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ARTICLES

Ethics at the Edge of Extinction: Assisted Reproductive Technologies (ART) in the Conservation of the Northern White Rhino

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Abstract
Since assisted reproductive technologies (ART) are becoming increasingly important in wildlife conservation breeding programs, we need to discuss their implications to ensure their responsible use regarding the environment, the animals, and the people involved. In this article, we seek to contribute to the ongoing ethical and philosophical debate on ART in conservation by discussing the current attempt to save the northern white rhino (*Ceratotherium simum cottoni*, NWR) from extinction. Only two female NWRs are known to the world, both unable to carry a pregnancy, and the last chance to avoid sure extinction relies on pushing the boundaries of contemporary science through the use of advanced ART and stem cell-associated techniques. The attempt to save the NWR constitutes a valuable testbed for assessing the use of ART in conservation and an occasion for identifying possible critical issues. It touches upon several ethically relevant points—that we identify and organize in an Ethical Matrix—such as the need to guarantee animal welfare, and it provides the opportunity to discuss some significant questions related to conservation. For instance, how far is it legitimate to go in trying to save a taxon? Is using sophisticated technologies to remedy anthropogenic harm a part of the problem rather than the solution?

Keywords Conservation ethics · Ethical matrix · Northern white rhino · Assisted reproductive techniques · Ethics of assisted reproductive techniques

Introduction

Conservation breeding programs are poised to be pivotal in addressing the ongoing mass extinction event, with assisted reproductive technologies (ART) becoming increasingly crucial in assisting the establishment of self-sustaining populations for

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reintroduction or as genetic reserves (Bolton et al., 2022; Comizzoli et al., 2019; Herrick, 2019; Hildebrandt et al., 2021a; Lueders & Allen, 2020). This context calls for a deeper discussion of the ethical and philosophical implications of ART in conservation (Biasetti et al., 2022; Bolton et al., 2022; Mastromonaco, 2024). We need to figure out how to ensure their responsible use concerning the environment, the animals, and the people involved. At the same time, we also need to consider their significance: Why are we resorting to them? What is their place in biodiversity conservation? How do they redefine our concepts of reproduction and extinction?

In this article, we seek to contribute to the ongoing ethical and philosophical debate on ART in conservation by discussing current efforts to save the northern white rhino (*Ceratotherium simum cottoni*, NWR) from extinction. Only two female NWRs remain, both unable to carry a pregnancy, and the last chance to avoid certain extinction relies on ART—including ovum-pick-up (OPU), intracytoplasmic sperm injection (ICSI), and embryo transfer—and in vitro gametogenesis from induced pluripotent stem cells (iPSCs) derived from reprogrammed fibroblasts (Hildebrandt et al., 2021a). This case constitutes a valuable testbed for assessing the use of ART in conservation and identifying potential critical issues. It touches on several ethically significant points and provides an opportunity to address broader questions (Saragusty et al., 2016; Ryder, 2020; Callender, 2021). For instance, how far is it legitimate to go in attempting to save a taxon? Is using sophisticated technologies to mitigate anthropogenic harm to biodiversity part of the problem rather than the solution?

To collect and organize for the discussion the ethically relevant issues involved we use a version of the Ethical Matrix (Mepham, 1996, EM) specifically tailored to conservation (Biasetti & de Mori, 2021).

Methodology and Case Study

Several conceptual tools and methodologies are available for analyzing the ethical impact of biotechnology in conservation (for instance, Biasetti et al., 2022; Millar et al., 2007; Sandler et al., 2021). Among these, the EM stands out for its versatility, its ability to unpack complex cases, and its capacity to systematize ethically relevant issues. The EM does not operates under a single dominant ethical theory, but through a structured framework that acknowledges multiple potential stakeholders—such as ecological entities, animals, and humans—and organizes their value demands under general ethical principles. Importantly, these general ethical principles are not arbitrary but reflect widely shared tenets of common morality, such as well-being, fairness, and autonomy (Beauchamp, 2010; Mepham, 2000). In this way, the EM strives to be both pluralistic and comprehensive, possibly ensuring a balanced consideration of diverse ethical requirements and stakeholder perspectives (Biasetti et al., 2020; Kaiser et al., 2007; Kermisch & Depaus, 2018; Millar & Tomkins, 2007; Oughton et al., 2004; Smith, 2022).

A significant advantage of employing conceptual tools such as the EM is the ability to apply standardized methods. However, conservationists operate from different underlying narratives and may prioritize values in varying ways (McShane, 2011; Gamborg et al., 2012; Jax, 2024). Consequently, even when the same tools are employed, interpretations and outcomes can differ. The value of these tools, therefore, lies not in determining "correct" conclusions but in making the reasoning behind decisions explicit and transparent. This approach prevents the concealment of value judgments and underlying assumptions—whether intentional or inadvertent—by presenting them openly for public scrutiny. Conservationists should more clearly articulate their values and the rationale behind ethically significant decisions, enhancing transparency not only to ensure public accountability but also to strengthen the effectiveness of their efforts. (Stuart & Rizzolo, 2019).

