Extended Essay in Geography

May 2017

What is the environmental impact of limestone quarrying and processing on the Gesso valley?

Word Count: 3,993

Abstract

Globally there have been numerous cases of environmental degradation caused by limestone quarrying and processing: research has proven that such anthropogenic activities give rise to an exceedingly alkaline river water, vegetation growth inhibition and fungi and bacteria proliferation. The Gesso valley, in north-western Italy, has been a hub for mineral extractions for decades.

The waters of the river Gesso were monitored by determining pH and TDS values at 10 different sites along the river. Two spikes in the vicinity of a limestone refinery (9.25) and a cement plant (9.34) were detected, but the overall trend was a continuous increase downstream due to the local calcareous geology.

Given the large number of quarries in the Gesso valley, only one - near San Lorenzo - was selected because of the presence of a limestone refinery nearby. The survey encompassed the measurement of tree density and biodiversity, vegetation composition and cover, the presence of parasites and the height, girth and nearest neighbour of the dominant tree species - *Quercus pubescens*, as well as the assessment of abiotic factors such as wind, humidity and soil pH. As the distance from the quarry decreased, a significant decline in all these parameters was observed whilst the increasing presence of the parasite *Clematis vitalba* is also noteworthy. Whether the white colour on Oak leaves is caused by the alkaline dust or by the fungus *Erysiphe alphitoides* is unknown and would be a valid area for further research.

[Word Count: 238]

Acknowledgments

I would like to thank the Communications Director of the Maritime Alps Natural Park Giorgio Bernardi for granting me access to the outstanding library of the Head Office, whose books allowed me to identify the species I encountered in my fieldwork and compare my findings with more professional authors. I also want to thank the rangers for their help and encouragement, as well as the meteorological station Datameteo for lending me important instrumentation. This research, however, could not have been possible without the support of my family and in particular of my grandfather Guido Pasqua for his knowledge of vegetation, his witty advice and his enlightening spirit which tirelessly accompanied me throughout the arduous process of data collection.

Table of Contents

Introduction

Purpose & Significance

There has never been a publicly accessible investigation by an official state agency to assess the effects of limestone quarrying and processing on the Gesso valley (Italy). This research will mainly look at the impact on vegetation, whose health is a reliable indicator of the state of the local natural environment. Environmental degradation is also closely intertwined with human health, e.g. respiratory diseases, which is why this study is so significant.

Geographical Knowledge

Limestone quarrying and processing has been the subject of investigation since the 1910s (Pierce, 1909) due to the vast range of environmental impacts the dust has on the surrounding ecosystems. Limestone quarry dust and cement (kiln) dust are highly alkaline (Farmer, 1991, p. 2) and it has been proven that dust depositions affect soil and river pH, as well as fundamental processes in plants like **nutrient absorption**, **transpiration** and **photosynthesis** (Farmer, 1991, p. 1). This can lead to a shift in the type of habitat for the vegetal species in the area which may cause a change in the local vegetation health, diversity, density and composition. If vegetation health is compromised, it is likely that there will be repercussions on the environment, such as a damaged habitat for the **endemic fauna** (Zobrist, 2011, p. 1), increasing surface runoff and **soil erosion**, and a decreasing water table.

Water drains from cement works, like those in San Lorenzo and Borgo San Dalmazzo (figure 1.1 and 1.3), are **highly alkaline** and very **toxic to aquatic organisms** according to the City of Newark Public Works Department (2012, p. 1). The more diluted sediments, such as $CaCO_3$, the higher the pH will be. Davis and Stuart from the UK Environment Agency (2002, p. 3) noted that “winnable mineral reserves mostly extend beneath the water table and hence many workings are likely to encounter groundwater at some stage in their operation: consequently these operations have the potential to impact upon the quality, levels and flow regime of groundwater and surface water resources”, i.e. water pH. In a recent study by Gemma Warren on the river Bubble in the Yorkshire Dales National Park (2013, p. 19) it was found that the river water in the site closest to the limestone quarry had a pH of 11, with all the consequent implications for aquatic wildlife.

Figure 1.1: Water drain from the Borgo San Dalmazzo cement plant (Gambaro, 2016)

In southern India, Sree Rangasamy *et al.* (1973) studied the distribution of grasslands species around a cement plant: of the 54 species found in the area, only nine were able to grow close to the factory (Farmer, 1991, p. 4). These species all possessed small leaves, which were considered to enable them to reduce their dust loading. Limestone and cement dusts are in fact thought to physically **smother the leaves** and block the stomata as Farmer (1991, p. 1) noted.

