The Quarry-to-Alvar Initiative:

Creating New Alvar Habitat from Abandoned Limestone Quarries

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Introduction

Mineral aggregate is indispensable to our modern infrastructure. In Ontario, over 7000 sites on both private and Crown land produced 167 million tonnes of aggregate in 2008 (The Ontario Aggregate Resources Corporation 2008). Limestone, the most important type of aggregate in Ontario, is a key ingredient in the production of concrete and asphalt, and the demand for it is predicted to rise steadily with increasing urbanization.

Until the 1980s, pits and quarries in Ontario were simply abandoned once all accessible aggregate was removed. Since the passing of the provincial Aggregate Resources Act in 1990, quarry operators have been responsible for rehabilitating all newly decommissioned sites. The Act further specifies that a portion of the annual aggregate license fee must be set aside and used to rehabilitate sites abandoned prior to 1990. Since 1997, these funds have been administered by the Ontario Aggregate Resources Corporation (TOARC) and disbursed via a program known as MAAP, or the Management of Abandoned Aggregate Properties program. MAAP's mandate also includes the funding of research to develop new techniques for pit and quarry rehabilitation.

Abandoned limestone quarry floors and the challenge of their rehabilitation

Abandoned limestone quarries present a serious land management problem. Hard-rock extraction destroys the original landscape, leaving behind a high-stress environment that is too harsh for most previous inhabitants to reoccupy. Spontaneous recovery by primary succession is a slow process and often produces undesirable outcomes in the form of ecosystems that provide few ecological services. Assisting ecosystem recovery toward pre-disturbance conditions such as agriculture or forest would require the deposition of a thick layer of topsoil over the entire quarry floor, a difficult and expensive undertaking with no guarantee of success given the frequent failure of this approach where landscapes have become drastically altered. Thus, the lack of feasible rehabilitation techniques, the absence of a clear restoration target, and a general lack of information on the remediation of hard-rock landscapes have all contributed to MAAP's historical focus on abandoned gravel pits, whose rehabilitation is relatively straightforward, rather than hard-rock quarries.

A new approach to rehabilitation: Using degraded-state analogs

At the heart of a novel approach to site rehabilitation is the concept of 'degraded-state analogs' (Richardson 2009). In conventional restoration, the goal is to re-create the appearance of the original system despite the fact that this historical restoration target may be ecologically far removed from the current state of the site. In contrast, the new approach targets a high-value natural ecosystem that is biophysically analogous to the present, degraded state. Focus is placed on establishing biodiversity and ecosystem processes associated with this target state, rather than on restoring the historical appearance. By facilitating the immigration of native species that are already adapted to the conditions of the degraded site, the damaged landscape is ecologically enriched and functional and conservation value is enhanced. Ideally, such rehabilitation projects will result in the expansion of rare habitats, the enhancement of biodiversity, the connection of fragmented habitat, and an overall increase in ecological function. The possibility of turning degraded anthropogenic landscapes into refugia for biodiversity provides hope that the need to exploit natural resources can be reconciled with the need for conservation.

Alvars as restoration targets for quarry floors

In 2003, the Cliff Ecology Research Group at the University of Guelph, Ontario, embarked on a MAAP-supported project to investigate alvars as possible restoration targets for limestone quarry floors. Alvars are natural limestone pavements that support a sparse vegetation of cryptogams, herbs, shrubs and few trees alternating with patches of bare rock. Their promise as restoration targets for abandoned quarries is based on two facts. First, they appear to be perfect degraded-state analogs of quarry floors; superficially, alvars and naturally regenerating quarry floors can be almost indistinguishable (Figure 1). Second, alvars are a habitat of high conservation value that is both rare and under threat. They are considered one of the most floristically-rich habitats in northern-temperate regions and contain many rare, endangered and endemic species as well as ancient trees (Figure 2). The Nature Conservancy has listed alvars as provincially and globally endangered, but less than one quarter of North American sites are protected (Catling and Brownell 1995). By providing refuge for alvar species at risk, 'artificial' alvar habitat created from nearby abandoned quarries could complement efforts to protect the remaining natural alvars from human impact.

