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An Ecological Redoubt: Assisting the Migration of Sensitive Flora in the Central Swiss Alps

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ABSTRACT

Switzerland's alpine ecologies are uniquely affected by climate change. Many of the country's plant species are migrating higher in altitude due to rising annual mean temperature with extensive habitat loss expected in as early as 2050. Given the compounded effects of the growing tourism economy and the expanding presence of aggressive pioneer plant species, regionally significant alpine meadows have been displaced before their sensitive and rare plant communities can adapt. This impending loss of biodiversity is quickly becoming a national ecological redoubt.

Situated at the crossroads of the Oberalp, the St. Gotthard, and the Furka passes, the town of Andermatt lies at the eastern end of the Urseren Valley, a floristically diverse region of Central Switzerland. Abandoned military bunkers and fortresses (Fort Stöckli and Artillery Works Gütsch) overlook Andermatt as relics of the Swiss National Redoubt defence plan.

This project investigates how specific military infrastructure integrated into the landscape can be repurposed into living archives for research, preservation, and propagation of alpine plant communities. Can this design strategy combining active and passive interventions mitigate anthropocentric pressures on these alpine ecologies while providing a new purpose to outmoded military infrastructure? Will a strategically managed ecological retreat preserve Swiss identity beyond the non-human?

KEYWORDS

Alpine Biodiversity; Swiss Military Infrastructure; Climate Change; Adaptive Reuse; Seed Dispersal

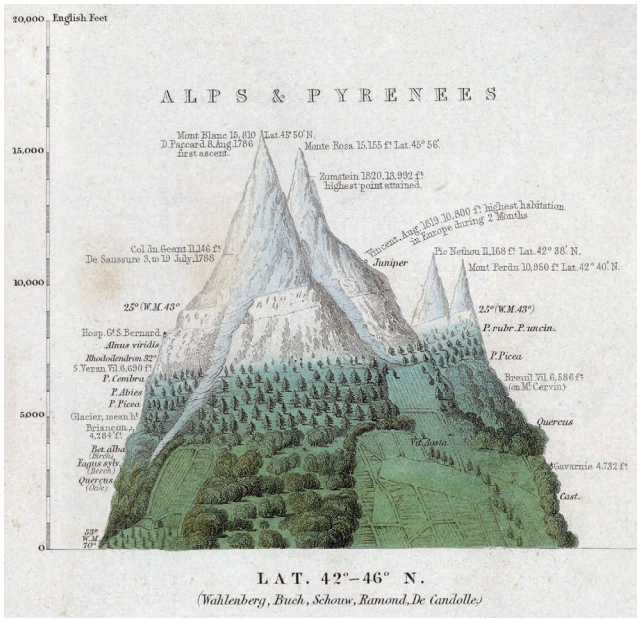
HIGHLIGHTS

- Reinvesting in pastoral management traditions addresses alder shrub encroachment
- Carbon-conscious *in-situ* seed banks complement *ex-situ* conservation
- Hybrid propagation technologies re-establish sensitive alpine flora
- Swiss military structures function as sites for ecological preservation and engagement

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1 Shifting Ecologies and a Historic Retreat

During a five-year voyage from 1799 to 1803, Alexander von Humboldt, a German polymath, geographer, and naturalist, travelled worldwide and recorded that plant associations shift as one ascends from sea level similarly to when one travels from the equator towards the poles[1]. These observations and subsequent representations of elevational gradients contributed to Humboldt's theory of altitudinal zonation in his *Essay on the Geography of Plants* of 1805 (Fig. 1). Alpine zonation and more pertinently, its change, is still studied extensively in mountain environments such as the Swiss Alps. The geomorphology of the Alps forms a diverse patchwork of microclimates within alpine and nival zones that contain a wide range of specialist flora. Of the 4,500 vascular plant species found across the Alps, 8% are endemic.[2] However, this biological richness and specificity mean these alpine areas are more sensitive to extremes of climate change. To date over 220 species of flora and fauna have become extinct or disappeared from Switzerland over the past 150 years. Almost half of Swiss animal life is currently on the red list of endangered species and more than a



© Alexander Keith Johnston, Alexander von Humboldt

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1. Drawn from the studies of Alexander von Humboldt, an original engraving drawn by W. & A.K. Johnston and published in an 1850 atlas by William Blackwood & Sons, Edinburgh & London.
2. One of the iconic camouflaged machine gun nests at one of the fortresses.
3. The peak of a fortress contends with severe winds and precipitation, creating distinct microclimates while enabling sustainable energy generation.

third of ferns and flowering plants, as well as moss and lichens, are considered "at-risk."[3] As summers become longer, hotter, and drier, many alpine species are forced to retreat to higher altitudes, facing decreased habitats and competition from generalist plant species such as green alder (*Alnus viridis*). This unmanaged upward retreat of Alpine flora parallels the famous preservation tactic utilized by the Swiss military involving the willful consolidation and upward migration of their military infrastructure.

The Swiss National Redoubt① was a military strategy developed in the 1880s as a response to foreign invasion. This managed retreat into centralized mountain fortifications took advantage of provided superior vantage points and protected critical alpine passes.

