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Towards calcareous wetland creation in flooded abandoned aggregate quarries: A 3-year field mesocosm study

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ABSTRACT

The purpose of this study was to demonstrate the feasibility of the rehabilitation of abandoned aggregate quarries to calcareous wetlands through a growth experiment at the quarry floor. We tested the effects of planting substrate (fine screenings, coarse rock, transplanted peatball, and topsoil addition to screenings) and springtime water depth (+15, 0, and −15 cm relative to ground surface) on the growth of *Carex aquatilis* over 3 years. Survival rate of the transplanted material was 100%. Minimal growth was observed after the first growing season, but by the end of the third growing season the transplanted material had added on average 80, 4, and 3 shoots in the topsoil-amended, intact peatball, and coarse rock treatments, respectively, but lost on average 4 shoots in the fine screenings treatment. The addition of topsoil significantly increased final aboveground biomass (285 ± 49 g per plot) compared to the peatball (40 ± 16 g), rock (36 ± 11 g) and screenings (35 ± 21 g) treatments, which were not significantly different. The effect of water depth did not lead to overall significant differences, as *Carex aquatilis* ramets were capable of growing in springtime water levels from 15 cm above to 15 cm below ground surface. Our data demonstrate that some flooded abandoned aggregate quarry floors represent suitable sites for conversion to calcareous wetlands, even with a strategy of minimum maintenance, and that wetland species are capable of growth in these largely inorganic settings.

1. Introduction

Calcareous fens are wetlands that are fed principally by groundwater rich in calcium and magnesium carbonate (Komor, 1994; Almendinger and Leete, 1998), exhibit very high species diversity (Motzkin, 1994; Johnson and Steingraeber, 2003), and serve as regional refugia for a number of rare plant taxa (Nekola, 2004; Bowles et al., 2005). Historically, calcareous fens have been subject to significant loss and degradation throughout North America and Europe due to groundwater extraction and/or diversion (Gilvear et al., 1993; Wassen and Joosten, 1996), as well as nutrient enrichment from encroaching agricultural land use and atmospheric deposition (Drexler and Bedford, 2002; Pauli et al., 2002; Lucassen et al., 2006). Because of their high biodiversity value these wetlands are now frequently targeted for protection and conservation (Bedford and Godwin, 2003). The restoration of degraded peatlands (e.g., Price et al., 1998; Sottocornola et al., 2007; Lucchese et al., 2010) and of degraded calcareous fens in particular (e.g., Beltman et al., 1996; Vinther and Hald, 2000; Jansen et al., 2001; Lamers et al., 2002) is the focus of much research. Recently, Amon et al. (2005) have demonstrated the possibility of calcareous fen creation on sites without evidence of former fen presence. We follow upon the concept presented by Amon et al. (2005) by initiating a research program to investigate the potential to create calcareous wetlands in a novel landscape setting: an abandoned flooded dolomite quarry floor.

In southern Ontario, Canada, the abundance of calcareous bedrock and glacial drift has generated an extensive quarrying industry for limestone and dolostone aggregate extraction. The Ontario Ministry of Natural Resources has mandated some form of site restoration and remediation must take place following the cessation of aggregate extraction (OMNR, 2006). Conversion to an open water ecosystem is currently the favoured rehabilitation method of the Ontario aggregate industry for below-water table extraction quarries; however, this produces an ecosystem of limited ecological and environmental value (Corry et al., 2008). Due to the presence of extensive calcareous groundwater discharge in these settings one very attractive option for restoration is the conversion of these abandoned quarries to calcareous wetlands. As a preliminary step in investigation of the

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feasibility of quarry conversion to calcareous fen we tested the effects of planting substrate and water depths on the growth of a single species: *Carex aquatilis* Wahlenb. (water sedge). This species is a fen generalist, that is, not a true calciphile, but a robust, perennial sedge (Bernard, 1990) that is frequently found in calcareous fens (Gignac et al., 2004), and is a dominant vascular plant in calcareous fens surrounding the abandoned quarry.

Through the use of controlled growth experiments previous research has revealed much information on the predominant variables affecting vascular wetland plant growth and biomass. Several studies have demonstrated that the relative availability of nutrients, particularly the N to P ratio, exerts a significant control on the biomass of wetland sedges and grasses grown under experimental conditions (Güsewell and Bollens, 2003; Güsewell, 2005c). Water regime has also been the subject of much recent research, and Kotowski et al. (2001) found that water depth had little effect on the growth of some wetland species grown at water levels from 0 to 45 cm below ground surface. Güsewell et al. (2003) found that the effects of water regime on growth were minor compared to nutrient levels, while Wetzel and van der Valk (2005) reported that hydroperiod had little influence on the growth of *Carex stricta* Lam., a species closely related to *C. aquatilis*. However, Fraser and Karnezis (2005) found significant differences in biomass in several wetland sedges grown in water levels that differed by just 2 cm. Consequently, a consensus on the effects of water availability on wetland sedge species growth is currently lacking.

