Can stone quarries contribute to preservation of endangered species in ephemeral water bodies?

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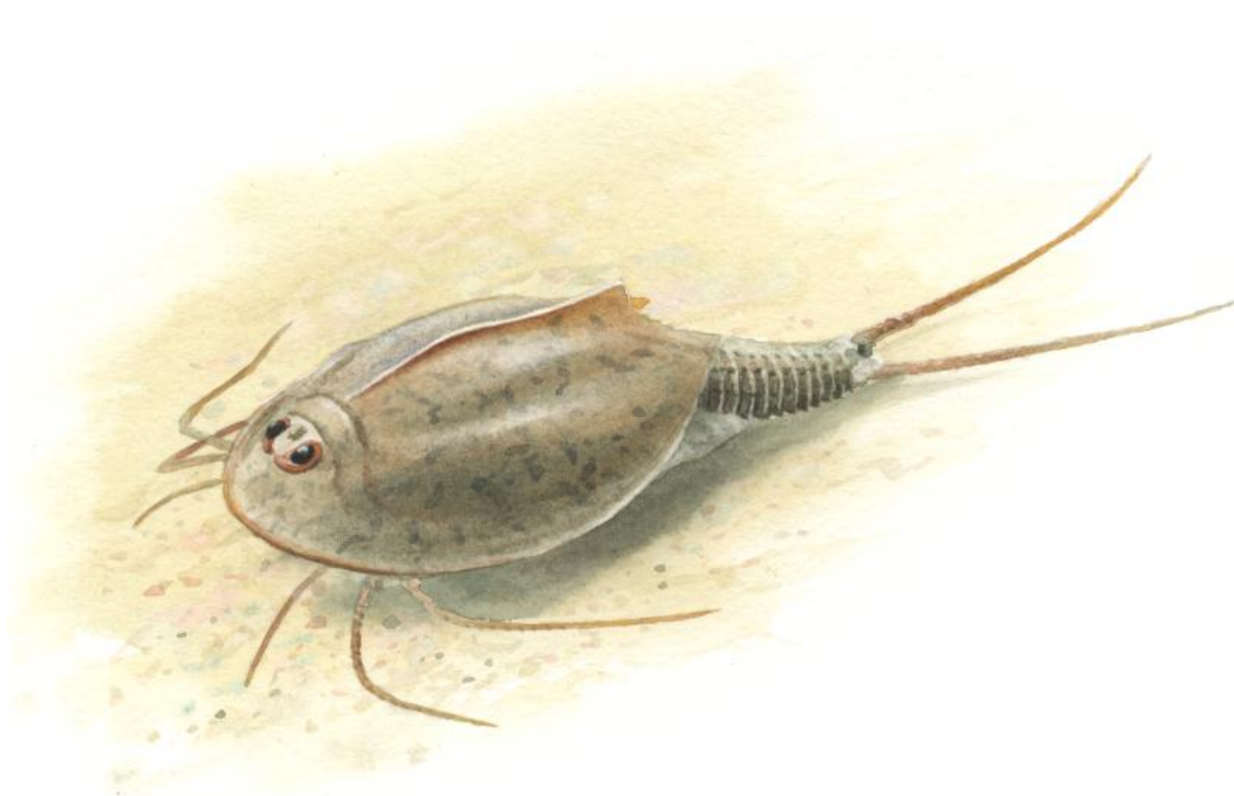

Abstract

Ephemeral waters and consequently its inhabitants are today endangered due to ditching and overgrowth. Quarries may be able to act as rescue sites for these species where they are spared from aforementioned disturbances. Quarries have the opportunity to play a major role in recreating important and valuable habitats and conserve red-listed species. A feasibility study has been made to assess possible opportunities in a quarry environment, and this paper provides suggestions on how to arrange temporary waters in limestone quarries.

Introduction

In the present day, temporary waters is an endangered habitat due to anthropogenic factors such as ditching, cultivation and drainage as well as overgrowth. Temporary waters comprise a unique flora and fauna that has adapted to life in both aquatic and dry phases and the future of these species is therefore jeopardized.