As a starting template for our analysis we used a version of the EM adapted for conservation (Biasetti & de Mori, 2021, Table 1).

Relevant Facts

By the IUCN, the NWR is regarded as a subspecies of the white rhinoceros species. Its original habitat spanned through what are presently northwestern Uganda, southern Chad, southwestern South Sudan, the eastern Central African Republic, and the northeastern Democratic Republic of Congo (Sidney, 1965), although historical clues suggest that the natural range of the taxon was once wider (Gowers, 1920). Starting from the 1960s, the overall population began decreasing due to poaching and the reoccurring political unrest, definitively collapsing during the first years of the present millennium. The last known population living in the wild resided in Garamba National Park and went from 22 individuals in 2003 to only 4 in 2005 (Emslie, 2004, 2006). No live NWRs were ever reported since 2006, and no spoor or dung since 2007. Afterward, the NWR was assessed as "possibly extinct in the wild" (Emslie, 2020a).

In the same years, the captive population also dwindled, with the last calf born being female Fatu in 2000 at Dvůr Králové Zoo in Czechia. White rhinos exhibit a low reproductive rate in captivity (Hermes et al., 2012), and by 2009, the four remaining individuals believed capable of breeding were relocated from Dvůr Králové Zoo to Ol Pejeta Conservancy in Kenya. Despite efforts, no calves were ever born, and following the death of the last male, Sudan, in 2018, only two females, Najin (born 1989) and her daughter Fatu, remain as the last of their kind. While artificial insemination has already been successful in white rhinos (Hildebrandt et al., 2007), neither Najin nor Fatu are capable of achieving pregnancy due to reproductive pathologies and, in Najin's case, due to problems with her hind legs. For these reasons, the NWR is considered "functionally extinct" (Emslie, 2020a). Nevertheless, there is still a chance to prevent ultimate extinction: by using biomaterial from both living and deceased individuals, methods exist to produce embryos that can be transferred into recipient cows of the southern white rhino (*Ceratotherium simum simum*, SWR), a closely related subspecies.

One first method is to collect oocytes from the NWR females via OPU and fertilize them via ICSI—the injection of a single sperm cell into a matured oocyte using a micromanipulator (Hildebrandt et al. 2023). Despite challenges posed by the Covid-19 pandemic (Hildebrandt et al., 2021b), this method has consistently

Table 1 General EM

	Well-being	Autonomy	Fairness
Biodiversity	Conservation	Preservation of naturalness	Equal treatment in relation to conservation
Animals	Health and functioning Absence of negative affective states and allowance of positive ones	Living natural lives and species-specific behaviors	Equal treatment in relation to welfare
People	Psychological and physiological welfare Sustainable social, economic, and cultural welfare	Freedom of choice Capacity to exercise the various fundamental aspects of one's own *persona* Self-determination	Equal and fair treatment

yielded good results, producing 30 cryopreserved NWR embryos by November 2024 (Korody & Hildebrandt, 2024). The primary limitation, however, lies in the restricted gene pool. On the female side, only Fatu has contributed oocytes, which, when fertilized via ICSI, have developed into blastocysts. Najin, due to age and health issues, has been excluded from the OPU program (Biasetti et al., 2023). On the male side, semen from five NWR bulls is available, but due to quality issues, only that of two individuals, Suni and Angalifu, has been used so far (Korody & Hildebrandt, 2024).

The second method could partially address these limitations by generating artificial gametes from iPSCs derived from reprogrammed fibroblasts (Hildebrandt et al. 2018, 2021a). This approach could expand the genetic pool to include all NWRs with cryopreserved tissue samples. However, this methodology is still being developed for NWR (Zywitza 2022; Hayashi, 2022). While iPSCs have been successfully created for various taxa (Stanton et al., 2019), including NWR (Ben-Nun et al., 2015), viable offspring from iPSC-derived gametes have only been achieved in mice (Hayashi et al., 2012; Hayashi & Saitou, 2013).

The ultimate goal of the project is to establish a self-sustaining and genetically healthy NWR population to be reintroduced into the wild. As a significant ramification, the data collected and the techniques and methodologies developed could likely contribute to the conservation of other rhinoceros taxa and possibly other terrestrial mammalian.

The Case-Specific EM

By applying the general template (Table 1) to the case, we built a specific EM for the project (Table 2).

The moral requirements in the EM should not be viewed as absolute. Rather, they represent values and demands that necessitate further analysis and balancing—especially when they cannot be fully satisfied simultaneously. The EM provides a starting point for discussing three key issues: (a) Does the project contribute positively to biodiversity conservation? (b) Does it respect the animals involved? (c) Does it respect people?

