DEPARTMENT OF BIOLOGICAL AND ENVIRONMENTAL SCIENCES

END-OF-LIFE FOR A QUARRY, WHAT IS THE ENVIRONMENTAL IMPACT?

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[1] Image Source: https://www.istockphoto.com/se/search/2/image?phrase=nature+rock+quarry+sweden

Abstract

Aggregates products are the largest non-energy mining industry in the world, which is the most extracted materials after water. The most prevalent source of aggregates is from quarries, or mines that target the rock itself. Quarries need the transformation of substantial land areas, ideally adjacent to the locations where aggregates are required, such as urban centers. These activities constantly alter the balance in the environment as a result of their operations. To improve the sustainability and minimize the issues a document called a permit is granted to a qualified individual for the extraction and utilization of resources before starting any activity related to quarries.

In this study, various quarry remediation and the effectiveness of the remedial strategies outlined in the quarry permits were analyzed to identify the current circumstances in Sweden. By applying the land cover classification as a method, the restoration land use of 129 closed quarries located in nine municipalities in Västra Götalands was examined. The results from the case studies reveal that the restoration designs from the former permits were taken into account properly which 96 percent of total restored outcomes were converted to the areas that help to minimize the negative environmental impacts with its several advantages. Furthermore, the most potential design is forest area (69%), farmland (13%), vegetation (6%), mixed vegetation (5%), water bodies (3%), urban area (3%), and bare land (1%) respectively. Not only these rehabilitations can enhance the ecological and land use situation, but also they can play a crucial role in biodiversity to boost the organism's either flora or fauna habitat. In addition, according to the results, although the aggregate products are more required in areas with high populations, these current restoration outcomes are independent of the population density and they are not statistically different in the less-populated and populated municipalities.

Keywords: *Quarrying, Aggregates, Life cycle, Environmental impact, Restoration, Permit*

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Popular scientific summary

The most significant non-energy mining sector in the world consists of aggregate products, which include sand, gravel, and crushed stone. These products are the second most extracted material after water. Although aggregates have numerous applications, including protecting coastlines, constructing accounts for the vast bulk of their uses. The majority of aggregates are obtained from rock-targeting quarries or mines.

Large land areas must be transformed for quarries, ideally not far from the regions where aggregates are needed, such as urban centers. This causes a number of environmental problems in the area both while the quarry is producing and after it ceases which distributes the ecosystem balance. These effects can include resource depletion, noise pollution, soil erosion, dust pollution, emissions of greenhouse gases (GHGs), particulate matter (PM10), and floodplain ponding, as well as water contamination (lowering the water table, oil leakage, changing the color, and cadmium acidification), land use (landscape destruction), biodiversity loss (destruction of habitats), changes and loss in vegetation patterns, and resource depletion.

Understanding the end-of-life of a quarry is crucial as the industry begins to apply more life cycle thinking to environmental concerns. Restoration (either naturally occurring or artificially) of the quarry after the operation is required to help the mitigation of the consequences of mining and quarrying in the long run, and the possibility of consequences might persist if they are not repaired. The primary goal of it is the transformation of neglected and deteriorated sites into ones that are repaired and sustain natural ecosystems which would ultimately enhance the ecosystem and human health. For quarry remediation, there is guidance accessible, but information on how successful recovery is carried out, whether plans are followed, and if further consequences arise is difficult to find outside of individual cases.

In this study, various quarry remediation and effectiveness of the remedial strategies outlined in the quarry permits were analyzed to identify the current circumstances in Sweden which are relevant to the end of life of the quarry. Nine municipalities (Gothenburg, Mölndals, Kungälv, Karlsborg, Åmål, Tidaholm, Vårgårda, Hjo, and Herrljunga) in Västra Götalands as case studies were selected. Land Cover Classification was applied as a method and the results reveal that the restoration plans were considered properly in Sweden which overall, 96 percent of outcomes were converted to green areas either Forest or Vegetation, Farmland, and Water bodies having benefits for the environment. The rest proportions are Urban area and Bare land occupying 4 percent of the total outcome (Urban area: 3% and Bareland: 1%). Not only restoration can mitigate the negative environmental impact of the quarry's activities, but also current land use can play a crucial role to enhance the biodiversity in long run by creating various appropriate habitats for diverse species either flora or fauna such as vascular plants, lichens, and birds such as sand martins, ravens, eagle owl, and black redstart, as well as many snails, bats, insects, frogs, yellow-bellied toad, Eurasian otter, fungus and bacteria species' homes.

Abbreviations

C&D – Construction and Demolition

EIA – Environmental Impact Assessment, Swedish: Miljökonsekvensbeskrivning (MKB)

GHG – Greenhouse gases

GIS – Geographical Information System

MB – Environmental Code, Swedish: Miljöbalken

PM – Particulate Matter

RA – Recycled Aggregate

SBMI – Swedish rock material industry, Swedish: Sveriges bergmaterialindustrin

SCB – Swedish Statistics Database

SGU – Geological Survey of Sweden, Swedish: Sverige geologiska undersökning

UEPG – European aggregate industry

1- Introduction

Aggregate products such as sand, gravel, or crushed stone are the world's largest non-energy mining industry, which is the most extracted materials after water. Throughout Europe, there are approximately 26,000 extraction sites (15 000 companies) related to aggregates which the demand for aggregates is 3 billion tonnes per year (6 tonnes per capita per year) (UNEP, 2019). Although aggregates are used for a variety of purposes, including coastal protection, the great majority of applications are in construction. The most common source of aggregates comes from quarries or mines that target the rock (Koehnken & Rintoul, 2018; Marinković et al., 2010; Salgueiro et al., 2020).

Quarries need the transformation of substantial land areas, ideally close to the locations where aggregates are required, such as urban hubs. This creates several local environmental issues both while the quarry is operating and after it stops producing (Salgueiro, P. A et al., 2020). These negative effects disturb the balance in nature which can cause secondary effects on the ecosystem and reduce ecological value. The issues can include water contamination (lowering the water table, oil leakage, changing the color, cadmium acidification), coastal and river erosion because of extracting sand significantly from the riverine and active marine ecosystem, land use changes (landscape destruction), biodiversity loss (destruction of habitats), changes and loss in vegetation patterns, resource depletion, noise pollution, land degradation (soil erosion), dust pollution, flood plain ponding, emissions of greenhouse gases (GHGs), and particulate matter (PM10) leads to air pollution (Ako. et al., 2014; Lameed & Ayodele, 2011; Lee et al., 2022; UNEP,2019).

Quarries constantly alter their environment as a result of their operations. For enhancing sustainability and minimizing the issues during quarrying, a document called a permit is granted to a qualified person for the extraction and utilization of resources before starting any activity related to quarries (Länsstyrelsen, 2006). In Europe, permits are required to run quarries if the site's remediation is planned for closure (Miljösamverkan, 2006). In Sweden, according to Chapter 9 of the Environmental Code (Miljöbalken), permission is given by the County Administrative Board in order to harvest rock, natural gravel, or other forms of soil (Rubenson, 1999). Restoring abandoned quarries provides a chance to address damage, restore biodiversity, and encourage ecosystem growth while generating new, societally useful landscapes (Svevia, 2022). In the permit, biological diversity is emphasized in the restoration sections to create environments for several species either animals or vegetation. The post-treatment should be processed after finishing the quarry according to the environmental code by the owner (Booth, 2021; Rubenson, 1999).

For quarry remediation, there is guidance accessible, but information on how successful recovery is carried out, whether plans are followed, and if further consequences arise is difficult to find outside of individual cases. Understanding a quarry's end of life is essential as the sector starts to apply more life cycle thinking to environmental problems (Lameed & Ayodele, 2011; Morley et al., 2022).

1.1- Aim

The goal of this project is to assess the land use of aggregate quarries to:

- ✓ Identify any environmental effects that quarry closure may have in current remediation plans that are of concern and are not already taken into account.
- ✓ Analyse the various quarry remediation outcomes in Sweden and the effectiveness of the remedial strategies outlined in the quarry permits.

1.1.1- Research Questions

To achieve the aim of the thesis, the following research questions were raised:

1. What ecological or physical changes have occurred in the aggregate quarries?
2. How disadvantages were noticed the most from the quarry's activities sites that could be minimized and restored?
3. Are there any variations between a highly populated and a sparsely populated location in the rehabilitation of the closed quarry?
4. What beneficial impact would the restoration of quarries have on the state of biodiversity?
5. Which restorations have been already done and could be done in the future to achieve a sustainable quarry life cycle?

To acquire insight into the goals and research questions of this study, a literature review was conducted to better understand the field and existing methods.

2- Literature review

Before evaluating previous studies that are pertinent to this project, the literature review initially provides background information on the aggregate industry and sand and gravel quarries in Europe and Sweden. The various websites related to aggregate industries such as Geological Survey of Sweden (SGU), Swedish rock material industry (SBMI), and European aggregate industry (UEPG) were used. In addition, the environmental effects of quarries, particularly sand and gravel quarries, were also researched in several studies and reports. The background of the Environmental Impact of quarries was obtained through Google and searching articles of previous studies for this thesis project by using Scopus search which has been published since 2013. The terms 'quarry', 'aggregates', and 'environmental impact' within the article title, abstract, or keywords were applied. This yielded 15 results which dropped to 6 results when 'land use' was added (Al-Awadhi et al., 2013; Kerbiriou et al., 2018; Sarp & Ozcelik, 2018; Sinnett, 2019; Tejpal et al., 2014; Roncallo, 2018). By changing the 'land use' to 'biodiversity', the number decreased to only one result (Millon et al., 2021). A Google search resulted in further reports, and project supervisors who were involved in it suggested others considered were useful (Länsstyrelsen, 2006; Sairanen & Rinne, 2019; Salgueiro et al., 2020; Sten & Bengtsson, 2011).

The definitions of essential terms linked to the aggregate industry and quarry permits will be addressed in this section. In addition, an explanation of the study's first and second research questions about the impact of quarrying on the environment as well as techniques for restoring land will be discussed.

2.1- The Aggregate Industry

Granular materials called aggregates are the largest non-energy mining industry by far in the world and also in Europe. They include crushed rock, sand, gravel, recycled, and artificial aggregates, as well as marine deposits (Lee et al., 2022; Marinković et al., 2010). The aggregate products are divided into two types which are called Primary and Secondary aggregates. Primary aggregates are created from raw materials that are obtained from quarries, sand and gravel pits, and in certain nations, marine dredges. Recycled (RA) and manufactured aggregates are examples of secondary aggregates. Reprocessed materials that were once utilized in construction constitute recycled aggregates which are alternative resources to the river or natural aggregates (UEPG, 2020). Waste produced during the building, remodeling, repair, and destruction of homes, big building structures, highways, bridges, piers, and dams are referred to as "construction and demolition" (C&D) waste that is applied as a recycled aggregate. In Europe, 850 million tons of C&D waste are produced annually. Common by-products of various industrial operations, such as blast or electric furnace slags or clay residues, include manufactured aggregates (Marinković et al., 2010; W. J. Park et al., 2019; UEPG, 2020).

Although aggregates have a wide range of utilization such as coastal protection, the vast majority of aggregates are applied in construction products like concrete, asphalt, and cement (Koehnken & Rintoul, 2018). Gravel and sand, the most often extracted resources, are the two crucial building materials after water which are abundant on land, in the sea, rivers, streams, hills, and flood plains. In the previous two decades, the consumption of aggregates (sand, gravel, and crushed stone) has tripled (UEPG, 2022). Nowadays approximately 32 to 50 billion tonnes of sand and gravel are extracted annually worldwide. Almost 3 billion tonnes of extracted sand and gravel were reported in Europe in 2019. According to European Aggregate Association (UEPG), each person indirectly uses 1KG of the aggregates per hour (Bendixen et al., 2021; Esguerra et al., 2008, UEPG, 2019).

The most common source of aggregates comes from quarries or mines that target the rock. Quarries and recycling plants need the transformation of substantial land areas, ideally close to the locations where aggregates are required, such as urban hubs. This creates several local environmental issues both while the quarry is operating and after it stops producing (Salgueiro et al., 2020). These negative effects disturb the balance in nature and this has multiplier effects on the ecosystem which are discussed more in section 2.2.

2.1.1- The Quarry in Sweden

A significant local Swedish raw material is rock material which is the largest industrial product. The statistics of Swedish aggregate production have been documented since 1984. In recent years, Sweden's quarries have provided over 80 million tons of aggregate materials; moreover, the demand for aggregate per capita in Sweden is more than 8 tonnes. Historically, aggregate has mostly consisted of natural gravel from the collected glaciofluvial sediments, however, nowadays crushed rock has long been in progress and makes up more than 80% of the ratio due to the prioritization of groundwater protection (SGU, 2020; UEPG, 2020). Sweden has 1 256 quarries that produced aggregate principally in 2016, producing an average of around 68 000 tonnes per quarry. Since 2000, the proportion of sand and gravel provided for construction filling has declined, from 21% to 7% in 2016. The amount of sand and gravel from natural deposits used per capita varies widely amongst the counties. In 2016, Sweden's average per-capita usage fell from 2015's 1.1 tonnes per capita to 1.0 tonnes 2016 (SGU, 2017).

2.2- The Environmental Impact of Quarry

(What ecological or physical changes have occurred in the aggregate quarries?)

Nowadays natural aggregate is being replaced by crushed stone aggregate and sea sand significantly. Although natural aggregate consumption is steadily declining as a result of growing environmental awareness and resource depletion, these materials have negative environmental effects both locally and internationally (W. Park et al., 2019).

These effects which cause by the act of gathering the required aggregate can include water contamination (oil leakage, changing the color, cadmium acidification), coastal and river erosion because of extracting sand significantly from riverine and active marine ecosystems, altered or increased downstream sedimentation that affects habitat quality, salinization of coastal aquifers and groundwater reserves, land use changes (landscape destruction for instance, cutting trees), biodiversity loss in the land and marine ecosystem (destruction of habitats), changes and loss in vegetation patterns, noise pollution, land degradation (soil erosion), dust pollution, emissions of greenhouse gases (GHGs), and particulate matter (PM10) (A. et al., 2014; Lameed & Ayodele, 2011; Lee et al., 2022; Koehnken & Rintoul, 2018; UNEP,2019; Endalew, 2019; Opondo, 2022; Svobodova et al., 2023; Sten & Bengtsson, 2011; Ozean et al., 2012).

Aggregate extraction can change the topography of the area by causing depressions on floodplains, incisional pits in river and lake bottoms, and loss of beach level, coastal sand, and shallow shelf ecosystems (Bendixen et al., 2021). Furthermore, for the last few decades, indiscriminate riverside sand mining has destroyed riparian vegetation, which serves as many migrating birds' resting and nesting places (Sreebha & Padmalal, 2011). Additionally, transporting materials, such as cement and aggregate, to concrete producers also uses energy, and when concrete is made in batch facilities, a number of high-emission compounds are released into the air, water, and land (Kori & Mathada, 2012). The shading impact of dust deposition might slow down transpiration and photosynthesis. Dust can block the stomata on the leaves, therefore it leads to minimizing the level of transpiration and photosynthesis which impacts vegetation diversity (Sten & Bengtsson, 2011).

