



TECHNICAL REPORT

ANIMAL BEHAVIOUR MODULE

ZOO SCIENCE COURSE

Zoo Science Course

Animal Behaviour Module



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**BANNERUGHATTA
BIOLOGICAL PARK**
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Technical report: Zoo Science Course (Animal Behaviour Module)



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Foreword

The role of modern zoos continues to evolve. Beyond their traditional functions, zoos are increasingly recognized as centres for animal welfare, conservation, education, and scientific research. A sound understanding of animal behaviour is fundamental to achieving these objectives, as it provides the basis for evidence-based husbandry, welfare assessment, enclosure design, environmental enrichment, and conservation management.

It was with this understanding that the Animal Behaviour Module of the Zoo Science Course was conceived. Building upon the foundation established through the successful Population Management Module conducted earlier in the year, this initiative represents another important step towards strengthening the scientific and technical capacity of zoo professionals across India.

Held from December 1-5, 2025 at Bannerughatta Biological Park, Bengaluru, the course brought together zoo personnel from diverse institutions and backgrounds. Through lectures, practical exercises, discussions, and field-based learning, participants explored key concepts in animal behaviour, behavioural observation techniques, welfare assessment, enrichment, positive reinforcement training, and the application of behavioural science in zoo management. The enthusiasm and engagement demonstrated throughout the programme reaffirmed the growing recognition of behavioural science as an essential component of modern zoo management.

This report documents the objectives, structure, and outcomes of the module while reflecting the commitment of zoo professionals to advancing animal welfare and evidence-based management practices. It is my sincere belief that initiatives such as the Zoo Science Course will contribute significantly to building a skilled and collaborative zoo community capable of addressing the challenges and opportunities of contemporary zoo management.

On behalf of Bannerughatta Biological Park, I take this opportunity to thank the Zoo Authority of Karnataka, the Karnataka Forest Department, the course faculty, and all participants for their valuable contributions to the success of this programme. I look forward to continued collaboration in strengthening professional capacity and advancing the role of zoos in conservation, animal welfare, and scientific management.



(Shri A V Surya Sen, IFS)

Executive Director,
Bannerughatta Biological Park.

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Executive summary

The Animal Behaviour Module was conducted from 1–5 December 2025 at Bannerughatta Biological Park, Bengaluru, as the second module of the Zoo Science Course, a structured professional development initiative developed to strengthen scientific and technical capacity among zoo professionals in India. Building upon the Population Management Module conducted earlier in 2025, the programme aimed to equip participants with the knowledge and practical skills required to incorporate behavioural science into evidence-based zoo management.

The five-day module combined lectures, field observations, practical exercises, group discussions, and computer-based analytical sessions to provide participants with a comprehensive introduction to behavioural science and its application in zoological collections. The curriculum covered the foundations of animal behaviour, behavioural ecology, ethogram development, behavioural sampling methods, study design, animal learning and husbandry training, abnormal behaviours, welfare assessment, social behaviour, behavioural management of reptiles, and the use of behaviour to inform captive management. Practical sessions introduced participants to behavioural observations in the field, behavioural data management and analysis using the R programming language, digital behavioural monitoring tools, observer reliability, and statistical considerations in behavioural research.

The programme emphasised that behaviour provides one of the most objective and sensitive indicators of animal welfare, health, and management effectiveness. Participants were encouraged to adopt systematic behavioural monitoring as a routine component of zoo management and to use behavioural evidence to evaluate husbandry practices, enrichment programmes, enclosure design, social management, conservation breeding, and veterinary interventions. Throughout the module, strong emphasis was placed on scientific study design, reproducible analytical workflows, and evidence-based decision-making.

Pre-course assessments indicated that while participants recognised the importance of animal behaviour in zoo management, most had limited experience with structured behavioural sampling, ethogram development, behavioural data analysis, and digital recording tools. Post-course evaluations demonstrated high levels of participant satisfaction, increased confidence across all major learning domains, and a strong intention to apply the knowledge and skills acquired during the programme within their respective institutions.

Overall, the Animal Behaviour Module successfully strengthened participants' capacity to observe, measure, analyse, and interpret animal behaviour within a scientific framework. By integrating behavioural ecology, welfare science, animal learning, and quantitative analysis, the programme provided participants with practical tools that

can be readily applied to everyday zoo management. The module also established behavioural science as a central theme underpinning the remaining components of the Zoo Science Course, providing an important foundation for subsequent modules on Zoo Animal Nutrition, Enclosure Design and Welfare, and Zoo Master Planning, thereby promoting a coherent and integrated approach to modern, evidence-based zoo management.

1 Introduction

Modern zoos are increasingly recognized not only as spaces for public engagement, but as institutions of conservation, research, education, and animal welfare. As the role of zoos continues to evolve, there is growing recognition that understanding animal behaviour is fundamental to evidence-based husbandry, welfare assessment, conservation breeding, enclosure design, and veterinary care. Behavioural science has therefore become an integral component of modern zoo management, providing the knowledge and tools needed to improve both animal welfare and conservation outcomes.

1.1 Zoo Science Course

The *Zoo Science Course* was conceived as India's first structured professional development programme tailored to the needs of zoo personnel. Developed with the support of the Zoo Authority of Karnataka and hosted by Bannerughatta Biological Park, the course is designed as a modular, recurring framework to build technical and strategic capacity in zoo management. Its long-term vision is to address key thematic areas — including population management, animal behaviour and welfare, zoo nutrition, enclosure design, and master planning—through a blend of lectures, practical exercises, field demonstrations, and peer learning.

Following the successful implementation of the inaugural *Population Management Module* in June 2025, the *Animal Behaviour Module* was developed as the second component of the Zoo Science Course. The module sought to strengthen the capacity of zoo professionals to observe, interpret, and apply behavioural principles in the management of captive wildlife, thereby promoting evidence-based decision-making and improved standards of animal welfare.

This report documents the implementation of the Animal Behaviour Module held from 1–5 December 2025 at Bannerughatta Biological Park, Bengaluru, and outlines its rationale, structure, content, and outcomes.

1.2 Background and rationale

India is home to nearly 150 recognized zoos, managing a remarkable diversity of native and non-native species under a wide range of environmental and management conditions. As zoos increasingly embrace their roles in conservation, education, research, and animal welfare, there is growing recognition that animal behaviour is central to achieving these objectives. Behaviour provides one of the most direct and sensitive measures of how animals interact with their environment and respond to husbandry practices, making it indispensable for evidence-based zoo management.

Despite this importance, behavioural monitoring and assessment remain underutilized in many Indian zoos. Routine observations are often informal and lack standardized recording methods, limiting their value for management and research. Consequently, opportunities to evaluate animal welfare, identify behavioural abnormalities, assess enclosure effectiveness, measure enrichment outcomes, or support husbandry training are frequently missed. Developing the capacity of zoo personnel to systematically observe, record, analyse, and interpret behaviour is therefore essential for improving both animal welfare and management decisions.

The *Animal Behaviour Module* was developed to address this need by strengthening technical skills among zoo biologists, veterinarians, curators, educators, and other personnel involved in animal management. The curriculum introduced participants to the principles of animal behaviour, behavioural observation techniques, ethogram development, behavioural research methods, animal learning, husbandry training, welfare assessment, and the practical application of behavioural science in zoo management. By equipping participants with these competencies, the module promotes evidence-based husbandry, improved animal welfare, and informed decision-making across Indian zoos.

1.3 Animal behaviour in zoos

Animal behaviour forms the foundation of modern zoo management. The expression of species-typical behaviours provides valuable insights into an animal's health, welfare, social relationships, and adaptation to captive environments. Systematic behavioural observations enable zoo professionals to evaluate husbandry practices, measure the effectiveness of environmental enrichment, monitor behavioural development, detect early signs of stress or disease, and assess the outcomes of management interventions.

Modern zoo behavioural science extends beyond descriptive observations to include standardized data collection, experimental design, statistical analysis, and evidence-based application. Behavioural information is routinely used to guide enclosure design, optimize feeding strategies, support positive reinforcement training, improve reproductive success, manage social groups, and evaluate welfare. As behavioural data become increasingly integrated into daily husbandry, they provide an objective basis for adaptive management and continuous improvement.

To support these applications, the course emphasized:

- i. Systematic behavioural observations using standardized recording methods.
- ii. Development of ethograms and behavioural sampling protocols.
- iii. Behavioural research design and data analysis.
- iv. Application of behavioural science to welfare assessment, husbandry training, enrichment, and management.

Strengthening behavioural science capacity within Indian zoos enables institutions to make informed management decisions while improving animal welfare, supporting conservation breeding programmes, and promoting a culture of evidence-based zoo management.



Sh. A V Surya Sen, IFS, Executive Director, Bannerughatta Biological Park, addressing the participants during the inaugural session of the Animal Behaviour Module (Zoo Science Course), December 1, 2025.

1.4 Course overview

The Animal Behaviour Module was conducted from 1–5 December 2025 at Bannerughatta Biological Park, Bengaluru. The programme targeted zoo biologists and other technical personnel responsible for animal management, behavioural monitoring, welfare assessment, conservation breeding, research, and education.

The five-day course combined classroom instruction with extensive field-based practical sessions, allowing participants to immediately apply behavioural observation techniques in a zoo setting. The curriculum covered the complete behavioural study process—from formulating research questions and developing ethograms to data collection, analysis, interpretation, and application in husbandry and welfare management. Participants were also introduced to concepts of animal learning, husbandry training, behavioural indicators of welfare, abnormal behaviours in captivity, and the integration of behavioural science into routine zoo management.

The programme emphasized active participation through behavioural observations, case studies, group discussions, and practical data analysis using R. By combining theo-

retical foundations with applied learning, the module equipped participants with practical skills that can be readily incorporated into everyday zoo operations and established a common framework for evidence-based behavioural management across Indian zoos.

2 Module framework

2.1 Goal

To strengthen the capacity of Indian zoo professionals to apply behavioural science in animal management by developing skills in behavioural observation, data collection, analysis, interpretation, and evidence-based application, thereby improving animal welfare, husbandry, conservation breeding, and management outcomes.

2.2 Objectives

The Animal Behaviour Module was designed to equip zoo personnel with foundational knowledge and practical skills in the observation, analysis, and application of animal behaviour in zoo management. Specifically, the module aimed to:

- i. Build a conceptual understanding of animal behaviour and its relevance to zoo management, conservation, and animal welfare.
- ii. Develop practical skills in behavioural observation, ethogram development, behavioural sampling, and standardized data collection.
- iii. Introduce participants to the design, analysis, and interpretation of behavioural studies using open-source analytical tools.
- iv. Demonstrate the application of behavioural science to welfare assessment, environmental enrichment, husbandry training, enclosure evaluation, and management decision-making.
- v. Foster a culture of evidence-based practice by encouraging participants to integrate behavioural monitoring into routine zoo operations.

2.3 Pedagogy and teaching approach

The module adopted a learner-centred pedagogy that combined classroom instruction with extensive field-based practical sessions. Emphasis was placed on experiential learning, enabling participants to directly observe animals, collect behavioural data, analyse findings, and translate results into practical management recommendations.

The teaching approach emphasized:

- i. Field-based behavioural observations using a range of zoo species.
- ii. Hands-on development of ethograms and standardized behavioural sampling protocols.
- iii. Behavioural data analysis and visualization using R.

- iv. Case studies and group discussions illustrating applications of behavioural science in welfare assessment, enrichment, husbandry training, and captive management.
- v. Reflection and collaborative learning through participant discussions, presentations, and problem-solving exercises.