On Stora Alvaret of Öland, after heavy precipitation, the ground is inundated and its hollows turn into a mosaic of water basins. Stora Alvaret is listed as one of the world heritage sites by UNESCO and its biological character is in many ways very unique. It harbours an important flora and fauna including numerous red listed species worth conserving (Swedish Environmental Protection Agency, henceforth SEPA), like *Triops cancriformis* (NT), *Tanymastix stagnalis* (NT), *Baldellia ranunculoides* (EN) and *Plantago tenuiflora* (VU), among others. The quarry of Degerhamn broadly shares the same abiotic conditions as the alvar, and can thus aid in conserving these species by creating ephemeral water habitats.

A direct ecological consequence of quarrying is that old habitats are lost and replaced by clean bedrock, essentially resetting the ecological succession into its early stages. This gives a unique opportunity to control succession and rehabilitate natural functions. Not only does this strengthen the populations of the inhabitant species, but it also increases the biodiversity of the quarry. A feasibility study is needed to recognize the possible difficulties a quarry environment may provide.

Objectives

- To highlight and review the importance of ephemeral waters.
- To develop ideas on how to arrange ephemeral waters in the quarry of Albrunna.
- To assess and acknowledge possible problems a quarry might provide when constructing ephemeral waters.
- To evaluate the possibility of creating functional temporary waters in the quarry and thus increasing its biodiversity.

Background information

The properties of temporary waters

On Stora Alvaret, snow thawing and heavy precipitation creates a mosaic of small water bodies - *ephemeral waters* - a habitat characteristic of Stora Alvaret on Öland. The absolute key property of these habitats is that they are only inundated through limited periods during the year. The soil of the alvar is very nutrient poor and so the ponds experience very low productivity. It is also very permeable which leads to short hydroperiods. They typically experience a dry phase in the middle of summer to flood anew in the fall and spring due to severe rainfalls and melting snow, respectively. The droughts clearly bring a great mortality to the species living there. However, the temporary waters comprise a unique fauna, consisting mainly of insects and crustaceans (Williams 2006), that have adapted to live completely or partly under water. Many possess adaptions to droughts, such as latent stages or drought tolerating eggs. These species have evolved towards fast development and early sexual maturity to successfully reproduce before the pond experience the dry phase (Welborn 1996).

Nearly all the fresh water species have a limited distribution along the hydro period gradient (Welborn 1996). Thus, the species that inhabit temporary waters generally don't inhabit the permanent waters, and vice versa. The rapidly developing species are typically very susceptible to predators. Fortunately, most freshwater predators are essentially absent from temporary ponds, while they are plenty in permanent lakes (Welborn 1996). In general, the potential species pool increases as the hydro period increases, however, if too long, the species composition might turn similar to the permanent lake species composition (Welborn 1996).

The Degerhamn quarry contains several permanent or semi-permanent lakes which contain a rich animal life scattered among many taxa. There are stationary red-necked grebes in the Albrunna Lake which suggests a rich invertebrate fauna (Wagner & Hanson 1998). The presence of red-breasted merganser also suggests that the lake contains fish as they mainly predate on shoals of small fish (Bur et al. 2008). The species community structure in the lakes is adjusted to the hydro period and seemingly contains predators such as fish, beetles, dragonflies and other predatory species that prevent sensitive temporary pond species from residing there. This means that there is no ecological niche for temporary water species in the quarry.

Figure 1. Plantago tenuiflora

To conclude, temporary water species rely on water bodies not to have too short or too long hydro period. Too long and it allows various predators or competitors to inhabit the pond, too short and they won't be able to complete their life cycle.

Plants

Plantago tenuiflora (VU) is a plant that grows in the periphery of nutrient poor and calcareous alvar ponds that dry up in early spring (Andersson 2001, Ekstam et al. 1984, Artdatabanken 2010). They are usually the only vascular plant at their growth sites and are very susceptible to interspecific competition. In some rare cases, they are even found on the ground of quarries (Andersson 2001). In Northern Europe, the distribution of *P. tenuiflora* is limited to Ölands alvar. Additionally *Baldellia ranunculoides* (EN) is a drench resistant plant which grows in humus-rich and slightly more nutritious and calcareous mud. Like the *P. tenuiflora*, it is a very weak competitor. It thrives in higher temperature areas and is usually found in Atlantic and Mediterranean areas. The quarry habitat is in an early successional stage which makes the ecology and habitat requirements of these species suitable for implantation.