As far as trees and woodlands are concerned, limestone and cement dusts may cause **physical injury to tree leaves and bark**, **reduced fruit setting**, a **general reduction in growth** and **pollen germination inhibition** (Farmer, 1991, p. 5). Any **disturbance to the soil**, like digging, grading or construction (e.g. in quarries), within the last 6-10 years can also negatively affect **tree health** (Zobrist, 2011, p. 2). Brandt and Rhoades (1972) observed a significant decrease in biodiversity and tree density, as well as a worsening tree health (Farmer, 1991, p. 5). Farmer (1991, pp. 5-7) suggests that limestone quarrying also seems to promote the **excessive growth of ivy** on quarry rock faces and tree barks damaging other species like lichens (Purvis, 1989), as well as an increase in the number of **fungi** and **bacteria** on trees (Manning, 1971) which may be a symptom of tree frailty (Zobrist, 2011, p. 2).

Wind speed, **humidity** and **rainfall** can influence dust accumulation on vegetation (Farmer, 1991, p. 2). Chamberlain (1967) proved that **deposition rates** are higher with high wind speeds and wet surfaces.

Geographical Context

The **Gesso Valley** is situated in the north west of Italy (figure 1.2), in the Cuneo province (Piedmont). It is crossed by the **Gesso river** and is aligned south west - north east for around 34 km (Google Earth, 2016). The valley is located in the **Maritime Alps**, the south-western part of the alpine mountain range: its climate is thus alpine, with temperatures reaching -10 ºC in Winter (ARPA, 2016).

Mineral extraction of marble began in the valley as early as 14 B.C. with the Roman invasion (online: Parco Alpi Marittime, 2014). Mineral extraction of limestone started near Andonno (figure 1.3) during WW2 due to the surging demand of construction materials, along with the extraction of shale near Madonna Bruna (Italcementi Group, 2007, pp. 4-5). The **cement plant** in the lower course of the Gesso (figure 1.3) was opened in 1947. The asset was acquired by a semi-private company, Italcementi, in 1955. Two other limestone quarries were opened in 1965 in Roaschia and later in **San Lorenzo**. Production of lime in the cement plant went on up to 1971, when the output of concrete began.

Location of Research

Figure 1.2: Location of the Gesso valley in the north west of Italy (adapted from Google Earth, V 7.1.5.1557, December 2015, Italy, 41° 36' 0.36'' N, 14° 38' 40.37'' E, elev. 994 m, eye alt. 1,571.9 km, Image Landsat, 2016 Google, US Dept of State Geographer, 2009 Geobasis - DE/BKG)

Figure 1.3: Gesso valley drainage basin - within the blue dashed line (adapted from Google Earth, V 7.1.5.1557, August 2014, Valle Gesso, Italy, 44° 14' 5.04'' N, 7° 24' 17.63'' E, elev. 941 m, eye alt. 31.29 km, 2016 Google). The main tributaries of the river Gesso are the Vermenagna and the torrent Colla; the Gesso is itself a tributary of the Stura.

Investigation

River Sampling & Methods of Investigation

The survey on the waters of the river Gesso (**systematical sampling**) was carried out on 17th July 2016 at 10 sites from source to mouth (figure 2.1, black-red dots). The **antecedent conditions** - sunny weather and high temperatures - are not thought to have affected the measured parameters.

Figure 2.1: Location of the sites (adapted from Google Earth, V 7.1.5.1557, August 2014, Valdieri, Italy, 44º 17' 2.71'' N, 7º 26' 30.71'' E, elev. 900 m, eye alt. 16.15 km, 2016 Google). The key is the same as that in figure 1.3. The red circles represent the river sites.

TDS (Total Diluted Solids[1]) and **pH** were measured with a pH meter (figure 2.2).

Figure 2.2 (Gambaro, 2016)

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[1] Measured in ppm (mg/l)

Figure 2.3: Access to the San Lorenzo quarry (Gambaro, 2016)

Site selection was biased due to health and safety concerns, but also access permissions issues - for example measurements of the vegetation around the cement plant on the valley floor could not be carried out because the area is highly restricted. These special permits are usually not granted to private citizens. Moreover, if one is not asked to leave the area, approaching quarries still requires great care because of the danger extractive activities pose to individuals. In some cases, the steep slopes made the survey more complicated, but this problem was overcome by tying ropes to trees or guardrails upstream in order to hold onto them (figure 2.3).

For these reasons, it was assessed that the most easily accessible quarry is the one near **San Lorenzo** (figure 2.1), where the effects of such activities are amplified by the **limestone refinery**. **Systematical sampling** was also chosen here, with 15 sites aligned west-east (figure 2.4, red stars). Each site is about 100 m apart from the other.

The survey was carried out on 24th July 2016. The **antecedent conditions** were dry and hot weather. The **aspect** of the quarry is south.

