired trust which was essential to working across diverse cultures. Resulting confidence and friendships facilitated later invitations to coordinate the training workshops. Enthusiasm for capacity building was enhanced by having the most skilled Chinese counterparts serving as co-trainers. Finally, it was critical that every priority emanated from the range country scientists and managers. The most significant contribution of the Western partners was sharing expertise and transferring tools to these local people who, ultimately, are responsible for preserving the biodiversity of their country.

## THE NEED TO STUDY MORE SPECIES

Although the giant panda is a useful model for 'how to advance knowledge' in an integrative fashion, an equally important question is, 'how many species need this kind of attention?'

### Most attention on too few species

Wildlife species harbour a wealth of new information on the mysteries of self-perpetuation and survival itself. There are more than 40 000 vertebrate species on Earth (Mittermeier *et al.*, 1997). Data in Figure 1.4*a* represent a highly conservative estimate of the actual number of extant species. How many of these 40 000 species have been studied?

From a reproductive biology perspective, most research to date has focused on common species. For mammals, there is a core group of 14 species, including the human, domestic livestock (cattle, horse, sheep, pig, goat) and various laboratory animals (dog, cat, rabbit, hamster, gerbil, guinea pig, rat, mouse), that have received virtually all of the attention. Billions of research dollars and thousands of scholarly papers have been devoted to this special group that represents only 0.3% of all known mammalian species (Figure 1.4*b*). How much comparable effort has been directed toward wildlife?

To objectively address this question, we examined the literature, specifically 10 well-known scientific journals. Half of these (*Journal of Reproduction and Fertility*; *Biology of Reproduction*; *Reproduction, Fertility and Development*; *Molecular Reproduction and Development* and *Theriogenology*) are exclusively

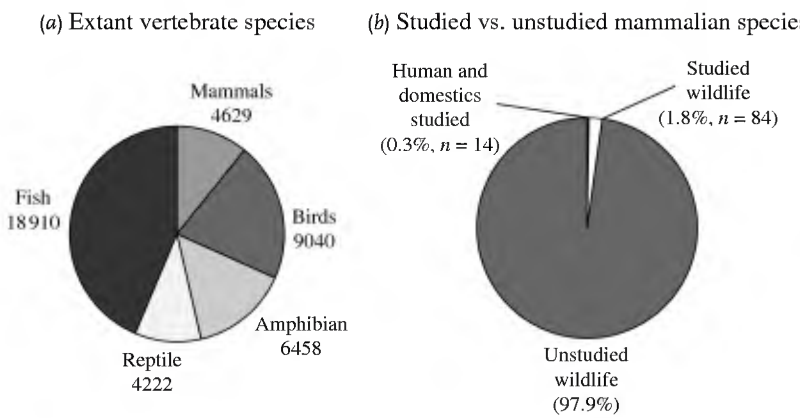


Figure 1.4 (*a*) Estimated numbers of species of mammals, birds, amphibians, reptiles and fish (adopted from Mittermeier *et al.*, 1997). (*b*) Among wild mammals, only 84 species (1.8%) have been well studied in terms of reproduction (on the basis of three or more citations in the described journals over the last decade; see text for more detail).

devoted to reproduction, and could be considered leading journals for the discipline. The others (*Journal of Mammalogy*; *Zoo Biology*; *Journal of Zoology (London)*; *Journal of Experimental Zoology* and *General and Comparative Endocrinology*) also are prestigious and, often devote papers to non-reproduction topics, but also assign space to reproductive biology issues. Every citation in each table of contents of each issue of each journal was examined (from January 1990 to May 2000) for the name of a species (mammal, bird, reptile, amphibian or fish), which then was recorded in a database. When the title failed to reflect the species studied, that paper was excluded. Species were categorised as domestic or wild, and all non-human primates (even those studied as 'laboratory animals') were considered wild.

### Contributions of leading journals to wildlife

Far fewer than 17% of all papers in the five leading reproductive biology journals were devoted to wildlife species (Table 1.2). Journals published in the USA (*Biology of Reproduction*; *Molecular Reproduction and Development* and *Theriogenology*) were especially negligent. For example, if laboratory non-human primates were excluded, fewer than 6% of *Biology of Reproduction*'s papers addressed other than common species (Table 1.2). When data were averaged across the publications, then we concluded that more than 90% of all space in these leading reproduction journals was allocated to already well studied species.