Given Switzerland's limited resources in equipment and military personnel during World War II, the Redoubt strategy served primarily as a symbolic deterrent. For over fifty years, millions of francs were poured into a myriad of camouflaged fortifications and bunkers, amounting to nothing more than a politically controversial display of Switzerland's armed neutrality.[4] As fortifications fell into obsolescence in the 1990s with the end of the Cold War, over 8,000 military fortifications remain in various states of decay, many camouflaged into the landscape (Figs. 2, 3). Some architects and historians call for the preservation of this military heritage.[5] Yet several have been privately purchased and converted into boutique restaurants and hotels, data centres, wine cellars, and even cheese factories.[6] Only one former military camp has been renovated into the Alpine Research Station Furka (ALPFOR) within the Central Gotthard Redoubt.[7]

2 Biodiversity at Risk: The Urseren Valley

The Central Gotthard Redoubt contains several strategic positions situated at the convergence of the Oberalp, St. Gotthard, and Furka passes overlooking one of the most floristically diverse regions of central Switzerland, the Urseren Valley (Fig. 4).[8] Approximately 14 km east of the ALPFOR are two abandoned military fortresses integrated within the mountainside—A8682 Fort Stöckli, first established in 1893 (Fig. 5)[9], and the A8685 Artillery Works Gütsch Complex (hereafter Gütsch), constructed in 1944 (Fig. 6). Until its 1994 decommissioning, Gütsch remained Switzerland's highest operational fortress at 2,300 m above sea level.[10] Within the valley below the fortifications, the once sleepy town of Andermatt-Sedrun area is now the site of a 1.3-billion-dollar reinvestment transforming the surrounding mountainsides into an all-season recreational destination. The climate of the area is distinctly alpine, where Foehn winds② create distinct microclimates on the northern and southern slopes of the Gütsch mountainside,



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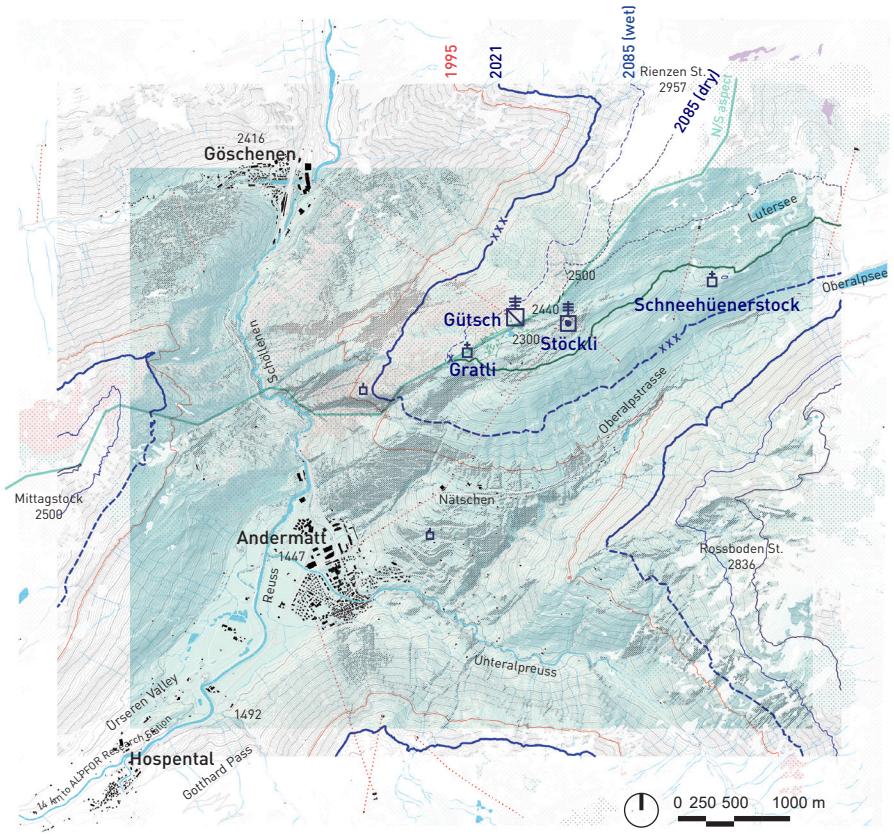


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① The Swiss Redoubt (Schweizer Alpenfestung or Réduit Suisse) was a defensive plan that culminated with a three-part, managed retreat strategy to discourage an Axis forces invasion in World War II by destroying lowland infrastructure and consolidating the army in high-altitude fortifications in the High Alps.

② Foehn winds are warm and dry winds descending the leeward side of mountains responsible for a mosaic of microclimatic conditions within the alpine valleys of the Alps.