Water flow is changed when sand and gravel are removed from riverbeds. The near-bed structure of turbulence may alter as a result of flow across mining pits, which encourages the erosion of the pits downstream, the collapse of the flank walls, and the longitudinal extension of the pit (Kori & Mathada, 2012; W. Park et al., 2019). The environment for microorganisms and macroorganisms may be disturbed by sand mining in riverbeds. The balance and health of the biological environment of the river are significantly influenced by aquatic plants and microorganisms, and when this ecosystem's equilibrium is disturbed, a tipping point may be reached or exceeded. Sand extraction causes turbidity to rise and the water to be stirred. In consequence, this action decreases photosynthesis and respiration while also having the potential to obstruct aquatic creatures' respiratory systems (Rentier & Cammeraat, 2022).

2.2.1- The Quarry Permission in Sweden

Quarries constantly alter their environment as a result of their operations. For enhancing sustainability and limiting the possibility of risk during the quarrying, a document called a permit is granted to a qualified person for the extraction and utilization of resources before starting any activity related to quarries. An Environmental Impact Assessment (EIA), drawings, and technical descriptions that allow for an evaluation of the extent of the operation and the environmental effect must all be included in the application for a mining permit. This could involve using treatment equipment, choosing suitable raw materials and fuels, limiting the scale of the operation, taking technical precautions, avoiding emissions in specific weather conditions, taking noise protection measures at the source, only performing harmful operations at particular times, properly packaging and handling chemicals, and providing information about the use and handling of various substances. In order to protect wild animal and plant species or the natural environment, a ban may be imposed on the release of animal or plant species into the environment. Instead of a ban, the release of such species may be associated with special conditions. In addition, the need for the material to be removed is evaluated against the harm that the quarrying operation is anticipated to do to the environment and animals as a whole when applications for quarrying licenses are taken into consideration. A permit cannot be provided for a quarrying activity that might harm an animal or plant species that is uncommon, endangered, or needs special maintenance (Rubenson, 1999).

In Sweden, according to Chapter 9 of the Environmental Code (Miljöbalken), permission given by the County Administrative Board is necessary in order to harvest rock, natural gravel, or other forms of soil. The applicant is responsible for the consultation and initiates it by communicating with and supervising the County Administrative Board and the municipality's environmental committee to outline their goals. Prior to the post-treatment of each resource, the resource managers for the county administrations should make it a routine to consult both internally as well as externally in order to maximize nature conservation measures (Länsstyrelsen, 2006). Besides the Environmental Code, the Ordinance on Environmentally Hazardous Activities and Health Protection also controls quarry activities, among other things. The County Administrative Board must be notified of consultation notifications for activities that are not required to receive permission or notice items may nonetheless significantly alter the natural environment. Chapter 12, Section 6, of the Environmental Code, contains regulations about it (Länsstyrelsen, 2006; Miljöförbundet, 2022).

Permits are not infinite and according to Chapter 16, Clause 2 in the Environmental Code, the time-limitation of permits (15-25 years is most common) is important to plan, although in some cases it can be extended if it may be needed (Svevia, 2022; Rubenson, 1999). In addition, permits should increasingly be provided for a finite period, as is emphasized in the work done in preparation for the Environmental Code. Time-limited permits imply that, in order to continue operating, the operator must do more research and submit a new application before the permission expires. The reason for this is that changes in and increasing emphasis on society's environmental requirements are brought about by technological advancement and increased knowledge. Time-limited permissions have the benefit of requiring ongoing business testing. This implies that the circumstances are updated, and as a result, it is verified that the appropriate technology is being applied (Naturvårdsverket, 2023).

2.3- Quarry Restoration and the Previous Studies of Quarry Rehabilitation for Biodiversity and Land Use

(How disadvantages were noticed the most from the quarry's activities sites could be minimized and restored?)

Quarrying can be a limiting factor for biodiversity and surface which dramatically changes the local soil, land use, flora, and animal life. According to several studies, the organic soil has been removed, and hydrological regimes may have been disturbed as a result of quarrying activities, which have significantly impacted prior ecosystems (Ako. et al., 2014; Kerbiriou et al., 2018). Restoring abandoned quarries provides a chance to address damage, restore biodiversity, and encourage ecosystem growth while generating new, societally useful landscapes (Booth, 2021; Svevia, 2022), and several disadvantages can be minimized mentioned in section 2.2. In the permit, biological diversity is emphasized to create environments for several species. The post-treatment should be processed after finishing the quarry according to the environmental code by the owner (Booth, 2021). Ecological rehabilitation of former quarry sites could be time-consuming and in some cases, rehabilitating affected ecosystems will be difficult due to the vast number of abandoned quarries and the landscape's state. Success depends not just on the restoration plan but also on the target species and any unique characteristics, such as rarity, habitat requirements, or dietary preferences (Kerbiriou & Parisot-Laprun, 2020; UEPG, 2019).

The operation phase is a great time to pay attention to any biotope existing on the site. The permits specify the deadline for submitting suggestions for a final treatment plan. It typically means no later than three or five years before the permission expires and is phrased as "in good time before the permit expires." (Neova, 2023). Obstacles that restoration practitioners must face include unstable foundations or rocky steep slopes, nutrient-poor, acidic, or alkaline soils, and a diminished biotic component that extends to failed ecosystem services (Salgueiro et al., 2020).

The two most popular post-treatment methods for quarry lands are to rebuild forest there or, in the case of suitable terrain, to build a lake. A mosaic of open late-successional forest habitats on higher sites and wetlands in depressions is highly valued for their ecological value (Prach et al., 2011). The results from various studies demonstrate that these habitats had a good impact on a variety of different species such as vascular plants, lichens, and birds such as sand martins, ravens, eagle owls, and black redstart, as well as many snails, bats, insects, frogs, yellow-bellied toad, Eurasian otter, fungus and bacteria species' homes (Till & Skapa, 2015; Huntsberger, 2022; HeidelbergCement, 2022). Woody plants are kept to a considerable extent when it is not required to remove them, especially trees and shrubs useful for pollinating insects and trees and shrubs containing berries (Swerock, 2019). It is reported that several blackthorn bushes, willow trees, and wild apple trees are planted in the Swerock quarry located in Vänersborgskrossen (Almefelt, 2019).

Vegetation is one restoration opportunity for the quarry site maintaining it can improve the species diversity of ecosystems. Also, it is a necessary condition for the restoration of animal populations and ecological processes because high plant variety encourages high production and provides a material foundation for the ecological diversity of the ecosystem (Qin et al., 2020; Zhang et al., 2018; Esguerra et al., 2008). Seed dispersal is one alternative for revegetation in close to natural and semi-natural regions. Dispersing seed that is provided by birds was found to be a restoration success to enhance the vegetation (Sampaio et al., 2021). Planting flowers and making appropriate nesting places will probably produce an effective reaction and benefit other organisms (Lövbom & Jarhede, 2018). Many insects, including bumblebees, wild bees, butterflies, pollen-eating beetles, and others, depend on flowering plants that establish themselves in this sort of environment as food supplies (Quarry Life, 2014; Till & Skapa, 2015). Butterflies like the common blue, tiny blue, and dingy skipper can also be drawn to closed quarries because there is frequently sufficient habitat for the plants and they can live and like them as larval food sources (Sten & Bengtsson, 2011).

Sun-facing sand slopes (southwest- to southeast-facing) and overburdened soil which contains seeds can be utilized for revegetation and also a great habitat for bees, and rock piles for frogs, reptiles, and birds. Man-made nesting locations like sun-exposed sand hills and bee hotels might be crucial for wild bees, and by establishing nests, the population of wild bees in a region should rise (Lövbom & Jarhede, 2018; Länsstyrelsen, 2006). Some birds are attracted to sand and gravel pits because they serve as nesting sites and have rocky surroundings. For cliff-nesting birds, quarries can provide crucial roosting and nesting locations. These birds use the ledges created by quarrying activities (rock wall) as nesting grounds for instance barn owls, ravens, and peregrine falcons. Several barn owls were reported in Jehander's sand, gravel, and rock quarry in Ledinge outside Norrtälje. Benches offer places for many species of birds to build nests and places for plants to flourish. Many lichens and mosses require stone as a substrate since it is so crucial to their growth (Till & Skapa, 2015; Quarry Life, 2014). It is reported that a couple of Peregrin falcons are inside the Swerock quarry located in Kållered (Swerock, 2019). Moreover, numerous yet undiscovered microbial species coexist in sand deposits with many different taxa seeds, spores, and eggs (Bendixen et al., 2021).

If rehabilitation pays attention to certain environmental aspects, gravel pit lagoons may be able to offer adequate homes for semiaquatic species in anthropogenically created environments (Salgueiro et al., 2020). Water environments such as wetlands in the sites can be utilized for the aquatic environments such as amphibians, insects, and aquatic plants (Svevia, 2022). According to Miljöförbundet, amphibians, salamanders, dragonflies, and damselflies among other creatures, thrive in the small ponds, and they may also use the cairn for wintering. More permanent ponds are more likely to serve as newt’s breeding grounds. In the Swerock report is stated that nearby artificial Lake Ullasjön, where birds, newts, frogs, pollinating insects, and other two-, four-, six-, and eight-legged species coexist together. Lake Ullasjön is one water body close to Vänersborgskrossen quarry (located in southwestern

Sweden) which dragonflies use both for their reproduction and foraging (Almefelt, 2019). Lesser sandpipers can build their nests in open sandy regions close to the water bodies (Miljöförbundet, 2022; Quarry Life, 2014). An Island in the water environment is the perfect spot for Sand Martins because of the privacy for nesting; furthermore, the shoreline of the island could be suitable for many micro-habitats and it could be ideal for shorebirds (Jasinska, 2016; Kanter et al., 2016).

Completed quarries (closed quarries) may also be an appropriate location for outdoor activities and recreation such as natural gardens, fishing areas, agricultural landscapes, and sports areas (Lollino et al., 2015; Till & Skapa, 2015). Creating islands in water bodies and towers is one option that can be applied in the garden as a habitat for animals and plants. Not only it could be great for visitors to watch several species such as birds but also help to avoid disruption by visitors. Species can use it for nesting and the bird lays its eggs directly on the ground in the islands and towers. Footbridges can be constructed on the islands that can be applied for fishing activities on the lake (Quarry Life, 2014; Jasinska, 2016). The lake Sagsjön has been restored for several years and its rich bird life now attracts many visitors. It has been made easily accessible to the public with paths, information boards, and bird towers (Swerock, 2019).

3- Method and Material

To figure out the already completed restorations in Sweden according to the goals and the fifth research question, land cover classification was conducted in this study as a method to evaluate the current situations of previous restoration designs for quarry closure. Various satellite images related to the location of quarry closure were applied for classification during the process.

Lantmäteriet is considered as material for data collection. It is important to mention that before the measurement in Lantmäteriet, ArcGIS was selected which is the most popular platform for large data processing and land cover classification to gather the data. This platform provided a prepared color classification related to land cover analysis throughout the world with the data and proportion of each category. However, after evaluating the satellite images from the Google Earth Engine, Lantmäteriet, and Google Maps, a large number of errors were observed in ArcGIS color classification which was not associated with the satellite images. It need to be updated, then it was excluded as material for analysis.

3.1- Land Cover Classification

Land cover mapping from satellite data in this study consists of four steps: data acquisition, measurement, analysis/classification, and documentation.

Data acquisition:

In this research, the province of Västra Götalands was selected as a case study, and nine of its municipalities were chosen to audit the land cover. In order to examine the variations of restoration plans, Gothenburg, Mölndals, and Kungälv were considered to be inhabited places. In addition, Karlsborg, Åmål, Tidaholm, Vårgårda, Hjo, and Herrljunga were chosen as less populated locations. Information related to the location of polygons for closed quarries was collected from the County Administrative Board of Västra Götalands which granted the permit to aggregate companies. In addition, historical maps uploaded to Lantmäteriet were explored as a second database and some additional quarries were found that the County Administrative Board was not considered as a closed quarry. Therefore, they were added to the list for measurement. Figure 1 displays an illustration of a closed quarry in Kungälv that can be seen on both satellite and historical maps of the same area. It would be important to mention that the last version of uploaded historical maps was explored in this study. Lantmäteriet (www.lantmateriet.se) is an authority related to land survey in Sweden that belongs to the Ministry of Rural Affairs and Infrastructure. It provides services and documentation of Sweden's geography (geodata) and diverse maps.

Figure 1- Displaying a closed quarry in both satellite image and historical map (*Dösebacka 2:8*)

In this study, the satellite maps of Lantmäteriet were applied as a Geographical information system (GIS) tool for data collection and measurement of polygons. The period of taken images was chosen since 2018 as the worst scenario case for observing the restoration situation. The reason was that the year of taken map's updated date is unknown in Lantmäteriet and also, the latest version of satellite images in Lantmäteriet was updated between 2018 and 2023. In addition, several differences related to the landscape were observed in the satellite images from Lantmäteriet, Google Maps, and ArcGIS online. By observing the satellite images in ArcGIS online, the time of taken images was mentioned in it which was related to 2021 and the discrepancies between the two maps were not significant.

Measurement:

For measurement, first, the whole area of each polygon was measured with the measurement tool provided in Lantmäteriet to get the size of the total area. These total areas were divided into several classifications of land use to be measured. After that, the total size of the restoration outcome was calculated by summing each category in the land cover classification. The reason was to assess variance of the total size of polygon area and total restoration outcome to estimate the margin of error. For estimating the margin of error, the t-test data analysis was done in the Excel sheet to check the significant differences between the two items. The data relating to the measurement of total area and total outcome is shown in Table 5 in the Appendix section. The example of measurement related to total area was revealed in Figure 2.

The next step is evaluating each polygon for categorization after obtaining the overall area size which in the part that follows, the measurement and categorization were covered in more detail.

Figure 2- A measured polygon of quarry closure located in Åmål (*Vallsjön 1:3*)

Classification:

Regarding the classification of land covers the categories that were designed for that are explained in the following lines:

1. Forest which was chosen for observed large areas covered chiefly with trees regardless of the differences amongst the type of forest and species related to trees.
2. Vegetation was chosen for flat and open areas where grasses, plants, and shrubs are dominated regardless of the differences related to species and types.
3. Mixed vegetation was considered for the areas that are the combination of two first categories, forest, and vegetation, and could not be separated which the example is shown in Figure 3.
4. Farmland was selected for the arable lands that are farmed such as croplands used for agriculture regardless of the species and type of farmland.

5. Water body was chosen for the lands that were covered with water such as sea, surface water including lakes, rivers, part of streams, and wetland.
6. Urban was chosen for the areas relating to a city or town for instance any residential area (building), industry area, roads, and recreational areas.
7. Bare land was chosen areas with no dominant vegetation cover or areas covered by lichens/moss.

Figure 3- The mixed vegetation category, Polygon: *Angered 2:22*

Each polygon was observed and according to the considered classification, the area was separated to measure each category. Figure 4 illustrates the measurement of each category. The measured data of land cover classification is shown in Table 6 in the Appendix.

