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International Journal of Avian & Wildlife Biology

Mini Review

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Aurochs revival and rewilding to nature

Abstract

The aurochs (*Bos primigenius*) is the ancestor of all modern cattle (*Bos taurus*) and was one of the most important animals in human history. This mega-ruminant roamed across Europe, Asia, and North Africa for 2 million years, shaping ecosystems. Although it is now extinct, its DNA remains alive and distributed across many ancient, primitive cattle breeds. Many breeders and organizations aim to bring the aurochs back as a functional animal into the wild, where it served as a vital part of the ecosystem for millennia. Therefore, over the past 20 years, scientists have aimed to create a modern equivalent of this long-extinct animal based on DNA analysis of skeletal remains, using the "back-breeding" technique with select cattle breeds whose physical traits, behavior, and genetics closely match those of the original wild aurochs. The goal of this method is to create a physically and genetically similar, self-sufficient grazing cattle species living in herds of at least 150 animals across several European rewilding areas. Ecologists believe its comeback is vital to protecting biodiversity in parts of Europe.

Keywords: cattle, Bos primigenius, genetic analysis, back-breeding, rewildin

Volume 10 Issue 2 - 2026

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Received: August 25, 2026 | **Published:** September 7, 2026

Introduction

The aurochs is an extinct species of large ungulate and the direct wild ancestor of all modern cattle breeds. The process of transformation, namely the domestication of the wild aurochs 10,000 years ago, ranks among the most critical milestones in human history. Without the milk, meat, and especially the draft power of these bovines, neither the Neolithic Revolution nor the development of modern civilizations would have been possible. The aurochs was widely distributed across Europe, the Middle East, Asia, and, through its subspecies, also in North Africa (*Bos primigenius africanus*) and India (*Bos primigenius namadicus*).[1] It was the heaviest terrestrial mammal on the continent following the mammoth and the rhinoceros, with bulls weighing around 1 tonne and reaching a wither height of nearly 180 cm (cows 135-155 cm). Thanks to their long legs and a slender, athletic build, they were agile animals capable of fending off large predators, such as wolves. In addition to their greater weight and dimensions, bulls were dark brown to black in color with a whitish eel stripe running along the spine, a powerful neck, and a deep chest (Figure 1). Cows were significantly smaller than bulls and exhibited a chestnut-brown or reddish-brown coat. Calves were born chestnut, with male calves shifting to a very deep brown or black after a few months. Both sexes typically had a light-colored muzzle and impressive long, thick, curved horns (up to 107 cm long/18 cm thick) with black tips.[2,3]

Figure 1 Extinct aurochs – bull and cow.

The aurochs was an impressive animal, perfectly adapted to the diversity of landscapes it inhabited, ranging from open steppes and semi-deserts to savanna-like landscapes, wetlands, several forest types, and mountains high above the tree line. Because of its adaptability, it was part of Europe's native fauna for thousands of years. With the advance of human civilization, deforestation, and the expansion of domestic cattle, which competed with the aurochs for grazing land and transmitted diseases, their populations declined dramatically. Central Europe became the final refuge for the aurochs, where they were protected as royal game. It is here that the last historically documented individual, a female who died in 1627 in the Jaktorów Forest in Poland, is recorded. With her death, the aurochs became one of the first globally documented cases of anthropogenic extinction.[1]

Today, conservationists and scientists are striving to reintroduce the aurochs into the wild and into habitats it previously occupied. They are using genome characterization and selective breeding of hardy cattle breeds that most closely resemble the extinct species. The objective is to breed an animal that closely matches its extinct wild ancestor in appearance, behavior, and genetics, enabling it to fulfill its ecological role in nature.[4]

Genetic analysis and crossbreeding of selected cattle breeds

To this end, the Heck brothers in Germany made an early attempt during the post-war period of the 20th century, seeking to rapidly showcase a 'reborn' animal. Because genetic testing did not exist at the time, they crossed domestic cows with aggressive Spanish fighting bulls based solely on their dark coloration and large horns. The result was an aggressive, yet anatomically undersized domestic animal that modern science does not consider a faithful replica of the aurochs.[4,5]

Since 2008, the Dutch Taurus Foundation has been working on the 'back-breeding technique' for the aurochs in collaboration with scientists from Wageningen University. Today's modern aurochs restoration project, known as the Tauros Programme, initially began with a comprehensive genetic analysis of the aurochs, utilizing DNA extracted from historical bone specimens. Subsequently, scientists sought out ancient European breeds that retained the highest percentage of original DNA. The leading practice in the Tauros breeding programme utilizes highly resilient and primitive cattle breeds that resemble the aurochs to the greatest possible extent.[5]

For aurochs restoration, the principal technique is 'back-breeding': by combining cattle breeds with desired characteristics, a bovine can

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be created with physical attributes, behavior, and genetics that closely match those of Europe's original wild aurochs. Such crossbreeding should establish new, robust lineages that approximate the aurochs as closely as possible and are suitable for release into European wild reserves. The breeding focus centers not only on phenotype and robustness but also on the aurochs' genetic information, ensuring it is preserved within these breeds to the highest possible degree of compliance.[4]

