

Method of restoration of degraded mining landscapes

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Abstract. The authors propose a technology for restoring high-altitude systems in the territory of the Udokan copper deposit development in the Kalarsky district of the Trans-Baikal Territory with the participation of *Rhododendron aureum* Georgi. The implemented measures allowed to accelerate the process of overgrowth of the disturbed area and preserve the rare species.

1 Introduction

Russia boasts a wealth of mineral resources and a well-established mining sector. However, intensive mining activities have left a significant ecological footprint, resulting in the widespread degradation of land.

The country harbors over 100,000 mining sites, accounting for approximately 10% of the total area utilized for economic purposes. These disturbed lands are a major contributor to the decline in biodiversity. According to Rosprirodnadzor, the area of reclaimed land amounts to 193.7 thousand hectares. As of the end of 2022, the total area of disturbed lands in Russia reached 1,096.8 thousand hectares, an increase of 4.9 thousand hectares compared to 2021. Overall, the past decade has witnessed a growing trend of land degradation, particularly in industrial and other designated areas [1].

The restoration of degraded mining landscapes with the involvement of rare plant species represents a crucial ecological and social endeavor that can have far-reaching consequences for biodiversity conservation and the improvement of local communities' quality of life.

The Kodar-Udokan mountain region in Zabaykalsky Krai serves as a stark example of land degradation. The region's flora harbors 28 endemic vascular plant species, constituting 53.6% of the total endemic flora of the region. Of these, 23 species are found in the Udokan Range flora. The region's flora exhibits a high level of distinctiveness [2]. Overall, the Kodar-Udokan mountain region stands as a unique area with diverse vegetation, landscapes, and geological features that underscore its ecological and natural value.

Rare and endangered plant species discovered in the area of the Udokan copper deposit (56.57° N, 118.49° E) and the placement of facilities of the Udokan Mining and Metallurgical Plant (GMK) in the Kalarsky district of the Zabaykalsky Krai [3].

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The golden rhododendron (*Rhododendron aureum*) is a relic tree-like shrub that thrives on the slopes of the Khamar-Daban, Barguzin, Udokan, Stanovoy, and Sikhote-Alin mountain ranges, as well as the Kuril Islands and the Udokan Range. It stands as one of the most valuable rhododendron species, renowned for its captivating flowers and prized medicinal properties. This resilient shrub favors mountain slopes with rocky soil and ample drainage, perfectly adapted to the harsh conditions of high altitudes, characterized by low temperatures, a short growing season, and abundant snowfall.

The golden rhododendron (*Rhododendron aureum*) plays a pivotal role in maintaining the delicate balance of mountain ecosystems. It serves as a dominant species within plant communities, forming dense thickets that provide a multitude of essential functions:

- *Soil Protection*: The golden rhododendron's extensive root system effectively anchors slopes, preventing soil erosion and safeguarding the integrity of mountain landscapes.
- *Microclimate Regulation*: Rhododendron thickets create a unique microclimate within their environs, characterized by increased humidity and lower air temperatures compared to surrounding open areas. This microclimate fosters a favorable environment for various organisms and contributes to the overall health of the ecosystem.
- *Biodiversity Conservation*: These dense rhododendron thickets serve as havens for a diverse array of wildlife, including birds, mammals, and insects. They provide essential habitat, food sources, and protection for these creatures, contributing significantly to the region's rich biodiversity.
- *Aesthetic Value*: The golden rhododendron's captivating beauty adorns mountain landscapes, adding a touch of vibrant color and elegance to the rugged terrain. Its presence enhances the scenic appeal of these ecosystems, attracting visitors and fostering appreciation for the natural world.

In recognition of its ecological significance and conservation status, the golden rhododendron has been listed in the Red Books of the Zabaykalsky Krai, the Republic of Sakha (Yakutia), and the Kemerovo Oblast [3–5]. This designation highlights the urgency of protecting these precious populations and ensuring their continued existence within these fragile mountain ecosystems.

The preservation of the golden rhododendron, a relic species dating back to the Pleistocene era, underscores the harshness of the region's climatic conditions. These extreme conditions pose significant challenges for land restoration efforts, hindering the development of a resilient soil-plant complex with self-regeneration capabilities.