Biodiversity

Biodiversity here includes both biodiversity itself and its components directly or potentially affected by the projects—the NWR taxon, SWR taxon, the other extant taxa in the *Rhinocerotidae* family, etc.

Conservation

One primary reason to conserve taxa is their historical-naturalistic value. Extinction is not per se morally wrong—components of biodiversity are continuously lost in evolution, and, in all these cases, nothing morally bad is happening. However,

Table 2 EM for the ethical assessment of the NWR project

	Well-being	Autonomy	Fairness
Biodiversity	*Conservation* NWR has historical-naturalistic value NWR has ecological value The project could help in the conservation of other rhinos taxa However, the project could be considered problematic if it turns out to be: •A form of conservation obstinacy •In contrast with the mission of conservation (by: stealing the opportunity to learn a lesson from extinction; creating a moral hazard; being backward-looking; being a techno-fix; being hubristic) •Focusing on an irrelevant conservation unit	*Preservation of naturalness* The project does not fully preserve naturalness in its specific meaning of "absence of human interference". However, no conservation actions can truly satisfy this condition The project preserve naturalness according to several other definition of the concept: •Naturalness as integrity •Naturalness as ecological complexity •Naturalness as non-artifactuality •Naturalness as evolutionary descent •Naturalness as authenticity	*Equal treatment in relation to conservation* Rhinos are charismatic animals. In general, charismatic animals receive a disproportionate amount of attention However, rhinos are: •Perhaps the most endangered mammals in the world •A flagship species •An umbrella species •A keystone species The efforts to save the NWR could potentially attract positive attention to biodiversity conservation On the other hand, the project could backfire on conservation if it fails to meet high ethical standards
Animals	*Health and functioning* Some conditions and procedures may pose a direct or indirect risk of harming the health and function of the animals On the other hand, animals involved in the project are offered superior veterinarian and behavioral screening and care *Absence of negative affective states and allowance of positive ones* Some conditions and procedures may pose a direct or indirect risk of causing negative affective states on the animals	*Living natural lives and species-specific behaviors* Some conditions and procedures may pose a direct or indirect risk of impairing the capacity of the animals to live natural lives and express species-specific behaviors On the other hand, some animals involved in the project are offered the possibility to exercise parts of their behavioral repertoire currently precluded	*Equal treatment in relation to welfare* Animals in conservation programs are treated differently than similar animals under different conditions This differential treatment may be counterbalanced by the possibile benefits in terms of superior screening and care

Table 2 (continued)

	Well-being	Autonomy	Fairness
People	*Psychological and physiological welfare* Handling large animals such as rhinos can involve some risks for people If animals are harmed, the people who have established emotional bonds with them would suffer *Sustainable social, economic, and cultural welfare* Reintroducing a NWR population could provide opportunities for sustainable economic development of local communities through ecotourism	*Capacity to exercise the various fundamental aspects of one's own persona* The execution of the project provides plenty of opportunities for professional growth, knowledge transfer, and capacity building among participants NWR is a source of relational values (aesthetic, reverential, and scientific values) NWR is a source of existential value	*Equal and fair treatment* As for every other conservation project, there is the need to assure fair and equitable benefit-sharing measures, and participatory decision making processes A critical concern in case of success will be assuring a fair distribution of the benefits created by the reintroduction of the NWR population

the NWR is not a loser in evolution: its only flaw is that its skin is not bulletproof. If it were to disappear today, we would lose a unique and unrepeatable product of evolution for anthropogenic reasons. This could be considered morally wrong for a variety of reasons (De Beaux, 1932 [1930]; Soulé, 1985; Katz, 1993; Carter, 2010; Wienhues et al. 2023).

The same reasoning can be extended to the entire *Rhinocerotidae* family. Rhinos are probably the most endangered group of megavertebrates (www.iucn.org). Of the five extant species, three—the Javan rhino (*Rhinoceros sondaicus*), the Sumatran rhino (*Dicerorhinus sumatrensis*), and the black rhino (*Diceros bicornis*)—are classified as "critically endangered". SWR populations are decreasing, and even the least concerning species—the Greater one-horned rhino (*Rhinoceros unicornis*)—is still considered "vulnerable". Through this project, it is possible to accumulate knowledge, develop and refine technologies, and design strategies that can be adapted for the conservation of all the *Rhinocerotidae* family, thereby helping to preserve their historical-naturalistic value.

Another kind of value pursued through the project is ecological value. With the anthropogenic disappearance of a taxon, not only a vital branch of the coral of life disappears, but also the ecological relationships it entertained with the rest of the ecosystem. Mega herbivores such as rhinos are important ecosystem engineers (Owen-Smith 1988). White rhinos, in particular, play a crucial role in maintaining the savannah ecosystem (Cromsigt & de Beest, 2014; Waldram et al., 2008) and entertain ecological connections with many other species. For instance, they serve as seed dispersers for plants, sources of feces for insects, hunting platforms for birds, and providers of escape routes from predators for small mammals (Korody & Hildebrandt, 2024). By providing new tools for rhino conservation, the project helps with defending the ecological value of these animals.