Legend

- *Alnus* sp. vulnerable slopes
- Rock and stone rubble
- Forest and shrub cover
- Gondolas and cable cars
- North/south aspect divide

Treeline limit (year)

- 1995
- 2021
- 2085 (wet)
- 2085 (dry)

Urseren military infrastructure

4 © Stefan Herda



5 © Von Paebi - Eigenes Werk, CC BY-SA 3.0



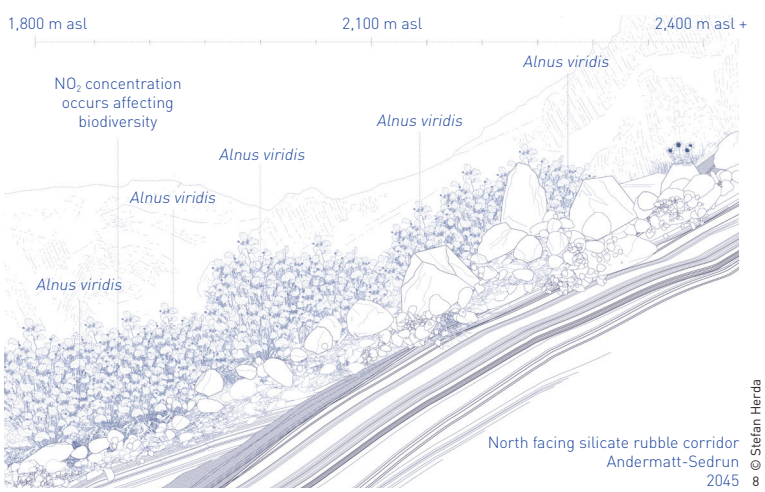
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ranging from scree and rubble corridors to high-elevation alpine grasslands and meadows. Atop Gütsch, four large wind turbines provide carbon-neutral power to the popular Andermatt-Sedrun ski area. Despite this sustainable initiative, the influx of boutique hotel developments and slope regrading for new alpine ski parks has resulted in significant disturbance within alpine dry meadows of the area (Fig. 7).[11]

If left unattended, the unmanaged retreat of this region's distinct flora will result in less biodiversity, soil chemical imbalances, and monocultures of alder thicket (Fig. 8). The Andermatt area's biodiverse sub-alpine and alpine regions could be displaced by green alder in as early as 2045.[12] Anticipating a loss of biodiversity spurned by combined pressures of tourism development and zonation shift, can the bunkers of Andermatt be repurposed into sites for the research, preservation, and eventual propagation of fragile plant communities?

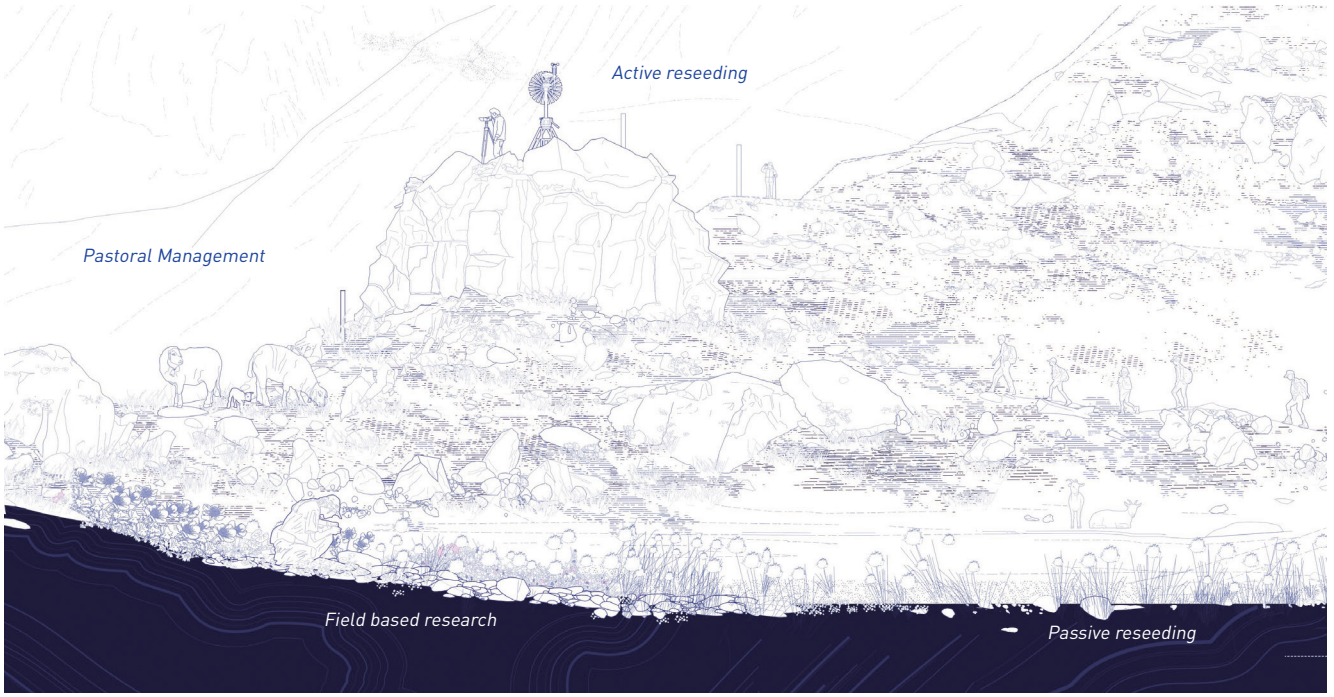


7 © Urs Wüthrich



8 © Stefan Herda

4. Plan of the Andermatt region at the convergence of several high-altitude passages, dark blue contours indicating predicted zonation shifts by year.
5. The A8682 Fort Stöckli
6. The emergency exits of Gütsch
7. Disturbed habitat due to slope regrading at the Nätschen-Gütsch ski area in 2017.
8. Alder encroachment on the north-facing slopes of Andermatt-Sedrun.