How similar are abandoned limestone quarry floors to alvars?

We began the quarry-to-alvar initiative by collecting quantitative evidence for the apparent similarity of alvars to the 'degraded state' of quarry floors, as well as identifying how the

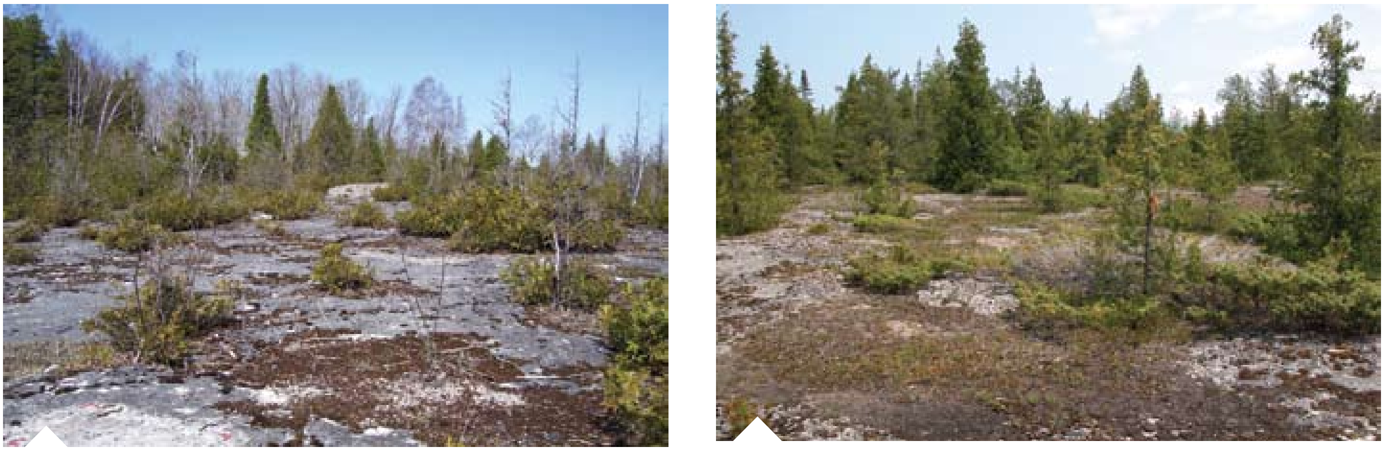

Figure 1. Alvars are degraded-state analogs of abandoned quarries. The photo at the left shows a quarry site (Fletcher's Creek near Puslinch, Ontario) that had been regenerating naturally for 76 years; Right photo shows a natural alvar on the Bruce Peninsula, Ontario. (Quarry photo by P. Richardson, alvar photo by J. Gerrath.)

Figure 2. Alvars harbour a diverse flora that includes rare species such as lakeside daisy (*Hymenoxis herbacea;* top left, photo by N. Kiers), Indian paintbrush (*Castilleja coccinea;* top right, photo by N. Kiers), dwarf lake iris (*Iris lacustris;* bottom left, photo by P. Richardson), upland white goldenrod (*Solidago ptarmicoides;* bottom middle, photo by P. Richardson), and cylindrical blazingstar (*Liatris cylindracea;* bottom right, photo by P. Richardson).

two habitat types differed (Tomlinson *et al.* 2008). Thirteen abandoned limestone quarries in southern Ontario were selected for study, and vegetation and physical characteristics were sampled at each site. The study design closely followed an earlier survey of 7 natural alvars in southern Ontario (Schaefer and Larson 1997) to allow for direct comparisons between habitats.

The data confirmed that quarry floors and alvars were remarkably similar in terms of both species composition and physical environment. The two habitats were indistinguishable with respect to key environmental variables such as bare rock cover, soil depth, pH and soil bulk density. Quarry floors supported almost as many plant species as did alvars (246, as opposed to 283 for alvars). Seventy-nine species were common to both habitats, among them 24 considered characteristic of alvars (Catling and Brownell 1995) and five alvar endemics. We concluded that natural processes had accomplished roughly a 50-60% conversion of quarry to alvar in terms of species composition.