Despite this, one could still argue that, from the conservation standpoint, the project is controversial. The reasons could be that: (a) it is conservation obstinacy; (b) it conflicts with the mission of conservation; (c) it focuses on an irrelevant conservation unit.

Conservation Obstinacy

Conservation obstinacy—analogous to therapeutic obstinacy in human medicine—refers to beginning or prolonging a conservation effort even when it is evident or highly probable that it will not yield significant results, leading to a waste of energy, time, funding, and other resources (Biasetti et al., 2022). This often results from a missing or misguided definition of success for a project. For instance, the mere survival of few NRWs in a condition of prolonged dependence on management without a realistic prospect of returning to self-sufficiency, cannot be considered a success. True success in producing NWRs requires more than just the ability to generate embryos. It necessitates: (i) the presence of suitable habitat; (ii) a sufficiently large number of physiologically and behaviorally healthy individuals; (iii) a sufficiently large gene pool; and (iv) the removal of the factors that led to the species' current predicament.

The first requirement can be satisfied, and it is not unimaginable that the second requirement could be met with a sustained effort. The third requirement will be challenging to meet but is not unattainable, thanks to the availability of cryopreserved biomaterials. Success hinges on significant advancements in gamete production from iPSCs. Encouragingly, the SWR population, now the most numerous rhinoceros taxa, originated from a genetic bottleneck of only 20–50 closely related individuals (Emslie, 2020a, 2020b). Furthermore, the cryopreserved material from NWR exhibits greater genetic variability than that found in the existing SWR population (Tunstall et al., 2018). Additionally, future gene-editing technologies could further expand the genetic pool of a future NWR population by recovering genetic material preserved in natural history museum collections (Korody & Hildebrandt, 2024). Nevertheless, this approach may introduce new ethical challenges that warrant careful deliberation.

Concerning the fourth requirement, it is instead not reasonable to imagine that the issue of poaching could be resolved in the short and perhaps even in the medium term. However, the SWR provides an encouraging precedent: despite persistent poaching, its population recovered to sustainable numbers. Additionally, the population of SWRs in Ol Pejeta Conservancy, the area where the first new NWRs will live, has been growing these last few years, similarly as in Ziwa, a conservancy in Uganda (a country of possible reintroduction of the NWR), showing that maintenance of a thriving population is feasible.

Mission of Conservation

Is using sophisticated technologies to mitigate anthropogenic harm to biodiversity part of the problem rather than the solution? In this context, the project could be criticized because it (i) creates a moral hazard; (iii) is backward-looking; (iii) represents a form of techno-fix; and (v) is hubristic.

According to some, the extinction of a species presents an opportunity to reflect on our attitudes and relationship with nature (Minteer, 2014, 2015). Attempting to redefine the boundaries of reproduction and extinction could foster the misconception that environmental problems can be easily and painlessly solved through technology alone. While this approach may yield short-term successes, it is likely to exacerbate the situation in the long run. Therefore, it is crucial to acknowledge and mourn the loss of a species, as this process can help us cultivate virtues such as humility and temperance, fostering a deeper respect for nature. However, the problem with this kind of argument is that, with the current extinction rate, there are already ample opportunities for mourning and reflecting. Given the opportunity to reflect on the many extinctions that are unavoidable, it would be unreasonable to choose to mourn those that can still be averted. Moreover, conservation communication needs opportunities for delivering messages of hope. Reflecting on the mistakes and the tragedies of extinction is certainly important, but insisting on this point beyond due can encourage a sense of hopelessness and tragedy about our capacity to act on behalf of biodiversity.

Another objection could be that the optimism induced by an eventual success could create a moral hazard. A moral hazard occurs when one individual's or group's actions shield others from the potential negative consequences of their behavior, leading to an inefficient increase in risk-taking (Lean, 2024). It is a common accusation against biotechnologies that tries to reverse extinction (for instance, Sherko & Greely 2013; Minteer, 2019). The idea is that having methods such as those provided by ART that can revert the decline of a population could make us reckless and careless. The safety net provided by these technologies may push us to behave like a spoiled child who does not care about her toys knowing that if they break, her parents will fix them. This could have a negative effect on our moral character, and further fuel the attitudes that underlie the current biodiversity crisis. The possibility is real, but it is rather doubtful that the eventual negative effects of this moral hazard could outweigh the benefits produced by the new technologies. After all, this is what we observe for many other "safety nets" that may make us—potentially—behave more recklessly: car insurance, lifeboats, seat belts, etc. In all such cases, the benefits associated are fairly superior to the negative effects that may arise.