9. A three-pronged approach to conservation of the alpine community: pastureland restoration, seed bank establishment, and active and passive propagation tactics at Gütsch.
10. Engadine Sheep flocks enjoying green alder.

③ The Engadine Sheep (*Ovis aries*) is a traditional Swiss breed of domestic sheep known for its rusty red wool. Once endangered in the 1980s, it has since recovered.

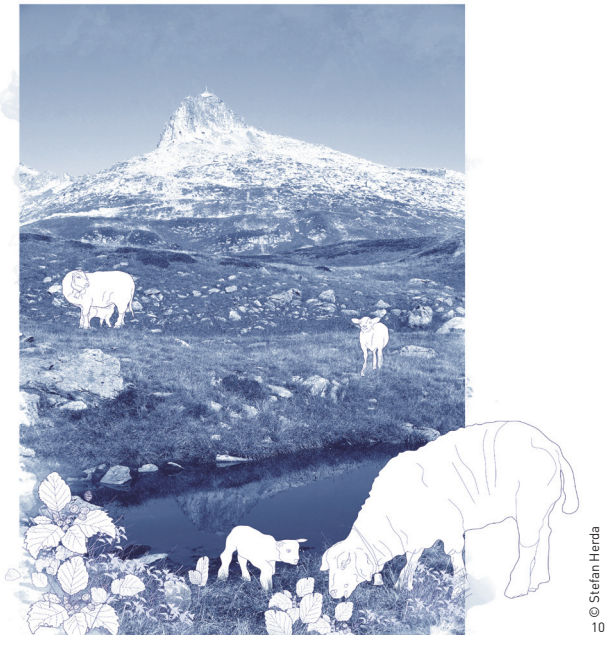
3 *In-Situ* Conservation: Living Archives

Floral diversity loss will be addressed through a three-pronged approach that reframes traditional relationships between plants, animals, and people (Fig. 9). First, a conscious reinvestment in pastoral traditions can control alder encroachment. Both Alpine goats and local Engadine Sheep③ enjoy browsing alder stems and have been effective in controlling alder thicket formation in other areas of the Urseren Valley (Fig. 10).[13] Repurposing aspects of the former Gütsch fortress barracks complex for browsing livestock creates a "forward-operating base" for further pastureland restoration.

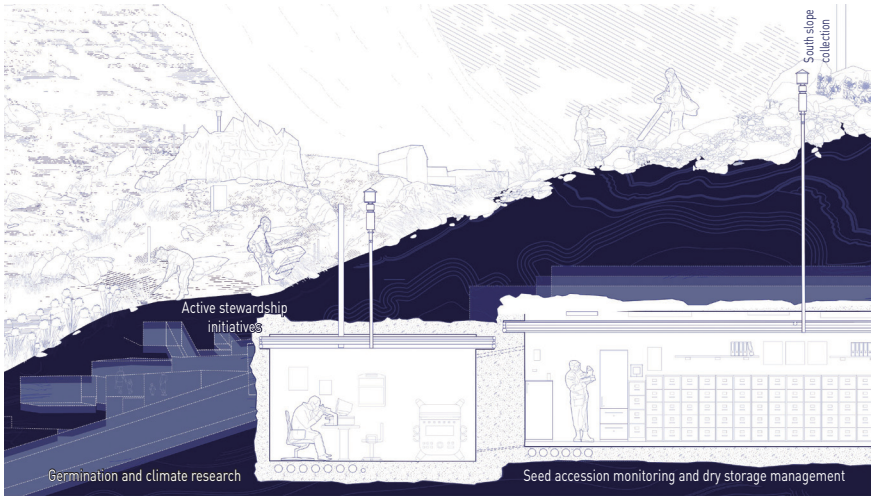
This second approach entails developing high-altitude seed banks at Gütsch and Fort Stöckli. The Alpine Seed Conservation and Research Network and the Millennium Seed Bank Partnership with Kew Gardens argue that seed preservation efforts are cost-effective for preserving Alpine biodiversity, relying on ethical standards of high-quality seed collection methodologies and monitoring for eventual *ex-situ* storage.[14] These conservation standards could be supplemented by localized conservation practices to create an effective and low-carbon solution for propagating and protecting seed stock of sensitive flora *in-situ*.