However, there were several important differences between the habitats as well. Quarry floors supported significantly fewer bryophytes and a much larger number of non-native, 'weedy' species. Key environmental differences were lower nitrogen levels in quarry substrates and a mineral fraction of $CaCO_3$ in the form of crushed limestone tailings that substituted for the exogenous silica sand characteristic of southern Ontario alvars (Stark *et al.* 2004).


FIGURE 3. EXPERIMENTAL PLOTS TO INVESTIGATE THE FACTORS LIMITING THE ESTABLISHMENT OF ALVAR SPECIES ON QUARRY FLOORS. LEFT, PLOT BEFORE ADDING ALVAR SEED; RIGHT, ALVAR-SEEDED PLOT AFTER ONE GROWING SEASON, WITH THE ALVAR COMMUNITY WELL ESTABLISHED (PHOTOS BY P. RICHARDSON).

WHAT LIMITS THE SPONTANEOUS REGENERATION OF QUARRY FLOORS TO ALVARS?

Could substrate differences or lack of nitrogen explain why even quarries abandoned for half a century have come only halfway to becoming alvars? If so, soil amendments might help convert quarries to alvars more completely and more quickly. Or are hardy, fast-growing weeds outcompeting the native alvar species? If so, then periodic weeding might be the remediation treatment of choice. Or is it simply that seeds of alvar species do not reach quarry floors and seed addition is needed? It is easy to see why targeted and efficient restoration techniques can only be devised if the factors limiting the establishment and survival of alvar species on quarry floors are known. Therefore, we conducted an experiment at four abandoned quarry sites to identify some of these factors (Richardson 2009).

At each site, plots were laid out and randomly assigned to one of six treatments (Figure 3, left). Five of the treatments consisted of seeding the plots with 18 alvar species and (1) making no changes, (2) adding a soil supplement consisting of silica sand plus compost to dilute high $CaCO_3$, (3) adding fertilizer and soil supplement to both dilute $CaCO_3$ and enrich the nitrogen-poor substrate, (4) removing weeds to reduce competition, and (5) adding seeds of



FIGURE 4. TOP: USING A ROCK HAMMER TO CREATE SPATIAL HETEROGENEITY IN THE ROCK PAVEMENT OF AN ABANDONED QUARRY (FLETCHER'S CREEK NEAR PUSLINCH, ONTARIO; PHOTO BY L. CORREALE). BOTTOM: PLOTS SUBSEQUENTLY SEEDED (LEFT) OR PLANTED (RIGHT) WITH ALVAR SPECIES; PHOTOS BY P. RICHARDSON.

weed species that naturally colonize quarry floors to increase competition. Treatment (6) consisted of seeding only weeds to provide a comparative standard of success for species limited by seed availability but not the environment. Colonization success was judged by the number of species establishing (species richness) and the density of vegetation in each plot.

The results showed that seed limitation – the lack of propagules of alvar species reaching quarry floors - is the primary constraint on the natural succession of abandoned quarry floors to alvars. The addition of seeds alone, without further intervention, was enough to initiate establishment of alvar plant communities in all plots (Figure 3, right). Plots receiving alvar seeds performed about equally well as plots seeded with the weeds that normally colonize quarry floors. Neither the addition of weed seeds to increase competition, nor the removal of competing weeds had any effect on the density and richness of establishing alvar species. The addition of soil supplement in addition to alvar seed resulted in plots that were slightly richer and denser than plots receiving seeds only; this shows that substrate is a weak secondary limitation. Nitrogen addition, in contrast, had no benefit and even reduced the number of alvar species and individuals establishing in each plot. We concluded that fertilization and weeding are unnecessary; a more rapid and complete development of quarry floors into real alvars seems to require nothing more than the addition of alvar seeds and possibly a small amount of soil.

The role of habitat heterogeneity

While both alvars and quarry floors are characterized by limestone pavement, quarry floors tend to be more uniform due to lack of weathering. Since fine-scale variability in microtopography controls where soil and seeds collect, we wanted to investigate how the establishment of alvar species on quarry floors is influenced by microhabitat heterogeneity (Richardson 2009). We seeded 13 alvar species in plots that were thoroughly characterized with respect to 16 microhabitat features, and surveyed the plots over 2 years. The results confirmed that both the number of species establishing in each plot and the total vegetation cover increased with increasing habitat heterogeneity. This was attributed to different species utilizing in complementary ways various microhabitat features critical to germination and establishment.