In contrast, one might judge the project as conservative and backward-looking—as clinging to a past that cannot be saved, thereby losing sight of the need to better prepare for the future ahead. This ignores that one of the central aspects of the project is the development of new technologies that can be used in situations similar to those of the NWR. ART will not reverse the current biodiversity crisis (Swanson, 2023) but their use in conservation will, nevertheless, become increasingly crucial for the management and recovery of fragmented and small populations, including those of other rhinoceros taxa and mammals (Roth, 2024). From this perspective, the project does not look backward but rather looks forward to the challenges that will come in the future.

However, ART can be judged of being an aggressive form of conservation, a technological shortcut acting on the effects, without remedying the causes (Ryder, 2020). This "techno-fix" argument can be interpreted in two ways. The first is that technological shortcuts, despite the illusion of success they may create in the immediate, are ineffectual in the long run. In this case the argument can be simply rebutted as an undue generalization, especially when criteria for medium and long-term success and their feasibility can be stipulated and discussed as we have done before. A second interpretation would be that technological shortcuts are wrong not because they are ineffectual, but per se. Techno-skepticism in conservation is not so rare and can have several possible explanations. One is the observation that a technologically aggressive style of conservation is born on the same soil that germinated the anthropocentric attitudes that led to the current ecological crisis. However correct this observation may be, it must be still recognized that certain scenarios of imminent extinction can only be reversed by adopting technologically sophisticated interventions. The alternative is to let taxa disappear merely to defend a matter of principle.

This attitude should not be confused with hubris. Hubris is often regarded as the ultimate environmental sin, a key cause of the ongoing environmental crisis. Typically, hubris is understood as a narcissistic form of overconfidence—a reckless arrogance marked by a disregard for sensible limits. It reflects the presumption that we can dismisses the complexity and interconnectedness of the world and consider ourselves above anything else. Because biotechnologies often redraw what we once thought to be insurmountable barriers or natural orders, they are frequently criticized as hubristic. This is also the case with ART used in wildlife conservation—which redefine the ways and possibilities through which reproduction can take place beyond the boundaries set by nature, and allow us to consider species with no reproductively viable individuals as not yet extinct. Yet, two arguments can be raised against this accusation (Cohen, 2014). The first is that the true hubristic act was committed before the intervention of biotechnologies—it was the extermination of the taxa, not the subsequent attempt to reverse the damage. The second is that it is the motivation behind an action, not its technological sophistication, that determines whether it is hubristic. Acts of hubris are characterized by a self-centered, self-aggrandizing attitude—an outlook fundamentally different from the respect, care, and even love for non-human life that underpin conservation efforts, regardless of how technologically advanced they may be.

Irrelevant Conservation Unit

NWR and SWR exhibit some morphological and behavioral differences and have been considered both as sister subspecies and as separate species depending on the species concept adopted (Groves et al., 2010; Harley et al., 2016). Their genetic divergence has been assessed as 0.1% (Korody & Hildebrandt, 2024).

The IUCN currently classifies them as subspecies (Emslie, 2020b), a designation with significant implications for their conservation strategies. While subspecies are typically viewed as important conservation units, with their preservation advocated under the precautionary principle (Gippoliti & Amori, 2007), hybridization is considered a legitimate strategy for conserving their genetic diversity and has been proposed for the NWR (Moodley et al., 2018). However, in this case, preserving genes alone may offer a suboptimal conservation outcome, especially when other alternatives are available.

As demonstrated by the case of the Florida panther, hybridization can be a valuable tool for ensuring long-term conservation and improving population welfare (Pimm et al., 2006; Onorato, 2024). However, there are two reasons why hybridization should not be considered the primary option. First, it would still require the use of ART, thereby duplicating both the costs and risks of current conservation efforts to achieve a potentially less ambitious outcome. Second, if maintaining a healthy, self-sustaining NWR population proves unfeasible, hybridization could nevertheless remain a viable backup plan. This approach is further supported by the fact that the NWR already exhibits greater genetic variability than the SWR (Tunstall et al., 2018). Moreover, although still speculative, integrating genetic material preserved in collections through gene editing could further increase the genetic variability of the NWR.

Naturalness

Diversity and richness hold unique value when they are not products of our will and actions—but are instead *natural*. What we may mean with this expression “natural” is notoriously complex to decipher, primarily because it encompasses multiple meanings that can be applied to very different objects, events, and activities. (Siipi, 2004, 2010). Concerning a taxon, the possible properties that can allow us to define its "naturalness" could be: a) absence of human interference; b) integrity; c) ecological complexity; d) non-artifactuality; e) evolutionary descent; f) authenticity.

