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Environmental Restoration in Hydropower Development—Lessons from Norway

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Abstract: Hydropower is expanding globally and is regarded a key measure for mitigating climate change, but it also results in major environmental degradation, both at local scale and more widely. We can learn lessons about how restoration can be used to alleviate these problems from failures and successes in countries with a long history of hydropower development, such as Norway. Here, hydropower projects grew larger over time, and in the 1960s, the emerging environmentalist movement started to challenge hydropower developments because of their negative impacts on the environment. The Norwegian Water Resources and Energy Directorate then appointed a landscape architect who became very influential, particularly due to his skills in aesthetics and photo documentation. He developed principles for designing self-sustaining environments which he called "living nature", and in particular proposed methods of restoring barren, unattractive, alpine spoil heaps. Later, restoration methods and goals have changed in response to new insights and the changing goals of ecological restoration. Here, we present current best practice for the alpine biome and sum up general lessons in three points: restoration can represent a sustainable, 'third way' in the conflict between conservation and development; including a wider group of professionals may improve restoration goals and methods, and effective use of visual communication can be a good way of gaining support for new restoration principles.

Keywords: renewable energy; restoration ecology; environmental degradation; Norway; landscape architecture; hydropower; management; planning

1. Introduction

Hydropower harnesses the energy of water moving from higher to lower elevations. The first known use of the normal water cycle for labour-intensive work in the form of watermills dates back more than 2000 years, in the Near East [1]. People then used hydropower for a wide variety of purposes up to the late 19th century, when it was first used to generate electricity, boosting the industrialisation process. In the northern hemisphere, countries with the natural assets for large-scale hydropower (high mountains and high precipitation)—such as Canada, the US, and Norway—implemented large hydropower projects. More recently, hydropower has contributed to the growth of the emerging BRICS economies. Various European countries including Scotland, Germany, and countries around the Alps, in Fennoscandia, and in the Baltic regions [2–7] are developing hydropower, and a global boom in dam construction is anticipated [8].

Modern hydropower projects benefit from a mature technology, and include dams with reservoirs, run-of-river projects and in-stream projects. In many cases, hydropower developments provide drinking water, irrigation, flood, and drought control as well as energy [9]. Assessed in sustainability terms, hydropower scores well on a broad range of social and economic factors, and also has the potential to play a part in reducing greenhouse gas emissions by replacing fossil fuels, thus making it easier to reduce global warming [10,11]. Promoting sustainable development and combating climate change have become integral aspects of energy planning, analysis, and policy making [12]. Because energy production accounts for two-thirds of total greenhouse gas and 80% of CO_2 emissions, any effort to reduce emissions and mitigate climate change must include the energy sector. Meeting the long-term climate objectives of the Paris Agreement requires urgent measures to reduce energy-related greenhouse gas emissions.

However, hydropower developments also have a price. In particular, large hydropower developments in the Global South have caused the loss of livelihoods and social disruption due to flooding of houses, cropland, and pastures, thus making development less socially sustainable. However, this paper focuses on the ecological impacts of hydropower and how these can be reduced. Renewable energy requires much larger areas of land than fossil energy for production of the same amount of energy [13]. In other words, it has a larger 'land footprint' than fossil forms of energy, and this means that replacing fossil fuels with renewable fuels will inevitably increase the area used [14–18]. Hydropower contributes to global habitat degradation, which is causing a global decline in biodiversity [19,20] and, on a local scale, the degradation of scenic landscapes [10], see Figure 1. This means that solutions must be found for individual river systems that have suffered negative impacts as a result of regulation of river channels [21,22], and construction of terrestrial structures, including dams, roads, pipelines, tunnels and spoil heaps [23]. The latter are piles of surplus material from tunnel excavation that are deposited on site, in many cases in vulnerable areas such as open alpine landscapes where harsh climate and modest thickness of quaternary deposits and soil slow down revegetation [24], see Figure 2.

Figure 1. Hydropower development create large land footprints, for instance through dam and reservoir construction. Open alpine landscapes with harsh climate and modest quaternary deposits and soil, are particularly vulnerable to such environmental degradation. The figure shows the 100 m tall Sysendammen with its connecting reservoir of 427 billion m^3, which covers 10.42 km^2. Sysendammen, Hordaland, W. Norway, 1979 and 1981, 945 m. Photo credit: Knut Ove Hillestad/Norwegian Water Resources and Energy Directorate.