Could the success of quarry-to-alvar restoration be improved if an effort was made to add spatial heterogeneity to quarry floors, using heavy machinery prior to decommissioning a site? This was explored in an experiment where we used a rock hammer to create substrate heterogeneity at two spatial scales (Stabler 2009; Figure 4). Untreated plots were used as controls, and alvar species were added to all plots either as seeds or as greenhouse-grown adult plugs. After one growing season, the benefits of 'manufacturing' spatial variability were already apparent. Regardless of the way in which alvar species were introduced, plots with manufactured heterogeneity at either

FIGURE 5. AN EXPERIMENT TO DETERMINE THE EFFECT OF SPECIES DIVERSITY ON THE STABILITY OF RESTORED ALVAR COMMUNITIES INVOLVED SETTING UP TRANSPARENT DOMES OVER PLOTS TO SIMULATE HEAT AND DROUGHT CONDITIONS. (PHOTOS BY P. RICHARDSON).

scale supported more diverse and productive alvar plant communities that had better survival compared with plots where no change was made to the bedrock.

LONG-TERM PROSPECTS: PERSISTENCE OF RECONSTITUTED ALVARS ON QUARRY FLOORS

To be successful in the long term, a restored community must not only survive during 'normal' conditions but also withstand the extremes of environmental fluctuations and be able to recover from perturbations. We had the opportunity to gain some insight into the determinants of resistance to disturbance in restored communities by studying the effects of a catastrophic drought which befell an ongoing experiment in the early summer of 2005 (Richardson 2009).

The drought diminished species richness and density in all restored plots, but there were some interesting patterns. Introduced alvar species had significantly higher survival rates than the resident, weedy quarry species - confirming that not only is it possible to use alvar species in the restoration of quarry floors, but alvar communities are more suitable colonizers of quarry floors in the long term than the weedy communities presently occupying abandoned sites. The superior adaptations of alvar species to the degraded state of quarry floors may not be apparent during 'normal' years, but become clear during extreme conditions such as the 2005 drought.

The results also showed that the most severe losses were incurred by plots fertilized with nitrogen. And the greater the species diversity in a plot, the greater was the survival rate.

The effect of species diversity on the stability of restored communities was further explored with an experiment that used transparent polycarbonate domes over plots to stop rain infiltration and increase air temperature in order to simulate severe drought and heat-wave conditions (Richardson 2009; Figure 5). For this experiment, a large number of alvar species were combined into different treatments in a way that allowed us to separate the effects of three factors: plant density (the number of individuals in a plot); species diversity (the number of different species in a plot); and species identity (which species were combined). The results were clear: plots with low species diversity suffered steep losses of vegetation cover under the domes relative to the controls, while plots with high diversity (but comparable density and species identity) remained completely unaffected.

CONCLUSIONS AND RECOMMENDATIONS

Natural processes of soil development and species recruitment can bring abandoned limestone quarry floors about halfway in the process of becoming alvars. The following simple steps can be taken to accelerate the development of structural and functional similarity to alvars and increase the likelihood that the restored community will persist over time.

- Adding substrate heterogeneity at small and large scales. Manufacturing crevices, fractures, and rock piles will help retain soil and moisture, trap seeds, and provide habitat diversity that encourages a large variety of species to establish.

- Adding small amounts of sand and compost, especially if the quarry is recently abandoned and no soil is present.

- Introducing the largest possible number of alvar species in the form of seeds or plugs. Restored communities with high species diversity resist perturbation and environmental extremes and are less likely to revert back to more degraded states.

The following measures are not beneficial or necessary:

- Removing the existing vegetation. Alien weeds do not prevent the establishment of alvar vegetation, and in the long term are less able to withstand environmental extremes than alvar species.

- Adding nitrogen. It has a detrimental effect on the establishment and stability of restored alvar communities. ■

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