Naturalness as *absence of human interference* indicates the absence of direct or indirect historical alterations caused by our species. If we understand this as an all-or-nothing condition, there is very little naturalness in this sense left on Earth, given the extent of our influence. If we instead consider it as a continuum, it is possible to establish hierarchies among more or less natural things. Any recreated NWR population would be low on this scale as its history is marked by two crucial events—the genetic bottleneck and subsequent reestablishment—both products of human actions. However, this scenario is common among many threatened or recovered species, such as the SWR, which faced near-extinction and recovery primarily due to human interventions (Emslie, 2020b). What could really make a difference from this perspective is if the population does not regain the long-term ability to be self-sustaining.

Another possible interpretation of naturalness is *integrity*—a criterion met when a population is well-integrated into an ecosystem and actively participates in its network of ecological relationships, rather than being detached from them (Lee, 2005). The reintroduced NWR population could quickly reestablish these ecological connections in a suitable habitat.

Ecological complexity can also be a measure of naturalness (Soulé, 1985). Reintroducing a population of NWR would enhance ecological complexity by enriching the ecosystem. In fact, it would fulfill this criterion more than a potential translocation of SWRs into the original range of NWR, as, on a global scale, two separate subspecies contribute more to overall ecological complexity than a single taxon.

Artifacts are often contrasted with natural objects (Katz, 1993; Siipi, 2010). Most artifacts can be defined through three fundamental characteristics: (i) they are created through an intentional process; (ii) they are very different from the raw materials used to produce them; (iii) they have one or more designed functions. This definition can also be applied to living creatures. First-generation NWRs would have the first characteristic of artifacts. However, they would not share the second and third characteristics, as they would be indistinguishable from their biological parents except insofar as offspring differ from parents, and have no designed functions. For these reasons, they could not be considered bio-artifacts.

Being of *evolutionary descent* is another property that can be used to define naturalness. The criterion is usually considered fulfilled when natural and not artificial selection has shaped the gene pool of a population (Lee, 2005). Conservation breeding stands in a gray zone, as reproduction happens in captivity accordingly to an intentional design. However, at the same time, the goal of this intentional design is not to select certain traits and the transmissible information that can express them as it is in artificial selection. The goal of conservation breeding is instead to preserve the existing transmissible information putting every form of selection in stasis—so that natural selection can resume normally after reintroduction. In this way, evolutionary descent is only frozen, not compromised.

Naturalness as being an *authentic* member of a taxon can be understood in various ways (Siipi, 2014). Here, we define it as being part of the same generational continuum. This continuum is not based on numerical identity—since each generation inevitably differs from the previous—but on a reproductive link. This link depends on certain requirements: material overlap between parents and offspring, contributions from inherited parts to the development of the offspring's reproductive capacity, and the potential for these parts or their replicas to be transmitted further (Piotrowska, 2017). ART do not inherently prevent the fulfillment of these requirements. Even surrogate gestation of a NWR in a SWR, while significant as an environmental factor influencing identity, does not disrupt the generational continuity between offspring and their genetic parents—and thus their authenticity.

Equal Treatment in Relation to Conservation

The goals of a conservation project can sometimes be shaped by subjective preferences not supported by significant reasons, giving rise to unfair treatment of different elements of biodiversity. One example is the preference accorded to charismatic species—like rhinos. However, as noted, we have good reasons to be concerned about the conservation status of rhinos. Given the threats, particularly poaching, rhino populations are at risk of rapid decline, even when starting numbers appear high. Investing in their conservation is more urgent than ever. Moreover, rhinos are flagship and umbrella species, and their preservation (Foose, 1993) can foster the conservation of other smaller, less charismatic species.

Despite that, it could be argued that such a profusion of efforts to save a functionally extinct subspecies is an unreasonable way to allocate resources—that could be better spent on habitat protection, restoration, or on the conservation of other rhinos taxa. Why should we focus "so much" on the NWR? From this angle, the project may appear to be a form of luxury conservation, modest in terms of benefits, and demanding in terms of resources. However, this critique does not take into account several factors. The project does not draw on funds earmarked for conservation, but rather for biotechnologies, thus it does not burden traditional conservation methods. If successful, it could help the cause of conservation by gaining media attention, obtaining public support, and attracting new funds and talent. Moreover, it is a technological driver, establishing new techniques and methods that could be used for the conservation of other *Rhinocerotidae* taxa and customized for other large mammals. These elements broaden the benefits of the project far beyond merely saving a functionally extinct subspecies.

However, there is potential for several backlash in the event of an "ethical failure"—a failure to address ethically sensitive aspects. A central feature of this project is the message of hope it offers amidst an overwhelming ecological crisis. In such instances, ethical failure can be more damaging than practical failure, as it undermines public trust in conservationists and erode confidence in the technologies. Therefore, it is crucial to ensure that the project adheres to high ethical standards and adopts responsible communication practices, including transparency about the values and rationale behind decisions, as well as openness to public scrutiny. It is equally important to remain realistic about promised results and timeframes, clearly communicating potential complications and avoiding overstated outcomes.