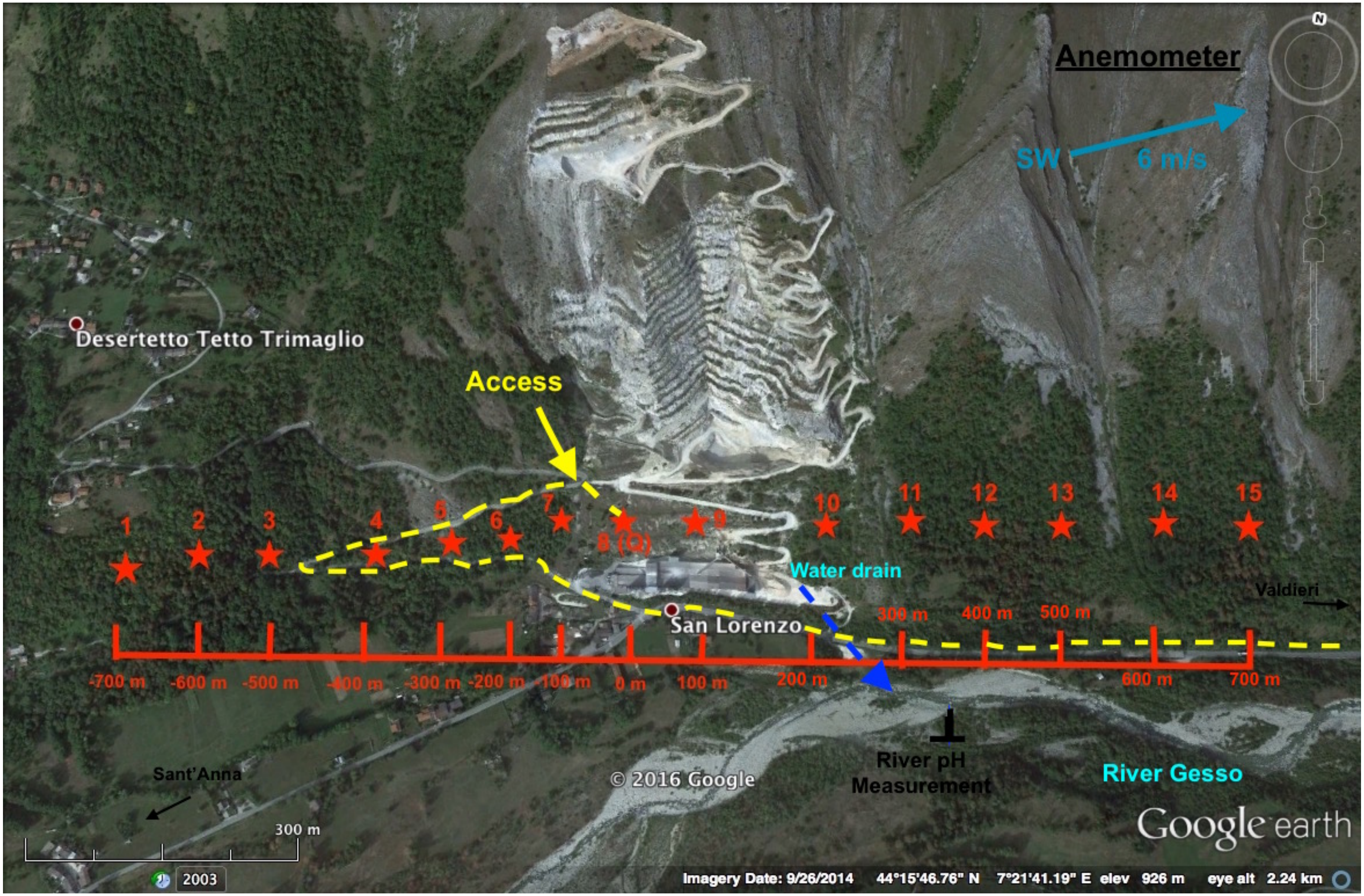

Figure 2.4: San Lorenzo quarry and refinery (adapted from Google Earth, V 7.1.5.1557, August 2014, San Lorenzo, Italy, 44° 15' 46.76'' N, 7° 41' 21.19'' E, elev. 926 m, eye alt. 2.24 km). The map shows the location of 15 sites, represented as red stars ("Q" stands for "Quarry"); the red line below shows the distance from the quarry. The speed and direction of the wind was also measured with an anemometer (upper right).

The assessment of abiotic factors encompassed the measurement of **wind** (speed and direction), **humidity** and **soil pH**. Wind and humidity were measured with an anemometer and a hygrometer respectively. As suggested by NSW Agriculture (2000, p. 3), the soil pH was measured by digging 10 cm into the soil with a spade and moistening with distilled water; readings were then taken from this ‘solution’ with a pH meter.

