# The Bugs In Our Backyard: Beetles Used As Indicators Of Land Reclamation Success

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## Introduction

Globally we are experiencing the sixth mass extinction event primarily caused and accelerated by anthropogenic activity. More than 400 vertebrate species projected to go extinct in 10,000 years, did so in 100 years (Ceballos et al. 2020). The global population is projected to increase to 9.7 billion in 2050 (Elmjid, 2019). With more people in the world, more resources are required to sustain quality of life. There is an increased need for food, building materials, land for development, and energy. This in turn amplifies natural resource consumption and creates larger and more frequent anthropogenic environmental disturbances. The long term effects of anthropogenic activities on the land can be seen in the increase of frequency, severity, and intensity of natural disturbance events. These events have affected human populations and surrounding ecosystems. Natural disturbance events create more habitat loss in addition to the existing loss due to increases in resource demand.

Natural resource development changes an ecosystem, and without intervention further environmental degradation can occur. Reclamation is the process of returning disturbed lands to an original or equally productive state (Alberta Environment, 2002). Common disturbances requiring land reclamation are oil and gas activities, mining, general industrial activities, and agriculture. In Alberta, companies must provide a postoperative reclamation plan prior to the start of a project. The *Environmental Protection and Enhancement Act* legally requires energy and mining companies to reclaim land disturbed by their activities. Reclamation includes remediating potential contaminants, salvage, storage and replacing soil, and revegetation (Alberta Environment, 2002). A reclamation certificate is issued to companies that meet reclamation requirements and demonstrates proper land function with no further intervention or management. When assessing reclamation certificates, the Alberta Energy Regulator (AER) examines vegetation quality and quantity, soil quality and quantity, site landscape, the absence of facilities, and visual signs of contamination; occasionally subsoil contaminants are examined (*Reclamation Process and Criteria for Oil and Gas Sites*, 2020).

Indicators currently used in legislation and regulators to assess reclamation success are quick, cost-effective, and simple. Strong ecological indicators display the impacts of environmental changes and should correctly reflect an ecosystem's state (Perner and Malt, 2006). A good indicator is sensitive to environmental changes, has short reproductive cycles, and has high diversity. Research has found that insects are sensitive to environmental conditions (Buchori et al. 2018). Insects have been used to assess effects of various contamination. Heavy metal contamination can decrease insect body size and mass, and lead to locomotive and reproductive issues (Ghannem et al. 2017). Previous research has shown that multiple insect groups cannot be used as indicators of reclamation success, to be more effective single insect groups should be used (Buchori et al. 2018). Insects could be considered in reclamation success monitoring, though not all insects are effective indicators (Buchori et al. 2018).

Many studies have proposed and examined the use of beetles as indicators of reclamation success. Beetles are sensitive to ecological change which makes them a strong indicator species. Beetles can be used to determine the effect of disturbances due to the increase or decrease in populations. Ground beetles (Carabidae) are often used as indicators due to their diversity, abundance, and sensitivity to the environment (Ghannem et al. 2017). Beetles have a well developed taxonomic key, but are not often used in reclamation monitoring. A proposed reason is that larger and smaller scales need to be examined to see beetle differences making it difficult to monitor (Rykken et al. 1997). There are limited papers examining beetles and their use as indicators of reclamation success. This paper summarizes the use of beetles as indicators of reclamation success.

**Beetles in Land Reclamation**

Research papers focused on land reclamation and beetles, spanned from 1997 to 2020 and encompassed diverse ecosystems including grasslands, tropical forests, temperate forests, and xeric (dry) regions. The majority of research has been conducted in Europe, specifically the Czech Republic, but also in North America, South America, and Asia. Common site disturbances were mining, quarrying, agriculture, oil extraction, and factories. Pitfall traps were the most common sample collection method, while some research projects added sweeping and light trap techniques. Pitfall trap duration ranged from 2 to 14 days prior to collection, and occurred from early spring to late fall. Traps were placed in reclamation sites ranging from 2 months to 75 years. Reclamation methods varied, including landscape design, re-establishing hydrology, adding soil amendments, placing topsoil, and planting vegetation. Reclamation methods were not always used, a disturbed area can be left to natural ecological succession. Succession is the natural evolution of plant and invertebrate communities, it occurs in stages and will be influenced by environmental and management factors (Alberta Environment, 2002).