Animals

The second category of stakeholders includes all the animals (understood as individuals and not as ecological groups) involved in the project: Najin, Fatu, the female SWR surrogate mothers and donors, the male SWR teaser bulls and the eventual calves born during the project.

Animal Welfare

Animal Welfare During the Project

The project involves a series of conditions, situations, and procedures (Table 3) that may directly or indirectly harm the welfare of the animal involved according to one or more of its dimensions (health and functioning, avoidance of negative cognitive states and allowance of positive one, living natural lives).

Measures can be taken to decrease the possibility of accidents and mitigate their consequences (for instance, using only proven breeders as surrogate mothers to reduce welfare risks in parturition and rearing that may derives from inexperience). However, even adopting the best standards, it is not possible to reduce every risk to zero. It is fair then to raise the question whether it is ethically legitimate to subject animals to procedures that may have a chance to jeopardize their welfare—even if this chance is decisively low—to benefit conservation. After all, animals do not have a conscious interest in conserving their or another taxa.

Unless we settle for the extreme position that any potential risk to animal welfare always outweighs every measure of benefit to conservation, one way out of the previous conundrum is to find a balance between the two issues. In this regard, an argument has been advanced that the use of ART should be not considered legitimate if alternative strategies for the conservation of a taxa are present (Campbell, 2021). This is not the case for the NWR, and accepting the limited risks concerning the welfare of the animals is the only way to avoid losing this unrepeatable product of evolution.

Even so, the project may be failing to meet ethical requirements by adopting a reckless approach—one that overlooks risk analysis, prevention and mitigation of possible adverse effects, and optimized protocols. To avoid this possibility, it is necessary to monitor both the procedures and the conditions in which the animals live. To this end, the project adopts not only the classical measures of behavioral and physiological observation but also a dedicated tool for evaluating procedures (de Mori et al. 2021, 2024).

Table 3 Potential welfare issues

	Animals involved	Goals	Potential welfare issues	Literature
Captivity and semi-captivity	All animals involved	Maintaining the animals in a controlled and semi-controlled environment	Translocation. Limited movement. Diet. Climate. Handling. Restraint	Hutchins and Kremers (2006), Cinková and Bičík (2007), Boomsma and van der Sijde (2010), Metrione and Eyres 2014, Ververs et al. (2017), Sheil and Kirkby (2018), Versteege (2018), Goodenough et al. (2023), Scott et al. (2023)
OPU	Fatu, SWR female donors	Obtaining oocytes for embryo production	Anesthesia. Superstimulation. Transrectal puncture. Repetition	Hermes et al. (2007), Hermes et al. (2009), Hildebrandt et al. (2018), Pennington and Durant (2019), Hildebrandt et al. (2021b) Hildebrandt et al. (2023)
Semen collection	SWR male donors	Obtaining semen for embryo production	Anesthesia. Electroejaculation	Hermes et al. (2005), O'Brien et al. (2015), Ververs et al. (2015), Hildebrandt et al. (2018), Pennington and Durant (2019)
Sterilization	SWR teaser bulls	Producing teaser bulls that can monitor the female cycle in a natural, non-invasive yet accurate manner	Anesthesia. Minimally invasive sterilization	–
Embryo transfer	SWR surrogate mothers	Implanting embryos in a surrogate mother	Anesthesia. Successive pregnancy checks	Hermes et al. (2007), Pennington and Durant (2019)
Pregnancy and parturition	SWR surrogate mothers	Obtaining calves	Possible twin embryo removal. Pregnancy monitoring. Amniocentesis	Hutchins and Kremers (2006), Sos et al. (2006), Boomsma and van der Sijde (2010), Versteege (2018), Hermes et al. (2020), Schwarzenberger and Hermes (2023)
Rearing	SWR surrogate mothers, Najin and Fatu, Newborn NWR	Obtaining mature individuals	Introduction of the surrogate mother and the calf to Najin and Fatu	Hutchins and Kremers (2006), Boomsma and van der Sijde (2010), Versteege (2018)

Animal Welfare After the Project

As far as possible, the ethical analysis of the project should also be extended beyond its immediate consequences. A first concern may involve the potential side effects of the procedures on newborn animals. In this regard, ICSI has not been associated with obvious developmental abnormalities in horses, the closest extant animal to rhinos (Duranthon & Chavette-Palmer, 2018). ICSI, cryopreservation and thawing of embryos can have some possibile epigenetic effects, but this is a factor generally accepted in human applications of ART. Surrogate gestation can have epigenetic effects too, but likely these are going to fade out in the subsequent generations of NWRs born from females of their subspecies. The existence of a NWR/SWR hybrid, Nasi, born from a NWR female (Nasima) in 1977 and died in 2007 (Holečková, 2009), provides important indications regarding the possibility of surrogate gestation. This does not detract from the need to carefully monitor the health and functioning of the eventual first generation.