If society is to increase renewable energy production, and at the same time safeguard the natural and cultural heritage and minimize habitat degradation, we need targeted approaches that can counteract species losses and restore degraded ecosystems [25,26]. This is recognized in the Aichi Biodiversity Target 15, which states that at least 15% of degraded ecosystems should be restored by 2020. Restoration ecology aims at reversing the widespread effects of environmental degradation. According to the Society for Ecological Restoration, it includes activities to assist the recovery of ecosystem structure and function [27]. The young science of restoration ecology emerged in the 1980s, but has its roots in management activities such as erosion control and game management [28]. Restoration ecology, conservation biology, and ecological engineering are all important elements of applied ecology [29]. Restoration ecology has been termed "an acid test for ecology", because we will not be able to reconstruct ecosystem processes and functioning unless we understand them [30].

Figure 2. Even after 50 years, many alpine spoil heaps from hydropower activities remain barren and devoid of vegetation cover, despite attempts to restore vegetation cover by addition of non-local soil, seeds, and fertilizer. Nørdstedalsseter, Sogn og Fjordane, W Norway, 2008, 1010 m. Photo credit: Knut Rydgren.

A core tenet of restoration is that it must have clear and achievable goals [31]. Restoration success, i.e., whether the goals have been achieved, is assessed by comparing the restored area to some sort of reference. This could be the historical situation at a chosen point in time, or a local site that has the required characteristics, assuming that close resemblance will ensure good ecological function [32]. Restoration goals, and implicitly the understanding of what constitutes a good reference, have changed over time in response to increasing knowledge development and changing values [33,34]. In addition, methods of assessing restoration success are constantly under discussion [35,36].

In this paper, we show how hydropower development has been an important arena for the development of restoration ecology in Norway. Hydropower development has a long history in Norway, where it has led to large-scale ecosystem degradation and to the creation of numerous conspicuous terrestrial structures (such as spoil heaps) locally, so that people are aware of its physical and visual impact. We ask whether experience from the application of restoration ecology in the Norwegian hydropower sector provides useful knowledge for future hydropower projects elsewhere. We investigate how understanding of good restoration practice has evolved in the Norwegian context and give an account of current best practice for ecological restoration of a particular case—spoil heaps in the alpine biome. We explore how the relationship between hydropower development, nature conservation and restoration practice has altered over time, partly as a result of changes in restoration goals connected to underlying views on the value of nature. In addition, based on experience specific to Norway, we discuss how visual communication can win support for the implementation of restoration methods.

2. Development of Hydropower and Restoration Ecology in Norway

The modern Norwegian hydropower industry started 130 years ago, but the early installations were modest in size [37]. Since 1909, the licensing system has provided a crucial institutional framework for the management of electricity. The legislation secured national control over natural resources, rather than allowing it to go to foreign or commercial interests. Another important milestone was the establishment of a government agency, now called the Norwegian Water Resources and Energy Directorate (NVE), in 1921. The Directorate grew over time until its golden era in the 1960s, and was given scientific, advisory, supervisory, and executive responsibilities for river systems and for electricity in general [37].

When the Directorate, at the time a monolithic technical body, in 1963 chose to employ a representative of the aesthetic arts—a landscape architect—this was a response to conflicts between hydropower and tourism and recreational use that had been growing since the late 1940s. In particular, there was conflict over large structures in the open alpine biome, especially the large, barren spoil heaps. The landscape architect, Knut Ove Hillestad, was skilled in a profession that focused on design as well as function, and his background distinguished him from his colleagues. During 30 years' service in the Directorate, he challenged established opinion, both the hydropower companies' utilitarian acceptance of environmental degradation as a price that had to be paid for economic growth, and the environmentalists' focus on wilderness and the intrinsic, non-utilitarian values of nature [37,38]. Hillestad avoided this politicized dichotomy and proposed an alternative ideal that he called "levende natur", or "living nature" [37]: a regime where nature was constructed, but self-reproducing. His idea was that once the process of restoration had started, the constructed environment should develop and be self-sustaining, preferably without further human support. These ideas echoed the "ecological view" presented by the landscape architect Ian McHarg in his influential book *Design with Nature* [39].