**Land Reclamation Methods**

Research conducted in Brazil used dung beetles (Scarabaeinae) as indicators to evaluate the success of reclamation by examining the population's functional diversity (Audino et al. 2014). The effect reclamation age had on dung beetle composition, abundance, species richness, biomass, and functional diversity was assessed. Reclaimed sites were aged 2 months to 18 years. Primary and secondary reference forests aged 40+ years and degraded pasture were compared to reclaimed sites. Beetle composition results indicated that reclaimed areas are projected to be primary and secondary forests. The similarities between sites increased with reclamation age, with reclaimed areas becoming less similar to the pasture. With reclamation age, forest dwelling species, and biomass increased, while pasture dwelling species decreased. Species richness, total number of individuals, and rare species richness did not have a significant relationship with reclamation age. The functional richness in reclaimed sites was significantly lower than the degraded pasture and primary and secondary forest sites. The reclaimed area composition becoming similar to primary and secondary forests is positive. However, species diversity and functional diversity are similar to or worse than the degraded pasture, suggesting land reclamation is not as successful as first thought. It is unknown if diversity will recover and if further action is needed. This paper indicates that beetles can be used as indicators and reclamation was not completely successful.

Research examined different soil placement and landscaping techniques using invertebrates as indicators of reclamation success. Moradi et al. (2018) examined the effects of surface heterogeneity on invertebrate species richness and diversity during early stages of brown coal spoil heap reclamation. Research sites with wavy surface expression had higher invertebrate species richness, however spiders and beetles showed no significant difference between wavy and flat surface expression. Results indicate that soil surface type can have a significant effect on invertebrate community composition. Surface dozing had a negative effect on invertebrate species richness, except beetles and millipedes. A combination of flat and wavy soil surface expression is recommended to promote invertebrate diversity.

Work out of Germany utilized the reclamation of different habitats. Researchers examined the effects of soil reclamation methods and environmental variables on ground dwelling beetle assemblages and assessed their use as an indicator (Topp et al. 2010). Variables included reclamation age, distance to undisturbed forest, landscape pattern, shade, soil clay percentage, and soil moisture content. Research sites had varying reclamation methods and physical landscapes, including forest reclamation sites, grassland reclamation sites, and sites left to natural succession. Results showed sites with uneven slopes had the highest species richness. Ground beetle assemblages were distinct at most sites and diversity increased due to surface sculpting. Diversity increased when overall site shade decreased. Natural succession and reclaimed grassland sites exhibited higher beetle diversity than forested sites. Diverse vegetation in the reclamation site increased beetle diversity. Forest reclamation sites were not able to support forest restricted species, transfers from existing forests may be needed. When examining different reclamation methods, natural succession stood out as it exhibited higher diversity and supported specialist species. Further research is needed to determine the potential of natural succession in land reclamation practices.

Further work out of Poland examined effects of reclamation methods on beetle community structure (Skalski and Pośpiech 2006). Research sites were a 60+ year reclaimed forest, where birch and poplar trees were directly planted on calcium carbonate and chloride waste materials with no soil capping. A 10 year reclaimed site with a meadow of shrubs and herbs established using soil cover application and plant shifting. The final research site was a transitional ecotone between the two reclaimed sites. The most diverse beetle groups were ground beetles (Carabidae) and weevils (Curculionidae). Results concluded species richness and Shannon diversity index were similar between sites. Mean abundance significantly distinguished between old forest and meadow sites. Results for the ecotone were similar to the meadow. Rank abundance curves showed newly established sites are characteristic of poor species distribution that rely on a single important environmental resource. While the mature stand, without soil reclamation, followed a stable and well-developed distribution. Older reclaimed sites still exhibit habitat generalists as the dominant species. Reclamation methods had no effect on species composition and richness. All sites had low decomposer abundance, predators dominated in the old reclamation forest site, and herbivores in the younger reclamation site.

**Indicators in Natural Succession vs Reclamation**

Studies comparing natural succession and reclamation have emerged out of Europe. Research was conducted to determine if ground beetle (Carabidae) assemblages can predict the effectiveness of forest reclamation and natural succession in Poland (Kędzior et al. 2020). Carabid beetle life stages were studied to indicate success. Body size, dispersal power, food preferences, breeding type, and habitat preferences were assessed. Research sites included undisturbed forest reference sites, forest reclamation sites, and sites undergoing natural succession. All research sites recorded a different beetle species with highest abundance. In forest reclaimed sites, small bodied herbivores with high dispersal rates and spring breeding, were found. These sites had low abundance of forest specialists with high abundance of species with broad habitat ranges. In natural succession sites, medium bodied predators, with low dispersal and autumn breeding were found. Natural succession sites were more similar to the forest reference sites than reclaimed forests. Forest habitat species were found in natural succession sites even though vegetation was similar between reclaimed sites. Results indicate that ecosystem recovery type influences beetle species distribution. Beetle species that are predators with low dispersal, large bodies, and autumn breeding seasons, are indicators of successful forest reclamation.