Reaching the number of individuals needed for the reintroduction will require a sustained effort over time, well beyond the birth of the first animals. Our knowledge about rhino husbandry is steadily increasing, and data show a rising capacity to manage the populations of white rhinos living in captivity and make them grow in numbers (Wittwer et al., 2023), allowing some optimism in this regard. It will be nevertheless important to analyze and discuss past attempts at conservation breeding so as to understand the mistakes and avoid repeating them.

Equal Treatment in Relation to Welfare

In general, it is only fair that similar animals receive similar treatment. But animals in conservation programs are treated differently than similar animals living under other conditions—they are subjected in varying degree to further risks and stress. The treatment of animals involved in the project may seem in this sense unfair. However, it is important to note that they also derive benefits from this differential treatment. For instance, all animals subjected to the procedures receive screening and veterinary care in superior amounts than similar animals kept in captivity. This can be especially important for animals such as female white rhinos that are very vulnerable to reproductive system pathologies (Hermes et al., 2004, 2006). Pregnancy itself decreases their likelihood of reproductive pathologies and is an important opportunity for exercising a relevant part of the behavioral repertoire. In addition, the behavioral and physiological data collected during the project can lead to improved veterinary and husbandry practices.

People

The last category of stakeholders includes all the persons directly or indirectly affected by the project, from the keepers, caretakers, veterinarians and scientists, to the local communities and the larger public opinion.

Well-Being

Handling such large animals as rhinos can pose risks, which must be carefully monitored and prevented. Additionally, the psychological impact of accidents on animals should be considered, particularly for those individuals who, through daily contact, have developed significant bonds with the animals and are deeply concerned about their welfare.

Regarding the well-being of the communities involved, coexisting with rhinoceroses tends to be less problematic than with other species, as they do not typically raid crops or pose a direct threat to human life. The eventual re-establishment of a NWR population could offer promising opportunities for sustainable economic growth, particularly through its potential to boost the ecotourism industry, benefiting from the species' charismatic appeal and the positive media attention it has garnered in recent years.

Autonomy

From the perspective of self-determination, the project offers numerous opportunities for personal and professional growth to its participants. This includes the chance for knowledge exchange and capacity building by involving a diverse set of professionals from different fields, institutions, and countries.

Conserving the NWR is also important from the perspective of relational values—values that are grounded in the opportunities for personal flourishing that our relationships with the natural world and biodiversity can provide. The NWR, for example, can be a source of significant aesthetic, reverential, and scientific experiences. It also holds existential value, as many people may prefer a world with NWRs, even without having the opportunity to directly experience them.

Fairness

The distribution of costs and benefits in conservation projects often varies across spatial, temporal, cultural, and social dimensions. This variation may result from power dynamics between different social groups, or from objective circumstances that must still be taken into account. In addressing part of these challenges, the project adheres to the principles outlined in the Nagoya Protocol, ensuring fair and equitable benefit-sharing agreements and cooperative frameworks with the countries and communities involved. Decision-making processes are handled in a participatory manner, with active involvement from local authorities and other relevant stakeholders.

At the current stage, any potential critical issues arising from the project within the communities in the regions where the animals are located and where the procedures are carried out do not appear to be significant. However, this is likely to change if the project succeeds in recreating a NWR population. In such a case, the potential economic interests at play, along with the need to protect the animals from poaching, will introduce a new layer of complexity into the decision-making process, with the need to take into account broader economic and social factors. A central question, as noted by Ryder (2020), will be whether the benefits of reintroducing the NWR will be primarily enjoyed by tourists and people from affluent countries or whether they will be fairly distributed across all stakeholders. The challenge is not only to ensure that economic benefits trickle down to local communities but also to address the broader implications of biodiversity conservation in an unequal world.

It is important to remember that the NWR's near extinction was, in many ways, the consequence of social and political unrest—factors that led to the displacement and collapse of local populations in key regions. History underscores the necessity of navigating the social and political issues that threaten biodiversity. In light of this, an equitable conservation approach is not just ethically preferable but also more effective in the long term.

Conclusion

The NWR case exemplifies the transformative potential of ART in conservation while also highlighting the ethical and practical challenges they entail. Despite the skepticism surrounding hi-tech conservation strategies, ART, by redefining the boundaries of reproduction, offer a potential path to recovery for declining and fragment population, making extinction a less likely outcome. However, we must ensure their responsible application to avoid ethical failures. This entails a commitment to animal welfare, setting realistic goals, and fostering broader community involvement and support. Ultimately, we should never forget that conservation issues are inherently human issues, shaped by our actions, values, and the decisions we make about our relationship with the natural world.

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