In contrast to the research on nutrients and water levels, the influence of the physical structure of the planting substrate has received little attention. Indeed, in an effort to isolate the effects of nutrient additions and/or water regime, the planting material is not only standardized, but often consists of sand or sand-peat mixture (Wetzel and van der Valk, 1998, 2005; Güsewell and Freeman, 2005), mineral soil (Budelsky and Galatowitsch, 2000, 2004; Miller and Zedler, 2003; Perry et al., 2004), or horticultural mould (Güsewell, 2005a,b; Güsewell and Bollens, 2003). These planting conditions may be advantageous for determining other controlling factors on plant growth, but they do not represent the *in situ* growing conditions, and therefore mask natural variability. Furthermore, as applied to restoration efforts, it is particularly useful to assess plant success in conditions as close to the natural setting as possible.

While great effort has been devoted to carefully designing controlled experiments to investigate environmental constraints on the growth of wetland vascular vegetation, researchers have conducted these experiments over a very variable timeframe, sometimes too short to be of much use for restoration purposes. Indeed, there are many examples where growth experiments are run for less than a full growing season (<4 months: Wetzel and van der Valk, 1998, 2005; Kotowski et al., 2001; Güsewell and Bollens, 2003; Janecek et al., 2004; Güsewell, 2005a,b). There are also a number of studies lasting for approximately one full growing season (4–8 months: Visser et al., 2000; Miller and Zedler, 2003; Perry et al., 2004; Fraser and Karnezis, 2005; Güsewell and Freeman, 2005; Kettenring and Galatowitsch, 2007). Controlled growth experiments in which treatment responses are monitored for two or more growing seasons (e.g., Yelka and Galatowitsch, 1999; Budelsky and Galatowitsch, 2000, 2004; Güsewell, 2005c; Güsewell et al., 2003; Edelkraut and Güsewell, 2006; De Steven and Sharitz, 2007) are more useful for the study of vegetation ecology in natural and restored sites. In this first step towards full quarry rehabilitation to calcareous wetlands we chose to study the growth of *Carex aquatilis* in this setting over three growing seasons.

Our restoration design of the abandoned aggregate quarry adopted the concepts of minimum maintenance and self-design (Mitsch and Gosslink, 2007). That is, in contrast to the piping and valve efforts of Amon et al. (2005) to regulate water flow, because of the groundwater discharge zone created by the quarrying activities, we chose to assess wetland initiation with the *in situ* water availability. Moreover, our continuing restoration efforts are investigating the natural development of the rehabilitated quarry. The purpose of the present study was to determine whether sedges typically found in organic-rich substrate would successfully transplant and grow in a mineral substrate setting, and what physical environmental conditions yielded the greatest success. We used field mesocosms to investigate our research questions. As the overall goal was to rehabilitate an abandoned quarry to a calcareous wetland, we adopted this approach, even though it is less controlled than utilizing greenhouse experiments and/or smaller microcosms. The following questions were posited. (1) Will transplanted ramets of *C. aquatilis* initially survive and subsequently grow over a 3-year period in largely inorganic mineral substrate that may be found in quarry sites post-extraction? (2) Will transplanted ramets demonstrate a potential for sexual reproduction? (3) In the rehabilitated quarry setting, what are the effects of water depth and substrate type on *C. aquatilis* annual growth, reproductive potential, and aboveground biomass over the 3-year period? With this last question, we hypothesized the following in relation to our treatments (discussed below): the sedges in the peatball substrate would perform the best, in terms of survival, growth, reproduction, and aboveground biomass, with the rock treatment yielding the least growth; and, the intermediate water depth would prove most beneficial to the sedges, with the shallow water treatment proving worst.

2. Study area

The quarry rehabilitation and calcareous wetland creation experiment is located in the Fletcher Creek Ecological Preserve, a 197-ha natural area owned by the Hamilton Conservation Authority in Puslinch Township, 30 km north of Hamilton, ON, Canada. Many small, isolated calcareous fens are situated throughout the ecological preserve, and a large portion of this property is designated as a provincially significant Wetland as well as an environmentally sensitive area. The preserve is underlain mostly by dolomite of the Guelph formation, with an overburden of glacial outwash silt in the northwestern most section (Chapman and Putnam, 1984). The preserve is a regional groundwater discharge area from the Galt moraine to the northwest and serves as one of the headwaters to Spencer Creek, a key river that flows through Hamilton into Lake Ontario.

Historically, Steetley Industries operated a small (~3.5 ha) aggregate quarry in the northeast corner of the preserve. Operation of this quarry consisted of a below-water extraction of ~0.8 ha that was between 4 and 6 m in depth. The operation was abandoned abruptly in the early-1930s and no attempt was made to rehabilitate the site. In addition to the 4–6 m below-water table extraction, exposed dolomite cliff faces of up to 6 m were created. Due to potential liability regarding the high cliff faces, in 2003 the Hamilton Conservation Authority with the assistance of The Ontario Aggregate Resources Corporation decided to lower the quarry walls and rehabilitate the quarry into a calcareous wetland.

In 2003–2004 the quarry walls were lowered using a hoe ram and backhoe, and the associated shot rock was positioned to create a landscape design consisting of four shallow bays surrounding a slightly deeper central pool. Lowering the cliff faces into the quarry is a relatively common rehabilitation technique used in the aggregate industry (OMNR, 2006). The use of the native dolomite shot rock to create these shallow bays ensured that the groundwater quality and quantity remained unchanged. At the start of the