Both Gütsch and Fort Stöckli would serve as case studies to assess the viability of both passive and active means of seed dispersal and propagation. Gütsch remains equipped with lodging, electrical generators, and workspaces for over three hundred soldiers.[10] As such, the former ammunition storage bays could be transformed into temperature-controlled seed banks and germination laboratories (Fig. 11) housing seed stock of rare plant species across the Urseren Valley. Fort Stöckli, now a historical monument and commons, has been renovated to accommodate amenities for alpine research residencies.

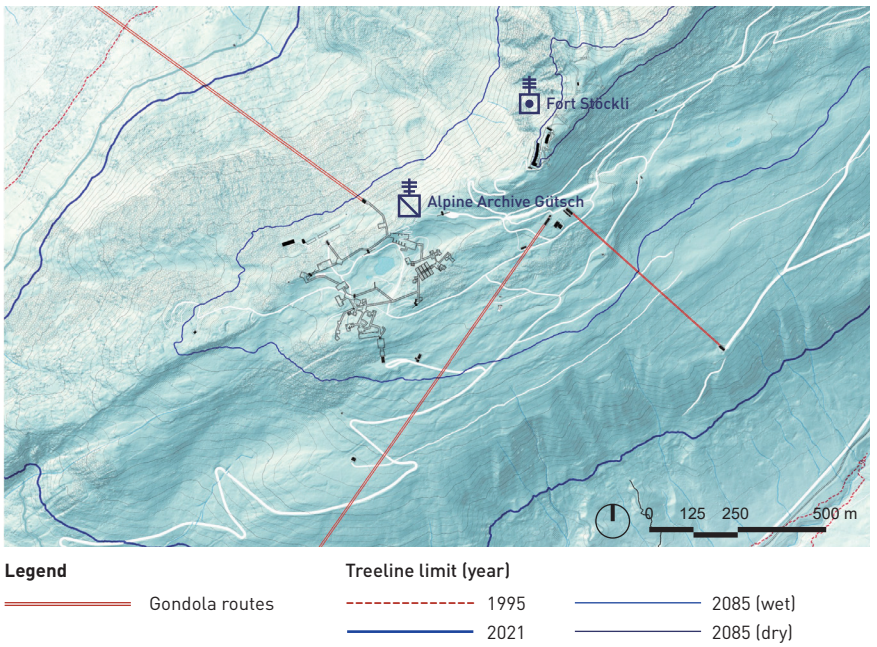
Circulation routes between both fortresses would permit guests and visitors to engage with the site and assist in seed



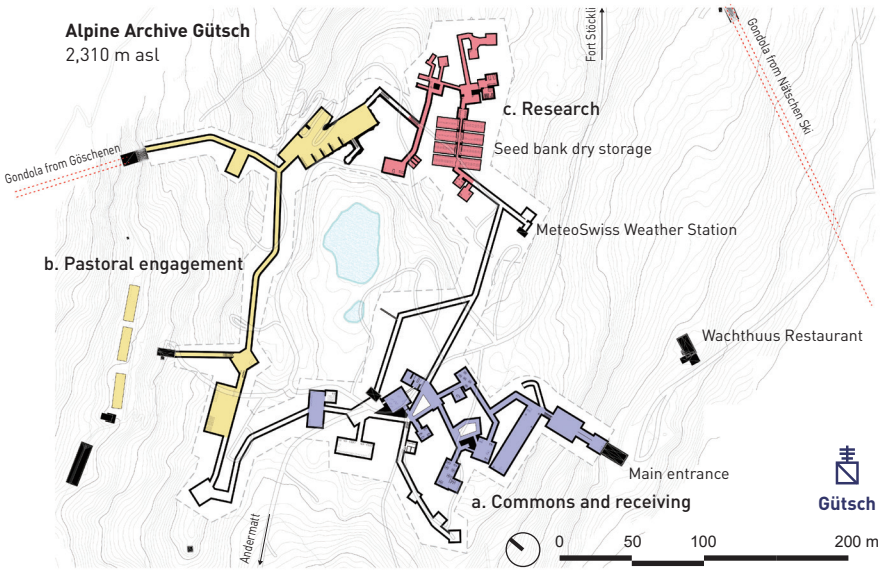
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11. Subterranean section of germination laboratories and dry storage seed banks
12. Detail plan of Alpine Archive Gütsch and Research Station Stöckli highlighting nearby gondolas and circulation routes
13. Subterranean floorplan of the repurposed Alpine Archive Gütsch