Tree and herb species were recognised thanks to: *Trees of Britain and Europe* by Keith Rushforth (1999) for tree species, and *The Vegetation of the Ligurian and Maritime Alps* (*La Vegetazione delle Alpi Liguri e Marittime*) by Bruno Gallino and Giorgio Pallavicini (2002) for herb species.

After identifying the main shrub and herb species present in a selected area of 400 m^2 (20 m x 20 m), **vegetation cover** was calculated. The area occupied by each species was calculated with a tape measure by multiplying the ‘sides of the rectangle’. The **percentage cover** was then worked out by dividing this area by 400 x 100%.

$$D = 1 - \left(\frac{\sum n(n-1)}{N(N-1)} \right)$$

Figure 2.5: The formula for the Simpson’s Diversity Index (online: World Economic Forum, 2016), where D = diversity index, N = total number of organisms of all species found and *n* = number of individuals of a particular species

After recognising the tree species in the same selected area, the number of specimens of each species was counted. For the estimation of **tree density** (stems/ha), these values were multiplied by 25 and then summed up to obtain the number of stems per hectare (10,000 m^2). However, few somewhat rare species not present homogeneously were not added to the final count as not statistically significant. The counted trees were also used to determine the **tree biodiversity**, calculated with the **Simpson’s Diversity Index** (figure 2.5). It quantifies biodiversity by taking into account richness and evenness: the greater the biodiversity in an area, the higher the value of the index (Allott & Mindorff, 2014, p. 639).

Tree health was assessed by taking into account a range of different factors. The presence of **fungal fruiting bodies** or **plant parasites** (e.g. *Hedera helix* or *Clematis vitalba*) on tree bark may signal tree frailty (Zobrist, 2011, p. 2). The **foliage colour** as well as the the **pattern of foliage decline** (figure 3.7) are also key indicators of tree health, as they can reveal the presence of certain parasites, like insects or bacteria, as well as the impact of dust accumulation on leaves. Therefore, photos of leaves were taken at different distances from the quarry and compared; the number of trees affected by fungi and plant parasites were counted at each site.

Quercus pubescens - the **Downy Oak -** was chosen as the indicator of the forest health as it is the dominant species of the forest near San Lorenzo. 5 specimens per site were randomly selected. **Tree height** was calculated by using a tape measure and clinometer. Angle readings were taken around 5 metres away from the Oak trunk and one metre above the ground. The height was then worked out by using **trigonometry** and by adding one metre to the result, as expressed in the following equation:

$$\tan(\hat{A}) = \text{Opposite side} / \text{Adjacent side}$$

Tree girth and distance between the analysed tree and the nearest Downy Oak specimen (**nearest neighbour**) was found with a tape measure.

Two **statistical tests** were used to detect any correlation between the biotic and abiotic factors mentioned above and the distance from the quarry and refinery - the Pearson Product-moment correlation coefficient and the Spearman’s Rank correlation coefficient.

Data Presentation & Analysis

River Findings

The findings in figure 3.1 are not significant enough to claim that these workings negatively affect the waters of the valley. In fact, although there is indeed an increase in the river pH from 7.95 to 9.25 (67 to 92 ppm) at Site 2 (San Lorenzo quarry and refinery) and a spike in Site 9 (9.34) near the Borgo San Dalmazzo cement plant, these values are not significantly different from the other ones. The extractive activities near Sites 2, 4 and 6 do not seem to have any repercussion. Likewise, except small spikes near the refinery and the plant, we can observe an overall continuous increase downstream of both parameters.

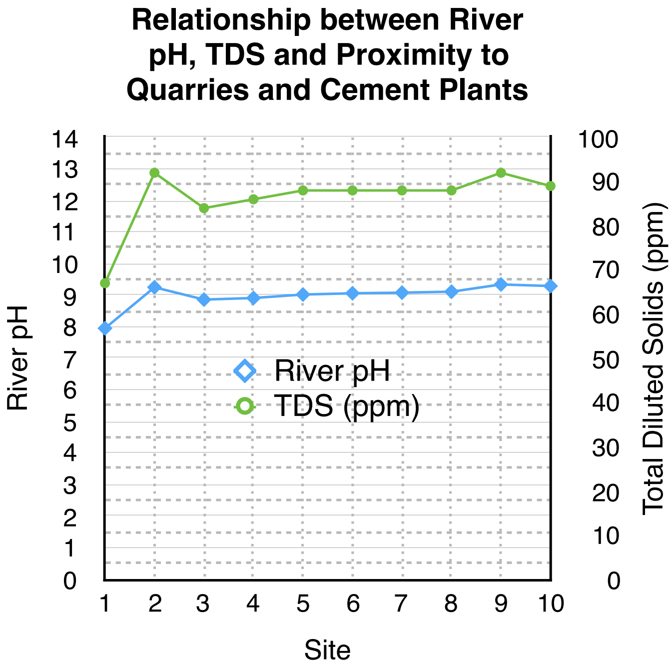

Figure 3.1: The graph shows the relationship between the river pH and TDS downstream; the sites are those in figure 8.