The properties of Branchiopods

Branchiopoda, a class of crustacea inhabiting ephemeral waters, comprises many threatened species around the world (Nhiwatiwa et al. 2014). Two members of this class, *Tanymastix stagnalis* and *Triops cancriformis*, are distributed over several parts of Öland and mainly but not limited to Stora Alvaret. They are red listed (NT) and subject to conservation (Artdatabanken 2010). In fact, *T. cancriformis* is one of Swedens most critically endangered species (Berggren 2007) and also believed to be one of the oldest extant species on earth (about 220 million years without notable morphological changes) and thus of great natural historical value. One of the closest locales containing *T. cancriformis* is found only about 2.5 km from Albrunna quarry (Karlsson 2008).

Figure 2. Tanymastix stagnalis. Male on the left, female to the right.

T. stagnalis and *T. cancriformis* largely share the same ecology which broadly consists of (i) hatching early (ii) rapid development to sexual maturity (iii) copulation (iv) laying eggs (v) dying, completing a full life cycle in a matter of one to three weeks (Vanschoenwinkel et al., 2010). They are both annual, with *T. stagnalis* having both a spring and autumn generation, while *T. cancriformis* only have an autumn generation. The eggs are drought and freeze resistant and lie dormant in the sediment and hatch the next season if the environmental cues are triggered. What these environmental cues are exactly is unknown and subject to future science but they probably involve temperature, light and water levels among others (Vanschoenwinkel et al. 2010). If the cues aren't triggered, the eggs can lie dormant for several years (Daamgard & Olesen 1998), there are even records of up to 25 years. Studies show that egg density ranges from several thousands to hundred thousand per m^2 for some fairy shrimp species (Vanschoenwinkel et al. 2010). The eggs disperses to new locations by any process that in one way or another relocates sediment, i.e., wind during dry phases, birds and animals walking in ponds, and in some cases even with boots and vehicles (Waterkeyn et al. 2010). Some sources claim that the eggs float, which means that they can spread through overflowing basins. Since the shrimp inhabit inundated alvar basins, they live in so called meta-populations, a network of separated smaller populations where every individual sub-population has a significant chance of extinction. Though, total extinction is generally avoided due to continual recolonisation between sub-populations. Still, due to continual loss of habitats, the distance between patches increases and re-colonisations are harder to achieve.

One goal in SEPA's Branchiopod action program is to preserve existing habitats, but to a lesser degree also create new habitats where previous ones have been destroyed. Nowhere in this action plan are quarries mentioned as possible refuges.

Method

The literature was explored in order to acquire information on temporary water habitat characteristics of Öland and the environmental requirements of Branchiopods and similar species. Using this information we shaped a number of habitat design criteria from which we derived suggestions for habitat restoration.

Results

Design criteria

1. Hydro period

A requirement for branchiopods to exist is that the water body lasts *at least* long enough for them to hatch and complete a life cycle before the water disappears. After hatching, a life cycle takes about one to three weeks to complete (Vanschoenwinkel et al. 2010). If the hydro period is too short for reproduction to take place, egg banks can over time become depleted due to abortive hatching (Vanschoenwinkel et al. 2010). If environmental cues aren't fulfilled, (for example, temperature or temperature fluctuations) they don't hatch immediately after inundation, and remain unhatched until their cues are triggered. This means that the hydro period should encompass both the **pre-hatching period** as well as their **life cycle**. An estimate should be about a month, maybe two, depending on environmental conditions.

2. Morphometric characters of water bodies

Previous inventories show that habitat sizes vary largely. This suggests that the individual pond size is of secondary importance. The real significance lies in having a large range of differently sized and shaped pools. The weather in terms of precipitation, sun time and wind, are all random variables and changes from year to year. To ensure that at least a few ponds are optimal every year despite stochastic weather conditions, ponds of a broad range in terms of size and depth should be aimed for. This creates a risk diversification that maintains stable meta-populations.