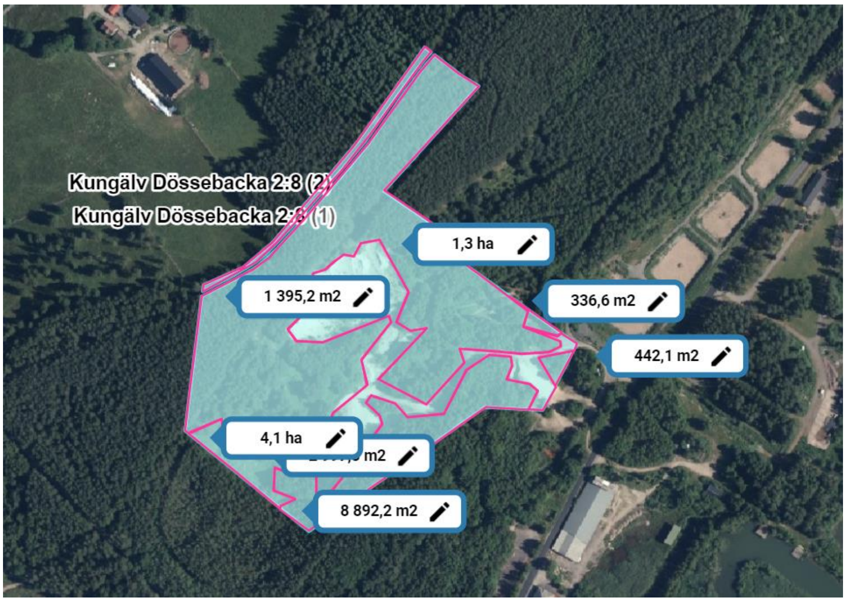

Figure 4- The measurement of each category in classification (*Dösebacka 2:8)*

It should be taken into account that in certain instances, a mixture of two groups that could not be distinguished was seen, with one of them taking up more than 75% of the available space. The measurement was done using the dominating category.

Documentation:

Finally, the locations were measured according to the considered categories to get the data of restoration plans for closed quarries which are revealed in Table 4 in the Appendix. The t-test and graphs were carried out in Excel sheets, and the estimation of the margin of error was evaluated statistically with a probability of 5% (α= 0.05) for the t-test.

3.1.1- The analysis of the correlation between population and restoration outcomes from land cover classification

The correlation between population density and the outcomes of restoration of the land area was examined to address the fourth study question. Since it was anticipated that there would be more aggregate quarries and also quarry land areas in the municipalities with more residents. To assess the relationship between aggregate quarries and restoration outcomes with population, first, the population number and the size of the land area were collected for each municipality. Therefore, the population density was calculated according to the following equation:

$$Population\ density = \frac{Number\ of\ population}{Land\ area\ (km^2)}$$

In addition, by applying Pearson Correlation Coefficient for data analysis, the linear relationship between every two variables with population density. It was evaluated statistically with a probability of 5% (α= 0.05) in an Excel sheet. It is crucial to mention that the correlation coefficient value in the analysis is between -1 and 1 which reveals the positive and negative linear correlation.
-1 indicates a perfectly negative linear correlation and 1 indicates a perfectly positive linear correlation between two variables. In addition, 0 indicates no linear correlation between the two variables.

3.2- Limitation

According to the aim and research question of this study, land cover classification was chosen as one appropriate method to answer them; although there are several restrictions to the application that needs to be taken into account.

The limitation related to land cover remote sensing is that the data can give information related to each category, however, that information might not be accurate and current in comparison with the actual measurement done in the study site with suitable materials and equipment. Moreover, because of the vast scale, it is impossible to have a wealth of details about the objects in nature and landscape. In addition, it is possible for several phenomena to seem the same when being measured, which might lead to classification errors.

Taking the satellite images at the current time is unavailable, therefore the date of the taken images was considered the worst scenario in this study (2018), whether some differences can be observed in the current conditions. Atmospheric conditions such as light, cloud masking, and shadow can make some errors during the measurement (Al-wassai & Kalyankar, 2013; Basheer et al., 2022).

The lack of existing permits related to closed quarries was considered one limitation in this study due to the exact location of quarries, the information related to restoration, and natural characteristics being uncertain; therefore, the whole area of polygons was measured as the location of closed quarries.

Almost all Earth observation-derived information has certain fundamental limitations, such as sensitivity to the resolution, and categorization scheme utilized, as well as practical restrictions on what can actually be remotely seen and automatically categorized with the instruments and techniques now in use (Colorado & Network, 2011). The resolution (most commonly 2 and 5 meters) can impact the clarity, detail observation, and location which makes some errors.

4- Results

After exploring land cover maps to evaluate the restoration outcomes for classification, amongst 155 closed quarries which were existed only 129 polygons related to closed aggregate quarries were found in nine municipalities. 26 closed quarries could not be found because of lacking data and inaccurate information based on the location data available. Table 1 shows the information and number of closed quarries in detail amongst nine municipalities.

Table 1- The information on Closed quarries in nine municipalities

Municipality Name	Total registered polygons	Not Found	Found
Gothenburg	29	10	19
Mölndals	14	2	12
Kungälv	13	2	11
Åmål	20	4	16
Karlsborg	8	0	8
Vårgårda	25	3	22
Tidaholm	15	1	14
Hjo	8	0	8
Herrljunga	23	4	19
Total	155	26	129

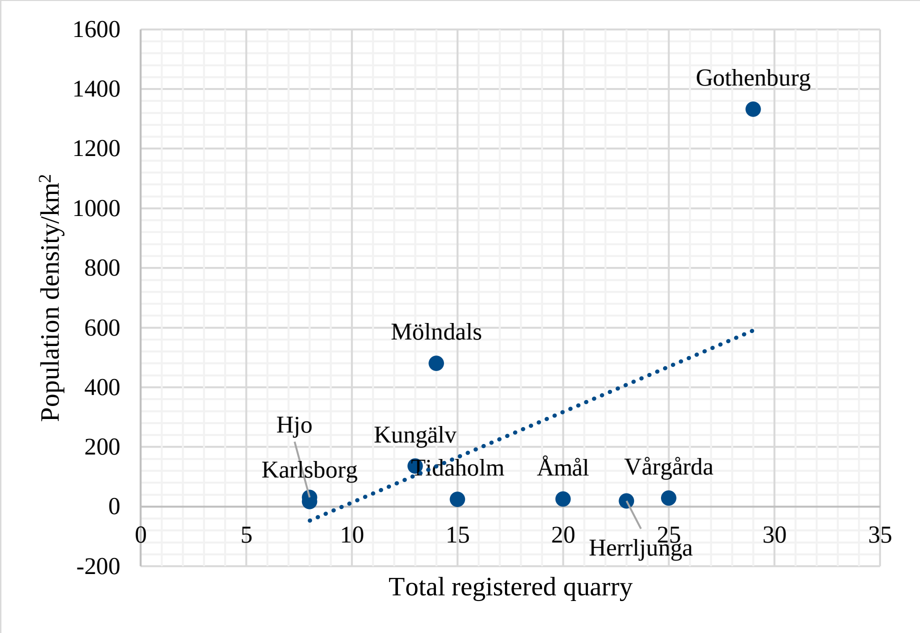

Figure 5- The relationship between total registered quarries and population density for each municipality

Figure 5 illustrates the linear relationship between total registered quarries and population density which was examined for nine municipalities. Correlation coefficient data analysis was applied for analyzing the relationship between two variables. The result reveals that there is a positive linear correlation between the two variables and the trend line is ascending which means that by increasing the population density, the number of total registered quarries rose. Moreover, the correlation coefficient result is 0.51 (between 0 and 1) but the result according to the P-value is not statistically significant (P-value is 0.15). Gothenburg has the highest number of total registered quarries (29 quarries) and also it has the highest population density amongst them. Mölndals has the second rank in population density, although the relationship with total registered quarries in Mölndals and other municipalities has a fluctuating trend which is the reason it is not significant.

4.1- The Analysis of Restoration Classification Outcomes in quarry closure

The measurement of restoration related to old quarries in the classification was investigated. The result of the total restoration outcome illustrates in Figure 6. A high proportion is allocated to the forest category, in which 69 percent of the land area was converted to forest amongst 129 closed quarries. The farmland possesses the second rank occupying 13 percent of the pie chart; moreover, the vegetation and mixed vegetation are 6 and 5 percent respectively. Obviously, the lowest percentage of the figure (7%) is composed of barren ground, metropolitan areas, and aquatic bodies.

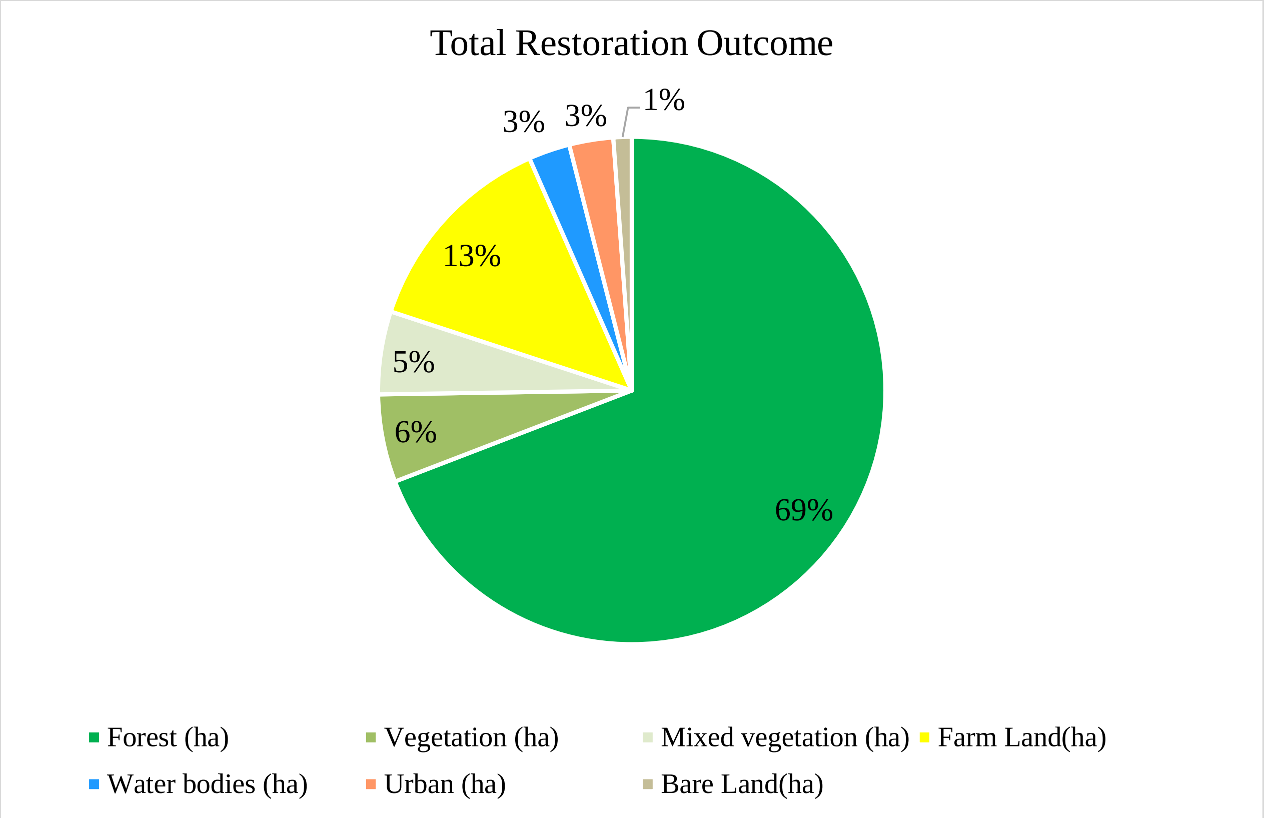

Figure 6- The result of total restoration outcome in nine municipalities

4.1.1- Nine municipalities' categorization of land cover according to each category

For comparison, the examination of each category from the restoration outcome was analyzed into nine communities.

The forest category among municipalities is shown in Figure 7. For all municipalities, the amount of forest varies from 53 to 77 percent, indicating minimal variation. In total, Gothenburg and Åmål have the greatest percentage with 77 percent, followed by Karlsborg, Herrljunga, and Kungälv, all of which are over the average. Mölndals, Vårgårda, Tidaholm, and Hjo are under the average line.

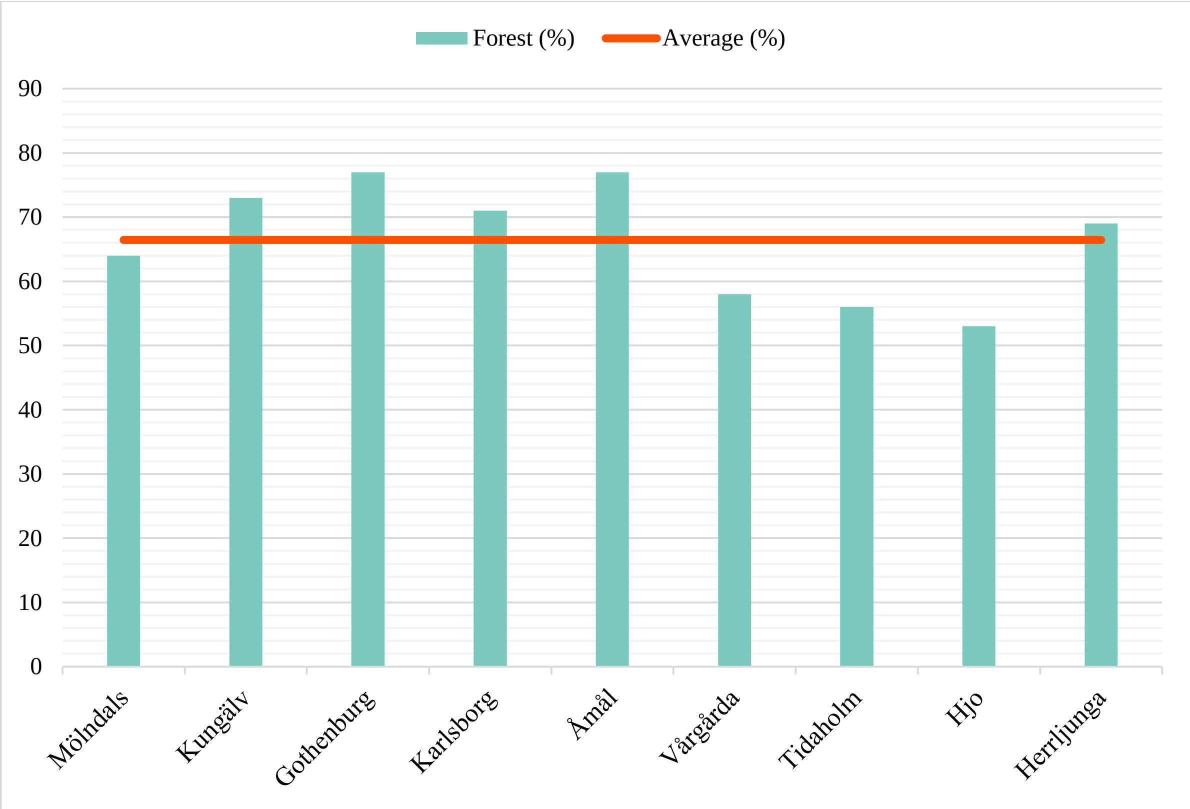

Figure 7- The outcome of the forest restoration category

Figure 8 displays the proportion of vegetation restoration outcomes for nine municipalities. Mölndals has the highest proportion with 10 percent and on the contrary, Åmål has the lowest amount total with 3 percent. The percentage for others is approximately the same and ranges from 6 to 8 percent.