Such an increase is not caused by the quarry water drains, but by the rising velocity and thus erosion which corrodes sediments, as expressed by the Bradshaw Model (Nagle & Cooke, 2011, pp. 108-120-121). The diluted bedload is then transported through solution, influencing the river's water parameters. Indeed, most of the Gesso valley geology is composed of calcareous substrates, similar to limestone, apart from the upper valley made of "ancient crystalline basements" (Parc National du Mercantour & Parco Naturale delle Alpi Marittime, 2013, p. 72), which explains why the first pH value is not as high. Since limestone is alkaline, the ever-heightening corrosion and dilution make the river's water more and more alkaline.

The data in figure 3.2 reveal a huge decline in tree density in the proximity of the quarry (100-150 stems/ha). According to the Forestry Commission for England (online, 2016), normal forest densities range from 2,000 to 2,500 stems/ha, values that are only reached about 300-400 m away from the quarry on the western side (figure 2.4); on the eastern one the maximum density is 1,650 stems/ha. My values can thus be considered significant and fit my purposes despite the high inaccuracy of this measurement - as I assumed that the density of these 400 m^2 is the same in the whole hectare.

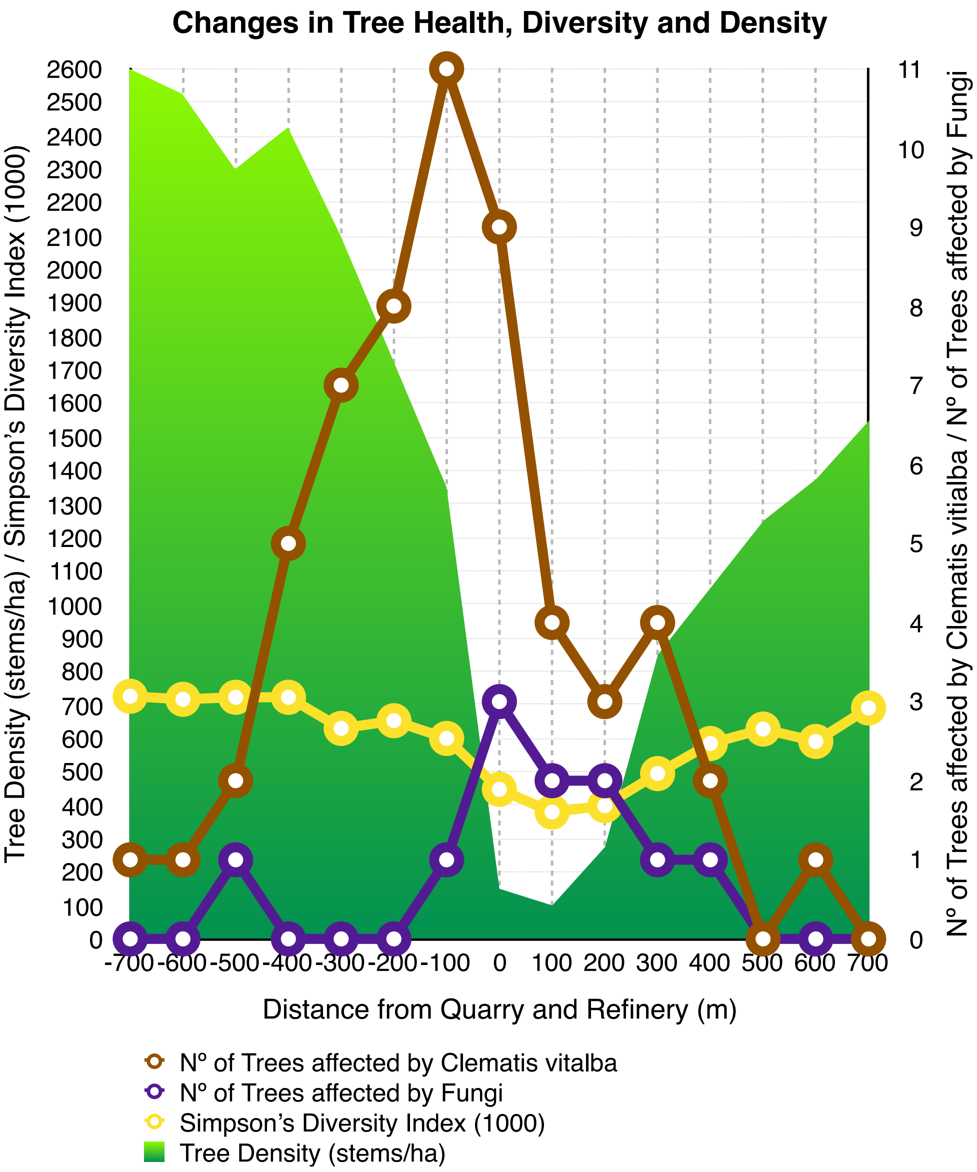

Figure 3.2: The graph shows the trends in tree density, biodiversity and health

The progressive thinning out of the forest is likely to be caused by limestone dust depositions produced by the refinery: as already mentioned, these particles can accumulate on leaves smothering them or promoting the growth of bacteria and fungi, and on the soil raising its pH. These phenomena do not allow trees and plants with large leaves to grow near the quarry, nor those whose optimum soil pH is slightly acidic like Beech Trees. Such environmental conditions