This approach ensured that participants progressed through the complete behavioural research cycle—from asking meaningful questions and collecting reliable data to analysing results and applying behavioural evidence to improve animal management and welfare.

2.4 Speakers and participants

The module brought together participants from zoos primarily located in the southern region along with resource persons representing expertise in behavioural ecology, animal welfare, zoo management, and applied behavioural research. Details of the participants and speakers are provided in Appendix A.



Group photograph of the participants, instructors, and organizers of the Animal Behaviour Module, Zoo Science Course, held at Bannerughatta Biological Park, Bengaluru, from 1–5 December 2025.

3 Module schedule

The Animal Behaviour Module was conducted over five days from 1–5 December 2025. The programme combined classroom lectures with field-based practical sessions, allowing participants to progressively develop competencies in behavioural observation, research design, data collection, analysis, and application. Each morning (Days 2–5) began with behavioural observations in the zoo, providing datasets that were subsequently used during classroom exercises and discussions. The detailed schedule is presented below.

Time	Session
Day 1 – Monday, 1 December 2025: Foundations of animal behaviour	
09:30–10:30	Inaugural
10:30–11:00	Introduction to the Zoo Science Course (L)
11:00–11:30	Break
11:30–12:30	Introduction to Animal Behaviour (L)
12:30–13:30	Animal Behaviour in the Zoo (L)
13:30–14:30	Lunch
14:30–15:30	Animal Behaviour in the Zoo (continued) (L)
15:30–17:00	Introduction to R for Behavioural Data Analysis (H)
Day 2 – Tuesday, 2 December 2025: Behavioural observations and study design	
07:30–08:30	Field Behavioural Observations (H)
08:30–09:30	Break
09:30–11:30	Choosing a Research Question (L)
11:30–12:00	Break
12:00–13:30	Ethogram Development (H)
13:30–14:30	Lunch
14:30–16:30	Designing Behavioural Studies (H)
16:30–17:30	Behavioural Metrics, Recording Methods and Data Quality (H)
Day 3 – Wednesday, 3 December 2025: Behavioural ecology and analysis	
07:30–08:30	Field Behavioural Observations (H)
08:30–09:30	Break
09:30–10:30	Behavioural Metrics, Recording Methods and Data Quality (L)
10:30–11:30	Animal Learning and Husbandry Training (L)
11:30–13:30	Behavioural Development and Parental Care in Captive Animals (L)

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Time	Session
13:30–14:30	Lunch
14:30–17:30	Behavioural Research Data Analysis using R (H)
Day 4 – Thursday, 4 December 2025: Behaviour, welfare and management	
07:30–08:30	Field Behavioural Observations (H)
08:30–09:30	Break
09:30–10:30	Abnormal Behaviours in Captivity (L)
10:30–11:30	Behaviour as an Indicator of Welfare – Case Study: Felids (L)
11:30–13:30	Integrating Social Behaviour into Captive Animal Management (L)
13:30–14:30	Lunch
14:30–15:30	Behaviour as a Tool to Improve Captive Management of Reptiles and Amphibians (L)
15:30–17:30	Behavioural Research Data Analysis using R (continued) (H)
Day 5 – Friday, 5 December 2025: Applications and synthesis	
07:30–08:30	Field Behavioural Observations (H)
08:30–09:30	Break
09:30–11:30	Evaluating Husbandry Interventions (L)
11:30–12:30	Ethics and Welfare Considerations in Applied Behaviour Research (L)
12:30–13:30	Behaviour and Captive Management – A Holistic Perspective (L)
13:30–14:30	Lunch
14:30–16:00	Reflection and Participant Feedback
16:00–16:30	Valedictory

4 Session details

4.1 Inaugural session

The inaugural session of the Animal Behaviour Module was held on 1 December 2025 at Bannerughatta Biological Park, Bengaluru. The session was presided over by Shri A. V. Surya Sen, IFS, Executive Director of Bannerughatta Biological Park, who welcomed participants and emphasised the importance of strengthening technical capacity in zoo management through structured professional development initiatives. The technical report of the previous module on population management was released.



Release of the technical report of the Population Management Module (Zoo Science Course) by Shri A. V. Surya Sen, IFS, Executive Director, Bannerughatta Biological Park, during the inaugural session of the Animal Behaviour Module, 1 December 2025.

4.2 Introduction to the Zoo Science Course

Speaker: *Lakshminarasimha R*

The opening session introduced participants to the vision, philosophy, and long-term objectives of the Zoo Science Course, positioning it as India's first structured professional development initiative dedicated to strengthening scientific capacity within the

zoo community. The session highlighted the ongoing transition of Indian zoos from traditional animal keeping towards evidence-based zoo management, emphasizing that effective management requires an integrated understanding of species biology, ecology, behaviour, nutrition, and husbandry. Zoo science was presented as the application of biological, ecological, and management principles to improve animal care, welfare, conservation, and institutional effectiveness.

An overview of the current status of Indian zoos was presented, highlighting both the opportunities and challenges facing the sector. While Indian zoos collectively manage a diverse collection of native and non-native species and have considerable potential to contribute to conservation, research, and education, the session identified the absence of a structured and institutionalized training framework as a major limitation to scientific zoo management. The Zoo Science Course was presented as a long-term initiative designed to address this gap by developing a national framework for continuous professional development.

The vision, mission, and goals of the programme were then outlined, with particular emphasis on species-centred management, evidence-based decision-making, standardization of professional training, collaboration among institutions, and the institutionalization of continuous learning. Participants were introduced to the modular structure of the course, comprising Population Management, Animal Behaviour, Zoo Animal Nutrition, Enclosure Design and Welfare, and Long-term Planning. The Animal Behaviour Module was positioned as the second module in this sequence, building upon the scientific foundations established during the Population Management Module while providing behavioural tools that underpin nutrition, welfare assessment, enclosure design, and conservation management.

The session concluded with an overview of the pedagogical approach of the Zoo Science Course. Participants were encouraged to engage actively through lectures, field observations, practical exercises, behavioural research, data analysis using R, collaborative learning, and critical reflection. The intended outcome was to enable participants to progress from observation to scientific interpretation and ultimately to evidence-based management decisions that improve animal welfare and conservation outcomes.

4.3 Foundations of animal behaviour

4.3.1 Introduction to Animal Behaviour

Speaker: *Prof. Maria Thaker*

This session introduced participants to the foundations of animal behaviour and its relevance to zoo science. The lecture traced the development of the field from early ethology, which focused on describing what animals do, to behavioural ecology, which examines how and why behaviours arise in relation to ecological conditions. Participants were en-

couraged to view behaviour as a flexible trait shaped by both inherited predispositions and environmental experience, rather than as a fixed or purely instinctive response.

A central theme of the session was adaptation. Behaviour was presented as a trait shaped by natural selection, individual learning, and, in some cases, social learning. The lecture emphasized that animals may alter their behaviour when their environment changes, including in captivity, where the ecological conditions differ substantially from the wild. This provided an important framework for zoo management: before interpreting captive behaviour, managers must ask what has changed in the animal's environment and how the animal may be responding to those changes.

The session also introduced Tinbergen's four questions as a framework for studying behaviour: mechanism, development, adaptive function, and evolutionary history. Using examples such as bird song, participants were shown that the same behaviour can be explained at different levels of analysis, and that clearly defining the type of question being asked is essential for meaningful behavioural research. The lecture also cautioned against anthropomorphism and against assuming that behaviours evolve "for the good of the group"; instead, behavioural explanations should be grounded in fitness, selection, and individual-level costs and benefits.

Applied examples from research on lizards in urban and rural environments illustrated how behaviour can change under altered ecological conditions. Urbanization was presented as a useful analogue for captivity because both involve shifts in microhabitat, resource availability, sensory environments, risk, and selection pressures. Examples related to perch choice, refuge use, cognition, colour signalling, courtship, stress, and coping styles demonstrated how animals may adjust behaviourally and physiologically to modified environments.

For zoo management, the key message was that behaviour must be interpreted in relation to environmental context. Captive animals may differ from their wild counterparts because their surroundings, risks, opportunities, social conditions, and sensory environments have changed. Participants were encouraged to adopt a systematic approach: identify how the captive environment differs from the wild, define specific behavioural questions, develop species-informed ethograms, collect objective data, and use behavioural evidence to guide husbandry, enrichment, welfare assessment, and management interventions.

Key takeaways

- Behaviour is shaped by both evolutionary history and environmental experience.
- Captive behaviour should be interpreted in relation to the ecological and social context in which it occurs.
- Tinbergen's four questions provide a useful framework for defining behavioural

research questions.

- Behavioural explanations should avoid anthropomorphism and should be grounded in costs, benefits, fitness, and adaptation.
- Zoo management should use systematic behavioural observation to understand how animals respond to captive environments.

Further reading

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- Davies, N. B., Krebs, J. R., & West, S. A. (2012). *An Introduction to Behavioural Ecology* (4th ed.). Wiley-Blackwell.

4.3.2 Animal Behaviour in the zoo

Speaker: *Lakshminarasimha R*

This session examined the central role of animal behaviour in modern zoo management and demonstrated how behavioural science provides the foundation for evidence-based husbandry, welfare assessment, enclosure design, conservation breeding, and species recovery. Behaviour was presented not merely as something animals exhibit, but as a measurable biological response that links animal biology with management decisions and conservation outcomes. Participants were introduced to the concept of "behaviour as data", emphasizing that behavioural observations must be objectively defined, systematically recorded, and analysed using standardized and repeatable methods before they can inform management decisions.

The session traced the evolution of zoo biology from a discipline primarily concerned with maintaining animals in captivity to one focused on understanding species through their ecology, natural history, and behaviour. Modern zoos were described as biology-driven institutions in which the primary objective is not merely the survival of animals, but the maintenance of behavioural competence—the capacity of animals to express species-typical behaviours, respond appropriately to environmental challenges, and retain the skills necessary for welfare, reproduction, and, where relevant, reintroduction into the wild. The successful recovery programme for the Golden Lion Tamarin was presented as a case study illustrating how behavioural competence can determine the success or failure of conservation translocations. Early reintroduction attempts suffered high mortality because captive-born animals lacked essential behavioural skills; subsequent modifications to pre-release training and the release of younger individuals substantially improved post-release survival.

Participants were introduced to several theoretical frameworks that provide ecological context for understanding behaviour in captivity. The concepts of species-typical behaviour, behavioural diversity, and ethograms were discussed as essential tools for behavioural assessment. Behaviour was presented as an adaptive trait shaped by a species' evolutionary history, ecological niche, and environmental conditions. Using Eisenberg's analytical model, the session demonstrated how diet and substrate use influence movement patterns, activity budgets, cognition, social organisation, and enclosure requirements. Behavioural syndromes were introduced to illustrate that behaviours occur as integrated suites of traits rather than as isolated actions, highlighting the importance of understanding the ecological niche of a species before interpreting or managing its behaviour.

The lecture further explored how animals make decisions across multiple spatial and temporal scales using Holling's decision hierarchy. In natural environments, animals make nested decisions regarding habitat selection, patch choice, resource selection, and resource use. Captivity often restricts these opportunities, limiting exploration, choice, and problem-solving. Consequently, effective enclosure design should not focus solely on increasing enclosure size, but on recreating opportunities for animals to make ecologically meaningful decisions through habitat complexity, environmental heterogeneity, refuge provision, and appropriate spatial organisation. Participants were encouraged to view enrichment as only one component of a broader strategy aimed at restoring behavioural opportunities across multiple ecological scales.