Table 1.2 *Proportion of published papers devoted to wildlife (mammal, bird, reptile, amphibian, fish) by leading reproductive biology journals (January 1990–May 2000)*

| | Number of wildlife papers/total number of papers | Number of wildlife papers (excluding non-human primates)/ total number of papers |
|---|---|---|
| *Journal of Reproduction and Fertility* | 292/1754 (16.6%) | 261/1723 (15.1%) |
| *Reproduction, Fertility and Development* | 81/615 (13.2%) | 78/615 (12.7%) |
| *Biology of Reproduction* | 291/3088 (9.4%) | 176/2973 (5.9%) |
| *Molecular Reproduction and Development* | 60/946 (6.3%) | 41/927 (4.4%) |
| *Theriogenology* | 68/1995 (3.4%) | 64/1991 (3.2%) |

Wildlife is being ignored, which may reflect extreme naïveté on the part of most reproductive biologists, a lack of interest or, perhaps, simply too few resources for such studies.

### Numbers of species studied

The database was analysed for the number of species studied during the more than 10 years of publications in the 10 journals. By far, most of the publications were mammal-based in which 256 individual species were identified. When mammal species number was plotted against the number of publications per species, 51.9% (133 species) was represented by only a single publication (Figure 1.5). More than 75% of the 256 species ($n = 192$) was represented by three or fewer publications. Further, of the wild species studied rather extensively (10 or more citations), most were relatively common, ranging from macaques to marsupial mice (Table 1.3). Only three species (Asian elephant, African elephant, cheetah) were found on the IUCN Red List of Threatened Species (IUCN, 2000).

Finally, we arbitrarily defined a 'well studied' species as one with three or more citations in the database. Using this generous criterion, only 84 mammalian species (1.8% of all known mammals) were 'well studied' in reproductive biology. When this number was added to commonly studied species (i.e. human, livestock and laboratory animals, $n = 14$), it was concluded that 97.9% of all mammalian species have gone unstudied (Figure 1.4*b*).

Table 1.3 *The most common wildlife species studied in the reproductive sciences (number of citations in parentheses)*

| | |
|---|---|
| Macaque, rhesus (87) | Macaque, cynomologus (12) |
| Wallaby, tammar (47) | Shrew, musk (12) |
| Deer, red (36) | Elephant, Asian (12)[a] |
| Baboon (33) | Hyaena, spotted (12) |
| Possum, brushtail (24) | Elephant, African (11)[a] |
| Possum (19) | Deer, fallow (11) |
| Mink (16) | Cheetah (10)[b] |
| Dunnart (14) | Marsupial mouse (10) |
| Macaque, bonnet (13) | |

[a] Endangered or [b] Vulnerable, according to the IUCN Red List.

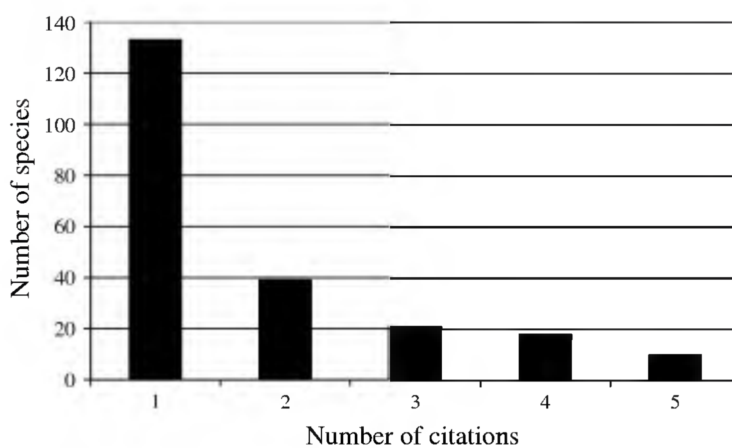


Figure 1.5 Of the 256 species identified in a literature survey of wildlife reproductive biology studies (see text for details), 133 species were represented by only a single citation with 192 species (75%) represented by three or fewer references.

Because of even less effort for other vertebrate groups, the proportions of unstudied birds, reptiles, amphibians and fish certainly would exceed 99%. Clearly, we have scarcely begun to investigate the most fundamental reproductive science in virtually all vertebrate species on Earth.

## CAPACITY BUILDING FOR THE NEXT GENERATION

Conducting integrative research on more species will require more resources of all kinds.

## Public interest in reproduction

It is rare to encounter anyone who is not interested in the sexual anatomy, proclivities or challenges of controlling reproduction in wild animal species. People have an inherent interest in procreation and sex. Therefore, the reproductive sciences have a distinctive edge over other scientific disciplines in attracting attention. Yet reproductive scientists have done little to take advantage of this natural curiosity for raising funds or for education. We have begun to address the power of reproductive science for inspiring and educating children, the next generation of conservationists.