3. Water quality

The chemical water properties should mimic those of the alvar. The temporary waters containing branchiopod species on Öland all share a few properties, clean and clear water with low productivity. According to chemistry tests conducted in the quarry from 2008 to 2013, heavy metal levels ranges from "very low" to "low" (Bydén, Larsson & Olsson 2003), which is good news. Chloride levels, as well as general conductivity are a bit high, especially closer to deposits. Conductivity should preferably not be higher than 200 µS (Heins, 2012, measurements in alvar ponds measure values between 20 and 70 µS).

4. Soil

Alvunger et al. (2012) performed a sediment analysis that established that the sediment composition of the Albrunna Lake is distinctly different than from a natural alvar lake. This sediment composition is created by the run-off that carries particles from the quarried area to the lake. The summation of these particles in turn forces their character onto water bodies. Because of the small size and volume of the temporary waters, the surrounding environment has a huge impact on the abiotic properties of the water (Welborn 1996). The soil has a significant role in designing the character of the biota present. Since the alvar is a nutrient poor environment, one has to make sure that the soil isn't too fertile, as this will cause overgrowth and possibly poisonous algal blooming.

Current quarry conditions

First of all, the particular area we find most interesting is the open area between the lakes and the mining site (see figure 3). This area is in an early stage of succession and is subject to treatment. This central quarry area should be relatively disconnected from the leachate sourcing from the deposits in the northern part of the quarry. These are in process of being covered, meanwhile, rain water sips through them and affect the water quality downhill from them (Alvunger et al. 2012, Heins 2012). The central area is also interesting because of its relative abundance of craters of different sizes (which can also be seen on figure 3).

In april of 2014, we visited the Albrunna quarry for a checkup. We particularly noticed how much drier the quarry was compared to Stora Alvaret in general. In the quarry, every potential water basin except for a few was completely dried out. The alvar still contained a good abundance of small ponds (with a size around 5-100 m^2 and a few decimeters of depth). This premature drought was troubling. One contributing factor is that the groundwater levels are manually lowered to allow for mining activity (Aqualog 2006), which limits or removes groundwater flow into the pools. This means that the ponds have no aquatic support from below. Another significant reason may be infiltration. The previously mined bedrock may

Figure 3. A flight picture of the quarry area encircling the area of highest interest.

contain cracks and crevices and thus any precipitation that fills basins quickly seeps through the ground. Thus, some action measures are needed to prolong the hydro period.

Figure 4. An illustration depicting the current state of the quarry.

Suggestions

1. Hydroperiod

If the window of opportunity is too narrow, one has to find ways to increase it. The hydro period is determined by factors such as precipitation and run-off, groundwater flow, evaporation and infiltration. Of these factors, infiltration is the most modifiable factor. The rate of infiltration depends largely on the type of soil, or the presence thereof, in ponds (Williams 2006). Thus, introducing top soil to the ponds should prolong the aquatic phase. The mixture of small gravel and soil particles clog the crevices, lowers the permeability of the ground, slows infiltration and thus delays draught (Williams 2006). If the soil clogging solution appears to be insufficient and there still is a significant infiltration, one can fill the crevices or fully seal the pond floor with cement. This nearly eliminates the infiltration and completely limits the water loss to evaporation.

2. Morphometric properties

The area between the Albrunna Lake and the mining site is partially covered with craters (see fig. 1) of different sizes and depths, most of which are suitable for arrangement of temporary waters. To estimate the optimal pond size, the inventory information (Berggren 2006, Karlsson 2008) suggests that the pond size should be around 5 to 50 meters across with a depth of 5-40 centimeters. However, as stated in the design criteria, the morphology of individual ponds is of secondary priority. The most important thing is creating a mosaic-shaped network of many water basins to ensure stable meta-populations.

3. Water quality

Where should you put ponds?

