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## Role of Assisted and Advanced Reproductive Technologies in Food Security and Biodiversity Conservation

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### Abstract:

The accelerating loss of biodiversity and increasing pressure on global food security have intensified interest in assisted reproductive technologies (ARTs) and advanced assisted reproductive technologies (aARTs) as tools for sustainable livestock production and wildlife conservation. Human-driven environmental changes have reduced population sizes and genetic diversity in many species, threatening their long-term survival and adaptive potential. In parallel, rising global demand for animal products and climate-related challenges necessitate improved reproductive efficiency in agricultural systems. ARTs, including artificial insemination (AI), in vitro fertilization (IVF), embryo transfer (ET), and cryopreservation, play a significant role in enhancing reproductive performance, facilitating genetic exchange, and preserving valuable germplasm. Advanced approaches such as somatic cell nuclear transfer (SCNT) and induced pluripotent stem cell (iPSC)-based gametogenesis further extend reproductive possibilities, particularly for endangered species with limited access to viable gametes. Biobanking and cryopreservation technologies provide long-term preservation of semen, oocytes, embryos, and somatic tissues, supporting future genetic rescue and restoration programs. Although many ARTs are technically well established in livestock species, their application in wildlife conservation remains limited due to insufficient species-specific reproductive knowledge, lack of optimized protocols, logistical challenges, and welfare concerns. The effectiveness of these technologies varies depending on biological, technical, ethical, and socio-economic factors. Success in livestock systems is commonly evaluated through improved productivity and reproductive efficiency, whereas conservation programs prioritize maintenance of genetic diversity, demographic recovery, and establishment of self-sustaining populations. Continued refinement of ARTs and integration of emerging biotechnologies are expected to strengthen both global food security and biodiversity conservation efforts in the future.

**Keywords:** Assisted reproductive technologies (ARTs), Wildlife conservation, Cryopreservation and biobanking, Biodiversity conservation

### Introduction:

The Earth is experiencing a profound loss of biodiversity driven predominantly by human

activities, constituting a sixth mass-extinction event that threatens the persistence of many taxa worldwide (Ceballos *et al.*, 2015; Ceballos and Ehrlich, 2018). This accelerating decline reduces population sizes and genetic diversity, undermining both the ecological functions of species and their capacity to adapt to future environmental change. Concurrently, global food security faces mounting pressure from population growth and climate change, increasing the importance of efficient and resilient reproductive management in agricultural species. Assisted reproductive technologies (ART) and their advanced counterparts (aART) therefore occupy a dual and complementary role: they can enhance productivity and genetic management in livestock for food security, and they can serve as tools for conserving and restoring threatened wildlife populations, either directly through propagation or indirectly via genome resource banking and future genetic rescue strategies (Swanson, 2006; Bolton *et al.*, 2022; Kumar *et al.*, 2025a). Assisted reproductive technologies (ART) encompass techniques that utilise gametes or embryos to produce offspring, including artificial insemination (AI), in vitro fertilization (IVF), and embryo transfer (ET) (Howard *et al.*, 2016; Briski and Salamone 2022). Advanced ART (aART) refers to more recent and experimental methods that derive gametes or embryos from somatic cells or pluripotent intermediates such as somatic cell nuclear transfer (SCNT) and induced

pluripotent stem cell (iPSC)-based gametogenesis and that may enable propagation when traditional gamete sources are unavailable (Gómez *et al.*, 2004; Hikabe *et al.*, 2016). Biobanking or cryobanking denotes the long-term storage of viable gametes, embryos, tissues, or somatic cells at ultra-low temperatures to preserve genetic resources for future use (Comizzoli and Wildt, 2017). Success in applying reproductive technologies is context dependent and should be evaluated using multiple metrics that reflect the differing goals of livestock and wildlife programmes. For livestock and food-security applications, key outcomes include reliable production of viable offspring, improved reproductive efficiency, and measurable gains in productivity or desired genetic traits (Andrabi and Mawxell, 2007). For conservation applications, success metrics include retention or restoration of genetic diversity, establishment of self-sustaining populations, successful reintroduction or demographic recovery, and minimisation of welfare harms to individual animals (Harrington *et al.*, 2013; Brønstad *et al.*, 2016; Field *et al.*, 2019). Across both domains, the feasibility and ethical acceptability of interventions depend critically on species-specific reproductive biology, availability of baseline data, technical efficacy of protocols, and the socio-political and economic frameworks within which programmes operate (Herrick, 2019).

**Overview of ARTs: Methods, Metrics, and Technical Readiness**

Method	Brief Description	Conservation and Livestock Relevance	Technical Readiness and Constraints
<b>Artificial Insemination (AI)</b>	Deposition of processed semen into the female reproductive tract by artificial means.	Widely used in livestock to enable genetic exchange without animal movement; in wildlife, AI can connect ex situ and in situ populations and assist breeding where natural pairing fails.	High readiness for many domestic species; for wildlife, application is limited — only ~62 mammal species propagated by AI and 35 with frozen semen, often as isolated events — due to lack of species-specific reproductive knowledge and limited study access (Swanson and Penfold, 2018).
<b>Semen/Oocyte/ Embryo Cryopreservation</b>	Cooling gametes or embryos to ultra-low temperatures for long-term storage (biobanking).	Forms the backbone of biobanks (Frozen Zoo, EAZA biobank) to preserve genetic diversity and enable future genetic exchange between fragmented populations without moving animals.	Technically mature for semen in many livestock; oocyte/embryo cryopreservation often requires refinement for many wildlife taxa; vitrification shows promise as cost-effective technique for wildlife biobanking (Bhat <i>et al.</i> , 2021).
<b>IVF/IVP (in vitro fertilisation /production)</b>	Laboratory fertilisation of oocytes by sperm and culture of resulting embryos.	Standard in livestock breeding; increasingly applied in wildlife (e.g., cervids, felids) where species-specific protocols are being developed to support ex situ propagation and genetic management.	Feasible in some wildlife species but requires species-specific optimisation and baseline reproductive data; success variable and often limited by oocyte quality and lab expertise (Korzekwa <i>et al.</i> , 2021; Kumar <i>et</i>

			al., 2025b).
<b>Embryo Transfer (ET)</b>	Placement of embryos into recipient females to establish pregnancy.	Used in livestock for propagation and genetic dissemination; in conservation, ET can propagate valuable donor genetics using surrogate recipients and link ex situ and in situ populations.	Technically established in livestock; in wildlife, limited by recipient availability, need for synchronization protocols, and perinatal welfare considerations.

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