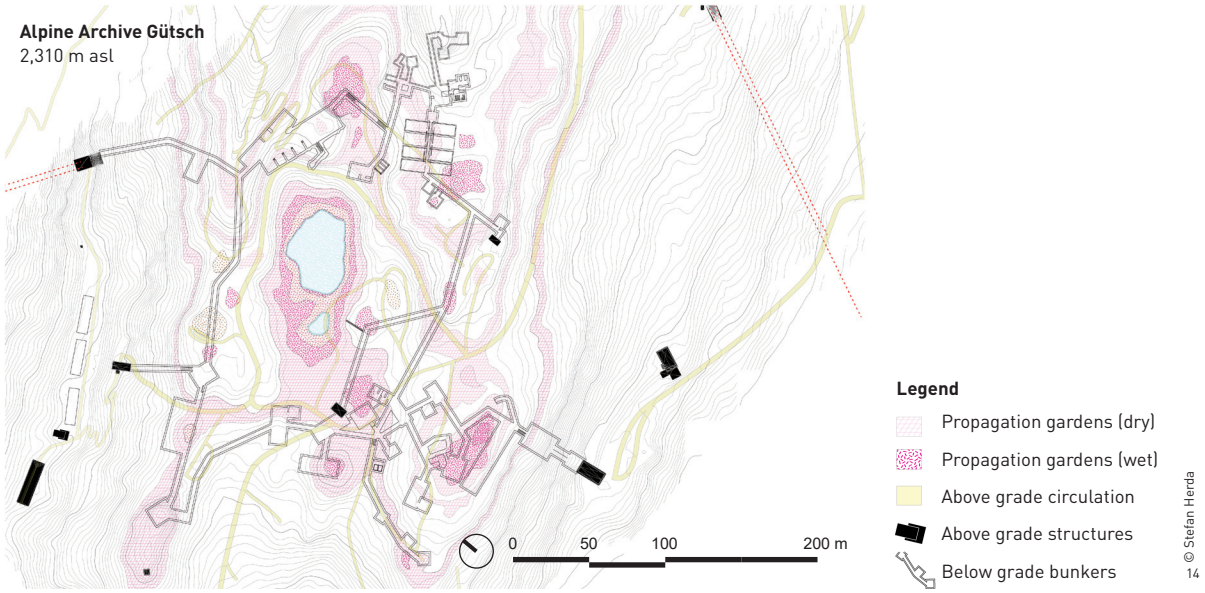
dispersal efforts, transforming the Gütsch mountainside into a complementary institution to ALPFOR (Figs. 12, 13). The third approach re-cultivates the rugged landscape situated above Gütsch as an ecological courtyard and gathering space in warmer months. Echoing the traditional Alpine demonstration garden, this windy and exposed fen becomes a nucleus site for propagation and a communal stage for practices of cultivation and seed harvesting (Fig. 14). Rezoning this space as a natural preserve, the new garden becomes a passive reseeding site, mitigating the effects of recreational trampling, hiking, and mountain biking so popular in the area in favour of educating the growing tourism economy on the importance of the regional ecology.

4 Hybrid Technologies

A majority of alpine plant species rely on wind dispersal (Fig. 15). Despite this, many alpine plant species without ideal seed morphology fail in efficient airborne dispersal and/or have a lower terminal velocity when compared to lowland species.[15] Alpine plants of the alpine and nival belts typically leverage intermittent alpine updrafts (vertical turbulence) to better colonize upslope areas (Fig. 16). However, being of low relative height, some alpine plant species, such as creeping avens (*Geum reptans*), could be dispersed even further if their relative dispersal height could be increased via artificial means. The new elevated active seed dispersal mechanisms may serve as hybrid extensions of natural seed dispersal vectors to maximize the germination of long-distance dispersal events resulting from Foehn winds.

The active reseeding dispersal mechanism reinvents the concept of a typical agricultural seed spreader (Fig. 17). Removable hoppers containing different seed blends can be interchanged throughout the season by research teams during fair weather periods depending on the germination and soil substrate requirements of varied alpine species.[16] A compact wind fan powers the seed dispersal mechanism while a servo motor tilts and twists dispersal paddles along its X- and Y-axes for controlled seed dispersal either upslope with Foehn winds or downslope during heavy precipitation events. An anemometer maximizes germination success and seed spread by controlling the release of seeds during ideal climate and meteorological periods (Fig. 18). This remote weather sensor allows the device to function autonomously, which is a safer alternative to time-consuming manual dispersal strategies.

Following five years of monitoring and adequate seed inventory establishment, the proposal evolves through cyclical re-seeding strategies, enabled by a fleet of seed-dispersal mechanisms applied



14. Plan view of the Alpine Botanical Garden above grade at Gütsch.
15. A case study of eight key colonizing alpine plants of the alpine and nival zones.
16. Illustrating key factors that determine alpine seed dispersal distance calculations.