## Scientists as role models

Scientists are bound to the creed of using the scientific method to increase general knowledge. But there also is a responsibility to advocate the value of what we do and to train and arouse interest in our profession. This is critical in the conservation community where there are too few resources, including scientists with abilities to generate and interpret data and apply knowledge to species and habitat preservation. But building science capacity includes more than mentoring graduate students and postdoctoral fellows or conducting training workshops in developing countries. There is a need to motivate children at a young age to consider careers in science.

In the early 1990s, we initiated an experiment in Washington DC schools, 'Scientists-in-the-Classroom'. The concept was simple – we speculated that contemporary stories about 'real' research presented by scientists in classrooms could inspire children. One project emphasised our studies of the genetically depauperate cheetah and its susceptibility to poor reproduction and disease epidemics (O'Brien *et al.*, 1985). The target was African American and Hispanic children 8–10 years of age being taught in inner city environments. To document children's perceptions before a researcher's visit to the classroom, teachers provided students with coloured pens and requested a drawing of a typical scientist. Figure 1.6 is emblematic of a child's view from virtually all of the schools tested. Scientists were classically represented as males (Caucasian, aged, bald and wearing glasses and white laboratory coats). These stereotypical traits certainly were uncharacteristic of how these children would ever perceive themselves as adults.

Children then met and talked with scientists, most of whom had travelled to exciting places abroad where they had studied amazing creatures. When asked again to draw a picture of a scientist, the drawings changed remarkably. Depictions became colourful with smiling faces, and the children

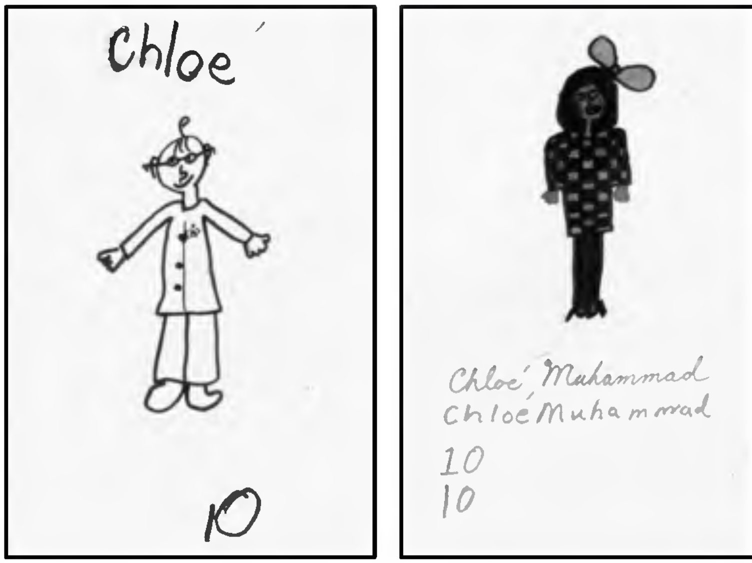


Figure 1.6 A 10-year-old African American's view of a scientist before (left) and after (right) meeting one.

most often drew themselves (including minorities and females) as a scientist (Figure 1.6). The message was clear – our research can have sway as functional stories that can change children's attitudes about the value of, and their own potential role in, science.

### Beyond Science-in-the-Classroom

The Washington DC experiment suggested that scientists should consider doing more than classical research studies and training. To ensure (1) a sound future for the profession and (2) that there is a subsequent generation passionate about science as a career, contemporary scientists have an obligation to assist in promoting science to children. The timing is appropriate. School systems internationally are undergoing radical reforms (Hungerford, 1998). Parents and community leaders are requiring schools to document students' learning capabilities through the development of 'standards' and by testing for skills and knowledge. Many educators are seeking innovative, hands-on ways to motivate students while still meeting these new standards. In turn, scientists have unique abilities to bring staid textbook lessons to life. Required science (as well mathematics and social studies) principles can benefit from exciting research stories that involve real-world situations.

The Washington DC experiment encouraged us to develop new outreach programmes at the National Zoological Park's Conservation & Research Center (CRC) in northern Virginia. The plan was not simply to visit classrooms to give slide presentations, but to develop programmes compatible with community needs that met Virginia's Standards of Learning. A workshop that included scientists, local teachers and administrators formulated a mission and a strategy. The CRC Education Office served as the link to integrate the scientists and teachers.