The session concluded by highlighting the implications of behavioural science for animal welfare and conservation. Captive environments impose novel developmental and evolutionary pressures that may alter behaviour over an individual's lifetime and, over successive generations, lead to divergence from wild populations. Maintaining natural behavioural repertoires, facilitating appropriate social and developmental experiences, and preventing unintended behavioural change are therefore essential not only for ensuring high standards of welfare but also for sustaining the long-term conservation value of ex situ populations. Participants were encouraged to integrate behavioural observations into routine husbandry, welfare assessment, enclosure evaluation, and conservation planning, thereby moving from intuition-based management towards objective, evidence-based decision-making.

Key takeaways

- Behaviour provides an objective and measurable basis for evidence-based zoo management, linking welfare, husbandry, enclosure design, veterinary care, and conservation outcomes.
- Modern zoo biology aims to maintain *behavioural competence*, ensuring that cap-

tive animals retain species-typical behaviours necessary for welfare, reproduction, and, where relevant, survival in the wild.

- Behaviour must be interpreted within the ecological and evolutionary context of a species, using natural history as the foundation for management decisions.
- Effective enclosure design extends beyond providing space to creating opportunities for animals to make ecologically meaningful choices across multiple spatial and temporal scales.
- Standardized behavioural observations, ethograms, and systematic data collection are essential for evaluating husbandry practices and guiding adaptive management.

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4.4 Behavioural observations and study design

4.4.1 Choosing and framing meaningful research questions

Speaker: *Lakshminarasimha R*

This session introduced participants to the process of developing rigorous, management-oriented research questions in behavioural biology. The discussion emphasized that the quality of a behavioural study is determined not only by the methods used, but fundamentally by the clarity of the research question being addressed. Participants were encouraged to move beyond descriptive observations and frame questions that are biologically meaningful, testable, and capable of informing zoo management decisions.

The session began with an overview of the scientific process, discussing the nature of scientific evidence, the hierarchy of evidence, and the importance of reproducibility in behavioural research. Using zoo-based examples, participants explored how weak study designs, inadequate replication, and poorly framed questions can lead to false positive and false negative conclusions, potentially resulting in inappropriate management decisions. Particular emphasis was placed on the importance of baseline observations, standardized protocols, statistical power, and replication when evaluating husbandry interventions and animal welfare.

Building upon the concepts introduced in the previous lecture, Tinbergen's four questions were revisited as a framework for formulating behavioural research questions. Participants examined how the same behaviour can be investigated from the perspectives of mechanism, development, function, or evolutionary history, and how this understanding helps determine appropriate study design and interpretation. The lecture also compared different approaches to studying behaviour—including psychology, ethology, behavioural ecology, and sociobiology—and highlighted how modern behavioural biology integrates these complementary perspectives.

The practical aspects of behavioural research design were then discussed, including selecting appropriate study species, defining observation periods, minimizing observer bias, and avoiding anthropomorphic interpretations of animal behaviour. Participants were encouraged to conduct preliminary observations before formal data collection in order to understand behavioural patterns, refine research questions, and develop appropriate behavioural categories and sampling protocols. The distinction between exploratory and confirmatory research was also discussed, emphasizing that exploratory observations generate hypotheses, whereas confirmatory studies rigorously test predefined predictions.

The session concluded by introducing a structured workflow for behavioural research, beginning with identifying a management problem, conducting preliminary observations, developing hypotheses and predictions, selecting appropriate sampling methods, collecting and analysing data, and finally interpreting results within a biological and management context. Through zoo-based case studies involving environmental modifications and behavioural interventions, participants gained practical experience in translating everyday husbandry challenges into scientifically testable research questions that could guide evidence-based management.

Key takeaways

- Strong behavioural studies begin with clear, biologically meaningful, and management - relevant research questions.
- Preliminary observations are essential for refining questions, defining behaviours, and selecting appropriate methods.

- Behavioural studies should distinguish exploratory observations from confirmatory hypothesis testing.
- Research questions, hypotheses, predictions, sampling design, and statistical analyses should form an integrated framework.
- Behavioural research should ultimately support evidence-based husbandry, welfare assessment, and adaptive zoo management.

Further reading

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4.4.2 Behaviour Measurement: Ethograms, Behavioural metrics and Recording methods

Speaker: *Paul Rose*

This session introduced participants to the principles and methodologies used to measure animal behaviour objectively and systematically. Behavioural observations form the foundation of behavioural research, welfare assessment, husbandry evaluation, and adaptive management. However, observations only become scientifically useful when behaviours are clearly defined, consistently recorded, and analysed using standardized methods. The session therefore focused on developing the skills required to transform routine observations into reproducible behavioural data suitable for scientific analysis and management decision-making.

The session began with the concept of the *ethogram*, the fundamental tool used in behavioural studies. Participants learned that an ethogram is a comprehensive catalogue of all behaviours exhibited by a species, with each behaviour accompanied by a clear operational definition. Rather than relying on subjective interpretations or anthropomorphic descriptions, behaviours should be described in terms of directly observable actions. For example, an animal should not be recorded as "happy" or "aggressive", but instead by objectively describing measurable actions such as locomotion, vocalization, body posture, or physical interactions. The importance of developing species-specific ethograms through preliminary observations and refinement before commencing formal studies was emphasised, together with the need for standardized terminology to facilitate comparisons among observers, institutions, and studies.

Building upon the ethogram, participants were introduced to the quantitative measurement of behaviour. The session distinguished between behavioural *events*, which occur instantaneously (e.g., vocalizations or aggressive interactions), and behavioural *states*, which persist over a period of time (e.g., resting, feeding, or grooming). Appropriate behavioural metrics—including frequency, duration, latency, intensity, and rates of occurrence—were discussed, together with their biological interpretation and practical applications. Emphasis was placed on selecting behavioural variables that directly address the research question, as incorrectly chosen metrics may result in misleading conclusions or overlook biologically important patterns.

Recognising that individuals within a population often differ in their behavioural repertoires, the session also addressed methods for individual identification and the importance of accounting for individual variation during study design and analysis. Participants discussed factors contributing to behavioural variation, including age, sex, reproductive status, personality, social relationships, and environmental influences. The need to evaluate observer reliability and establish consistent scoring among observers prior to formal data collection was highlighted as an essential step in reducing measurement error and improving data quality.

The latter part of the session focused on behavioural sampling and recording methods commonly employed in zoo research. Participants compared the strengths and limitations of focal animal sampling, scan sampling, behaviour sampling, and ad libitum observations, together with continuous recording, instantaneous sampling, and one-zero sampling techniques. Rather than identifying a single “best” method, the session emphasised that the choice of sampling strategy depends on the biological question being addressed, the characteristics of the behaviour of interest, species ecology, enclosure conditions, and logistical constraints. Examples from zoo-based studies illustrated how different sampling approaches influence estimates of activity budgets, behavioural frequencies, and social interactions.

The session concluded by integrating these concepts into a complete behavioural study workflow. Participants were encouraged to begin with preliminary observations, develop a robust species-specific ethogram, define objective behavioural metrics, select appropriate sampling methods, and establish observer reliability before commencing systematic data collection. This structured approach provides the foundation for producing high-quality behavioural datasets that can support welfare assessments, enrichment evaluations, husbandry interventions, behavioural research, and evidence-based zoo management.

Key takeaways

- Behavioural observations become scientifically useful only when behaviours are defined objectively using standardized ethograms.

- Operational definitions minimise observer bias and improve reproducibility.
- Different behaviours require different behavioural metrics, including latency, frequency, duration, and intensity.
- The choice of sampling and recording methods should be determined by the research question and the characteristics of the behaviour being studied.
- Standardized behavioural measurement forms the basis for reliable welfare assessment, behavioural research, and evidence-based zoo management.

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4.4.3 Data quality and reproducibility in behavioural research

Speaker: *Lakshminarasimha R*

This session focused on the quality of behavioural measurements and the importance of ensuring that behavioural data are both reliable and biologically meaningful. Participants were introduced to the concepts of reliability, validity, and independence of observations, and their implications for behavioural research, welfare assessment, and evidence-based zoo management. The session emphasized that management decisions are only as sound as the quality of the data upon which they are based, making rigorous study design and quality control essential components of behavioural research.

The distinction between reliability and validity formed the central theme of the session. Reliability was described as the consistency or repeatability of a behavioural measurement, whereas validity refers to whether a measurement accurately represents the biological phenomenon of interest. Through practical examples, participants explored situations in which measurements may be highly reliable but biologically irrelevant, illustrating that precise observations do not necessarily produce meaningful conclusions. Factors affecting measurement reliability, including observer experience, behavioural

definitions, observer fatigue, and environmental distractions, were discussed together with approaches for improving observer consistency through standardized protocols and training.

The session also highlighted common sources of bias and error encountered during behavioural studies. Participants learned the importance of refining operational definitions, improving observer calibration, and combining behaviour categories only when biologically justified. The discussion reinforced that behavioural measurements should prioritize biological relevance rather than convenience, and that imperfect measurements of biologically important behaviours are often preferable to highly precise measurements of irrelevant variables.

A further component of the lecture examined the statistical concept of independence in behavioural datasets. Participants were introduced to common problems such as repeated measurements from the same individual, non-independence among group members, mathematically related behavioural variables, mutually exclusive behaviour categories, and shared environmental effects. Using practical zoo examples, the session demonstrated how these issues can inflate sample sizes, bias statistical analyses, and lead to incorrect biological inferences. Strategies for minimizing these problems during study design and data analysis were discussed, including the use of repeated-measures approaches, group-level analyses where appropriate, and careful selection of independent behavioural variables.

The session concluded by emphasizing that producing high-quality behavioural data requires careful planning throughout the entire research process—from defining behaviours and training observers to selecting appropriate measurements, maintaining observer reliability, and ensuring valid statistical inference. These principles provide the foundation for robust behavioural research and for translating behavioural observations into reliable management recommendations.

Key takeaways

- Reliable measurements are consistent, whereas valid measurements accurately represent the biological phenomenon being studied.
- Behavioural definitions, observer training, and standardized protocols are essential for improving data quality.
- Biological relevance should take precedence over measurement convenience when selecting behavioural variables.
- Behavioural datasets must satisfy assumptions of independence to support valid statistical analyses.
- High-quality behavioural data provide the foundation for reliable welfare assessments and evidence-based zoo management.

Further reading

- Martin, P., & Bateson, P. (2007). *Measuring Behaviour: An Introductory Guide* (3rd ed.). Cambridge University Press.
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4.5 Behavioural ecology and analysis

4.5.1 Behavioral development and parental care in primates

Speaker: *Prof. Sindhu Radhakrishna*

This session explored the behavioural ecology of primate development, with particular emphasis on the evolutionary basis of parental care, social development, and life-history strategies. Participants were introduced to the relationship between brain evolution, prolonged development, and complex social systems, highlighting that primates invest heavily in learning and social interactions throughout infancy and juvenile stages. The discussion illustrated how behavioural development represents a dynamic interaction between inherited predispositions and environmental influences, with social learning playing a central role in shaping adult behaviour.

The lecture examined the diversity of reproductive and parental care strategies observed across primates. Participants learned how body size, litter size, developmental rate, and maternal investment are closely linked, resulting in extended periods of dependency in many species. Maternal care was discussed as a major determinant of behavioural development, with examples illustrating infant parking, mother-infant communication through ultrasonic vocalisations, and the ecological factors influencing different parental care strategies. Maternal, paternal, and alloparental care were compared, demonstrating how parental investment varies according to species ecology, mating systems, and the certainty of parentage.