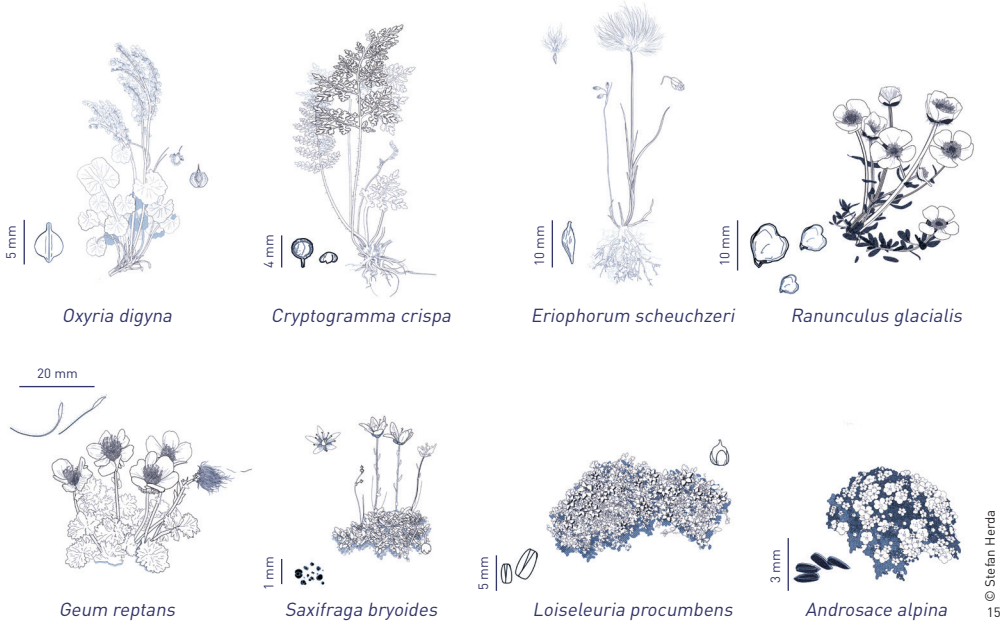
④ For instance, the GLORIA programme is a globally-based observation network that conducts monitoring programs centralizing alpine ecological data in the wake of climate shift.

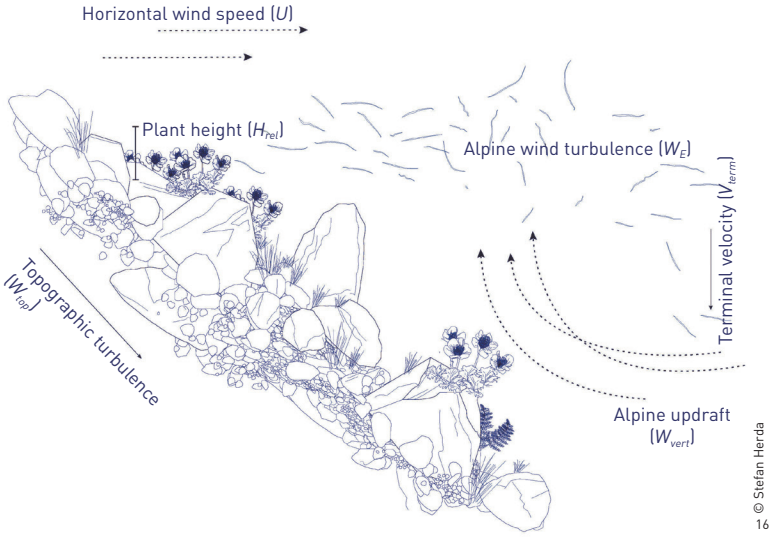
at vantage points along the perimeter of the Gütsch seed bank. This managed form of Alpine cultivation and conservation leverages new topographic vectors and adapts to uncertain climate conditions. This accessible and healthy seed stock encourages the success of future species occurrence into higher altitudes within shorter timelines not possible by natural means of dispersal alone.

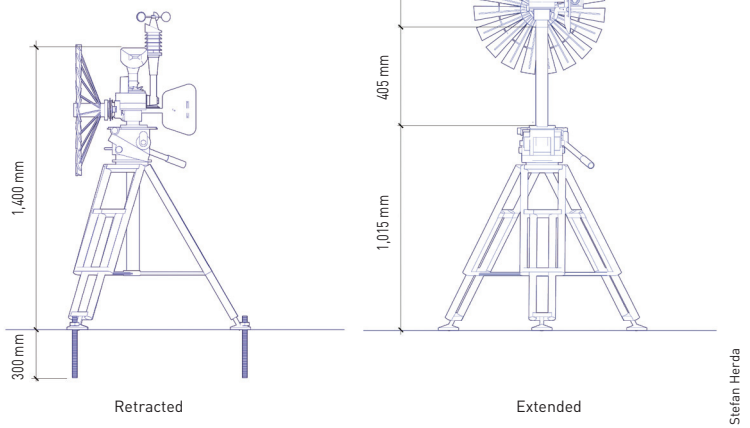
5 Propagating Alpine Identity

It is critical to acknowledge the labour of generations of land-based management practices that have cultivated the collective experience responsible for our notions of the Alpine landscape. These crucial practices are quickly disappearing as pastoral lifestyles become abandoned in favour of luxury tourism in the Urseren Valley. Careers that center on resourceful preservation efforts must be encouraged to aid in the upward migration and continued existence of Alpine flora. This proposal is not the only solution to the myriad of environmental challenges the region is facing, but one speculative proposal among many local and international initiatives to preserve species and monitor climate effects on alpine ecology④.