One in-school programme, the 'Scoop-on-Poop', emanated from CRC's endocrinology laboratory that measures hormones non-invasively (urine/faeces) from wildlife species. Virginia students 12 years of age are required to learn data plotting and interpretation (standards for mathematics) as well as life systems (e.g. digestion, respiration, blood circulation, reproduction) (standards for science). The 'Scoop-on-Poop' programme evolved to provide real-life examples of raw data collected by scientists. Children plot the data and (working with lesson plans developed by teachers, CRC educators and scientists) interpret the information to make management decisions. One example is the housing together of a dominant cheetah with a subordinate female. The former is hormonally cyclic, and the latter is not. Students create graphs to realise eventually that dominance can suppress reproduction, and triggering reproduction in the subordinate will require the two cheetahs to be separated. Reproductive research with the endangered black-footed ferret (Howard *et al.*, Chapter 16) is another outreach example. Here the educators address the implications of population bottlenecks on genetic and reproductive fitness. An 'ambassador' black-footed ferret is brought to the classroom to illustrate a species that once was believed to be extinct. These popular programmes combine the need of educators to be creative in the teaching of static subjects while using reproductive science and wild animals to capture a child's attention.

Scientists also benefit by the 'feel-good' experience of sharing with the community and, most importantly, making science less mysterious. Using authentic data helps to eradicate the myth that most science is so arcane and complex that it is incomprehensible to the general public. Teachers and students are fully capable of understanding research strategies and data if presented in an appropriate fashion, and with passion. Objective evaluations have consistently revealed that these programmes change the way children perceive the value of science.

### Multiplier effect through teacher training

The prominence of CRC's outreach efforts and the demand for assistance soon surpassed our educators' ability to provide service – some programmes are scheduled up to a year in advance. This pragmatic challenge then becomes linked to another observation, that is that educators are trained to 'teach' science, but not 'do' science. Teachers, as well as local, district and state administrators, have consistently indicated that a top priority is for teacher training. Interestingly, teachers articulate a personal need to spend time in laboratories and in the field to learn data collection, interpretation and species/habitat management. Teachers have a strong desire to learn, to adapt what scientists do for their own classrooms and to be inspired themselves to develop new creative approaches for educating their students.

We have realised that a more efficient plan is to allocate scarce CRC resources to more teachers and to fewer students. The outcome eventually will be a 'multiplier effect', training teachers to use our research methods that, in turn, will be taught to many more students than could be accommodated by CRC staff. We also recognise that this teacher interest is analogous to what many scientists routinely experience from advanced undergraduate students, people with an intense desire to learn, to be rejuvenated and perhaps to find new ways to impact the lives of others. Many teachers are expressing interest in internships in the laboratory.

Teacher training curricula have been developed at CRC and workshops conducted that are similar in form and function to training opportunities offered to conservation professionals from around the world. The success of these budding programmes is based on our scientists who teach the courses while our Education Office organises and facilitates the initiatives. The scientists are not trained educators. But learning theory, pedagogy and methodology are not the focus. Rather, the teachers prefer to learn about scientific content, including real-life examples, actions and conservation science protocols. Thus, scientists provide hands-on training of data collection, interpretation and use. Together the scientists, the teachers and the Education Office develop lesson plans that make the final link to the students. The importance and credibility of this programme is reflected in the Department of Education's recommendation that these resources be made available throughout the State of Virginia.

It is noteworthy that most scientists, especially biologists, were inspired to pursue science by some profound event during childhood – a discovery while walking in the woods, a National Geographic article, a motivated teacher or a one-on-one contact with an animal at the zoo. It is our obligation as scientists to consider how we can help create that magical, life-changing 'event' for a child who may not only understand the importance of science but who may even choose it as a career. The intrinsic allure of reproductive sciences in conservation biology is a potent tool for making this goal a reality.

## CONCLUSION

The ability to reproduce is quintessential to species survival, thus making the reproductive sciences vital to conserving species and, indirectly, the survival of ecosystems. But the public, academia and even the wildlife community itself poorly understand the definition or the purpose of this general field. Historically comprised of behaviourists, reproductive physiologists and endocrinologists, the reproductive sciences now should include any area of study that contributes to the maintenance or re-creation of a reproductively fit population (e.g. genetics, population biology, veterinary medicine, nutrition, animal husbandry). It also is clear that the high-tech components of the reproductive sciences are not a 'quick-fix' for enhanced reproduction (in the case of endangered species) or fertility control (in the case of over-abundant populations). Rather, the primary role of the reproductive sciences is to characterise the remarkable differences in mechanisms regulating reproductive success among species (even within the same family) through rigorous and scholarly study. Data then are useful for management decision-making and more effective control of reproduction though natural and 'assisted' means. We also have illustrated the power of integrating reproductive findings with those from other disciplines (especially in the life sciences) to tackle problems more holistically. More such studies are required, including for the thousands of species (especially non-mammals) that have received virtually no research attention. Finally, we have shown that the reproductive sciences can attract the attention of non-scientists. Although appealing to the general public and decision-makers, perhaps the greatest potential is using these scientific studies to expand a legacy beyond simply more scientific publications. In particular, stories emanating from the sciences can be inspiring and useful for training teachers and developing school curricula to educate children, the next generation of conservationists.

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