have lowered tree biodiversity around the quarry: the Simpson's Diversity Index reaches 0.447 and 0.379 at 0 and 100 m respectively from the quarry compared to 0.725 at -700 m. The Spearman's Rank correlation coefficient for tree density is 0.653 and 0.652 for the Simpson's Index, which correspond to a 99% significance - the likelihood that these correlations occurred by chance is only 1%.

However, other humans activities have to be taken into account: clear cutting near quarries to facilitate the transport of material is not unusual, which could explain the extremely low densities. Moreover, at -400 m (Site 4) the density anomalously decreases by around 100 stems, probably due to the presence of a road (figure 2.4) and the consequent anthropogenic intervention.

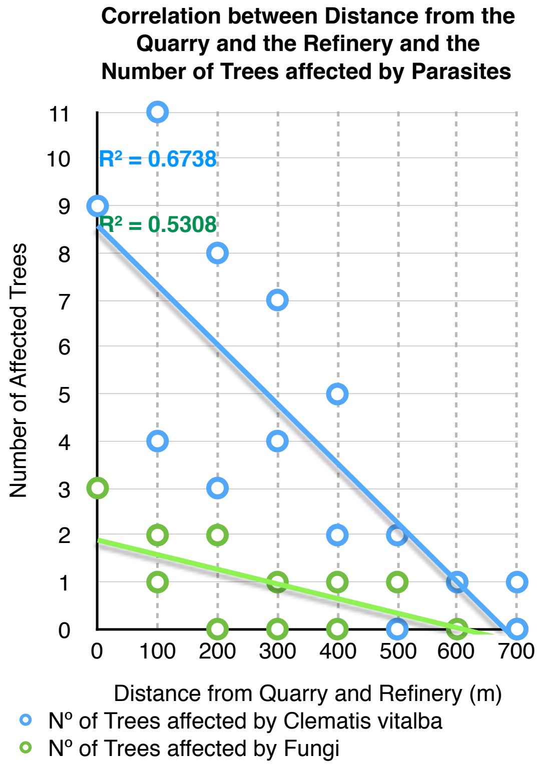

Figure 3.3

My findings also suggest that dust emissions may promote the excessive growth of fungi and plant parasites on tree bark, thus confirming Purvis's (1989) theory (Farmer, 1991, p. 7); nevertheless, the difference here is that the species is *Clematis vitalba* - not ivy. A surge in the number of trees affected by the parasite close to the quarry, especially at -100 m (11), can be easily discerned. These values tend to be slightly higher a bit farther from the quarry (e.g. 4 at 300 m, or only 9 at 0 m) simply because of greater tree densities. In addition, the number of trees affected by fungi[2] is generally higher on the eastern side. The significant presence of both organisms compound the impact of dust on lichens (Farmer, 1991, p. 7). Figure 3.3 shows the strong negative correlation between the distance and the number of trees affected by *Clematis vitalba* (r [3] = -0.821) together with the moderate negative correlation with the number of trees affected by fungi (r = -0.729). I considered 0.75 the boundary for a strong correlation (Buchanan *et al.*, 2012, p. 350).