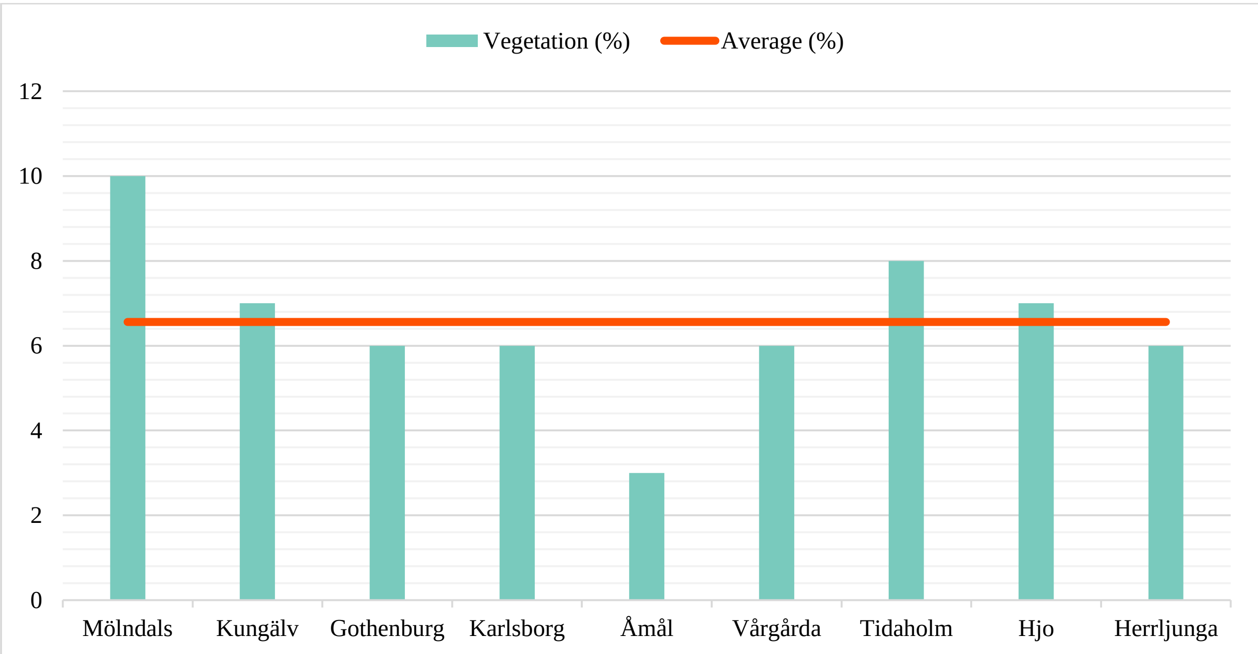

Figure 8- The outcome of the vegetation restoration category

Analysis of the category of mixed vegetation is shown in the following Figure (9). Mölndals and Vårgårda have doubled the average percentage by 10%. The lowest proportion is assigned to Gothenburg with 2%, and all restoration results, except for Herrljunga, have lower percentages than the average line.

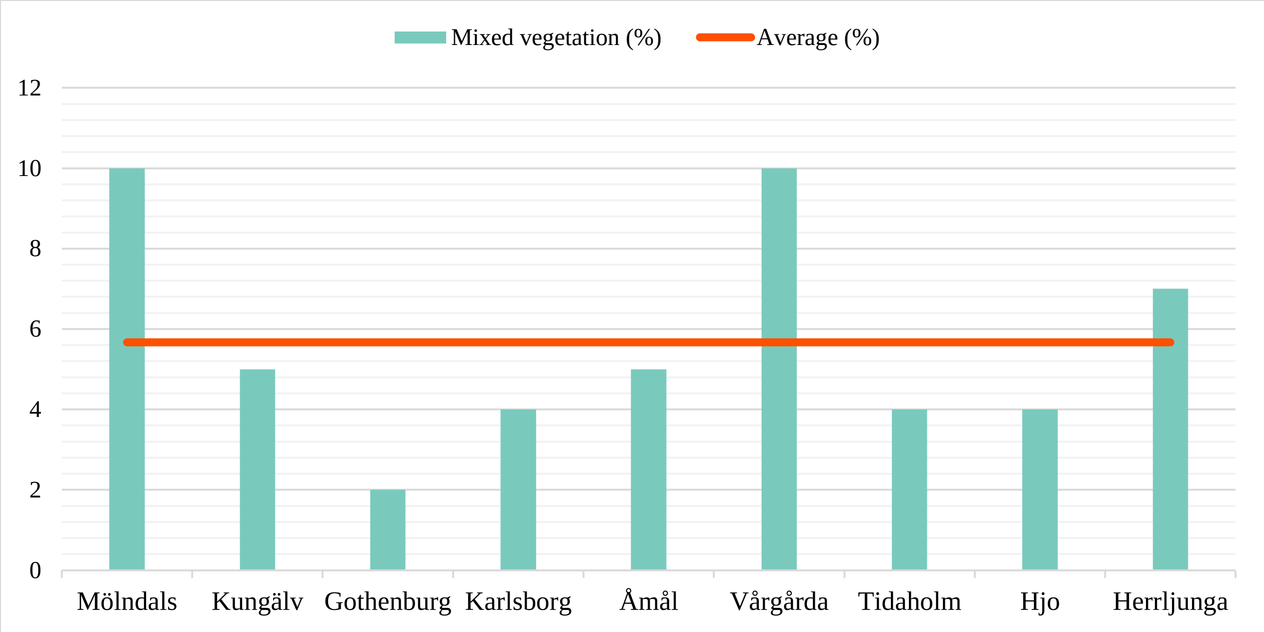

Figure 9- The mixed vegetation restoration outcome in nine municipalities

The information on the results of farmland restoration is depicted in the following Figure (10). It is apparent that Hjo has the highest percentage among the others, close to 30%, and Tidaholm is in second place with 29%. Other municipality's measurement results, with the exception of Vårgårda, are below average with a varying trend.

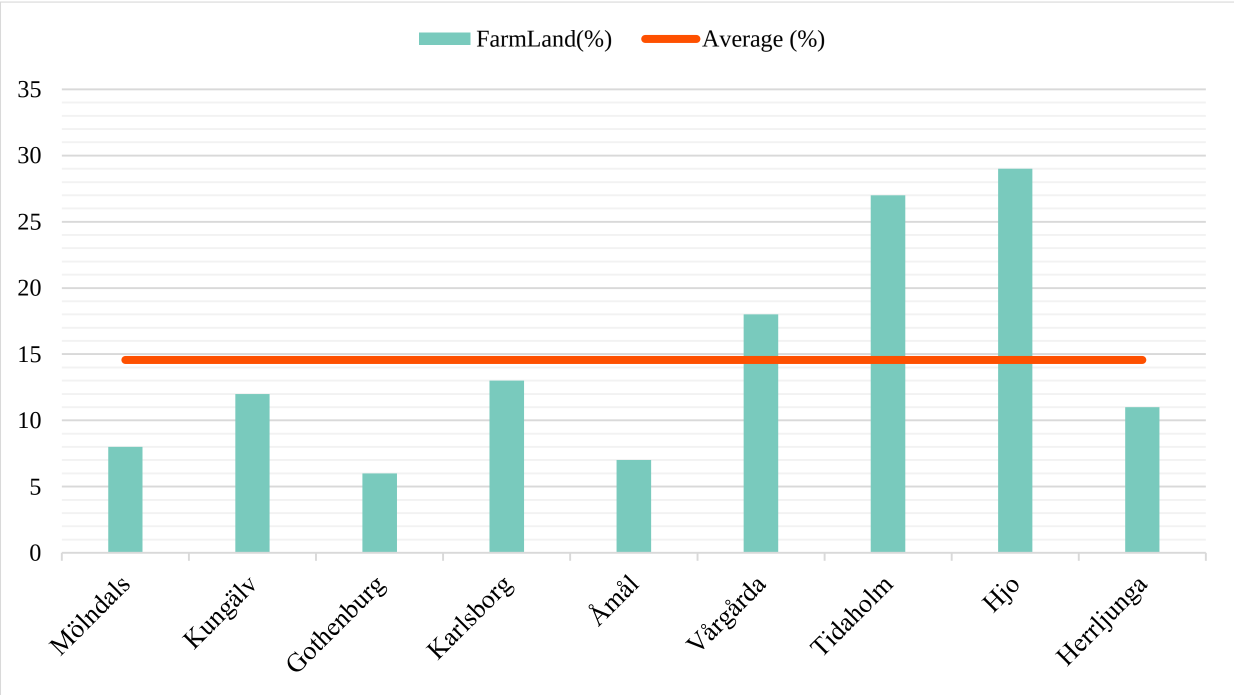

Figure 10- The Farmland restoration outcome in nine municipalities

Figure 11's statistics on the results of water body restoration show that Åmål and Mölndals have the highest rate in the bar chart, approximately double the average. Except for Gothenburg other municipalities have a lower ratio in comparison with the average. Additionally, this conclusion is negligible in the restoration plan of Hjo and Kungälv.

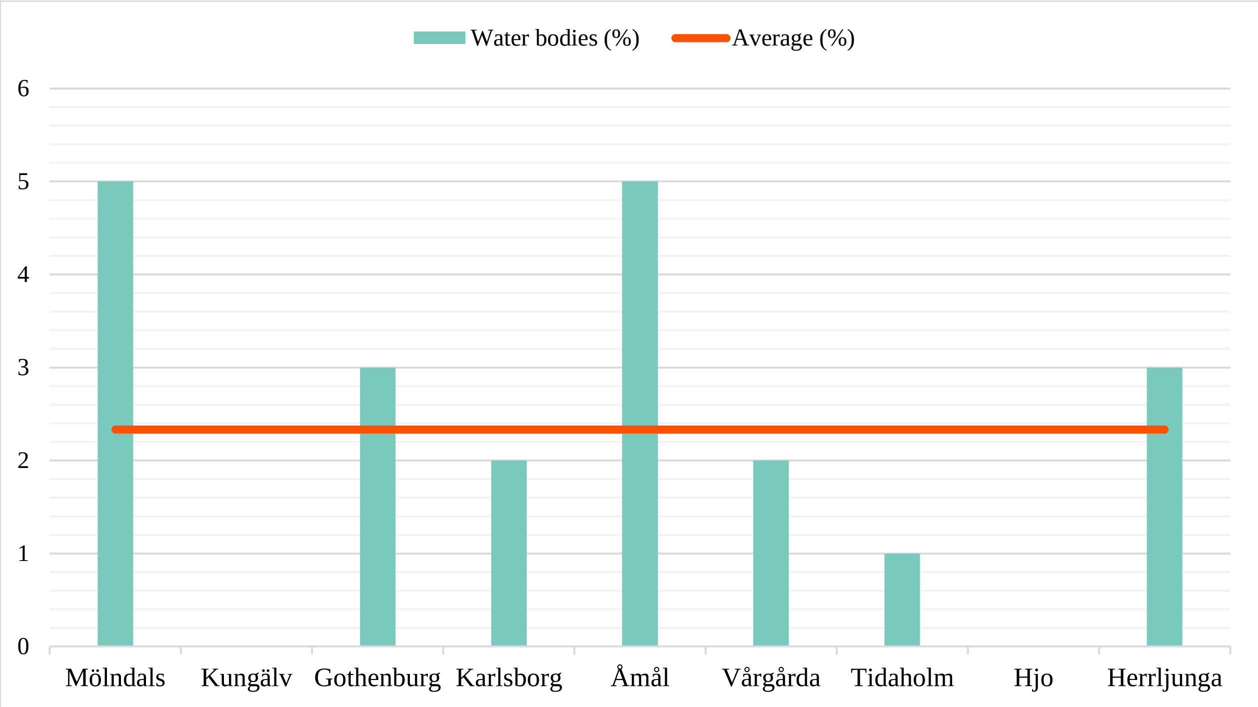

Figure 11- The outcome of water body restoration outcome of closed quarries

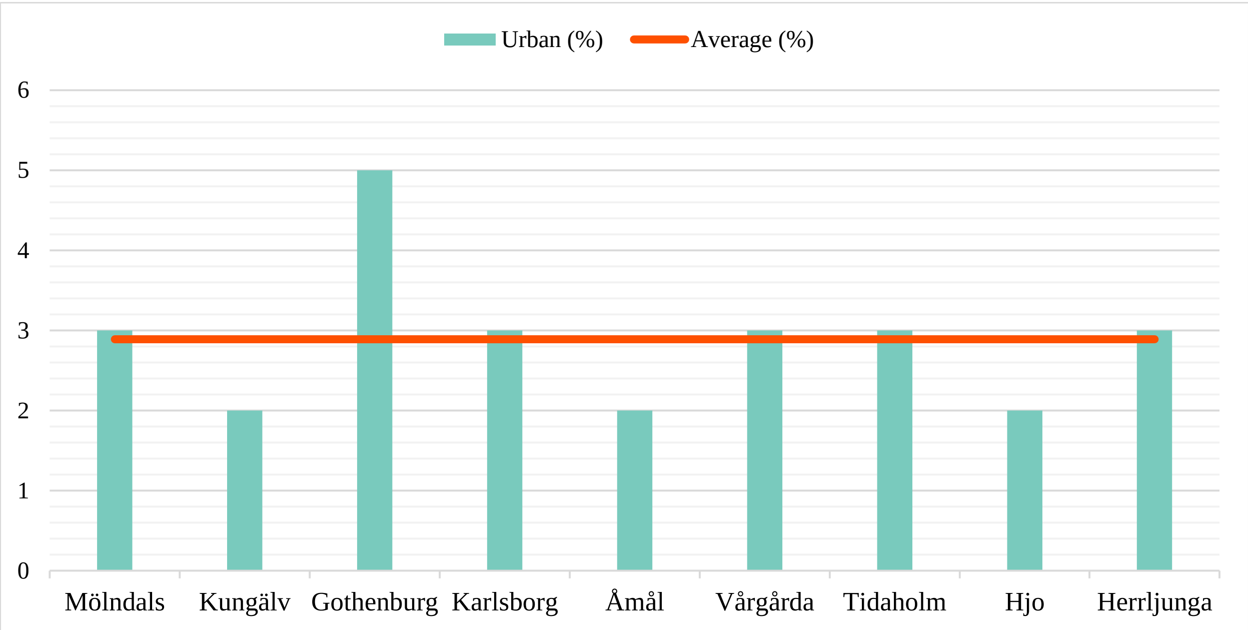

Figure 12- The Urban restoration outcome of closed quarry

The amount of metropolitan districts that were rebuilt from abandoned quarries is shown in Figure 12. The majority of them fall within the 3 percent range of the average. With a rate of 5%, Gothenburg has the highest rate. With a rate of 2%, Åmål, Hjo, and Kungälv are the lowest.

The barren ground is represented by the last Figure (13) in the restoration outcome. The percentage reveals that the majority is one percent; in addition, Hjo and Vårgårda have the highest rates at 5 and 3 percent, respectively.