The influence of social organisation on behavioural development formed another major component of the session. Female philopatry, sex-biased dispersal, dominance hierarchies, maternal rank, and individual differences in maternal style were discussed as important determinants of offspring behaviour, social status, and lifetime reproductive success. The lecture highlighted how maternal rank can influence access to resources, developmental opportunities, and social integration, while habitat fragmentation and restricted dispersal may disrupt natural social processes and increase the risk of inbreeding in fragmented populations.

Drawing upon examples from both wild and captive primates, the session emphasised that successful management requires an understanding of species-specific developmental trajectories and social systems. The participants were encouraged to con-

sider the behavioural consequences of nursery practices, hand-rearing, social grouping, enclosure design, and environmental disturbance on behavioural development. Maintaining opportunities for normal parent-offspring interactions and social learning was presented as essential for promoting behavioural competence, animal welfare, and long-term conservation breeding success.

Key takeaways

- Primate behavioural development is strongly influenced by prolonged parental care and social learning.
- Maternal investment, social organisation, and dominance relationships shape behavioural development and lifetime fitness.
- Species differ considerably in maternal, paternal, and alloparental care strategies, reflecting their ecology and evolutionary history.
- Captive management should support natural developmental processes and opportunities for normal social interactions.
- Knowledge of primate behavioural ecology is fundamental to breeding management, infant care, social housing, and conservation programmes.

Further reading

- Campbell, C. J., Fuentes, A., MacKinnon, K. C., Panger, M., & Bearder, S. K. (Eds.). (2020). *Primate Behavioral Ecology*. Routledge.
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4.5.2 Behaviour as a tool for improving the management of reptiles in captivity

Speaker: *Gowri Mallapur*

This session explored the application of behavioural ecology to the management of reptiles in zoological collections. Participants were introduced to the growing body of evidence demonstrating that reptiles possess a far greater diversity of behavioural and cognitive abilities than was traditionally recognised. Rather than viewing reptiles as behaviourally simple animals, the session highlighted their capacity for learning, social interactions, parental care, communication, and problem-solving. Participants were encouraged to move beyond mammal-centred interpretations of behaviour and instead

understand reptilian behaviour within the context of their unique physiology, sensory biology, and evolutionary history.

A central theme of the lecture was the importance of thermoregulation in shaping reptilian behaviour. As ectotherms, reptiles depend on behavioural mechanisms to regulate body temperature, and consequently many aspects of their daily activity—including movement, feeding, reproduction, digestion, and predator avoidance—are closely linked to thermal conditions. Participants examined behaviours such as basking site selection, postural adjustments, microhabitat choice, and seasonal activity cycles, illustrating how reptiles actively exploit environmental heterogeneity to maintain preferred body temperatures. The implications for zoo management were emphasised, particularly the need to provide diverse thermal environments, appropriate basking opportunities, and refuge areas that allow animals to thermoregulate without disturbance from visitors or conspecifics.

The lecture also explored behavioural adaptations associated with seasonal cycles and reproduction. Participants discussed the distinction between brumation in ectotherms and hibernation in mammals, together with the environmental cues that regulate reproductive activity in many reptile species. Temperature, rainfall, humidity, and photoperiod were presented as critical environmental signals influencing courtship, nesting, incubation, and hatching. Examples from crocodilians, turtles, lizards, and amphibians demonstrated how reproducing these seasonal cues under captive conditions can substantially improve breeding success.

Another major component of the session examined the sensory ecology of reptiles. Participants were introduced to behavioural adaptations associated with chemoreception, thermoreception, mechanoreception, acoustic communication, and colour signalling. Examples included the use of Jacobson's organ for chemical communication, integumentary sensory organs in crocodilians for detecting water movements, infrared-sensitive pit organs in snakes for prey detection, and species-specific vocalisations used during territorial interactions and parental care. These examples demonstrated that reptiles perceive and respond to their environment through sensory pathways that often differ fundamentally from those of mammals and birds, reinforcing the need to consider species-specific sensory ecology when designing captive environments.

The session concluded by emphasising that behavioural observations provide an effective tool for evaluating enclosure suitability and husbandry practices in reptiles. By understanding the ecological drivers of thermoregulation, habitat selection, communication, and seasonal behaviour, zoo professionals can design environments that enable species-appropriate behavioural expression, improve reproductive success, and promote positive welfare outcomes. The lecture reinforced that behavioural ecology should form an integral component of reptile conservation, captive breeding, and evidence-based zoo management.

Key takeaways

- Reptiles exhibit complex behavioural repertoires and should be studied within the context of their own ecology rather than through mammalian behavioural models.
- Thermoregulation is a primary driver of reptilian behaviour and should be a central consideration in enclosure design and husbandry.
- Seasonal environmental cues are critical for regulating activity, reproduction, and developmental processes in many reptile species.
- Reptiles rely on diverse sensory systems, including chemical, thermal, mechanical, and acoustic cues, which should be considered when managing captive environments.
- Behavioural observations provide valuable indicators for evaluating welfare, enclosure design, and the effectiveness of husbandry interventions in reptiles.

Further reading

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- Bels, V. L., & Russell, A. P. (Eds.). (2019). *Behavior of Lizards: Evolutionary and Mechanistic Perspectives*. CRC Press.
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4.5.3 Social behaviour and its importance in captive management

Speaker: Prof. Divya Uma

This session examined the diversity of social systems observed across the animal kingdom and highlighted their significance for captive animal management. Using examples ranging from social spiders and insects to birds, mammals, and primates, the lecture illustrated that social organisation is an evolutionary adaptation shaped by ecological pressures such as resource availability, predation risk, reproduction, and parental care. Participants were encouraged to recognise that sociality exists along a continuum, with species exhibiting solitary, pair-living, fission–fusion, cooperative breeding, or highly social group structures, each associated with distinct behavioural and management requirements.

The lecture emphasised that species differ not only in whether they are social, but also in how they interact with conspecifics. Group size, dominance hierarchies, kinship, dispersal patterns, territoriality, communication, and reproductive strategies all influence social relationships within a population. Consequently, successful captive management requires an understanding of the natural social organisation of a species rather than assuming that animals can be grouped or separated without behavioural consequences.

Examples from a variety of taxa demonstrated that inappropriate social management may result in chronic stress, abnormal behaviours, aggression, reproductive failure, or social instability. Conversely, maintaining compatible social groups, preserving established social relationships, and providing opportunities for natural social interactions contribute to improved welfare and breeding success. Participants discussed the importance of considering factors such as age, sex, relatedness, individual personality, and previous social experience when making decisions regarding animal introductions, transfers, group restructuring, or separation.

The session also highlighted that management decisions should reflect species-specific behavioural ecology. Solitary species should not be housed socially simply because space permits, while highly social species require opportunities for stable social interactions and the expression of natural social behaviours. Particular emphasis was placed on primates, where disruption of established groups, inappropriate grouping of unfamiliar individuals, or unnecessary separation of related animals may have profound behavioural and welfare consequences.

The session concluded by reinforcing that social behaviour should be regarded as a fundamental component of species biology rather than an optional aspect of husbandry. Understanding natural social systems enables zoo professionals to make informed decisions regarding enclosure design, breeding programmes, animal transfers, introductions, and long-term population management, thereby promoting both animal welfare and conservation outcomes.

Key takeaways

- Social organisation is an evolutionary adaptation shaped by species ecology and life history.
- Species differ widely in their social systems, and captive management should reflect these natural differences.
- Group composition should consider age, sex, kinship, personality, dominance relationships, and previous social experience.
- Maintaining appropriate social environments improves welfare, behavioural stability, and reproductive success.

- Social behaviour should be integrated into enclosure design, husbandry planning, and conservation breeding programmes.

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- Campbell, C. J., Fuentes, A., MacKinnon, K. C., Panger, M., & Bearder, S. K. (Eds.). (2020). *Primate Behavioral Ecology*. Routledge.

4.6 Behaviour, welfare and management: Applications and Synthesis

4.6.1 Animal learning and husbandry training

Speaker: *Lakshminarasimha R*

This session introduced the principles of animal learning and their application to modern husbandry training in zoos. Participants explored how learning theory has transformed zoo management from traditional approaches based on restraint and control towards voluntary cooperation between animals and keepers. Modern husbandry training was presented as a scientific process that improves animal welfare, facilitates veterinary care, enhances keeper safety, and provides cognitive stimulation, while reducing the need for stressful capture and physical restraint.

The lecture began with an overview of the development of learning theory, tracing the contributions of Edward Thorndike, Ivan Pavlov, and B. F. Skinner to our understanding of how animals acquire new behaviours. Participants examined the principles of classical conditioning, operant conditioning, habituation, and social learning, recognising that learning occurs through interactions between animals and their environment. Particular emphasis was placed on operant conditioning, where the consequences of a behaviour determine whether it is repeated, making it the foundation of contemporary husbandry training programmes.

Participants were then introduced to the practical application of learning theory in zoo settings. Concepts including positive and negative reinforcement, punishment, conditioned reinforcers, shaping through successive approximations, reinforcement schedules, and motivation were discussed using examples from a variety of zoo species. The lecture emphasised that positive reinforcement should form the basis of husbandry

training, as it promotes voluntary participation, strengthens keeper–animal relationships, and improves welfare outcomes. Punishment, by contrast, was presented as undesirable because it can increase fear, aggression, and unpredictability while compromising trust between animals and keepers.

A major theme throughout the session was that successful training depends on understanding species biology rather than simply applying generic techniques. Participants explored how evolutionary history, natural behaviour, sensory ecology, motivation, and individual life history influence an animal's ability to learn. Concepts such as biological preparedness, instinctive drift, species-specific sensory worlds (*Umwelt*), and individual differences were discussed to illustrate why training programmes must be tailored to both the species and the individual animal. The lecture reinforced that training should work with natural behavioural tendencies rather than attempting to override them.

The latter part of the session focused on the design and implementation of husbandry training programmes. Participants learned how to develop structured training plans by defining behavioural goals, selecting appropriate reinforcers, breaking complex behaviours into manageable steps, and monitoring progress throughout the training process. Routine husbandry practices such as shifting, crate training, cooperative feeding, injections, blood collection, hoof care, and voluntary medical examinations were presented as examples of how behavioural training contributes directly to improved animal care. The importance of consistency among trainers, facility design, protected contact systems, and regular evaluation of training outcomes was also emphasised.

The session concluded by emphasising that husbandry training should be regarded as an integral component of modern zoo management rather than an optional activity. When grounded in sound behavioural science and implemented using welfare-centred principles, training enables animals to participate voluntarily in their own care, improves operational safety, facilitates veterinary procedures, and strengthens evidence-based management across zoos.

Key takeaways

- Learning theory provides the scientific foundation for modern husbandry training.
- Positive reinforcement promotes voluntary participation, improves welfare, and strengthens keeper–animal relationships.
- Training programmes should be designed around species biology, sensory ecology, motivation, and individual history.
- Husbandry training supports routine management, veterinary care, research, and enrichment while reducing stress associated with restraint and handling.

- Effective training requires structured planning, consistency among trainers, and continual evaluation of behavioural progress.

Further reading

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4.6.2 Abnormal behaviours in captivity

Speaker: *Lakshminarasimha R*

This session examined abnormal behaviours in captive animals and their significance for animal welfare and husbandry. Participants were introduced to the different forms of abnormal repetitive behaviours (ARBs), including stereotypies, self-directed behaviours, abnormal aggression, altered activity budgets, and species-specific behavioural disorders. The discussion emphasised that "abnormal" behaviours encompass a diverse range of behavioural patterns with different underlying causes and should not be interpreted as a single behavioural category.