Research compared the biodiversity conservation benefits of technical reclamation and natural succession. Invertebrates were used to examine species richness and conservation value of black coal spoil heaps in the Czech Republic (Tropek et al. 2012). Species richness was higher in natural succession sites for the majority of invertebrate species. Herbivorous beetles (Elateridae, Rhymchitidae, Apionidae, Curculionidae) had higher species richness on reclaimed sites. The conservation value of natural succession sites increased, with Red List threatened invertebrate species preferring this habitat. There were more xeric specialist ground beetles (Carabidae) and herbivorous beetles in natural succession areas. Results indicate technical reclamation has negative effects on biodiversity. Invertebrate species preferred natural succession sites, indicating a high conservation value. Researchers recommend technical reclamation should be avoided unless public concerns force intervention. This brings up the question, is natural succession the best way if we want to preserve biodiversity?

Reclamation and natural succession sites have been compared to determine the value of post-quarrying sand pits as refuges for endangered species with decreasing habitats (Heneberg et al. 2016). Beetle and Orthopteroid assemblages were evaluated in an early natural succession site aged 2-5 years, intermediate natural succession site aged 6-15 years, older natural succession site aged 15+ years, and a reclaimed site aged 5 years. Clear reclamation methods were not defined, but included soil placement and planting. Early succession sites had the lowest invertebrate diversity and richness. Intermediate succession sites had higher diversity than early succession in beetle and Orthopteroid assemblages. Later succession sites had the highest diversity in beetle and Orthopteroid assemblages. In reclamation areas, species richness was significantly lower. Newly formed habitats from natural succession contained specialized psammophilous (sand loving) and/or xerothermophilous (temperature loving) invertebrate species. These sites also had a low beetle dominance index, due to nutrition limitations in the new habitat. Low beetle dominance continued in natural succession sites despite the effect of time colonization lag. Natural succession is recommended to promote the diversity and growth of endangered species.

**Conclusion**

Researchers suggest using vegetation for long-term reclamation monitoring with a short term approach utilizing sensitive invertebrates. Beetles have the potential to be used as an indicator of reclamation success and ecosystem recovery. They are diverse, sensitive to disturbances and environmental changes, and their taxonomy and ecology are well understood (Kedzior et al. 2020). Beetles pose as a good indicator of reclamation success, however, they should be used in combination with another indicator. Beetles represent many trophic levels that will react differently. Previous research examined if plant and beetle species richness and evenness would increase with reduced management intensity (Perner and Malt 2003). Carnivorous and detrivore beetle species richness was unrelated to management intensity. Herbivorous beetle species richness increased with decreasing management intensity. Clearly, there are knowledge gaps and unanswered questions that must be addressed prior to implementation and acceptance of beetles as indicators of reclamation success.

Existing research using beetles in the context of land reclamation has a very narrow niche; research is mainly being conducted in Europe. Industrialized countries like China are facing current and future problems surrounding land use and reclamation, solutions can be aided by research. Examining countries with undisturbed land, such as Canada, would allow for a stronger understanding of environmental function and recovery. Different countries provide unique ecosystems, results can be system specific and are not always applicable to other ecosystems. We need more research in different ecosystems such as hot deserts, older forests and arctic tundra. Each ecosystem presents different reclamation challenges. Researching different natural and anthropogenic disturbances with unique environmental conditions will enhance understanding and address challenges.

Comparing reclamation sites with deeply contrasting reclamation practices to understand how beetles recover. Very little research examined the effects of different reclamation methods and techniques on beetle and other invertebrate communities. Research has looked at landscape surface topography, re-vegetation, and natural succession, but there are more reclamation practices to be considered. Different reclamation methods will have various effects on beetle abundance and community composition. Research is needed to determine how different soil amendments and soil building methods affect beetles, other invertebrates, and reclamation success. Long term consequences of reclamation practices are not well understood. Thirty years post reclamation shows arthropod composition is not the same as surrounding undisturbed ecosystems (Sylvain et al. 2019) and it is unknown if pre-disturbance arthropod communities will return. Research often occurs within 2-5 years, very little is research long-term. More research is needed to provide knowledge on long term reclamation effects and results.

There is not enough information to support the use of beetles as indicators of reclamation success. There are multiple research projects needed to assess usefulness and address knowledge gaps. For beetles to be implemented into reclamation monitoring practices we need further research on different ecosystems, reclamation methods, and time scales. Improving communication with stakeholders and the public regarding land reclamation success and beetle research is required. Efficient science communication will engage stakeholders and the public, while raising awareness of ongoing environmental challenges and issues. With more public knowledge, governments and companies are held accountable for successful land reclamation. A report prepared for Alberta Environment and Parks released in 2018 raises concerns about the success of long-term reclamation sites in Alberta. On top of being concerned about long term reclamation success, there are concerns about climate change impacts on reclamation projects and overall success. Researchers at the University of Waterloo suggest that failure to account for climate change in land reclamation may cost billions of dollars (University of Waterloo, 2015). If we don't make changes soon, we will be facing bigger problems to solve and there may be no solution, resulting in reclaimed ecosystems being lost.

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