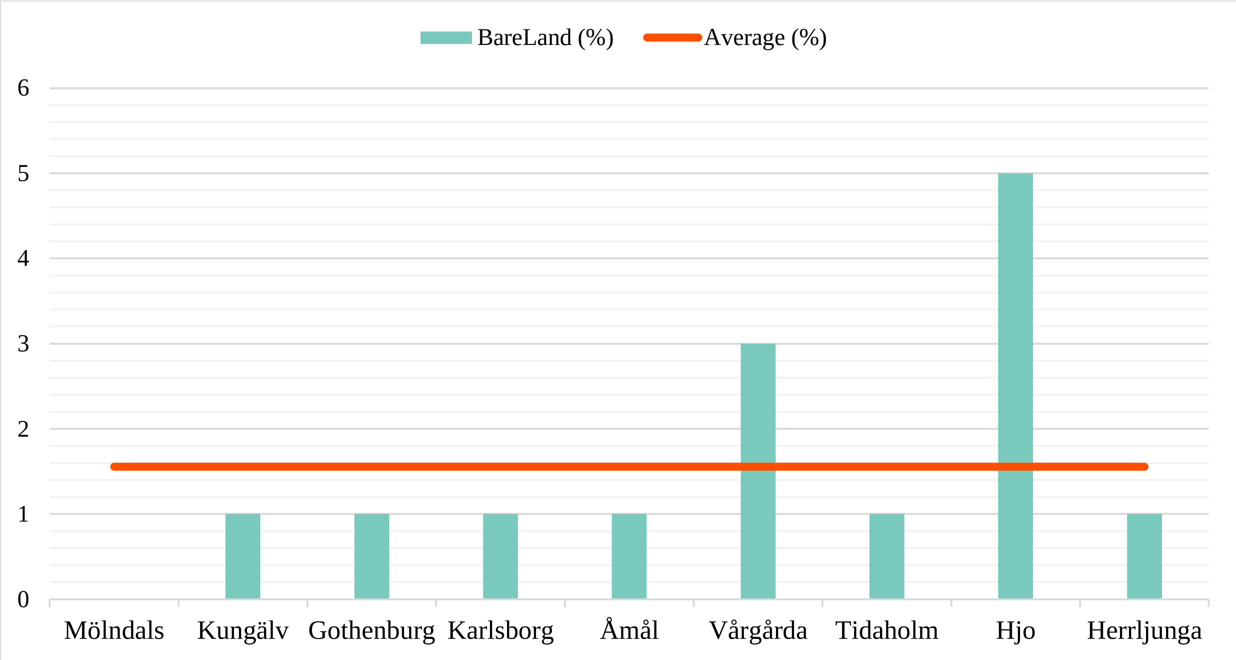

Figure 13- The bare land restoration outcome in closed quarries

4.1.1.1- The estimation of total margin errors between the total measured size and total size of restoration outcome

After collecting data from the classification the total size of the restoration outcome was calculated by summing each category in the land cover classification to estimate the margin of error between the total measured size and the total size of the restoration outcome. The analysis of the T-test data concluded following the observation of 129 closed quarries for the categorization of land cover. With a P-value of 0.49, the outcome indicates that there is no statistically significant variance between both total size and total restoration outcomes across all closed quarries.

4.2- The analysis of the relationship between the restoration outcomes and population density for each municipality

According to the fourth research question, the correlation between population density and the outcomes of restoration of the land area was examined. Since it was anticipated that there would be more restored quarries land area in the municipalities with more residents. The collected data of each classification in nine municipalities with population density were analyzed. Table 2 reveals the population density in nine municipalities and Table 3 shows the results of associations between the restoration outcome in populated and less populated with population density in correlation coefficient analysis.

Table 2- Population density of nine municipalities

Municipality	Land Area 2020 (km^2) (Regionfakta, 2023)	Population (2022) (SCB, 2023)	Population density $/km^2$
Karlsborg	406	7057	17.38
Åmål	481	12216	25.39
Herrljunga	497	9517	19.14
Tidaholm	518	12839	24.78
Vårgårda	427	12268	28.73
Gothenburg	448	596841	1332.23
Hjo	297	9243	31.12
Kungälv	362	49068	135.54
Mölndals	146	70109	480.19

The statistics demonstrate that the total restored outcome and each category have a negative linear correlation with population density. The P-value of the correlation coefficient reveals that there are no statistically significant variations between municipalities both less or high populations in terms of the restoration outcomes. Table 3 shows the correlation coefficient results and P-value of data analysis for each category with population density in nine municipalities.

Table 3- The result of correlation coefficient data analysis between population density and each restored category

Category	Correlation coefficient	P-Value
Total restored outcome (km^2)	-0.34	0.36
Forest restored outcome (km^2)	-0.29	0.43
Vegetation restored outcome (km^2)	-0.39	0.38
Mixed vegetation restored outcome (km^2)	-0.47	0.19
Farmland restored outcome (km^2)	-0.47	0.20
Waterbody restored outcome (km^2)	-0.23	0.54
Urban restored outcome (km^2)	-0.21	0.57
Bare land restored outcome (km^2)	-0.45	0.21

5-Discussion

Environmental alterations most of the time have been linked to human activities. A quarry is a significant example of a human intervention in nature that has a noticeable impact on the landscape. A significant change in the environment in post-mining sites and surrounding areas is experienced frequently. Restoration (either naturally occurring or artificially) would help to mitigate the consequences of mining and quarrying in the long run, and the possibility of consequences might persist if they are not repaired. The primary goal of it is the transformation of neglected and deteriorated sites into ones that are repaired and sustain natural ecosystems which would ultimately enhance the ecosystem and human health.

Although there are guidelines available for quarry cleanup, it might be challenging to gather information outside of specific situations about how well recovery is carried out, whether plans are followed, and whether additional repercussions occur. Restoration needs to go beyond a theoretical discussion and be implemented in practical investigations. Human technology cannot restore natural systems as existing landscapes (pristine environment) before starting quarrying, since maybe some wild species (animals or plants) existed in the area that quarrying may extinct and destroy them; in addition, the ecosystem value of the untouched environment is higher. However, technology can be used to improve them by examining the condition of land use to design it in the best situation and introducing major plants and animals into ecosystems which have merit for the environment to establish the basic habitat requirements, encourage natural evolution, and hasten ecosystem recovery. Rewilding the abandoned quarry area could be the potential to increase the ecosystem value as much as possible. The goal of rewilding is to create wild, biodiverse regions that will help healthy ecosystems recover. It rebuilds ecosystems that have previously been modified by human disturbance, using the plant and animal life that would have been present had the disturbance never occurred.

5.1- Which restorations have been already done?

In this project, the restoration plans for the several quarries in Västra Götalands province were reviewed in accordance with the goals of the investigation to determine the situation of restoration plans and which one was the most well-liked. According to the results which were revealed in the previous section, the considered restoration plan for all closed quarries was accomplished properly. 96% of the lands were converted to areas having a natural value such as forest, vegetation, mixed vegetation, farmland, and water body. These lands can impact positively the environmental situation of the area instead of leaving them after the operation. Not only can the areas enhance the environmental circumstances; but they can also be a potential habitat for a wide range of species either macroorganisms or microorganisms. It can also be worth suitable habitat for some species which are rare or on the red list. The most common restoration amongst municipalities forms land cover classification (Gothenburg, Mölndals, Kungälv, Karlsborg, Åmål, Tidaholm, Vårgårda, Hjo, and Herrljunga) is developing a forest and planting trees after the operations. The ultimate results of the restoration have forest for abundant quarries covering around $\frac{2}{3}$ of them. Farmland (13%), vegetation (6%), mixed vegetation (5%), and water bodies (3%) are the topics of the following three common restoration designs, respectively.

According to data, only 3% of the measured restored property in this project has been converted to urban space. The population may have risen more lately than it did when these quarries were in operation, which might be the cause. Therefore, even if the amount is not very large, additional land space is needed for inhabitants (housing, the road, recreational land). A small rate including 1% of the total restored area was converted to bare land which no restoration was observed in these areas. Since the period of closed quarries is uncertain, the restoration in these areas may not start. On the other hand, according to the Environmental Code, before the process, the examination may be accomplished by the supervisors whether the area is not suitable for restoration after the operation.

5.2- What beneficial impact would the restoration of quarries have on the state of biodiversity?

Ecosystem functioning in landscapes will become more and more crucial for conserving biodiversity worldwide as natural habitat areas decrease. Under the correct conditions, it has been discovered that quarries both active and inactive, can serve as a viable home for a range of species. Many of the conditions that exist in the quarries are uncommon and sporadically happen in regular life. It is noticeable to mention that out of the 21,740 known species assessed by the Swedish Red List 2020, 2,249 (10 percent) are threatened and an additional 2,497 (11 percent) are near threatened. Restoring these areas could be a great opportunity to promote biodiversity by creating a habitat for the species. For example, according to one published report in Quarry Life, in Sweden, there are about 250 species of wild bees, 177 live on Gotland which about 16% of these are nationally red-listed. Physical changes can occur during operation such as a variety of angles and slopes which will promote biological diversity following site closure. Whether there are exposed rocks or a lot of sand and gravel on the ground, the environment offers unique habitats where organisms that move about a lot can establish themselves.

The direction of the area's reclamation must be determined by the natural characteristics to improve the sustainability such as biodiversity of location and surrounding area, soil characteristics, and climate of the particular ecosystems in each unique sample and the value should only be supported by ongoing reclamation efforts.

Planting trees is seen to be the most beneficial, ecological-friendly action that can engage in improving the environmental situation of former quarry sites, either nature or landscape. Furthermore, according to Prach et al., 2011 creating forest is one most appropriate post-treatment in the abandoned quarry area. They are very effective at delivering ecosystem services including removing air pollutants (cleaning the air by reducing GHGs), capturing stormwater pollution, sequestering carbon, providing green infrastructure, improving food security, reducing soil erosion in the land area by wind and rain, regulating the water cycle, and regulating urban temperatures to protect the ozone layer. Therefore, they are crucial for any healthy, thriving environment and town. The quarry's activities related to extraction, transportation, and operation have the aforementioned detrimental effects. In addition, these places increase biodiversity and provide favorable habitats for a wide variety of animals such as birds, squirrels, and insects, and it is also possible to be a food supply for many species (Till & Skapa, 2015). These intricate ecologies are teeming with life. In fact, 80% of the planet's land-based plant and animal species plant and animal species in the world are thought to reside in forests (KaitlynBra, 2021).

These species' life is all intertwined. Even the fallen leaves that cover the forest floor have an ecological purpose by replenishing the nutrients in the soil that plants require to flourish. Trees employ a network of fungi underneath the ground to exchange nutrients with one another. Because forest life is so interconnected, the loss of any one component may disturb the equilibrium of the entire ecosystem. The presence of fungus and bacteria in various tree components encourages variety, which is facilitated by trees. In addition to improving the soil's fertility before planting trees, and they make it simpler for birds to build nests there. If the dead wood is existed in the area because of cutting former trees for using the land, it can be applied as a habitat for various microorganisms and microplants which can be put in the suitable area.

Farmland is another item for the restoration of closed quarries. Besides the economic and social advantages, it has ecological benefits if it is done sustainably. It can additionally preserve wetlands and watersheds, aid manage floods by applying farming techniques, and maintain air quality (capture GHGs in crops and soils). They may filter and absorb waste water while recharging the groundwater table; in addition, offer habitat for pollinators (bees) and wildlife for instance birds and insects (butterflies). Even the potential to replace fossil fuels exists for new energy crops may be possible, but it is important to consider the agricultural land area features, and the possibility for usage; for instance, the application should not have negative environmental impacts related to large-scale such as deforestation. In addition, biomass plants require a lot of space for storing and processing.

On the other hand, it is important to consider that agriculture may have serious negative environmental effects when the process is not sustainable, such as soil, water, and air pollution which can be harmful the biodiversity. In addition, depending on their toxicity, the level of contamination, and the length of exposure, pesticides can be harmful to people and other non-targeted creatures living in the farmlands (de Oliveira et al., 2014).

For landscape design, plant selection is crucial because great plant diversity may encourage high production and provides a material foundation for the ecological diversity of the ecosystem. It can help ecosystems have more species diversity which is a great option to improve the natural conservation of deteriorated sites. It holds several benefits such as prevention against soil erosion, which leads to minimizing water loss and boosting soil fertility, enriching native plant communities, and improving wildlife habitats (Carla Khater, et.al, 2014; Rademacher, 2015). Plants are releasing oxygen into the atmosphere and absorb carbon dioxide, also provide animals with nutrition, and control the water cycle, all of which are necessary for sustainable life on Earth.

Green spaces highlight possible connections between biodiversity preservation, source of energy, and food production. Additionally, in south-facing sand and gravel slopes where mining is not currently taking place, biologically valuable stands are abundant in unusual or less common plants. Diverse insect life is brought on by a large number of flowering plants, which also helps numerous birds and bats. In addition, heather, mountain thyme, sedge, goat's sedge, numerous species of vetch and clover, yarrow, the sand white, wild carrot, little bluebell, several kinds of fiber, etc. are a few examples of significant herbs which are reported in the restoration quarries. These plants are a vital part of the feeds of several insects that depend on the sand. For the sand lizard, which hunts insects and spiders in this area, the herbaceous field layer is a crucial need.

Today, the meadow is one of Northern Europe's smallest and most vulnerable ecosystems which can be used for restoration sites to enhance the variety (Kanter et al., 2016). There are several ways to plant vegetation; also, soils and the maintained sandy hills in the land may be utilized because they frequently contain a lot of seeds. It has been discovered that a variety of wild bee species may live successfully in quarries. If wild bees are eradicated from a location, it's possible that local plant species would go extinct. Wild bees are typically more successful at pollinating a wide range of crops and plants than honey bees are. There are over 250 species of wild bees in Sweden, and 16% of them are on the national red list which closed areas can be possible for to thrive the species. Sometimes there may be existing vegetation on the site that can be utilized by leaving it standing or by moving it to the desired location. It is suggested that avoid using non-native species in quarry restoration. prefer using native plants to ensure the creation of adequate habitats to draw in native animals and, at the same time, to benefit from the ecological benefits they bring (Sampaio et al., 2021).

The existence of water in the environment, in a variety of forms, contributes significantly to improving both the socioeconomic and ecological balance especially boosting the situation of urban areas (Bindu & Mohamed, 2016). The importance includes adapting to climate change (carbon sinks) and supporting wildlife which creates effective habitats for several species either animals such as insects, amphibians (frogs), lizards, and reptiles or aquatic plants. Only 2.5 percent of surface water is freshwater because there is a small amount of water, conservation is crucial. More than 10% of all known animals and around 50% of all known fish species are found in freshwater ecosystems such as lakes, rivers, streams, wetlands, and aquifers, which account for a remarkable amount of the biodiversity of the planet (WWF, n.d). Commonly, ponds and wetlands develop on former quarry and pit sites. It is essential to have progressively sloping coastal banks with shallow areas in order to maintain a variety of wildlife. The sunlight can easily penetrate in the shallow pond which can create a warm place for reproduction. In some cases, growing vegetation may affect reproduction which shades the pond and becomes less attractive to aquatic species. Moreover, by constructing islands and expanding the shoreline, a diversity of habitats and nesting locations will be produced. According to several reports, in the spring, when frogs and newts are laying their eggs, ponds and the flora that surrounds them should be conserved as much as possible.

Applying rock walls and rock slopes is another potential restoration design to preserve essential natural resources. Vegetation that is easily in rock walls and slopes. Crevasses and difficult rock shelves can be formed, which many birds use as valuable nesting locations. Large remaining stone blocks in certain locations have produced a very steep slope that is exceedingly difficult to reach due to the steep slope and rough construction. All nesting sites faced south, ensuring that they would get the majority of the day's sunshine. It would be interesting to look into whether this has had any positive effects on the birds in these areas. For example, Sand Martin is one bird which is attracted to sand and gravel slopes as a habitat. According to Sten & Bengtsson, 2011, to promote Sand Martin nesting, open seams of sand with vertical sides should be left in sand and gravel quarries. The Swerock report mentioned that about 80% of all Sand Martin breedings in southern Sweden are mostly in gravel pits. Furthermore, the rock and slopes can be assumed that some insects and other species can choose this place as a habitat. Bees, solitary wasps, and a variety of other invertebrates can find significant homes on south-facing sand banks and exposed surfaces. Shelters can also contribute habitat for birds in, for example, race slopes and protected cliff shelves. Applying disused shafts as a shelter for bat populations is one example of creating habitat in the restoration plans.