The lecture explored the ecological and developmental factors that contribute to the emergence of abnormal behaviours in captivity. Environmental restriction, limited behavioural opportunities, predictable husbandry routines, inadequate foraging complexity, inappropriate social environments, and adverse early-life experiences were presented as important drivers. Particular attention was given to stereotypic behaviours, which frequently arise when animals are unable to express highly motivated natural behaviours such as ranging, foraging, exploration, or escape. Comparative studies demonstrated that susceptibility varies considerably among species and is often associated with ecological characteristics, such as natural home-range size and behavioural specialisation.

Participants were encouraged to interpret abnormal behaviours within their biological and environmental context rather than using them as simple indicators of poor welfare. While stereotypies often reflect previous or current suboptimal conditions, they

may also function as coping mechanisms and can persist even after husbandry conditions improve. Consequently, successful management requires identifying and addressing the underlying causes of behavioural dysfunction rather than merely attempting to suppress behavioural symptoms. Examples from carnivores, primates, birds, reptiles, and fish illustrated how species-specific behavioural ecology should guide enclosure design, feeding strategies, social management, and enrichment programmes.

The session concluded by emphasising that abnormal behaviours should be regarded as valuable behavioural indicators that prompt further investigation. Careful behavioural monitoring, supported by knowledge of species biology and individual history, allows zoo professionals to identify welfare concerns early and implement evidence-based husbandry interventions that improve both animal welfare and management outcomes.

Key takeaways

- Abnormal behaviours represent diverse behavioural responses and should not be interpreted uniformly.
- Stereotypies often indicate behavioural needs that are not adequately met in captivity.
- Environmental, developmental, and social factors all contribute to the development of abnormal behaviours.
- Management should focus on addressing underlying causes rather than suppressing behavioural symptoms.
- Behavioural ecology provides an essential framework for designing effective husbandry and enrichment programmes.

Further reading

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4.6.3 Behaviour, Welfare and Ethics in Zoo Science

Speaker: *Lakshminarasimha R*

This session examined the close relationship between animal behaviour, welfare science, and ethics in modern zoo management. Building upon the preceding discussion on abnormal behaviours, participants were introduced to contemporary approaches for assessing animal welfare and the ethical responsibilities associated with behavioural research and captive animal management. The session emphasised that behaviour provides the primary evidence through which welfare is assessed, while ethical principles guide how research and management interventions should be designed and implemented.

The concept of animal welfare was discussed as the quality of an animal's physical and mental state in relation to the conditions in which it lives. Participants were introduced to multiple complementary approaches for evaluating welfare, including behavioural observations, physiological indicators, health assessments, cognitive measures, and environmental parameters. Rather than relying on a single indicator, welfare assessment was presented as an integrative process requiring consideration of the animal's species biology, life history, personality, developmental experience, and current environmental conditions. The session also distinguished between homeostasis and allostasis, illustrating that physiological or behavioural responses to environmental change are not necessarily indicative of poor welfare, but may represent adaptive mechanisms that enable animals to cope with challenges.

The discussion further emphasised the importance of considering individual variation when interpreting behavioural and welfare data. Animals of the same species may differ considerably in temperament, behavioural flexibility, developmental history, social status, reproductive condition, health, and previous experiences. Consequently, behavioural observations should be interpreted within the context of the individual rather than solely against species averages. Participants were encouraged to adopt longitudinal behavioural monitoring to detect meaningful changes in individuals over time and to evaluate the effectiveness of husbandry interventions.

The latter part of the session focused on ethics in behavioural research and zoo management. Ethical considerations were presented as extending beyond regulatory compliance to encompass the responsibility of ensuring that research and management activities contribute positively to animal welfare and conservation outcomes. Participants discussed the ethical justification for conducting behavioural studies, the need to minimise disturbance during observations, and the importance of designing research that addresses meaningful biological or management questions. The principles of necessity, proportionality, transparency, accountability, and refinement were highlighted throughout the research process.

The session also introduced the 4Rs framework—Replacement, Reduction, Refinement, and Relevance—as guiding principles for behavioural research in zoos. Participants discussed situations requiring institutional ethical approval, methods for minimising stress during data collection, and the importance of integrating welfare monitoring into research protocols. Particular emphasis was placed on the use of non-invasive observational methods wherever possible and on ensuring that the potential benefits of research outweigh any risks to the animals involved.

The session concluded by reinforcing that behaviour, welfare, and ethics are inseparable components of evidence-based zoo science. Behaviour provides objective information on how animals interact with their environment, welfare science provides the framework for interpreting those observations, and ethical principles ensure that research and management decisions prioritise the interests of the animals while contributing to conservation and scientific knowledge. Together, these principles support a holistic approach to captive animal management that balances scientific inquiry, conservation objectives, and animal welfare.

Key takeaways

- Animal welfare should be evaluated using multiple complementary indicators, including behaviour, physiology, health, and environmental context.
- Welfare assessments should account for individual variation in behaviour, life history, personality, and social status.
- Behaviour provides one of the most sensitive and practical indicators for assessing welfare in captive animals.
- Behavioural research should be scientifically rigorous while adhering to high ethical standards that minimise disturbance and maximise benefits to animal welfare and conservation.
- Behaviour, welfare, and ethics together provide the foundation for evidence-based and responsible zoo management.

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4.7 Introduction to ZooMonitor & R for Behavioural Data Analysis

Speaker: *Lakshminarasimha R*

This session introduced the participants to the R programming environment, which was used throughout the course for behavioural data management, visualization, and statistical analysis. Recognising that participants had varying levels of prior programming experience, the session focused on establishing a common computational foundation that would support subsequent practical sessions on behavioural research and data analysis.

Participants were guided through the installation and configuration of the required software and introduced to the basic interface, workflow, and organisation of R projects. Fundamental concepts—including objects, vectors, data frames, functions, packages, and working directories—were explained through practical examples. The session also covered importing datasets, inspecting data, basic data manipulation, and the execution of scripts, providing participants with the skills needed to work confidently within the R environment.

The session emphasised the advantages of using open-source tools for behavioural research, including reproducibility, transparency, flexibility, and the ability to analyse increasingly complex behavioural datasets. By the end of the practical, participants were familiar with the basic analytical workflow in R and were prepared to use the software for behavioural data analysis during subsequent sessions of the course.

4.7.1 Practical 1. Introduction to R and Data Handling

This practical established the computational foundation required for the remainder of the course. Participants learned the basic structure of R, including objects, vectors, data frames, functions, and packages, before progressing to data import, manipulation, and exploratory summaries using the `tidyverse`. The practical familiarised participants with script-based workflows for reproducible analysis and demonstrated how behavioural datasets can be organised, explored, and queried efficiently. By the end of the session, participants were able to navigate the R environment, manipulate datasets, and perform basic exploratory analyses on zoo-related behavioural data.

4.7.2 Practical 2. Behavioural Data Analysis using R

Building upon the introductory session, participants analysed simulated datasets representative of behavioural observations collected in zoos. The practical introduced a complete workflow for behavioural data management, from digital data collection to analysis and visualisation. Participants were introduced to ZooMonitor, a behavioural monitoring application developed by Lincoln Park Zoo, and learned how to develop ethograms, record behavioural observations using standardized sampling protocols, organise behavioural datasets, and generate activity budgets. They also explored the application's spatial mapping functions to quantify enclosure utilisation and evaluate patterns of space use by animals. The resulting datasets were subsequently analysed in R, where participants calculated behavioural frequencies, durations, activity budgets, and descriptive statistics, and visualised temporal patterns in behaviour. The practical demonstrated how digital behavioural recording and reproducible analytical workflows can be integrated to support welfare assessments, enclosure evaluations, enrichment programmes, behavioural research, and evidence-based zoo management.



Participants using the ZooMonitor application to record behavioural observations and spatial use data during a practical session at Bannerughatta Biological Park.

4.7.3 Practical 3. Advanced Behavioural Data Analysis

This practical introduced participants to the analysis of more complex behavioural datasets involving multiple individuals observed across repeated sessions under different experimental conditions. Using simulated datasets, participants explored methods for sum-

marising behaviour by individual, sex, treatment group, and observation period. The practical demonstrated how behavioural responses to management interventions can be compared using exploratory visualisation and statistical summaries, illustrating the value of structured data analysis for evaluating enrichment programmes, husbandry interventions, behavioural experiments, and other management questions.

4.7.4 Practical 4. Reliability and Observer Agreement

Reliable behavioural data depend upon consistency among observers. This practical introduced participants to methods for assessing both within-observer and between-observer reliability using simulated behavioural datasets. Participants explored correlation analyses and Cohen's Kappa coefficient to evaluate observer agreement and discussed the importance of observer training, clear behavioural definitions, and calibration exercises prior to formal data collection. The practical reinforced that observer reliability should be routinely evaluated as part of behavioural study design to ensure data quality and minimise measurement error. See Appendix C for details.

4.7.5 Practical 5. Statistical Power in Behavioural Studies

The final practical introduced the concept of statistical power and its importance in behavioural research. Through simulation exercises, participants explored how sample size, effect size, and behavioural variability influence the likelihood of detecting meaningful differences between management treatments. Using pacing behaviour as an example, the session illustrated how underpowered studies may fail to identify biologically important effects, while adequately designed studies improve confidence in management recommendations. The practical emphasised that statistical power should be considered during study design to ensure that behavioural studies are capable of detecting biologically meaningful effects while making efficient use of observational effort.

Collectively, these practical sessions provided participants with a complete analytical workflow for behavioural research, from data organisation and visualisation to statistical analysis, observer reliability, and study design. The use of open-source software enabled participants to develop reproducible analytical workflows that can be readily applied to behavioural monitoring, welfare assessment, and evidence-based management within zoological collections.

5 Concluding remarks

5.1 Pre- and Post-course Surveys

A pre-course questionnaire was administered to establish participants' background, prior experience, and confidence in behavioural observation and analysis, while a post-course questionnaire was used to evaluate learning outcomes, participant satisfaction, and perceived applicability of the course.

Participant profile Nineteen participants completed the pre-course assessment. Nearly half of the participants (47.4%) had two years or less of experience working in zoos or wildlife facilities, while 31.6% had between three and five years of experience and 21.1% had between six and ten years. The participant cohort therefore represented predominantly early-career zoo professionals, consistent with the objective of strengthening foundational capacity in behavioural science and evidence-based zoo management.

Pre-course assessment Participants entered the course with varying levels of prior experience in behavioural observation and research. While most participants reported at least some confidence in identifying common animal behaviours, only 36.8% considered themselves confident, with the majority (52.6%) describing themselves as somewhat confident. Experience with formal behavioural research methods was limited. Most participants (73.7%) reported only limited experience with structured behavioural sampling methods such as focal or scan sampling, while 26.3% had never used these methods. Behavioural observations were conducted only occasionally by 57.9% of participants, with relatively few recording behaviour frequently (21.1%) or daily (5.3%).

Familiarity with ethograms also varied considerably. Five participants (26.3%) reported being able to develop an ethogram independently, while the remainder had only a general understanding, had merely heard of the concept, or had never encountered it previously. Confidence in recognising signs of stress or abnormal behaviour was moderate, with 52.6% reporting that they were somewhat confident, 36.8% confident, and 10.5% not confident.

Almost all participants (89.5%) considered behaviour to be essential for daily husbandry and welfare assessment. However, prior experience with digital behavioural recording tools was limited: 78.9% had never used applications such as ZooMonitor, while only one participant (5.3%) had any practical experience. Similarly, only 36.8% reported being comfortable using graphs, spreadsheets, or simple analyses in R to support management decisions, while an equal proportion (36.8%) reported being only somewhat comfortable and 26.3% were not comfortable using these tools.