The new focus on aesthetic issues also resulted in attention being paid to improving the design of the large and until then unattractive spoil heaps, and in a systematic search for methods for fast restoration of the vegetation cover in the slowly recovering, alpine biome. Hillestad carried out experiments in a wide range of locations to identify which measures that needed to be taken to establish "living nature". These included addition of soil, a variety of fertilizers, and different seeds and plants (Figure 3), organised as network projects involving the Directorate, hydropower companies, and the Norwegian College of Agriculture [40].

Figure 3. A multitude of experiments involving addition of soil, fertilizers and seeds were carried out from the 1960s and onwards to identify optimal restoration methods for spoil heaps. Ulla-Førre, Rogaland, SW Norway. 1985. Photo credit: Knut Ove Hillestad/Norwegian Water Resources and Energy Directorate.

The experiments drew heavily on the College's expertise in agronomy, and although it was stressed that the restored vegetation should resemble the surrounding vegetation [40], the overarching restoration goals were fast establishment of a dense, green cover, and maximum yield [41]. The latter was considered important as the alpine areas were important grazing areas for cattle and sheep. Hillestad's views of how to create "living nature" have been embedded in a wide range of restoration initiatives in Norway right up to the present, not least due to his talents as an eminent photographer and communicator [23,37]. He often presented restoration issues as solved problems and completed projects, see Figure 4.

Figure 4. The restoration concept of "living nature" launched in Norway in the 1960s became very influential in hydropower projects, especially because of the embedded goal of fast establishment of dense, green, and aesthetically appealing vegetation, cleverly communicated through photographs. The upper panel shows a large project in its establishment phase, the lower shows the same site 21 years later after treatment with seeds and fertilizer. Vikafjellet, Hordaland, W Norway, 1967 and 1988, 994 m. Photo credit: Knut Ove Hillestad/Norwegian Water Resources and Energy Directorate.

Nevertheless, Norwegian hydropower developments became increasingly controversial from the late 1960s onwards, and the Mardøla conflict in Mid-Norway in the summer of 1970 was a turning point. All over the Western world, the environmentalist movement had made people aware of the need to protect the environment from development and degradation [38]. The opponents of the Mardøla project (who included many academics, amongst them ecologists related to the deep-ecology movement, and the prominent professor and eco-philosopher Arne Næss [38]) opposed the project with all the means at their disposal, including civil disobedience. Although they lost the battle—the Mardøla project was carried out—some would say that they won a small war. They made the public aware of the social and ecological drawbacks of hydropower in the vulnerable, alpine biome. From then on, the Norwegian hydropower debate became more ideological, and dealt more with ecology and society at a fundamental level than with tourism and aesthetics.

One of the last large-scale hydropower developments to be carried out was Alta-Kautokeino in Northern Norway in 1980. It was strongly opposed by environmentalists and the Sami people. Gro Harlem Brundtland, Prime Minister of Norway at the time, afterwards admitted that this project should have been avoided [42]. This admission came after Brundtland had served as chair of the World Commission on Environment and Development, which produced the report *Our Common Future*, that developed the principles for sustainable development.

During the 1970s, there was a series of large-scale applied ecological research projects funded by the Norwegian Water Resources and Energy Directorate that focused on the environmental effects of hydropower developments. These were also phased out [37] and changed character to become what were known as biotope adjustment projects during the 1980s. The majority of these projects focused on improving the conditions for marsh birds and freshwater fish in regulated rivers. They involved a wide range of expertise, including ecologists.

3. Alpine Hydropower Spoil Heaps—A Norwegian Case of Ecological Restoration

There have generally been few evaluations of restoration initiatives in Norway and the other Nordic countries [43], but there are some examples, such as the major, ongoing restoration of the former military training area at Hjerkinn, in the alpine biome [44,45]. In the 1990s, as part of one of the biotope adjustment projects, a fine-scale evaluation of the outcome of restoration of selected alpine spoil heaps in the southern half of Norway was carried out by Gudrun Skjerdal and Arvid Odland [41,46–48]. These studies, and subsequent reanalyses by Knut Rydgren and colleagues in 2008–2015 [24,49,50] (see Figure 5), assessed the restoration success of alpine spoil heaps in terms of their similarity to the vegetation of the surrounding areas, rather than their yield. The underlying assumptions were that similarity to surrounding vegetation would ensure that the vegetation was well adapted to local conditions, and that the best way of establishing such vegetation would be through natural seed input from the undisturbed, surrounding vegetation. There was also less emphasis on creating pasture for livestock on the spoil heaps in response to the decreasing stocking rates in alpine areas.