Besides enhancing the ecosystem condition of abandoned quarries, the recreational area can be created by planning an environmentally friendly recreational area with strong social values while collaborating with neighborhood organizations and authorities. It means that several aspects of quarries were examined to promote habitats for diverse animals and vegetation, therefore people can visit the place. It can be converted into popular tourist destinations, bathing locations, and eco-tourism. Wetlands and lakes can be used for several activities, for instance, fishing, swimming, and using the bridge which the visitors can see the aquatic herbs and animals. According to Quarry Life Report, the edges of the closed quarries are suitable for creating bird watching which visitors can watch panorama views of birds and surrounding areas. It is reported one closed quarry located close to Lake Bogeviken, which bird watching was constructed to visit *Carpodacus erythrinus* one endangered species in Sweden. Moreover, it is reported that the crayfish *Astacus astacus* is observed by visitors in the wetlands.

5.2- Which restorations could be improved in the future to achieve a sustainable quarry life cycle?

In addition, obtaining the permits of the evaluated quarries from the County Administrative Board was sought after data categorization analysis in order to assess the restoration outcomes and compare them to the actual restoration mentioned in the permit. Despite the existence of the permits, they are not currently available. Only four permits related to the quarries Angered 2:20 (Gothenburg), Hjällbo 117:4 (Gothenburg), Ryr 1:1 (Kungälv), and Ålgårdsbacka 1:12 (Mölndals) were received. In addition, the years of completing the closure of the quarries Kockhed 1:5, Maggered 1:3, Angered 7:195, and Angered 7:187 (Gothenburg) were also given by the County Administrative Board. The previous permits were investigated, except Angered 2:20, the restoration plan was not described in the document. In the permits of Angered 2:20 which it was expired in 1978, according to the forest protection organization, this area was suitable for the forest. However, in the current situation restoring the forest was not observed. Figure 14 shows the location of these abandoned quarries.

Figure 14- Quarry closure - *Angered 2:20* (current- 1976)

Therefore, the closed quarry located in Angered 2:20 was visited to check the current situation of this location. There were no differences between the satellite image and the actual land area. Forest, vegetation, residential area, and roads were observed in the neighborhood. The quarry was surrounded by vegetation, trees, and roads. Two butterflies were observed flying around the location and some plants were grown in the gravel land sparsely. Some parts of this quarry seem to be used as a road and discarded the building materials which Figure 15 was shown the location of this quarry.

Figure 15- The current land situation of Angered 2:20

On the other hand, the historical maps were reviewed to analyze the previous condition of the land before starting the quarries and the current condition after restoration (Kockhed 1:5, Maggered 1:3, Angered 7:195, Angered 2:20, Ryr 1:1, Ålgårdsbacka 1:12). The historical maps of Lantmäteriet regarding the versions of 1950, 1964 and 1976 were observed. The maps related to 1950 were not readable, since there were not any keys or information in the maps to distinguish the classification in the map. Since Kockhed 1:5, and Maggered 1:3, were completed before 1964, the former condition was not obvious in the historical map. According to the maps, for other closed quarries, it seems that there are not great differences between the two circumstances. Only in some cases, the road and urban area have increased and this situation means that current areas are close to the original nature and land use. Hjällbo 117:4 in both maps was in the progress of aggregate quarries.

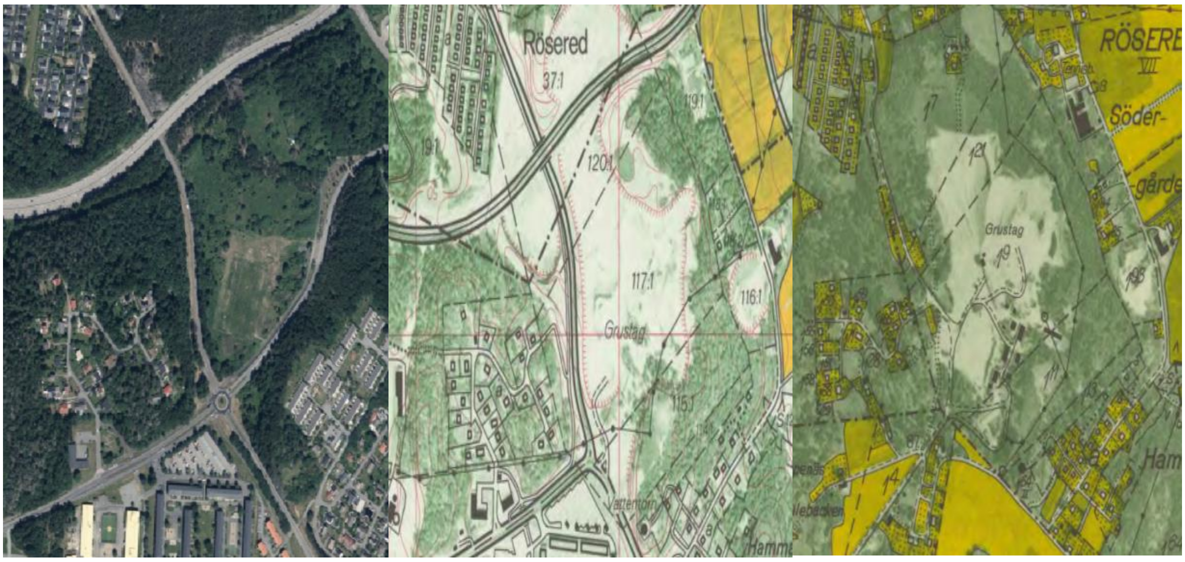

Figure 16- Hjällbo 117:4 in the three different periods (current- 1976- 1964)

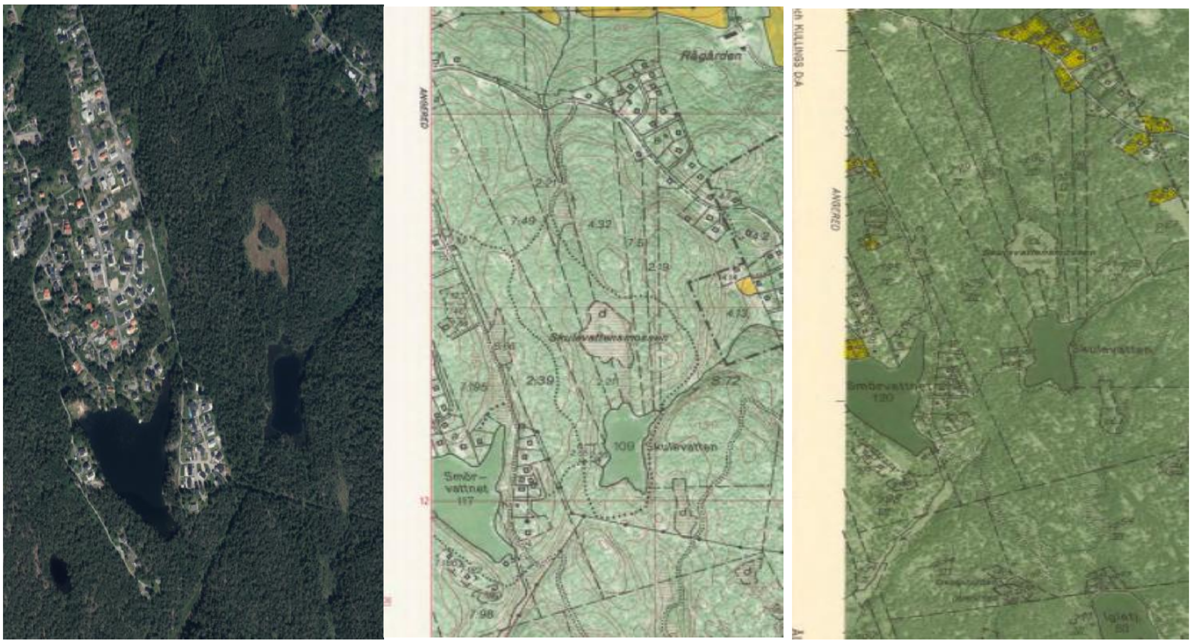

Figure 17- Angered 7:195 in the three different periods (current- 1976- 1964)

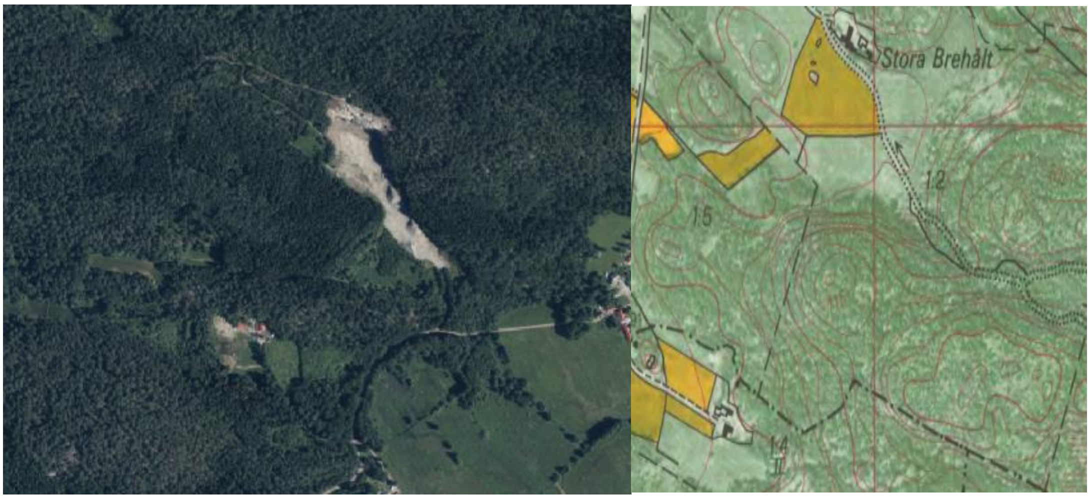

Figure 18- Ryr 1:1 in the two different periods (current- 1976)

Figure 19- Ålgårdsbacka 1:12 in the two different periods (current – 1963)

5.2.1- Correlation between the classification of restoration outcome and total classification land use for each municipality

Based on the comparison of each restoration result across nine municipalities (section 4.1.1), the proportion of restoration results in nine municipalities was close to each other. It appears that the same process was used for restoration efforts that were pertinent to overall land use. Therefore, the data were compared to total land use statistics from the Swedish Statistics Database (SCB) (https://www.statistikdatabasen.scb.se/) to determine whether there was any correlation between the two land use. Available data on forests, farms, water bodies, and urban areas land use was collected, as shown in Table 7 in Appendix. T-test data analysis was also completed to check the variation. The findings demonstrate that there are no statistically significant variations between the percentages of total forest and agricultural land use in nine municipalities and the percentages of forest and farmland restoration outcomes. On the other hand, the variation between the urban area and the water body is statistically significant which is shown in Table 4. It seems that only rehabilitation of aggregate quarries in each municipality uses the same procedure for restoring because having the close ratios in the results and it is not correlated to the total land use statistics of each municipality. According to the results which it is not relevant to total land use, the relationship between the amount of land use in each county and restoration varies depending on the category.

Table 4- The results of the T-test for the relationship between the percentage of total land use and total restored outcome for each category

Classification	P-value
Forest	0.13
Farmland	0.39
Waterbody	0.035
Urban area	0.031

In addition, the statistics of total land use classification in Sweden was compared with the results of the overall restoration outcomes for all municipalities in Västra Götalands shown in section 4.1 to evaluate whether the findings of restoration outcomes from this study can be applied to the rest of Sweden. Section 10.4 of the Appendix contains information on the data of Sweden’s total land use classification related to 2010 that were obtained from SCB. The statistics of overall Sweden’s land use classification are approximately identical with total restoration outcomes and each classification in section 4.1. This analysis indicates that the overall restoration results of Västra Götalands could be applicable to the rest of Sweden. However, it is crucial to consider that for each individual case, this finding can not be applicable due to the land use categorization and restoration outcomes may vary based on where the polygon is located.

The reason of the similar ratios may be that the County Administrative Board and Swedish Environmental Protection Agency are both components of the system of land use planning in Sweden. These organizations provide the guidelines that municipalities have to follow in their plan-making process of land use (OECD, 2017). However, the official report related to these guidelines and the decisions of how the restoration is carried out, are not accessible. This information may be discussed during the supervision and investigation that happened for restoration aggregate quarries to receive the permit from the County Administrative Board.

5.3- Are there any variations between a highly populated and a sparsely populated location in the rehabilitation of the closed quarry?

In response to a study question related to differences in restoration plans between highly populated and less-populated municipalities, they were considered to analyze the utilization of closed quarry land. It was hypothesized that a restoration source located in a highly populated city context may have completely different conditions than a source located in a sparsely populated area. A site close to the city may often have a greater opportunity to use for recreation, construction of homes/industries, and other social arrangements designed for human activities. A site located in sparsely populated areas may be better suited for nature conservation, forestry, or agriculture. The results reveal that although most populated cities have more aggregate quarries in comparison with less populated, the relationship between each category and population density is not statistically different. The reason for increasing the number of quarries in the populated area is that aggregates of products are more required for these areas. However, it seems that the restoration plans followed the same procedures for rehabilitation by only considering the natural characteristics of the site in Västra Götalands.

5.4- Uncertainty related to land use and biodiversity

This study focuses on the land use of abandoned quarries and as a result of the restrictions mentioned in section 3.1, several factors may have a minor but possible influence on the outcomes of the land categorization that are more suited to enhance. It is important to boost the available information related to polygons such as name, longitude, and latitude in the maps to consider the exact location and area for the classification because in some cases the information was not matched. In addition, the time period related to closing and compeleting restoration of most quarries was not mentioned to easily analyze the time possessed for rehabilitation until the current situation. Although in the long term, the restoration environment may be changed. In some cases, the satellite images were taken in periods which analysis of the maps was challenging such as autumn and winter. The errors during measurement will increase in these cases and boosting the quality of satellite images could help to analyze with more detail. It would be suitable to alter the image to the days that the landscape is easily understood in remote sensing. For analyzing the restoration and the life cycle is necessary to mention that.

Several limitations can be considered for biodiversity which are relevant to land use such as the type of forest, agricultural land, and species of either animals or vegetation that are lived in the different types of restored sites since this exsited information can be potential to classify the restoration in more detail. In addition, the biodiversity concepts such as the diversity of organisms (populations of animals) (Sandler & Rashford, 2018), species richness, genetics, and the diverse taxonomy and communities that living in the area are impossible to identify in remote sensing. For vegetation, it can impact the biomass of species and the data could not be accurate. These kinds of indicators are not obvious in the land cover classification; therefore other methods need to be applied to enhance the biodiversity classification in the quarry’s restoration.

6- Conclusion

Aggregates products are the world's largest non-energy mining industry, which is the most extracted materials after water. The most common source of aggregates comes from quarries which need the transformation of substantial land areas, ideally close to urban hubs. Activities that occurred in the quarry are a significant example of a human intervention in nature that has a noticeable impact on the environment. This creates several local issues both while the quarry is operating and after it stops producing which disturbed the balance in nature. These secondary effects can impact land use, air, water, and soil quality which these negative issues have a connection with biodiversity loss. Restoration (either naturally occurring or artificially) of the quarry after the operation is required to help the mitigation of the consequences of mining and quarrying in the long run, and the possibility of consequences might persist if they are not repaired. The primary goal of it is the transformation of neglected and deteriorated sites into ones that are repaired and sustain natural ecosystems which would ultimately enhance the ecosystem.