The best way to prevent conductivity problems is to avoid the problem source. The water in some ponds is affected by leachate from the deposits in the northern part of the quarry. Alvunger et al. (2012) did a range of aquatic measurements where they measured the conductivity in the Albrunna Lake as well as four ponds which were located between the deposits and the aforementioned lake. The conductivity in the smaller ponds greatly increased with a decreased distance from the deposit (from 280 µS furthest from the deposit up to about 1000 µS). The conductivity in the lake was approximately four times higher than in a natural alvar lake. Alvunger et al. (2012) also performed a survival-test of *Daphnia magna* (a freshwater crustacean species) using the water of the Albrunna Lake compared to the water from which the Daphnias were acquired. In the artificial lake water, the Daphnias experienced 100 % mortality after 6 hours, whereas in the original water the mortality was only 50 % after 72 hours. This suggests that water originating from the deposits is unfavorable to crustaceans. Therefore, strategic placing of water bodies is the best way to ensure good water quality.

4. Soil composition

To mimic the natural alvar conditions, the soil is preferably acquired from natural ponds from the alvar. In addition to the right soil particle and chemical composition, they also contain the correct egg and seed banks (branchiopods and plants alike). However, to not compromise the natural ponds, only small amounts of soil should be taken from each one. To acquire enough substrate, one might be inclined to use the top soil from the future mining site and mix it with the pond soil. A further suggestion is to clean the potential pond basins to get rid of potentially unfit particles prior to filling them with new soil or alvar pond sediment. The strong wind, overflowing basins, as well as vertebrates such as birds should take care of seed and egg dispersion, and so the initial implantation of organisms should be enough.

Figure 5. An illustration depicting our vision of the future quarry after habitat restoration.

Conclusions

Creating ephemeral waters in quarries is seemingly unheard of in today's literature. Even less so in conjunction with introducing branchiopod species and temporary water plants, which is the reason why this paper was so difficult to complete. Quarries offer a range challenges in terms of unusual abiotic factors such as lack of top soil, chemical conditions and odd physical shape. These factors, in both expected and unexpected ways, create obstacles in restoring ecological status. Obscurities arise when one has to suggest specific actions appropriate for a group of organisms of which there is barely any knowledge. In spite of this, we have tried to develop actions that guide and hasten the succession in the right direction.

The creation of habitats is by no means counteractive to the quarrying process. We suggest that future quarrying incorporates a creation of a mosaic shaped basin landscape to the bottom of the quarry to continually increase the number of habitats. Quarrying might even produce habitats where before there were none. When blasting, attempting to create a mosaic shaped environment with basins of different sizes is favourable. The risk of extinction of meta-populational species decreases as the number of habitats increases. Hence, as Cementa provides the world with cement, they also increase the biological status of ephemeral waters and its inhabitants.

When mining activity ends, many quarries turn into lakes due to ceased water-pumping. If this happens in the unknown future, the temporary species living in the quarry can be relocated to their natural habitat to strengthen the original populations. The future quarry is thus able act as a species distribution bank, similar to a botanic garden. The actions done are therefore by no means pointless even if the quarry end up as a lake.

Branchiopoda is a relatively unstudied group of organisms, due to their capricious nature. If Cementa can successfully implement ephemeral waters with regularly recurring Branchiopod species in the quarry, there is an excellent opportunity for scientists to study rare species. The many conditions (weather, air temperature, water temperature, sun hours, sediment composition) during implementation should be monitored. This creates the opportunity to create a more concrete action plans for other quarries around the world.

A final note

The initial goal of the QLA science project was perform a field experiment consisting of transplanting fairy shrimp (*Tanymastix stagnalis*) into the quarry and measure the survival and reproduction success under different conditions. However, the experiment wasn't able to be conducted due to hydro period problems. *T. stagnalis* would mainly act as a model species for the more endangered species *T. cancriformis*, but also for other ephemeral water species with similar ecology. The plan was to check their response to different types of soil. Soils of different sources distinctly characterize the water in the small ponds, and thus the shrimp are expected to react differently in terms of survival and fecundity. We would compare three different types of soil; (i) the original quarry soil, (ii) the top soil from the alvar and (iii) the soil from natural alvar ponds. This experiment would shine practical light on what kind of soil creates the best ponds and help create a more precise action plan.

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