Figure 5. The calcicole plant *Dryas octopetala* occurred in the surroundings of one of the spoil heaps investigated in the 1990s and 2015. Detailed vegetation analyses allowed comparison of spoil heaps and surroundings, and subsequent assessment of restoration success. In a few cases, rare and vulnerable species from the surroundings actually managed to establish themselves on the spoil heaps. Kleådalen, Sogn og Fjordane, W Norway, 2015, 1050 m. Photo credit: Inger Auestad.

The studies, performed by plant ecologists, and including detailed records of the species composition of permanent vegetation quadrats, revealed that the effects of the restoration methods included in the "living nature" regime on the restored alpine spoil heaps were unpredictable. Some spoil heaps that had been constructed before the 1960s still resembled pioneer ground in the 1990s [47]. Rydgren and colleagues' reanalyses [49,50] confirmed the modest success of the fertilization and seeding recommended by Hillestad and colleagues in developing the spoil heaps into self-sustaining "living nature", even after more than 50 years, see Figure 2. In other spoil heaps, a vegetation cover had developed, but it bore little resemblance to the surrounding vegetation—the non-native grasses that had been introduced proved to be persistent and dominated many spoil heaps even after 40 years of succession [50], see Figure 6. A comparison of 19 alpine spoil heaps [49] with their surroundings revealed that the coarseness of the substrate, rather than seeding and fertilizing treatments, explained the differences in species composition. From this, Rydgren and colleagues concluded that spoil-heap design affected restoration success more than fertilization and seeding, and they recommended discontinuing these measures. Instead, they advocated covering the spoil heaps with a fine-grained substrate of local topsoil, creating an uneven surface to mimic natural topographic variation, and allowing natural succession processes by encouraging natural revegetation from the surrounding areas. Well-integrated project management is essential for natural revegetation to succeed, since topsoil must be removed and carefully stockpiled during hydropower construction and subsequently replaced.

Figure 6. Vegetation analyses of alpine spoil heaps showed that, in some cases, restoration with seeding and fertilizing led to development of a grass-dominated vegetation that poorly resembled the surroundings, where heather species like *Vaccinium* spp. and *Empetrum nigrum* prevailed. Svartavatn, Sogn og Fjordane, W Norway, 2015, 1300 m. Photo credit: Knut Rydgren.

Rydgren et al. [50] moreover added a warning that introduced grasses might not only persist on alpine spoil heaps for decades, but also invade surrounding areas. The alpine biome was for a long time considered to be at low risk of invasion due to the harsh climate, but persistent propagule pressure from sowing of hardy non-native seeds, in combination with climate change, may change this picture [51,52]. The worldwide awareness of the problems associated with invasive non-native species has more recently resulted in new legislation. Norway's Nature Diversity Act was adopted in 2009, and highlights restoration in several ways, particularly through a general prohibition on using non-native species without a special permit, for example for revegetation [53,54]. In some cases, however, seeding is necessary to prevent erosion. In Norway, as in many countries (e.g., [55–57]), efforts have been made to identify seed transfer zones within which seeds of locally adapted genotypes of wild species can be used for ecological restoration. This has resulted in the establishment of four general seed transfer zones for alpine Norway [54], and subsequent commercial production of seed mixtures for use in these zones. Results from all these restoration projects have been disseminated both in reports to the Norwegian Water Resources and Energy Directorate [58] as well as in newspaper articles [59,60].

Today, the instructions published by the Norwegian Water Resources and Energy Directorate for terrestrial structures in new alpine hydropower projects broadly follow ecological restoration principles: using local topsoil to allow natural regeneration, avoiding non-native seeds and minimizing fertilization. Nowadays, however, there are few new large-scale hydropower projects in Norway, and it is generally a question of upgrading existing large hydropower projects. In these cases, natural revegetation is encouraged, but fertilizing and adding soil is still accepted. This is also the case for the large and increasing number of small-scale hydropower projects that have been carried out over the last 20 years.