Post-course assessment Eighteen participants completed the post-course evaluation. Fourteen participants (77.8%) rated the course as *extremely useful*, while the remaining four (22.2%) considered it *useful*. With respect to clarity of instruction, eight participants (44.4%) rated the sessions as *extremely clear*, another eight (44.4%) as *clear*, and two participants (11.1%) as *somewhat clear*.

Participants also assessed their confidence across the core competencies addressed during the module, including behaviour identification, ethogram development, behavioural sampling, welfare assessment, behavioural recording using ZooMonitor, and behavioural data analysis using R. Responses indicated consistently high levels of confidence following completion of the course, with the majority of participants rating themselves as *confident* or *extremely confident* across all competencies. Only a small number of responses remained in the *somewhat confident* category, while very few participants reported low confidence in any of the assessed skills.

Seventeen of the eighteen participants (94.4%) indicated that they intended to apply the knowledge and skills acquired during the course within their respective institutions, while one participant (5.6%) responded *Maybe*.

Participant feedback Participants identified field observations and species-based case studies, theoretical sessions, ZooMonitor training, R-based behavioural data analysis, and group discussions as the most valuable components of the module. Practical exercises and opportunities to apply behavioural concepts to real-world zoo management were consistently highlighted as strengths of the course.

Participants expressed a high level of satisfaction with the overall design and delivery of the module. Fifteen participants (83.3%) reported being *very satisfied* with the course structure, while two (11.1%) were *somewhat satisfied*, and one participant (5.6%) was neither satisfied nor dissatisfied. The pace of instruction was considered *just right* by 16 participants (88.9%), whereas two participants (11.1%) felt that certain sessions progressed too quickly.

Field sessions, scheduling, and logistics were generally well received. Fifteen participants (83.3%) indicated that these components were comfortable and well organised, while three participants (16.7%) suggested that aspects of the field sessions and logistics could be further improved. Common suggestions included increasing the duration of field-based practical sessions, incorporating additional hands-on exercises and demonstrations, allowing more time for group discussions and problem-solving activities, and providing continued mentoring and follow-up support after completion of the course.

Overall, participant feedback indicated that the module successfully combined theoretical foundations with practical application and provided participants with knowledge and skills that they intended to apply within their respective zoological institutions.

See Appendix B for the complete pre- and post-course survey results.

5.2 Way forward

One of the primary objectives of the Animal Behaviour Module was to encourage the routine integration of behavioural monitoring into zoo management. Participants are encouraged to apply the methods introduced during the course—including ethogram development, standardized behavioural sampling, welfare assessment, and behavioural data analysis—to species managed within their respective institutions. Establishing long-term behavioural monitoring programmes will enable zoos to objectively evaluate husbandry practices, enrichment programmes, enclosure modifications, social management, and conservation breeding interventions.

The Zoo Science Course is intended to extend beyond the five-day training programme through continued mentoring, resource sharing, and technical support. Participants will be encouraged to undertake small behavioural studies within their institutions, with opportunities for discussion and feedback through follow-up interactions. Training materials, R scripts, behavioural recording templates, and practical resources developed during the module will continue to serve as reference material to support implementation.

The Animal Behaviour Module represents the second component of the Zoo Science Course and establishes behavioural science as a cross-cutting discipline within modern zoo management. The concepts introduced during this module underpin subsequent modules on Zoo Animal Nutrition, Enclosure Design and Welfare, and Zoo Master Planning, where behavioural evidence will continue to inform management decisions. Together, these modules are intended to provide Indian zoo professionals with a structured and integrated framework for evidence-based zoo management that strengthens animal welfare, conservation, research, and institutional capacity.

APPENDICIES

A People

Table 2: List of participants

No.	Name	Affiliation
1	Aghosh P	Biologist, Parassinikkadavu Snake Park & Zoo, Kannur
2	Aishwarya K. S.	Biologist, Bannerughatta Biological Park, Bengaluru
3	Angeline Samuel	Curator, Madras Crocodile Bank Trust, Mahabalipuram
4	Anuj Kandpal	Biologist, G. B. Pant High Altitude Zoo, Nainital
5	Apoorva M. P.	Assistant Biologist, Bannerughatta Biological Park, Bengaluru
6	Arif	Biologist, Sanjay Gandhi Biological Park, Patna
7	Dr. B. Laxmi Narayana	Senior Biologist, Nehru Zoological Park, Hyderabad
8	Ganavi S	Biologist, Adumalleshwara Mini Zoo, Chitradurga
9	Ilavarasan I	Biologist, Kurumbapatty Zoological Park, Salem
10	Prashanth Ballullaya U	Zoo Biologist, Pilikula Biological Park, Mangaluru
11	Richa Kumar	Wildlife Biologist, Nandanvan Jungle Safari, Naya Raipur
12	Shylashree B. L.	Biologist & Education Officer, Shri Atal Bihari Vajpayee Zoological Park, Ballari
13	Sinchana J	Education Officer & Biologist, Tiger & Lion Safari, Shivamogga
14	S. Tejas	Biologist, Sri Chamarajendra Zoological Gardens, Mysuru
15	Sujitha P. C.	Biologist, Thrissur Zoological Park, Puthur
16	Sushmitha S	Zoo Researcher, Tiger & Lion Safari, Shivamogga
17	T. Lakshmi Harika	Wildlife Biologist, Sri Venkateswara Zoological Park, Tirupati
18	Valluri Lakshmi Sowjanya	Wildlife Biologist, Sri Venkateswara National Park, Tirupati Forest Division

Table 3: List of speakers

No.	Name	Affiliation
1	Lakshminarasimha R	Consultant, Zoo Science and Conservation Planning
2	Maria Thaker	Professor, Centre for Ecological Sciences, IISc
3	Paul Rose	Senior Researcher, University of Exeter, UK
4	Sindhu Radhakrishna	Professor, National Institute of Advanced Studies, Bengaluru
5	Divya Uma	Associate Professor, Azim Premji University, Bengaluru
6	Gowri Mallapur	Director, GaiaMitra Collective Foundation
7	Priyanka Adhikari	Teaching Assistant, GaiaMitra Collective Foundation

B Pre- and Post-course Assessment

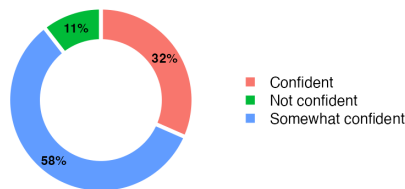
Animal Behaviour Module

Zoo Science Course

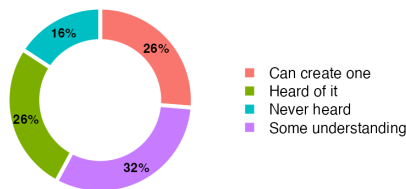
Pre-course baseline experience

Values shown as percentage of total responses (n = 19)

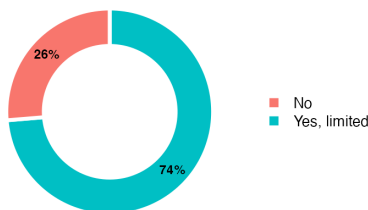
Behaviour identification



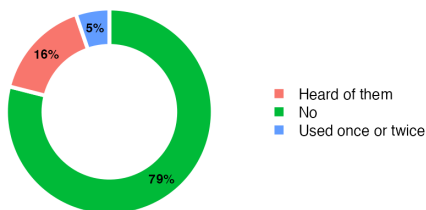
Ethogram familiarity



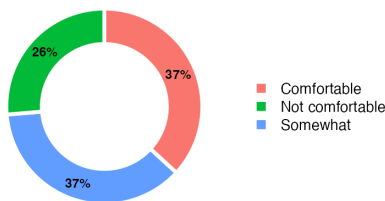
Structured sampling



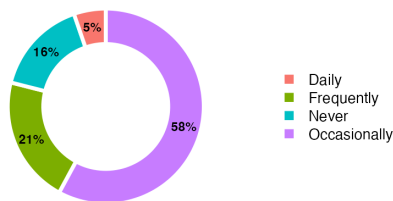
Digital tools



Data / R comfort



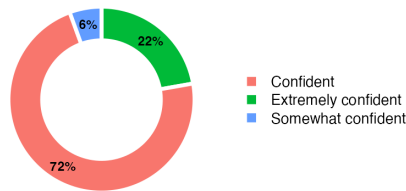
Systematic recording



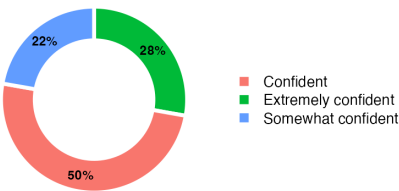
Post-course confidence and application

Values shown as percentage of total responses (n = 18)