For quarry remediation, there is guidance accessible, but information on how successful recovery is carried out, whether plans are followed, and if further consequences arise is difficult to find outside of individual cases. Understanding a quarry's end of life is essential as the sector starts to apply more life cycle thinking to environmental problems. The study results reveal that the restoration plans were considered properly in Sweden which overall, 96 percent of outcomes were converted to green areas either forest or vegetation, farmland and water bodies having benefits for the environment. The main potential restoration design is allocated to the Forest including 69 percent of the total restoration outcome. The following outcomes are related to Farmland (13 %), Vegetation (6%), Mixed vegetation (5%), and Water bodies (3%) respectively. The rest proportions are Urban area and Bare land occupying 4 percent of the total outcome (Urban area: 3% and Bareland: 1%).

It is important to mention that although the number of closed quarries more or less is higher in populated areas in comparison with less populated areas, the observation illustrates that the relationship between the total measured restoration outcome and the population density is independent. It seems that each individual follows the same procedure for the rehabilitation of aggregate quarries which are not relevant to total land use and the relationship between the amount of land use in each county and restoration varies.

7- Recommendation for the Future

Based on the findings of this study, my recommendations for the quarry’s restoration and materials are:

1. **Ehnace the data for finding the closed quarries:** Because of the lack of permits, the exact location and restoration plan of each examined quarry was uncertain in the mentioned polygons. It would be better to update the prior information related to the quarry to find and examine the restoration outcomes properly since in this study the whole polygons were measured, whether some areas were not aggregate quarries.
2. **Update the number of polygons related to the quarry closure in the archive file:** Since the two databases were selected to find the location of closed quarries, some polygons were not mentioned in the archive file that The County Administrative Board provided for this study existing in the historical maps. It is recommended to update the file.
3. **Boost the environmental situation of aggregate quarries:** Nowadays anthropogenic activities constantly alter the environmental situation in the world which leads to several concerning effects on the ecosystem and also humans. The aggregate industry is one of them. Under the right circumstances such as considering natural, and social features the environmental situation can be improved properly. As a result of the restoration, the area has undergone a significant alteration and new species have been discovered there. The appropriate restoration plan plays a crucial role in the environment since both active and inactive quarries have been found to be

potential habitats for a variety of species either microorganisms or macroorganisms. The restoration plan should be paid attention to significantly in the permits; although nowadays this section is considered in the quarry permits in a better way in comparison with the archived permits. Updating the monitoring can enhance the restoration and minimize the possible problems which enhance sustainability.

4. **Restore the bare land in the future:** Although the proportion of considered bare land in the case studies was negligible, it is better to improve the environmental situation of these areas, especially the polygon called Angered 2:20 which is the most covered by bare land. Figure 14 shows the location of this abandoned quarry. By analyzing the surrounding area and its natural characteristics, it can be converted to forest and vegetation. It is important to mention that the possibility of areas for restoring should be assessed before restoration. Moreover, various species are attracted to sand and gravel which by creating a sandy pile (south-facing) can benefit many species either plants or animals can live there such as Sand Martin.

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10- Appendix

The information related to measured polygons and the data on land cover classification is shown in the following table:

10. 1- Appendix 1

Table 5- The information of closed aggregate quarries in nine municipalities and total measured area

Name of municipality	Registered polygon	Quarry Name	Type	Total area (ha)	Total Outcome (ha)
Gothenburg	Hjällbo 117:1	Gatukontoret	Natural gravel[2]	12.32	12.6
	Kockhed 1:5	Olof Carlsson	Natural gravel	20.6	20.56
	Maggered 1:3	Per Persson	Natural gravel	53.59	53.53
	Angered 7:195	Rakel Erenmalm	Natural gravel	19.5	19.79
	Angered 7:187	Gunnilse Sand AB	Natural gravel	0.2	0.192
	Skogome 1:4	Stig Anderssons Försäljnings AB	Natural gravel	31.24	31.22
	Angered 2:20	Lastbilsåkarnas ordercentral	Natural gravel	2.7	2.483
	Angered 2:22	Janssons Sand AB	Natural gravel	1.3	1.216
	Backer 1:3	Kungälvs Lastbilscentral	Natural gravel	7.7	7.7
	Angered Eriksgård 4:38	Stig Hallgren, Evert Hallgren	Natural gravel	11.6	11.6
	Kärra 11:8	AB Skånska Cementgjuteriet	Natural gravel	15.2	15
	Bergum 1:7	Janssons Sand AB	Natural gravel	50.94	50.87
	Djupedal 2:3	Gunnilse Sand AB	Natural gravel	38.5	38.5
	Rönning 1:3	Bollebygds Sand AB	Natural gravel	24.01	23.73
	Backa 766:746, 766:739, 766:527	Stig Andersson	Natural gravel	4.26	4.1315
	Tuve 22:1	Arthur Andersson	Natural gravel	0.82	0.82
	Gökskulla 1:20, 1;25	Vest Kross AB	Natural gravel	119.75	119.82
	Gårdsten 37:1	Unknown	Natural gravel	7.79	7.817
	Angered 62:1	Göteborgs Sandaktiebolag	Natural gravel	255.96	250.38
Mölndals	Lindome 8:8	Gatukontoret Mölndals kommun	Natural gravel	2.5	2.46

[2] Naturally sorted soils that are dominated by sand, gravel and stone and are found in deposits, mainly ridges, formed in connection with the melting of ice sheets (SGU, 2015).

	Dvärred 3:7	Alvar Augustsson	Natural gravel	41.8	41.56
	Hällesåker 1:2	Bror Karlsson	Natural gravel	0.2	0.2
	Inseros 1:2	John & Ivan Olsson & Larsson	Natural gravel	19.68	19.95
	Ranntorp 2:2	Statens Vägverk	Rock[3]	3.16	3.19
	Strekered 1:5	Sven Ivarsson	Natural gravel	8.16	8
	Ålgårdsbacka 1:12	Johan Johansson AB	Natural gravel	0.94	0.94
	Backen 2:22	Gustav Eklund	Unknown	2.45	2.45
	Torkelsbohög 1:28	Thore och Tage Sivertoft och Karlsson	Natural gravel	74.52	74.22
	Skräppholmen 2:2	LBC i Kungsbacka ek för	Natural gravel	50.45	50.07
	Lindome 14:1	Yngve Persson	Natural gravel	7.56	7.48
	Inseros 1:5	Mölndals Lastbilscentral	Unknown	4.41	4.46
Kungälv	Ryr 1:1	Ingemar Karlsson	Natural gravel	34.7	34.7
	Rombacka 1:2, 1:6	Kungälvs Lastbilscentral	Natural gravel	17.8	17.8
	Signehög 1:39	AB Severinsson	Rock	41.3	41.3
	Barkeröd 1:1	Vilhelm Karlsson	Natural gravel	34.34	34.34
	Björkebacka 1:1	Vägförvaltningen i Göteborgs och Bohus län	Natural gravel	129.7	129.7
	Dösebacka 2:8	Saknas	Natural gravel	6.94	6.94
	Håffrekullen 1:2	Uno Carlsson	Natural gravel	1.6	1.61
	Livelycke 1:4	Sven Lundgren	Natural gravel	17.3	17.3
	Sanner 1:4	Eskil Petersson	Natural gravel	4.02	3.8
	Kållen 1:2	Kungälvs Lastbilscentral	Natural gravel	28.3	28.037
	Stenhålt 1:3	Erik Samuelsson	Natural gravel	0.67	0.66
Åmål	Bocklarud 1:4, 1:5	Tösse Gräv & Transport AB	Natural gravel	219.6	218.6
	Grättve 2:1	Tösse Gräv & Transport AB	Natural gravel	97.1	97.09
	Kallskog 1:3	Stora Skog Dalslandsskog	Natural gravel	12.3	12.27
	Kilane 4:32	Råsjö Kross AB	Rock	14.9	14.68
	Salebol 3:1	Calderys Nordic AB	Rock	315.7	315.6

[3] A quarry is a place where rock breaks down into gravel and smaller stones.

	Strömsberg 1:12	Tösse Gräv & Transport AB	Natural gravel	297.9	292.6
	Vallsjön 1:3	Tösse Gräv & Transport AB	Natural gravel	65	42.86
	Krusebol 1:4	S Melcherson dödsbo Väg & Schakt	Natural gravel	29.23	29.2
	Persbyn 1:28	Civert Jansson		4.2	4.23
	Kilane 4:30	Calderys Nordic AB	Rock	7.5	7.45
	Hensbyn 2:1	Tösse Gräv & Transport AB	Rock	194.13	194.41
	Fröskogs-byn 1:1	Calderys Nordic AB, Tösse Gräv & Transport AB	Rock, Natural gravel	374.8	374.45
	Kilane 4:42	Dalbo Kvartsit AB	Rock	14.7	14.62
	Vingnäs 1:24	Calderys Nordic AB	Rock	292	291.82
	Fröskogs stom 1:56	Säffle skogsförvaltning Stora Skog	Natural gravel	880.4	879.93
	Stora bodane 1:10	Vägverket	Natural gravel	33.3	33.29
Karlsborg	Dampegården 1:1	Ingemar Karlsson,Grävfirma Jan Lundblad AB	Natural gravel	143.3	143.27
	Forsvik 5:20	Kerstin Bjaröy	Natural gravel	305.1	304.79
	Nolkärr 1:51	Per-Olof Åkerstedt,Grävfirma Jan Lundblad AB	Natural gravel	59.32	58.72
	Svanvik 1:403	Fortifikationsverket	Natural gravel	784.8	784.47
	Sköverud 1:52	Grävfirma Jan Lundblad AB	Natural gravel	280.6	280.39
	Prästebolet 2:5	Undenäs Rör & Schakt	Natural gravel	1586.7	1586.05
	Rosendala 5:1	Grus & Entreprenad AB	Natural gravel	401.24	400.51
	Stjärnvik 1:11	Hans Björkman	Natural gravel	295.7	295.93
Vårgårda	Bänatorp 5:4	Gustaf Gustafsson	Natural gravel	49.38	50.13
	Bänatorp 1:4	Oskar Solberg	Natural gravel	6.6	6.57
	Bäne 4:3, 8:2, 4:2	Åkericentralen i Alingsås e.f	Natural gravel	2.53	2.49
	Fötene 6:6	LBC Vårgårda AB	Natural gravel	3.3	3.3
	Hol 7:4, 7:16	Sture Andersson	Natural gravel	10.15	9.76
	Hägrunga 1:2	LBC Vårgårda AB	Natural gravel	31.78	30.668

	Hökared 1:4	LBC Vårgårda AB	Natural gravel	28.1	27.81
	Kilatorp 2:1	LBC i Herrljunga ek för, Sven-Erik Larsson	Natural gravel, Rock	100.11	100.1
	Riddartorp 1:2	Vägverket	Natural gravel	32.65	32.35
	Svantetorp 1:1	Göte Josefsson	Natural gravel	7	6.89
	Tumbergs-galstad 4:6	Rojo Grus AB	Natural gravel	16.7	16.91
	Ödegärdet 1:3	Vägverket	Natural gravel	34.9	34.77
	Mo Östergården 2:8	Marie Härentorp	Rock	19.1	18.83
	Bäne 4:8	Saknas	Natural gravel	64.58	64.4
	Hedegården 1:1	Gunnar Perssons Grävmaskins AB	Natural gravel Natural gravel	71.7	71.86
	Hol 14:8	NCC Industry AB	Natural gravel	181.81	181.02
	Häradsvad 1:2	Dan Karlsson	Natural gravel	54.5	54.68
	Hökared 1:12	Leif Adolfsson	Natural gravel	41.98	42.26
	Jonstorp 1:3	AB Bresons Grävmaskiner	Natural gravel	7.4	7.32
	Pinnegården 1:1	Harry Andersson	Natural gravel	30.5	29.84
	Riddartorp 1:23	JesperSwedberg & Jan Arvidsson	Natural gravel	30.83	30.74
	Tumbergs-Galstad 4:1	Vårgårda Bergkross KB	Natural gravel	18.3	18.19
Tidaholm	Bondestorp 1:5	Roland Larsson, Kent Karlsson	Natural gravel	197.7	197.35
	Bosarp 8:2	Tidaholms Grus Entreprenad AB	Natural gravel	34.7	34.67
	Brissmestorp 1:1	Kurt Johansson Dala Grustag	Natural gravel	86.3	86.1
	Dimbo 17:2	LBC i Tidaholm	Natural gravel	94.1	94.13
	Lilla Gälleberg 1:11	Billy Sandström, Sture Käck	Natural gravel	15.61	15.43
	Havsjöberg 1:1	Ingemar Karlsson	Natural gravel	130	129.41
	Hjulåsen 1:21	Anders Adolfsson	Natural gravel	49.7	49.44
	Härja 2:1	Holgerssons Åkeri AB	Natural gravel	28.1	28.02
	Kymbo 2:4	Anders Andersson	Natural gravel	55.3	55.07
	Tidaholm suntak 2:22	Saknas	Natural gravel	346.4	345.78
	Otterstorp 4:1	Sand & Grus i Folkabo AB	Natural gravel	64.72	64.67
	Sjogerdala 1:3	Habo Betong AB, NCC Industry AB	Natural gravel	49.2	48.85

	Stora Gälleberg 1:39	Gustav Karlsson	Natural gravel	29.7	29.49
	Knipekärret 1:2	Holgerssons Åkeri AB	Natural gravel	84.8	84.33
Hjo	Hjo Svebråta 1:45	AB Mofalla Betongindustri	Natural gravel	8.3	8.01
	Hjo Gunnarstorp 1:24	Skanska Industrial Solutions AB	Natural gravel	5.3	5.18
	Mofalla-Torp 1:11	Galentos Bilservice	Natural gravel	22.1	22.1
	Hjo Sörberga 1:2	Saknas	Natural gravel	6.9	6.88
	Nedergraven 1:2	TJ Gräv AB, Lars-Erik Rothz`n	Natural gravel	36.5	36.59
	Hjo Stakahemmet 1:3	Roland Larsson	Natural gravel	30.9	30.66
	Bjärg 1:13, Svekhult 1:3, 1:4	AB Mofalla Betongindustri	Natural gravel	231.25	231.08
	Hjo Svekhult 1:8	Skanska Industrial Solutions AB	Natural gravel	7.1	7.07
Herrljunga	Vreta Bergsgården 2:25	LBC Vårgårda AB	Natrual gravel	16.6	16.38
	Herrljunga 7:28	LBC Vårgårda AB	Natural gravel	189.04	188.56
	Hult 1:10	Fristads Express AB	Natural gravel	545.97	545.3
	Hägdene 4:2	LBC i Borås AB	Natural gravel	15.8	16.04
	Katebo 1:3	Gunhild Sundh	Natural gravel	17.3	17.14
	Katebo 1:12	Leif Paulsson	Natural gravel	16.9	16.91
	Larstorp 1:5	Herrljunga Grus AB	Natural gravel	15.4	15.38
	Murum 1:2	Knut Larsson	Natural gravel	44.03	44.16
	Mörlanda 2:2	LBC Vårgårda AB	Natural gravel	100.3	99.9
	Sämsholm 2:1	Strängbetong	Natural gravel	345.6	345.35
	Torpåkra Lilleg. 2:2	Vägverket	Natural gravel	47.3	46.94
	Tostared Uppegården 1:6	Kent Lennartsson	Natural gravel	70.6	70.24
	Fölene 7:25	LBC Vårgårda AB	Natural gravel	32.68	32.62
	Åsen 1:19	Agne Frost	Natural gravel	21.8	21.26
	Åsen 2:5	Herrljunga kommun	Natural gravel	23.16	23.04
	Kyrkhult 1:4	Kent Lennartsson	Rock	10.6	10.6
	Ölanda 25:1	LBC Vårgårda AB	Natural gravel	116.93	116.4
	Jällby 5:3	Fredrik Svensson	Natural gravel	11.24	11.14
	Mollaryd 5:9	LBC i Borås AB	Natural gravel	9.7	9.62