Restoring disrupted ecosystems can be a protracted process, spanning decades, and the duration depends on the state of the technogenic ecosystem. To expedite this process and mitigate the negative impacts on disturbed lands, accelerated revegetation is recommended. This complex and multifaceted undertaking necessitates a harmonious blend of ecological and technical approaches.

2 Results and discussion

Transplanting rare plant species into disturbed mining areas represents a crucial step towards biodiversity conservation and ecosystem restoration. In this context, a technology for restoring mountain tundra systems with the participation of *Rhododendron aureum* has been developed and tested on the Udokan Range of the Kodaro-Udokan mountain region.

The restoration technology for mountain tundra systems with the participation of *Rhododendron aureum* consists of two stages: preparatory and main.

The preparatory stage involves a thorough investigation of potential transplant sites to identify areas with similar physical and geographical characteristics (elevation, exposure, slope gradient, and soil properties) to those of the donor sites where the golden rhododendron is currently found. This meticulous selection process aims to ensure the maximum compatibility of the transplant and donor sites, fostering optimal conditions for the reintroduction of the rare species.

Once suitable transplant sites have been identified, careful preparation of the area is essential to ensure optimal conditions for the reintroduction of *Rhododendron aureum*. This process involves meticulous attention to detail and adherence to specific guidelines to minimize potential stress on the transplanted plants and maximize their chances of survival and successful establishment.

The first step in site preparation involves leveling the transplant area using appropriate machinery. This process aims to create a uniform and gentle slope that closely matches the natural inclination of the surrounding terrain. Strict adherence to this step is crucial to prevent excessive water accumulation, erosion, or instability that could hinder the growth and survival of the transplanted rhododendrons. The maximum deviation from the natural slope should not exceed 10 degrees, ensuring a gradual transition between the transplant site and the surrounding landscape.

To address any depressions or uneven areas within the transplant site, including waterlogged spots, careful filling with crushed rock ranging in size from 10 to 60 centimeters is essential. This layer of crushed rock serves as an effective drainage system, preventing the accumulation of excess water that could damage the delicate root systems of the transplanted rhododendrons.

Once the drainage layer is in place, the next step involves replenishing the topsoil with a carefully prepared soil-peat mixture. This mixture should be sourced from the previously disturbed area to maintain ecological compatibility and provide the transplanted rhododendrons with familiar soil conditions. The mixture should also contain a significant proportion of mosses and lichens, replicating the natural habitat of the donor site and providing a suitable substrate for the rhododendrons to establish their roots. The depth of this soil-peat mixture should exceed 10 centimeters, ensuring adequate support and nutrient availability for the transplanted plants.

The main stage of the restoration process encompasses the critical steps of procuring, transporting, and planting the golden rhododendron specimens. This meticulous operation demands careful planning, precise execution, and adherence to strict guidelines to minimize stress on the transplanted plants and maximize their chances of survival and successful establishment in the new environment.

The procurement process begins with the removal of any existing woody vegetation from the donor site, ensuring that the area is cleared for the extraction of the golden rhododendron clumps. Once the site is prepared, the delicate task of extracting the clumps commences. This operation must be conducted manually, employing utmost care and precision to prevent damage to the fragile root systems and aboveground portions of the rhododendron plants.

Prior to the manual extraction, the soil-plant layer (SPL) surrounding the rhododendron clumps is carefully trimmed using appropriate machinery. The SPL encompasses both the aboveground and belowground components of the plants and requires delicate handling due to its inherent fragility.

Subsequently, individual plants and groups of plants are meticulously excavated from their mossy-lichenous cushions. These clumps, ideally measuring 40 by 50 centimeters, represent the units that will be transplanted to the prepared sites. During the excavation process, utmost care must be taken to preserve the integrity of the root systems and minimize damage to the delicate shoots and foliage.

Once the rhododendron clumps have been extracted, they must be carefully transported to the transplant sites. To ensure their safe arrival and prevent damage during the journey, the clumps are securely packaged in rigid transportation containers. These containers provide protection from physical shocks, temperature fluctuations, and excessive moisture, safeguarding the delicate plants during transit.

A crucial aspect of this stage is to limit the number of clumps per container, ensuring that each clump has sufficient space and ventilation. This approach minimizes the risk of overcrowding, physical damage, and overheating, which could compromise the health and survival of the transplanted plants.