These hybridized landscapes serve as the nexus for a new ecologically oriented cultural commons, addressing the ecological pressures of the area beyond outdoor recreation and ecotourism. Thus, reimagining the former Swiss military history once designed to protect the populace from the threat of invasion can give them





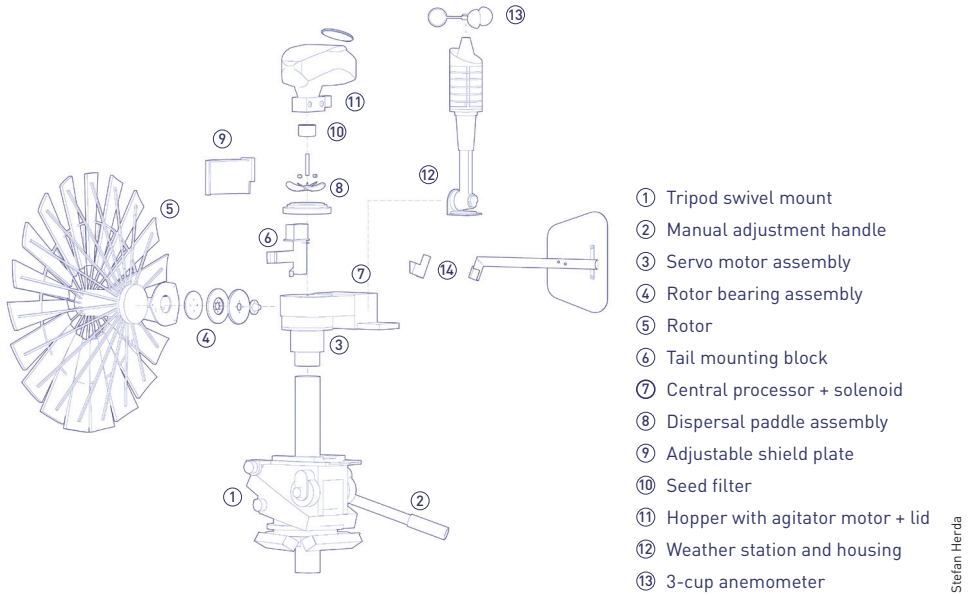


Front elevation with rock anchor

Right elevation at full extension

17

17. Front and left elevations of the active seed dispersal mechanism mounted to a heavy-duty tripod assembly



Dispersal unit axonometric

18

18. Exploded detail of modular components of the dispersal unit

new life as a catalyst for local involvement in conservation. Through strategic reinvestment, abandoned Swiss fortifications can be re-opened as sites of production, research, and education that no longer function solely for the preservation of nationhood or private interests. Instead, they preserve a diverse range of Alpine ecologies that define a facet of the Swiss pastoral identity. Actively and promptly addressing this impending ecological redoubt has the power to unify people, flora, and fauna, fostering future ecological resiliency and maintaining biodiversity before plant communities of the Alpine landscape become relegated to memory.

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生态堡垒：协助瑞士阿尔卑斯山脉中部地区敏感植物的迁移

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摘要

气候变化对瑞士的高山生态造成的影响是极为特殊的。由于年平均气温不断上升，当地许多植物物种的栖息地遭到破坏，它们被迫逐渐向海拔更高的区域迁移。在旅游经济开发和先锋植物物种不断入侵的双重影响下，敏感而稀有的植物群落将无力适应新的环境，以致当地具有重要价值的高山草甸日渐衰败。生物多样性丧失正迅速成为瑞士举国关注的重要生态问题。

安德马特镇位于瑞士中部乌塞伦河谷的东端，地处欧伯拉普、圣哥达山和富尔卡三个隘口的交汇处，拥有丰富的植物物种。周边的山脉上坐落着若干“国家堡垒防御计划”时期遗留下来的军事掩体和堡垒，其中包括建于1893年的斯托克利堡垒和建于1944年的古奇炮工厂。20世纪90年代，随着冷战的结束，逾8 000座防御工事逐渐丧失功能，其中一部分与当地景观融为一体。与此同时，精品酒店的大量开发、为建设高山滑雪公园而进行的斜坡改造等对当地的高山草甸造成了严重威胁。如不加以干预，该地区特色植物的生存空间将持续萎缩，加剧生物多样性缺失与土壤质量下降。

本文所述项目探究了如何将特定军事基础设施融入景观中，进而推动高山植物群落的研究、保护与复育。具体策略包括：1）重新引入传统的放牧管理方式，控制桤木的入侵；2）以斯托克利堡垒和古奇炮工厂为基地，建立高海拔种子库；3）将古奇炮工厂上方崎岖不平的景观改造为一处生态庭院，促进植物的主动与被动繁殖。考虑到部分高山植物生长于海拔较低的区域，本项目设计了一套新的种子主动传播机制，该机制与种子的天然传播途径相结合，充分利用焚风，可大大增加种子的传播距离，适应不断变化的气候条件。废弃的防御工事由此重获新生，成为了集生产、研究与教育功能为一体的重要场所。

关键词

高山生物多样性；
瑞士军事基础设施；
气候变化；
适应性再利用；
种子传播

文章亮点

- 重新引入传统的放牧管理方式可解决桤木的入侵问题
- 建设低碳的在地种子库可弥补非在地式保护的不足
- 杂交繁殖技术可重建高山敏感植物区系
- 瑞士的军事基础设施可发挥生态保护功能并吸引公众参与

编辑　王颖，王胤瑜