Overall, the extractive activities seem to have a larger impact on the eastern side of the quarry (from 0 to 700 m). It has a lower tree density, lower tree biodiversity - it almost reaches 0.7 after 700 m compared to 400 m on the western side -, a higher number of trees affected by fungi, and a higher soil pH (figure 3.8). This might be brought about by a higher humidity (figure 3.4) because of the lesser distance from the river Gesso (figure 2.4) - and hence higher deposition rates (Chamberlain, 1967) -, and the wind direction. As shown in figure 2.4, it blows from south-west, i.e. exactly towards the eastern side of the quarry; the speed, 6 m/s, is high enough to raise dust (online: Windfinder, 2014). However, in order to establish whether dust deposition is here more substantial, deposition

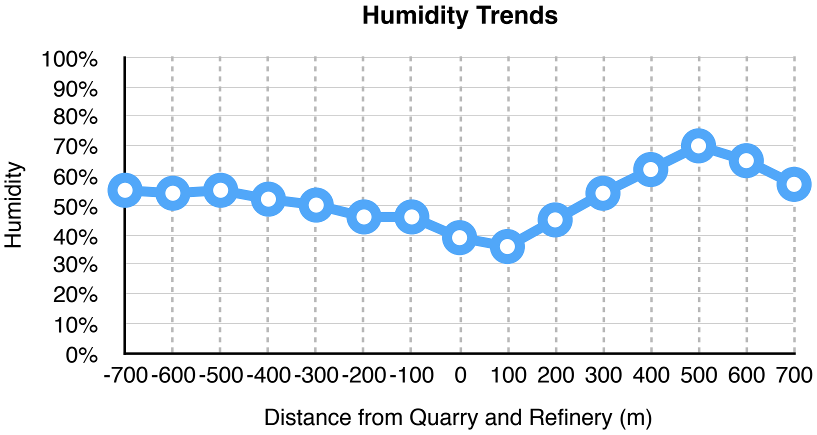

Figure 3.4: The graph confirms that humidity is higher on the eastern side of the forest (up to 70%). However, these values may be affected by plant transpiration, although no correlation between humidity and tree density was found.

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[2] It is important to note that in this instance ‘fungi’ refers to ‘fungal fruiting bodies’ and not species of fungi that cause diseases like the powdery mildew.

[3] Pearson Product-moment Correlation Coefficient

rates should be worked out with a frisbee type gauge (figure 3.5) as suggested by the ESG[4] (online, 2016).

Figure 3.5: Frisbee type gauge (online: DustScan Ltd, 2016)

The investigation on *Quercus pubescens* follows. Figure 3.6 shows the trends in the average height, girth and distance to the nearest neighbour with standard deviations. As Farmer (1991, p. 5) noted, limestone dust inhibits growth in trees. That is why the average Downy Oak only reaches barely more than two meters in height with a girth of around 0.2 m close to the quarry. Indeed, only 100 m westwards we can observe a five-fold increase in tree height and girths twice as large. According to Pasta *et al.* (2016, p. 156), Downy Oaks can grow up to 30 m, height observed only 700 m away from the quarry. The maximum average girth detected is 1.98 m at -700 m. Near the quarry the average distance to the nearest neighbour is close to 20 m, values which then dramatically drop to less than five 100 m westwards. The coefficient obtained for average tree height is 0.638, therefore just out of the 99% significance boundary. For average girth

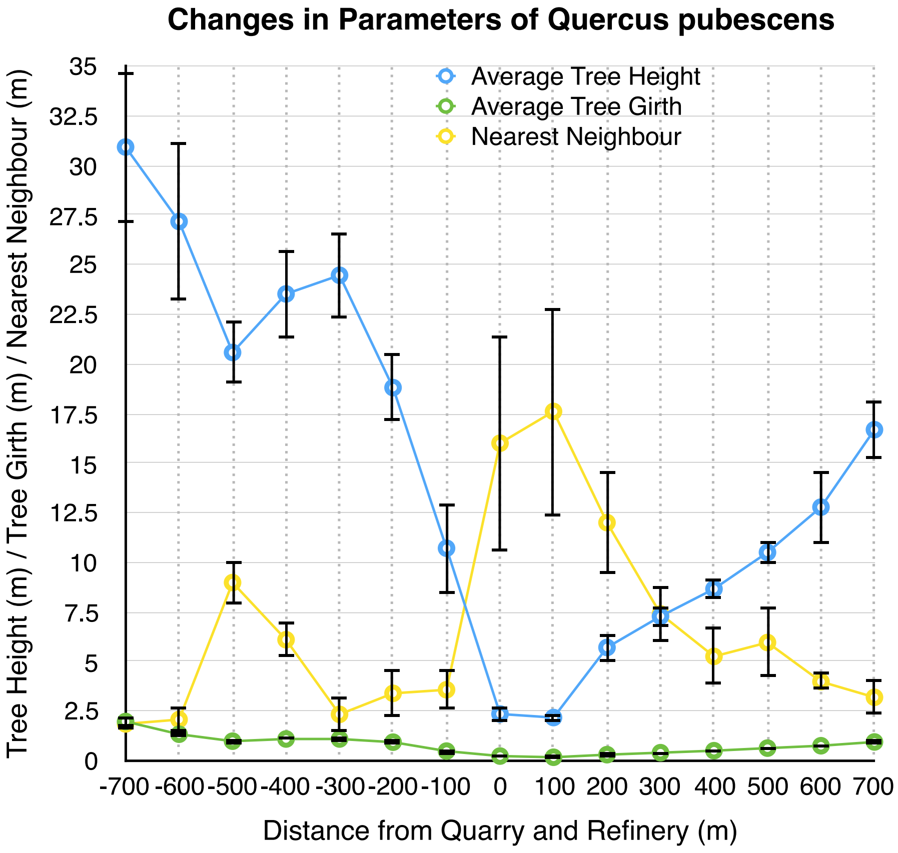

Figure 3.6

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[4] Environmental Scientifics Group