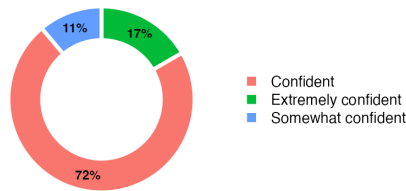
Behaviour identification



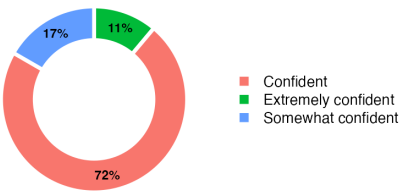
Ethogram use



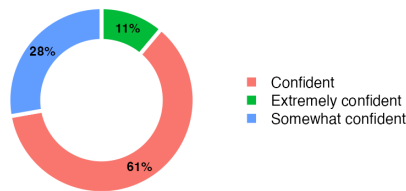
Sampling methods



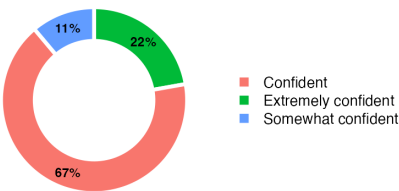
Stress / abnormal behaviour



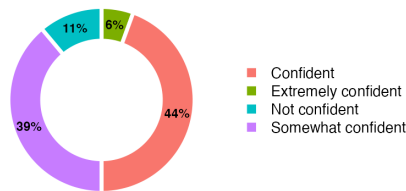
Welfare interpretation



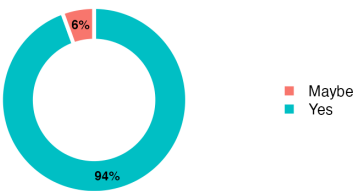
ZooMonitor



R analysis

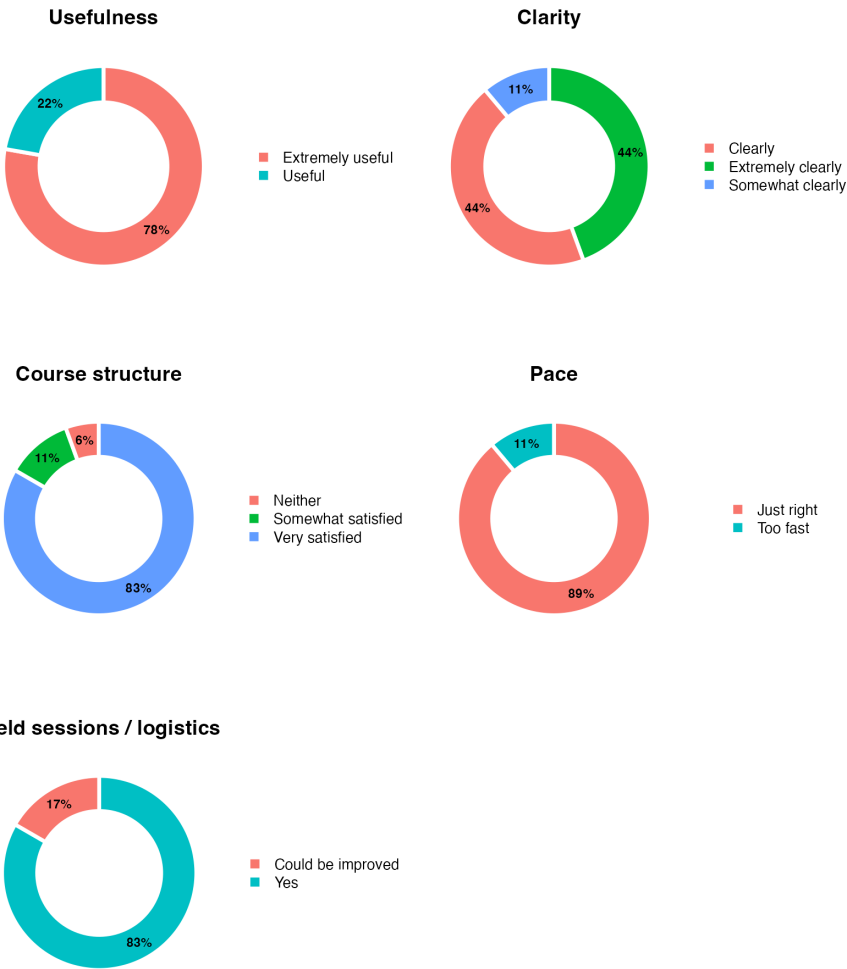


Ready to apply



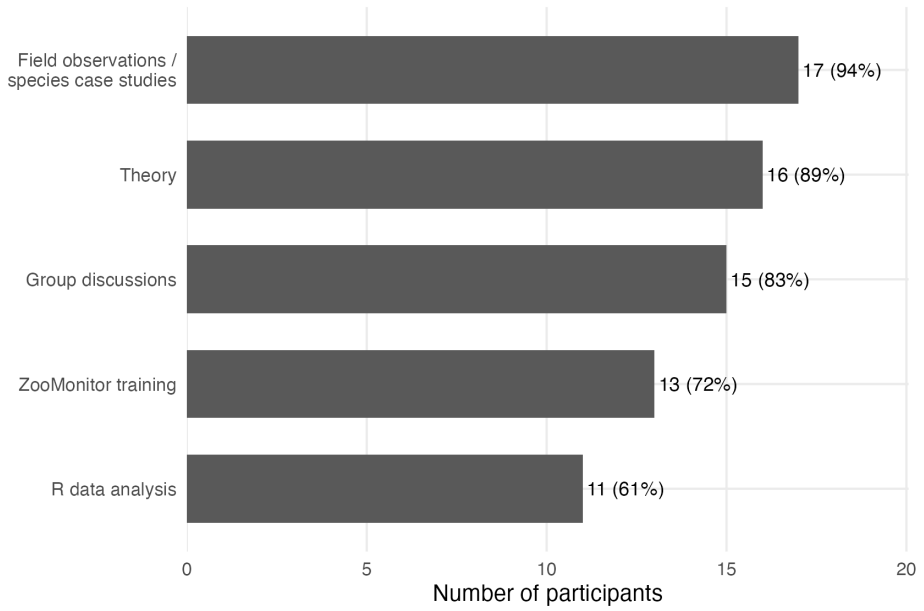
Post-course evaluation

Values shown as percentage of total responses (n = 18)



Course components identified as most helpful

Multiple responses allowed (n = 18)



C Reliability and Observer Agreement

Within-Observer and Between-Observer Reliability

Illustrative R Scripts for Behavioural Research

Zoo Science Course – Animal Behaviour Module

Introduction

Reliable behavioural data form the foundation of behavioural research and welfare assessment. Before behavioural observations can be interpreted confidently, it is essential to demonstrate that behaviours are being recorded consistently, both by the same observer over time and by different observers working independently.

This practical introduces four commonly used approaches for assessing observer reliability:

1. **Within-observer reliability** using Pearson's correlation.
2. **Between-observer reliability** using Pearson's correlation.
3. **Index of Concordance** for simple agreement.
4. **Cohen's Kappa coefficient**, which accounts for agreement expected by chance.

The examples below use simulated datasets for demonstration purposes.

```
library(tidyverse)

set.seed(123)
```

1. Within-observer Reliability

The same observer scores the same ten video clips on two independent occasions.

```
true_duration <- rnorm(10, mean = 20, sd = 1)

A_trial1 <- true_duration + rnorm(10, 0, 2)
A_trial2 <- true_duration + rnorm(10, 0, 2)

within_df <- tibble(
  clip = 1:10,
  trial1 = A_trial1,
  trial2 = A_trial2
)

within_df
```

```
# A tibble: 10 × 3
  clip trial1 trial2
<int> <dbl> <dbl>
1     1     21.9  17.3
2     2     20.5  19.3
3     3     22.4  19.5
4     4     20.3  18.6
5     5     19.0  18.9
6     6     25.3  18.3
7     7     21.5  22.1
8     8     14.8  19.0
9     9     20.7  17.0
10    10     18.6  22.1
```

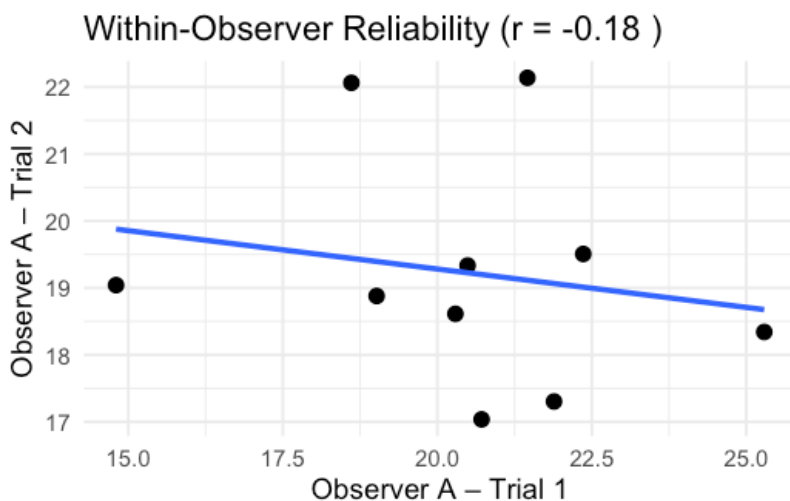
Calculate Pearson's correlation coefficient.

```
within_r <- cor(within_df$trial1, within_df$trial2)
within_r
```

```
[1] -0.1832726
```

Visualise agreement between the two scoring sessions.

```
ggplot(within_df, aes(trial1, trial2)) +
  geom_point(size = 3) +
  geom_smooth(method = "lm", se = FALSE) +
  labs(
    title = paste(
      "Within-Observer Reliability (r =",
      round(within_r, 2), ")"
    ),
    x = "Observer A – Trial 1",
    y = "Observer A – Trial 2"
  ) +
  theme_minimal(base_size = 14)
```



Interpretation

- High correlation indicates that the observer is consistent across repeated scoring sessions.
- Low correlation may indicate observer fatigue, ambiguous behavioural definitions, or inadequate observer training.
- Even when only one observer collects data, within-observer reliability should be evaluated.

2. Between-observer Reliability

Two observers independently score the same behavioural recordings.

```
true_duration <- rnorm(10, mean = 15, sd = 2)

obs_A <- true_duration + rnorm(10,0,2)
obs_B <- true_duration + rnorm(10,0,2)

between_df <- tibble(
  clip = 1:10,
  obsA = obs_A,
  obsB = obs_B
)

between_df
```

```
# A tibble: 10 × 3
  clip obsA obsB
<int> <dbl> <dbl>
1     1  14.5  16.4
2     2  14.0  14.4
3     3  14.3  16.7
4     4  21.1  19.5
5     5  19.1  16.2
6     6  14.1  19.4
7     7  15.3  13.0
8     8  13.9  16.0
9     9  15.9  14.6
10    10  14.1  14.7
```

Calculate the correlation between observers.

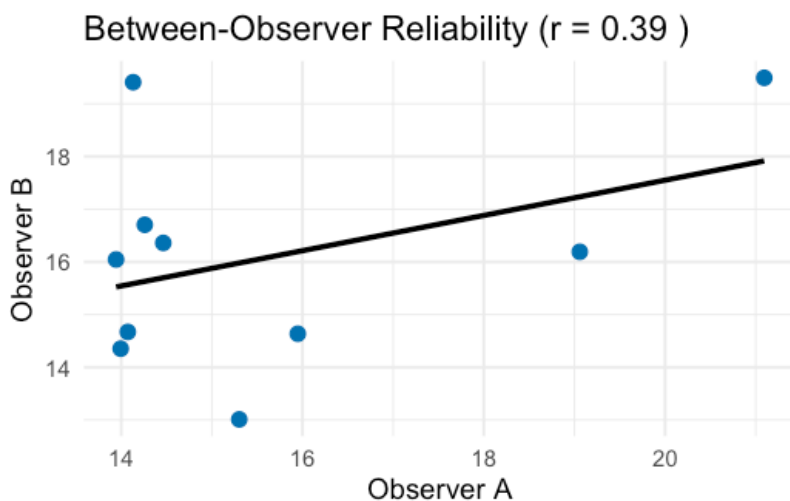
```
between_r <- cor(between_df$obsA,
                 between_df$obsB)
```

```
between_r
```

```
[1] 0.3947034
```

Visualise observer agreement.

```
ggplot(between_df,
       aes(obsA,obsB))+
  geom_point(size=3,
            colour="#0072B2")+
  geom_smooth(method="lm",
            se=FALSE,
            colour="black")+
  labs(
    title=paste(
      "Between-Observer Reliability (r =",
      round(between_r,2),")"),
    x="Observer A",
    y="Observer B"
  )+
  theme_minimal(base_size=14)
```



Interpretation

- High correlation indicates a shared understanding of behavioural definitions.
- Low correlation suggests differences in interpretation or an inadequately defined ethogram.
- Observer calibration should always be performed before commencing formal behavioural observations.

3. Index of Concordance

Correlation is suitable for continuous variables such as behavioural duration. When behaviours are scored as **present (1)** or **absent (0)**, simple agreement can be quantified using the **Index of Concordance**.

```
set.seed(123)

obsA <- sample(c(0,1),
               30,
               replace=TRUE)

obsB <- sample(c(0,1),
               30,
               replace=TRUE)

df <- tibble(
```

```

    Observation = 1:30,
    ObserverA = obsA,
    ObserverB = obsB
  )
df

```

```

# A tibble: 30 × 3
  Observation ObserverA ObserverB
    <int>      <dbl>      <dbl>
1         1         0         0
2         2         0         1
3         3         0         0
4         4         1         1
5         5         0         1
6         6         1         0
7         7         1         0
8         8         1         0
9         9         0         0
10        10         0         1
# i 20 more rows

```

Calculate the proportion of observations on which both observers agree.

```

A <- sum(df$ObserverA==df$ObserverB)
D <- sum(df$ObserverA!=df$ObserverB)

index_concordance <- A/(A+D)

index_concordance

```

```
[1] 0.4666667
```

Interpretation

The Index of Concordance varies between **0** and **1**.

- **1** indicates complete agreement.
- **0** indicates complete disagreement.

A limitation of this index is that it does not account for agreement expected purely by chance.

4. Cohen's Kappa Coefficient

Cohen's Kappa adjusts observed agreement by removing agreement expected by chance.