10. 2- Appendix 2

Table 6- The measurement data of land cover classification in nine municipalities

Municipality	**Registered polygon**	**Forest (ha)**	**Vegetation (ha)**	**Mixed vegetation (ha)**	**Farm Land (ha)**	**Water bodies (ha)**	**Bare Land (ha)**	**Urban (ha)**
Gothenburg	Hjällbo 117:1	12.32	5.5	1.2	3.1	1.6	0	1.2
	Kockhed 1:5	20.6	7.95	1.5	0	9.8	0	1.31
	Maggered 1:3	53.59	43.5	6.6	0	1.9	1.4	0.13
	Angered 7:195	19.5	17.95	0	0.56	0	0.53	0.75
	Angered 7:187	0.2	0.19	0	0	0	0	0.002
	Skogome 1:4	31.24	26.95	1.14	2.5	0	0	0.63
	Angered 2:20	2.7	0.32	0.49	0	0	1.6	0.073
	Angered 2:22	1.3	0	0	1.2	0	0	0.016
	Backer 1:3	7.7	1.52	2.59	0	2.68	0	0.91
	Angered Eriksgård 4:38	11.6	10.57	0.91	0	0	0	0.12
	Kärra 11:8	15.2	5.8	0	0	6.33	1.9	0.97
	Bergum 1:7	50.94	46.34	3.28	0.76	0	0.49	0
	Djupedal 2:3	38.5	31	0	0	6.3	0	1.2
	Rönning 1:3	24.01	14.4	1.9	0	5.17	0.85	0.99
	Backa 766:746, 766:739, 766:527	4.26	0	0	1.124	0	0.0175	1.9
	Tuve 22:1	0.82	0.57	0	0	0	0	0.25
	Gökskulla 1:20, 1;25	119.75	104.5	4.2	0	3.4	3.6	4.12
	Gårdsten 37:1	7.79	5.67	0.097	0.76	0	0	1.29
	Angered 62:1	255.96	196.47	17.39	1.22	3.9	11.11	15.35
Mölndals	Lindome 8:8	2.5	0.46	0.5	1.28	0	0	0.22
	Dvärred 3:7	41.8	26.4	4.64	5.16	4.4	0	0.96
	Hällesåker 1:2	0.2	0	0	0.16	0	0	0.04
	Inseros 1:2	19.68	11.12	0	8.3	0	0	0.53
	Ranntorp 2:2	3.16	0.43	0	0.85	1.2	0	0.71

	Strekered 1:5	8.16	2.76	0	1.67	2.62	0	0.95
	Ålgårdsbacka 1:12	0.94	0.94	0	0	0	0	0
	Backen 2:22	2.45	1.69	0	0.05	0	0	0.71
	Torkelsbohög 1:28	74.52	48.8	14.87	0	9.7	0.15	0.7
	Skräppholmen 2:2	50.45	38.29	0.4	0.03	0	10.8	0.55
	Lindome 14:1	7.56	2.78	0.89	3.28	0.14	0	0.39
	Inseros 1:5	4.41	3.54	0.46	0	0	0	0.46
Kungälv	Ryr 1:1	34.7	24.69	7.95	0	0	0	0.16
	Rombacka 1:2, 1:6	17.8	13.41	4.06	0	0	0	0.33
	Signehög 1:39	41.3	27.62	0	0	12.53	0.36	0.79
	Barkeröd 1:1	34.34	19.58	3.26	6.56	3.8	0	1.14
	Björkebacka 1:1	129.74	106.7	2.69	8.1	10.57	0	0.2
	Dösebacka 2:8	6.94	5.68	0	0	0	0	0
	Håffrekullen 1:2	1.6	0	0	0	0.51	0	1.1
	Livelycke 1:4	17.3	8.46	2.3	0	5.9	0	0.64
	Sanner 1:4	4.02	1.95	0.78	0.65	0	0	0.42
	Kållen 1:2	28.3	21.3	0.79	0	5.3	0	0.647
	Stenhålt 1:3	0.67	0.12	0	0	0	0	0.54
Åmål	Bocklarud 1:4, 1:5	219.63	179.1	10.8	0	0	25.8	1.67
	Grättve 2:1	97.1	2	38.341	53.5	0	0.69	2.55
	Kallskog 1:3	12.3	9.44	0	0	0	0	1.63
	Kilane 4:32	14.9	14	0	0	0	0	0.51
	Salebol 3:1	315.7	261.6	0	13.5	0	37.6	2.9
	Strömsberg 1:12	297.9	165.9	0	0	113.7	0	5.3
	Vallsjön 1:3	65	23.98	8.35	0	6.7	0	1.13
	Krusebol 1:4	29.23	18.09	0	5.4	3.61	0	2.1
	Persbyn 1:28	4.2	4.1	0	0	0	0	0.13

	Kilane 4:30	7.5	5.25	0	0	0	0	2.2
	Hensbyn 2:1	194.13	128.98	0	2.92	52.11	0	2.38
	Fröskogs-byn 1:1	374.8	310.82	3.76	41.8	0	12.03	5.93
	Kilane 4:42	14.7	3.9	0	0	0	0	10
	Vingnäs 1:24	292	232.02	5.25	26.63	15.26	1.14	11.52
	Fröskogs stom 1:56	880.4	766.33	15.71	3.3	11.85	58.65	8.69
	Stora bodane 1:10	33.3	32.54	0	0	0	0	0.75
Karlsborg	Dampegården 1:1	143.3	125.45	0.77	1.72	9.36	0	2.6
	Forsvik 5:20	305.1	253.71	19.53	15.63	0	13	2.48
	Nolkärr 1:51	59.32	22	0.32	4.72	26.43	0	2.05
	Svanvik 1:403	784.8	618.2	60.09	23.59	0.61	5.39	63.44
	Skäverud 1:52	280.6	66.53	13.06	34.67	133.46	27.03	5.64
	Prästebolet 2:5	1586.7	1248.01	67.04	45.29	195.27	6.74	21.53
	Rosendala 5:1	401.24	282.2	57.98	29.81	20.6	4.31	5.61
	Stjärnvik 1:11	295.7	119.57	4.3	21.4	130.1	5.99	12.77
Vårgårda	Bänatorp 5:4	49.38	25.94	5.92	2.42	13.3	0	2.08
	Bänatorp 1:4	6.6	4.41	0	2.1	0	0	0.06
	Bäne 4:3, 8:2, 4:2	2.53	1.1	0	1.1	0.29	0	0
	Fötene 6:6	3.3	3.2	0	0	0	0	0.1
	Hol 7:4, 7:16	10.15	0.95	0	0	7.36	0	1.45
	Hägrunga 1:2	31.78	17.17	3.43	4.59	2.6	0.008	2.56
	Hökared 1:4	28.1	17.61	0.13	0.97	8.06	0	1.04
	Kilatorp 2:1	100.11	49.39	11.96	21.14	5.69	10	1.78
	Riddartorp 1:2	32.65	23.17	0.79	3.26	4.69	0	0.44
	Svantetorp 1:1	7	4.31	2.2	0.23	0	0	0.15
	Tumbergs-galstad 4:6	16.7	2.22	3.18	1.53	2.81	0	0.8

	Ödegärdet 1:3	34.9	10.57	8.41	2	11.97	0	1.82
	Mo Östergården 2:8	19.1	13.58	0.34	0	4.33	0	0.58
	Bäne 4:8	64.58	31.3	1.72	2.41	21.23	1.99	4.35
	Hedegården 1:1	71.7	58.88	2.56	0.82	7.5	0	1.98
	Hol 14:8	181.81	122.26	3.77	35.06	0	7.4	1.53
	Häradsvad 1:2	54.5	35.49	2.97	1.2	12.5	0	2.52
	Hökared 1:12	41.98	14.36	0.97	0	25.03	0	1.83
	Jonstorp 1:3	7.4	6.4	0.23	0.2	0	0	0.37
	Pinnegården 1:1	30.5	19.8	0.1	0	8.97	0	0.97
	Riddartorp 1:23	30.83	20.28	3.08	0	6.3	0	0.5
	Tumbergs-Galstad 4:1	18.3	3.38	0	1.97	12.03	0	0.81
Tidaholm	Bondestorp 1:5	197.7	139.8	13.7	6.6	26.03	1.88	5.09
	Bosarp 8:2	34.7	29.6	0.37	0	0	2.9	0
	Brissmestorp 1:1	86.3	27.74	2.98	6.97	42.69	0	1.86
	Dimbo 17:2	94.1	20.98	7.86	0.62	62.7	0.07	1.9
	Lilla Gälleberg 1:11	15.61	9.8	1.92	2.07	0.62	0.06	0.78
	Havsjöberg 1:1	130	96.57	6.22	7	3.98	10.28	3.73
	Hjulåsen 1:21	49.7	22.86	2.26	2.22	19.12	0	2.98
	Härja 2:1	28.1	4.8	5.3	2.81	14.06	0	1.05
	Kymbo 2:4	55.3	26.22	5.06	0.58	21.51	0	1.7
	Tidaholm suntak 2:22	346.4	178.35	26.54	10.66	120.1	0.97	9.16
	Otterstorp 4:1	64.72	37.72	9.92	3.22	12.69	0	1.12
	Sjogerdala 1:3	49.2	22.81	7.88	1.72	11.66	0	1.98
	Stora Gälleberg 1:39	29.7	16.87	5.2	3.26	2.9	0	1.26
	Knipekärret 1:2	84.8	68.34	4.22	0	9.29	0.09	1.8
Hjo	Hjo Svebråta 1:45	8.3	2.64	0	0	0	0	0.57
	Hjo Gunnarstorp	5.3	1.85	0	3.2	0	0	0.13

	1:24							
	Mofalla-Torp 1:11	22.1	19.3	2.5	0	0	0	0.25
	Hjo Sörberga 1:2	6.9	6.5	0	0.38	0	0	0
	Nedergraven 1:2	36.5	18.63	3.25	0	12.76	0	1.26
	Hjo Stakahemmet 1:3	30.9	26.4	1.71	1.56	0.53	0	0.33
	Bjärg 1:13, Svekhult 1:3, 1:4	231.25	102.62	16.98	6.28	87.38	0	5.82
	Hjo Svekhult 1:8	7.1	5.2	0	0.86	0	0	0.31
Herrljunga	Vreta Bergsgården 2:25	16.6	2.26	1.16	2.11	9.69	0.36	0.8
	Herrljunga 7:28	189.04	170.66	7.1	9.44	0	0	1.21
	Hult 1:10	545.97	428.54	42.53	19.23	18.7	31.6	4.7
	Hägdene 4:2	15.8	7.63	0	6.8	1.56	0	0.05
	Katebo 1:3	17.3	5.29	0.11	0	8.24	0	3.5
	Katebo 1:12	16.9	8.09	0.78	1.4	4.25	0	1.4
	Larstorp 1:5	15.4	2.12	0	0	12.44	0	0.82
	Murum 1:2	44.03	22.05	1.9	1.1	18.6	0	0.51
	Mörlanda 2:2	100.3	85.42	0.24	1.31	0	0	11.8
	Sämsholm 2:1	345.6	215.62	14.93	64.84	16.86	18.41	11.75
	Torpåkra Lilleg. 2:2	47.3	30.3	2.38	2.73	10.72	0.04	0.77
	Tostared Uppegården 1:6	70.6	45.6	8.34	1.32	5.13	1.2	3.15
	Fölene 7:25	32.68	1.79	5.2	1.98	23	0	0.65
	Åsen 1:19	21.8	5.79	0	0.08	14.05	0	1.15
	Åsen 2:5	23.16	7.86	1.46	0.17	11.72	0	1.38
	Kyrkhult 1:4	10.6	7.3	3.3	0	0	0	0
	Ölanda 25:1	116.93	79.69	9.37	5.98	19.83	0	1.53
	Jällby 5:3	11.24	3.77	3.33	0.12	3	0	0.92
	Mollaryd 5:9	9.7	0.2	0.26	3.46	4.97	0	0.73

10.3 – Appendix 3

Table 7- The percentage of total land use (SCB, 2023) and total restoration outcome of each category in nine municipalities

Kommun	Total Forest Land use (%)	Forest Restored outcome(%)	Total FarmLand Land use(%)	FarmLand Restored outcome(%)	Total Water bodies Land use (%)	Water bodies Restored outcome (%)	Total Urban Land use(%)	Urban Restored outcome(%)
Mölndals	50.8	64	5.95	8	43.05	5	20.11	3
Kungälv	45.88	73	22.49	12	1.6	0	11.07	2
Gothenburg	29.02	77	9.39	6	0.85	3	31.93	5
Karlsborg	75.43	71	9.05	13	1.55	2	4.89	3
Åmål	74.99	77	10.86	7	1.61	5	4.9	2
Vårgårda	62.75	58	21.21	18	90.56	2	5.75	3
Tidaholm	60.32	56	28.03	27	99.4	1	4.77	3
Hjo	53.24	53	36.05	29	0.94	0	5.76	2
Herrljunga	63.64	69	22.75	11	94.42	3	4.72	3

10.4- Appendix 4

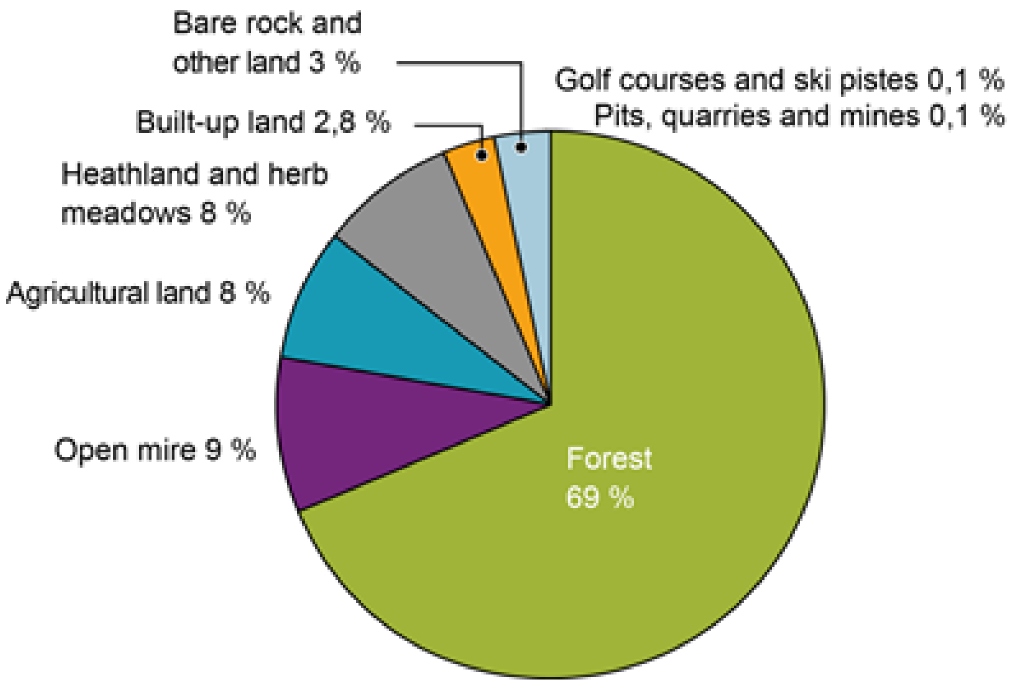

Figure 20- Total Landuse Classification in Sweden in 2010 (SCB,2013)