To this end, genetic analyses were performed on 34 cattle breeds originating primarily from the Iberian Peninsula, Italy, Germany, Poland, the Czech Republic, Croatia, Hungary, and Scotland. From these, six to eight breeds were selected based on their genetic and phenotypic (external) characteristics for crossbreeding and selection. These include most of the primitive breeds in Europe, such as Sayaguesas and Maronesas in Portugal, while in Croatia, grey cattle of Boškarin and Slavonian Syrmian Podolian origin were used. One of the existing herds of Maremmana Primitiva in Italy, consisting of 20 animals, was purchased to save the breed and incorporate it into the breeding programme **(Figure 2).**[6,7]

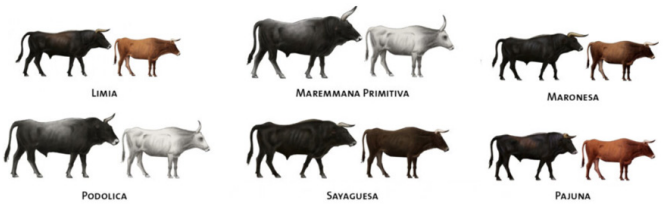

Figure 2 Cattle breeds used in combination crossbreeding.

Mathematical modeling and algorithmic crossover methods

Crossbreeding among the selected breeds was not random; instead, mathematical modeling and combinatorial algorithmic breeding methods were applied at this stage. These methods analyze the genetic profiles of available bulls and cows to calculate parental combinations whose offspring will have the highest probability of reconstructing the original wild alleles (gene variants). In the initial phases of this program, natural mating is supplemented by artificial insemination and embryo transfer (ET).[3,4] These techniques enable the combination of top-tier genetics from individuals located at opposite ends of Europe, thereby accelerating the entire process. ET in cattle is an advanced reproductive technology used to multiply offspring from genetically elite donor cows by implanting their fertilized embryos into synchronized recipient surrogate mothers.[8] Each new generation is subsequently genotyped and compared against aurochs DNA. Only animals that have shifted the genome percentage closer to the target are advanced to further breeding. Conversely, animals that exhibit undesirable domestic traits (e.g., poor body condition) or poor temperament (excessive aggressiveness or, conversely, complete docility) despite favorable DNA are culled from the program.[4]

Passive breeding phase and natural selection

Once the animals achieve a sufficient level of genetic consensus with the aurochs, the project transitions into its final phase: a complete release into the wild (rewilding). Based on the previously established mathematical crossbreeding model of the selected breeds, individuals with high genetic and phenotypic conformity have already been successfully bred **(Table 1).** Since 2013, these individuals have been used to establish trial herds of approximately 20 to 50 head, stationed in various European locations, but the Netherlands remains the hub and has the largest number of herds. Since 2015 and 2018, two herds have also been established in the Czech Republic, in Milovice Nature Reserve **(Figure 3)** and Modrá (Uherské Hradiště district), as well as in Croatia, Romania, Spain, and Portugal. Although these herds are kept in a natural environment, selection continues, particularly targeting phenotypically non-compliant animals. The animals live year-round without supplementary feeding and in the presence of predators (wolves). Only individuals with fully restored instincts, hardiness, and the resilience of the wild aurochs will survive and pass on their genes.[4,5]

Table 1 Phases of the Tauros programme

	Startup phase	Active breeding phase	Passive breeding phase	Natural breeding and natural selection
Period	2008–2013	2014–2018	2018–2025	After 2025
Nature Reserve	Small	Small	Medium	Large
Animal status	Domestic	Domestic/Feral	Feral	Wild
Breeding strategy	Active natural breeding Artificial insemination Embryo transplantation Mild selection	Active natural breeding Less artificial insemination Less embryo transplantation Selection	Natural breeding Strong selection	Natural selection
Human action	Strongly hands-on	Hands-on/Guidelines	Guidelines	Hands-off

Figure 3 Tauros population created by "back-breeding" technique localized in Milovice Nature Reserve, CZ.

Conclusion

From 2025 onward, the final stage of this species restoration program is expected to commence: reintroducing the aurochs into the wild as a self-sustaining grazing bovine. Given the advances in selective breeding and the genetic consensus within the F3 and F4 generations, this objective is highly relevant. To achieve full genetic dispersal within a wild population without human intervention, herd sizes must be increased to at least 150 head across several restored landscapes in Europe. Furthermore, these animals must cope not only with predatory pressure but also with rapidly changing climatic conditions that affect the extent and quality of grasslands.

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Acknowledgments

The study was supported by the Slovak grant KEGA no. 003UVLF-4/2026: Increasing higher education and practical experience for veterinary students in the subjects of Animal Husbandry and Breeds and Breeding of Companion Animals.

Conflicts of interests

The authors declare no conflicts of interest.

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