4. Discussion and Conclusions

In our opinion, experience of applying restoration ecology in the Norwegian hydropower sector has provided knowledge that will be useful in future projects. The specific methods suggested in this paper for successful ecological restoration of spoil heaps have particular relevance for a wide range of technical installations in the alpine biome, where harsh climate and poor soil conditions strongly hamper restoration speed. For example, in subtropical and tropical biomes with benign temperature and thick deposits, vegetation recovery can be expected to proceed faster, but still some general insight applies: it is important to select appropriate references, allow natural succession to take place, and avoid introduction of invasive, non-native species.

In a wider perspective, our Norwegian example demonstrates elements of both success and failure, and it shows how sustainable restoration practices develop from the interplay between specific types of habitat degradation (in our case terrestrial, hydropower-related structures in the alpine biome), institutionally embedded values and guidelines, and general insights from the science of restoration ecology. We have identified three specific insights.

First, in a discussion of the relationship between development, conservation and restoration, we wish to underline that although restoration can mitigate environmental degradation, it will always remain a poor second to the conservation of original habitats [61]. Hence, any successful management regime should start out by identifying which areas should not be utilized, but rather safeguarded against development. The controversies surrounding Norwegian hydropower developments 50 years ago led to the development of both a series of protection plans for water resources that safeguarded a selection of the most valuable and vulnerable river systems, as well as a Master Plan for Water Resources [62]. The latter was an essential basis for more sustainable development of the hydropower industry in Norway. Once a departure point of this kind is established, restoration can provide a useful 'third way' for sustainable development in the conflict between development and conservation.

Second, stakeholders' values and knowledge have a strong influence on restoration goals and restoration methods, which change over time. This is why including a broad group of professionals, trained in a wide range of disciplines, is useful for improving restoration goals and methods. In Norway, the early, engineer-dominated professionals paid little attention to revegetation issues up to the 1960s, when the negative impacts of hydropower development could no longer be ignored. Then came the period when aesthetic values, good design, and high yields were in focus, and the ideal of "living nature" was developed under the leadership of a landscape architect and agronomists. At that time, these ideals were considered to be modern and environmentally friendly, but newer insights into the negative impacts of non-native species, the decreasing importance of plant yields, and the unpredictable outcomes of the restoration methods that had been used, gradually led to the abandonment of these methods. We think that this exemplifies the problems of introducing new ideals whilst working under old paradigms: Hillestad and colleagues were unable to depart from the deeply rooted priorities of constructing technically safe spoil heaps and increase yields, and chose methods that reflected this priority. Nevertheless, we should recognise that the "living nature" ideal was a positive development compared with the preceding, technically orientated regime. The current emphasis on good ecological functioning can be viewed as a shift from an anthropocentric, via a biocentric to an ecocentric view of nature [34]. The latter emphasizes well-functioning ecosystem processes, naturalness, and the integrity of nature as a whole, and corresponds well with the restoration goal of similarity to surrounding vegetation. Moreover, the detailed analyses of the spoil heaps and surrounding vegetation, continued over a period of more than 20 years, have allowed us to pinpoint the most important success factors for spoil heaps, and made it clear that vegetation recovery in alpine areas is a slow process. The inclusion of ecologists trained in restoration methods that emphasize ecological function are in line with the general restoration principles recommended by the Society for Ecological Restoration [63].

The third insight relates to why the ideal of 'living nature' became so successful at the time it was launched and for the subsequent 30 years. Hillestad's great talent for communication, particularly his skilled use of photographs, allowed him to disseminate his ideal and its related goals and methods to a broad audience of professionals and to the public [37]. This was important to ensure that not only decision makers, but also those involved in the practical work, understood and worked towards the planned outcome. The dissemination of results from the spoil heap restoration, as well as the highly relevant Hjerkinn project [45,59,60] will be of great importance to succeed in the years ahead. However, the hydropower industry will have to deal with new restoration challenges as well as the traditional ones. For instance, rapid growth, in many countries, including Norway, particularly in small-scale hydropower, will increase the number of developers and stakeholders who need to know how to restore the environment after degradation. The widely accepted perception that small-scale hydropower has less detrimental effect on the environment than large-scale hydropower has lately been challenged. Comparisons have shown that small-scale developments reduce wilderness areas more per unit of energy produced [64], and that new small-scale developments have a relatively larger impact than large-scale developments or the expansion of existing plants [65]. Effective dissemination of insights into ecological restoration after large-scale hydropower developments will be vital for the sustainability of both large- and small-scale hydropower in the future.

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