First consider two observers with random classifications.

```

set.seed(123)

obsA <- sample(c(0,1),
               30,
               replace=TRUE)

obsB <- sample(c(0,1),
               30,
               replace=TRUE)

df <- tibble(
  A=obsA,
  B=obsB
)

df

```

```

# A tibble: 30 × 2
      A     B
  <dbl> <dbl>
1     0     0
2     0     1
3     0     0
4     1     1
5     0     1
6     1     0
7     1     0
8     1     0
9     0     0
10    0     1
# i 20 more rows

```

Calculate Cohen's Kappa.

```

O <- mean(df$A==df$B)

pA1 <- mean(df$A==1)
pA0 <- mean(df$A==0)

pB1 <- mean(df$B==1)
pB0 <- mean(df$B==0)

C <- (pA1*pB1)+(pA0*pB0)

kappa <- (O-C)/(1-C)

kappa

```



```
[1] -0.1059908
```

Now simulate two observers who agree approximately **80%** of the time.

```
set.seed(1)

obsA <- sample(c(0,1),
               30,
               replace=TRUE)

obsB <- ifelse(
  runif(30)<0.8,
  obsA,
  1-obsA
)

df <- tibble(
  A=obsA,
  B=obsB
)

df
```

```
# A tibble: 30 × 2
      A     B
  <dbl> <dbl>
1     0     0
2     1     1
3     0     0
4     0     0
5     1     0
6     0     0
7     0     0
8     0     0
9     1     1
10    1     1
# i 20 more rows
```

Calculate Cohen's Kappa again.

```
0 <- mean(df$A==df$B)

pA1 <- mean(df$A==1)
pA0 <- mean(df$A==0)

pB1 <- mean(df$B==1)
```

```
pB0 <- mean(df$B==0)
C <- (pA1*pB1)+(pA0*pB0)
kappa <- (0-C)/(1-C)
kappa
```

```
[1] 0.7804878
```

Interpretation

Unlike simple agreement, Cohen's Kappa accounts for chance agreement.

A commonly used interpretation is:

Kappa	Interpretation
< 0.00	Poor
0.00–0.20	Slight
0.21–0.40	Fair
0.41–0.60	Moderate
0.61–0.80	Substantial
0.81–1.00	Almost perfect

D Statistical Power in Behavioural Studies

Statistical Power in Behavioural Studies

Simulation-based Power Analysis for Pacing Behaviour

Zoo Science Course – Animal Behaviour Module

Introduction

This practical demonstrates how statistical power affects behavioural research in zoos. The example uses simulated data to compare pacing behaviour between two groups:

- a **control group**, with baseline pacing at 30% of observation time;
- an **enrichment group**, where pacing is reduced after an intervention.

For each simulation, random pacing percentages are generated for both groups, a t-test is performed, and the result is recorded as successful if the effect is detected at *begin* : *math* : *text* $p < 0.05$ *end* : *math* : *text*.

```
library(tidyverse)
```

Simulation function

```
simulate_pacing <- function(  
  n_per_group = 5,  
  effect_size = -0.10,  
  sd = 0.10,  
  runs = 1000  
) {  
  results <- replicate(runs, {  
  
    control <- rnorm(  
      n_per_group,  
      mean = 0.30,  
      sd = sd  
    )  
  
    enrich <- rnorm(  
      n_per_group,  
      mean = 0.30 + effect_size,  
      sd = sd  
    )  
  
    test <- t.test(control, enrich)
```

```

    test$p.value < 0.05
  })

  mean(results)
}

```

1. Power curve: effect of sample size

This section examines how statistical power changes as the number of animals per group increases.

```

sample_sizes <- 3:20

power_curve <- tibble(
  n = sample_sizes,
  power = map_dbl(
    sample_sizes,
    ~ simulate_pacing(n_per_group = .x)
  )
)

power_curve

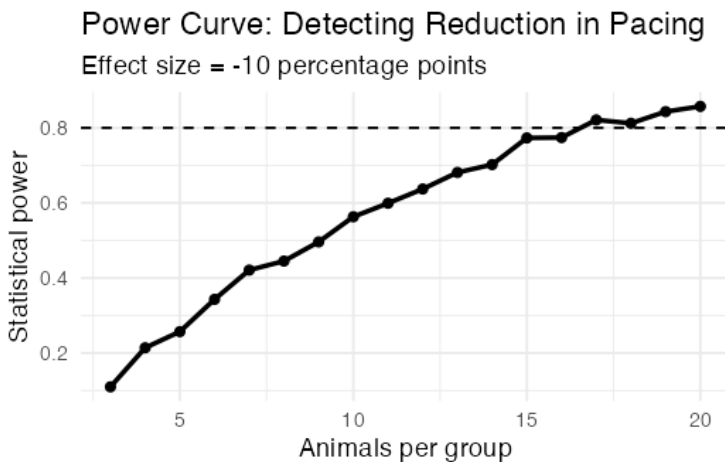
```

```

# A tibble: 18 × 2
   n power
<int> <dbl>
1     3 0.11
2     4 0.214
3     5 0.257
4     6 0.343
5     7 0.421
6     8 0.445
7     9 0.496
8    10 0.563
9    11 0.599
10   12 0.637
11   13 0.681
12   14 0.702
13   15 0.773
14   16 0.774
15   17 0.821
16   18 0.812
17   19 0.843
18   20 0.857

```

```
power_curve %>%
  ggplot(aes(x = n, y = power)) +
  geom_line(linewidth = 1.2) +
  geom_point(size = 2) +
  geom_hline(
    yintercept = 0.8,
    linetype = "dashed"
  ) +
  labs(
    title = "Power Curve: Detecting Reduction in Pacing",
    subtitle = "Effect size = -10 percentage points",
    x = "Animals per group",
    y = "Statistical power"
  ) +
  theme_minimal(base_size = 14)
```



Interpretation

- Small sample sizes often fail to detect real behavioural effects.
- Power increases as the number of animals per group increases.
- The dashed line represents 80% power, a commonly used planning target.
- Behavioural studies with small samples should be interpreted cautiously.

2. Power sensitivity to effect size

This section examines how power changes depending on the magnitude of the behavioural effect.

```

effect_sizes <- seq(-0.20, 0, by = 0.02)

power_by_effect <- tibble(
  effect = effect_sizes,
  power = map_dbl(
    effect_sizes,
    ~ simulate_pacing(effect_size = .x)
  )
)

power_by_effect

```

```

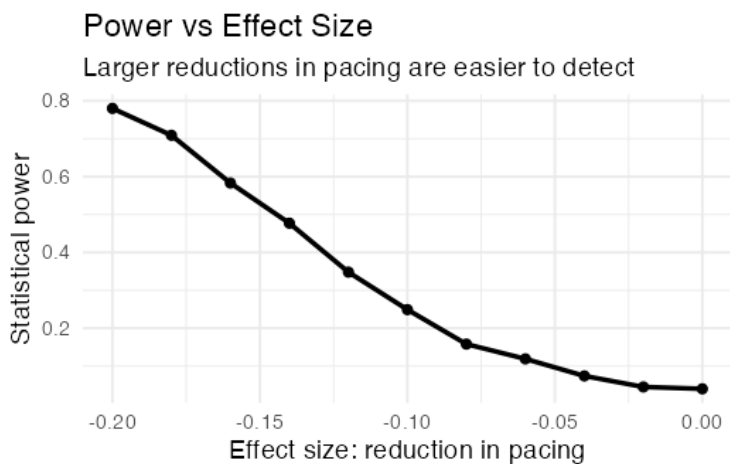
# A tibble: 11 × 2
  effect power
  <dbl> <dbl>
1 -0.2   0.78
2 -0.18  0.709
3 -0.16  0.583
4 -0.14  0.477
5 -0.12  0.348
6 -0.1   0.249
7 -0.08  0.158
8 -0.06  0.119
9 -0.04  0.074
10 -0.02 0.045
11 0     0.04

```

```

power_by_effect %>%
  ggplot(aes(x = effect, y = power)) +
  geom_line(linewidth = 1.2) +
  geom_point(size = 2) +
  labs(
    title = "Power vs Effect Size",
    subtitle = "Larger reductions in pacing are easier to detect",
    x = "Effect size: reduction in pacing",
    y = "Statistical power"
  ) +
  theme_minimal(base_size = 14)

```



Interpretation

- Large behavioural changes are easier to detect statistically.
- Small improvements may be biologically meaningful but statistically difficult to detect.
- Pilot studies are useful for estimating realistic effect sizes before designing full studies.

3. Effect of behavioural variability

This section examines how variation among animals affects statistical power.

```
sd_values <- seq(0.05, 0.30, by = 0.05)
```

```
power_by_sd <- tibble(
  sd = sd_values,
  power = map_dbl(
    sd_values,
    ~ simulate_pacing(sd = .x)
  )
)
```

```
power_by_sd
```

```
# A tibble: 6 × 2
  sd power
<dbl> <dbl>
1  0.05 0.76
```



```

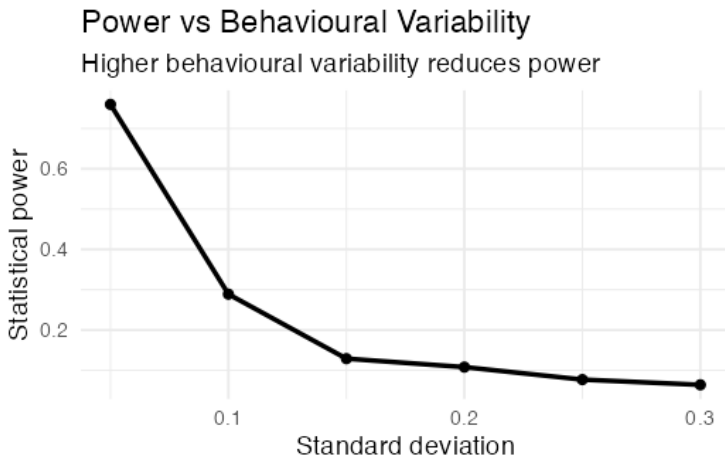
2 0.1 0.289
3 0.15 0.129
4 0.2 0.108
5 0.25 0.077
6 0.3 0.064

```

```

power_by_sd %>%
  ggplot(aes(x = sd, y = power)) +
  geom_line(linewidth = 1.2) +
  geom_point(size = 2) +
  labs(
    title = "Power vs Behavioural Variability",
    subtitle = "Higher behavioural variability reduces power",
    x = "Standard deviation",
    y = "Statistical power"
  ) +
  theme_minimal(base_size = 14)

```



Interpretation

- As behavioural variability increases, statistical power decreases.
- Studies of highly variable behaviours require larger samples or repeated observations.
- Sources of variability may include individual differences, weather, time of day, visitors, enclosure conditions, and keeper routines.

4. Example power estimates

This section compares power for selected sample sizes.

```
tibble(  
  animals_per_group = c(5, 10, 15, 20),  
  estimated_power = c(  
    simulate_pacing(n_per_group = 5),  
    simulate_pacing(n_per_group = 10),  
    simulate_pacing(n_per_group = 15),  
    simulate_pacing(n_per_group = 20)  
  )  
)
```

```
# A tibble: 4 × 2  
  animals_per_group estimated_power  
      <dbl>         <dbl>  
1             5         0.268  
2            10         0.551  
3            15         0.786  
4            20         0.874
```

Key Take-home Messages

- Statistical power is the probability that a study will detect a real effect when it exists.
- Power increases with larger sample size, larger effect size, and lower behavioural variability.
- Underpowered behavioural studies can miss meaningful welfare improvements.
- Pilot data help estimate realistic variability and effect sizes.
- Power analysis should be considered during study design, not after data collection.



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