Throughout the procurement, transportation, and packaging processes, every effort must be made to prevent damage to the rhododendron shoots. These delicate stems and leaves are particularly vulnerable to breakage and desiccation, which could significantly hinder the plants' ability to recover from transplantation and establish themselves in the new environment.

By adhering to these stringent guidelines and employing careful handling techniques, the golden rhododendron clumps can be successfully procured, transported, and packaged, minimizing stress and maximizing their chances of survival during transplantation and subsequent establishment in the restored mountain tundra ecosystems.

The transportation of *Rhododendron aureum* clumps is carefully executed to minimize stress on the plants and ensure their safe arrival at the transplant site. The clumps are securely packaged in polyethylene bags and placed within rigid containers to provide protection during the journey. This packaging strategy helps to reduce moisture loss and maintain the integrity of the plants. The containers are strategically arranged within the cargo area of the transport vehicle to prevent damage during transportation. Upon reaching the transplant site, the soft polyethylene bags are carefully cut open, and the entire clump, including any associated plants, is gently transferred to the prepared planting hole using the method of overturning. During this critical step, meticulous attention is paid to the positioning of both the aboveground and belowground portions of the plant within the planting hole. Proper placement ensures optimal root establishment and minimizes stress on the transplanted rhododendron.

The planting layout for *Rhododendron aureum* clumps can be selected based on the desired aesthetic effect and the specific site conditions. Three common options are:

- *Grid Pattern*: A grid pattern with spacing of 1.5 meters by 2 meters provides a well-organized and evenly spaced arrangement of the clumps.
- *Square Pattern*: A square pattern with spacing of 2 meters by 2 meters offers a more open and spacious layout, allowing for better air circulation and light penetration.
- *Row Planting*: Row planting involves arranging the clumps in parallel rows with a spacing of 2 meters between rows. This method is suitable for larger areas and can facilitate easier maintenance and access to the plants.

Regardless of the chosen planting pattern, the preparation of individual planting holes is essential for each *Rhododendron aureum* clump. The size of the planting hole should be determined by the size of the clump, typically ranging from 0.5 to 1 meter in diameter. The holes should be carefully excavated by hand using shovels, ensuring that the depth is sufficient to accommodate the root system of the clump without overcrowding or causing damage.

With the planting holes prepared, the *Rhododendron aureum* clumps are gently placed in their respective positions. The root ball should be situated at a depth that matches the original planting depth in the donor site. Once positioned, the clumps are carefully backfilled with the prepared soil-peat mixture, ensuring that the root system is firmly anchored and that the base of the clump is level with the surrounding ground surface.

To further protect the root system and maintain soil moisture, a layer of gravel-crushed stone mixture is applied around the base of each clump. This layer serves as a mulch, preventing soil erosion, suppressing weeds, and regulating soil temperature.

Regardless of the prevailing weather conditions, immediate watering of the transplanted *Rhododendron aureum* clumps is crucial to alleviate transplant stress and promote root establishment. Using a sprinkler or watering can, thoroughly soak the soil around each clump, ensuring that the root ball is fully hydrated. The recommended water quantity per clump is at least 10 liters.

Following the initial watering, regular monitoring of soil moisture is essential to maintain adequate hydration levels, especially during dry periods. Additional watering may be necessary to prevent the soil from drying out completely.

By adhering to these meticulous planting guidelines, the *Rhododendron aureum* clumps will be provided with the optimal conditions for successful establishment and long-term growth within the restored mountain tundra ecosystems.

To maximize the effectiveness of *Rhododendron aureum* transplantation, the duration between extraction from the donor site and planting in the transplant site is restricted to a single day. This stringent timeframe minimizes stress on the transplanted plants and enhances their chances of survival and successful establishment.

The meticulous implementation of the proposed *Rhododendron aureum* transplantation technology is accompanied by rigorous author oversight and comprehensive monitoring activities. These measures serve to identify and rectify any potential errors or deviations that may arise during the transplantation process, ensuring the adherence to established guidelines and the overall success of the restoration efforts.

1 Conclusions

The restoration of high-altitude landscapes with the participation of *Rhododendron aureum* represents a complex undertaking that demands meticulous planning and the execution of a series of well-defined steps. The proposed technology, carefully crafted with consideration for the ecological significance of this species, provides a robust framework for preserving both the golden rhododendron itself and its critical habitats within these fragile mountain ecosystems.

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