it is 0.729, well within the boundary. The negative correlation with nearest neighbour (-0.579) is instead 95% significant.

As per figure 3.2, between -400 and -500 m, all parameters slacken. Heights drop to 20 m, girths under 1 m and nearest neighbours up to almost 10 m.

The quarry seems to have a bigger impact on the eastern side yet again: the maximum average height detected is here 16.68 m (700 m), and girths do not reach 1 m. Likewise, the growth in all parameters is here slower.


Figure 3.7.1: 0 m


Figure 3.7.2: 100 m


Figure 3.7.3: 200 m


Figure 3.7.4: 300 m


Figure 3.7.5: 400 m


Figure 3.7.6: 500 m


Figure 3.7.7: 600 m

Figure 3.7 (Gambaro, 2016)

Figures from 3.7.1 to 3.7.7 present *Quercus pubescens* samples at different distances. The effect of dust depositions are very visible up to 400 m (figure 3.7.5). Up to 200 m (figure 3.7.3), virtually all trees are affected; from 300 m (figure 3.7.4) on, the share starts to diminish. Nevertheless, the white colouring on Oak leaves may be caused not (only) by the dust, but a disease known as Powdery Mildew, caused by the fungus *Erysiphe alphitoides* (online: Forestry Commission for England, 2016). In fact, Manning (1971) found an increased number of fungi and bacteria on leaf surfaces in dusty conditions (Farmer, 1991, p. 7). A joint collaboration with a biologist should be established to ascertain the cause, but this wasn't possible because of the so-called "holistic judgement".

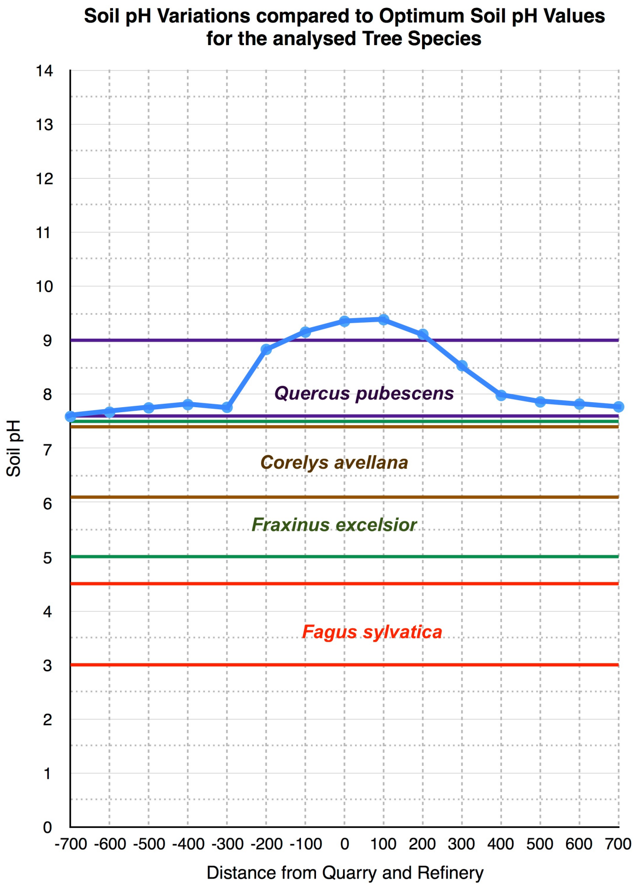

Figure 3.8

Quercus pubescens isn't the only species affected by the quarry: a brief study on the shift in the vegetation composition was thus conducted.

Figure 3.8 includes the optimum soil pH ranges of the main tree species observed - *Quercus pubescens* (Downy Oak, figure 3.9), *Fraxinus excelsior* (European Ash Tree, figure 3.10), *Pinus uncinata* (Mountain Pine, figure 3.11), *Corylus avellana* (Common Hazel Tree, figure 3.12) and *Fagus sylvatica* (Beech Tree, figure 3.13) - and the trend in soil pH (blue line). *Fagus sylvatica* (red band) usually prefers a soil pH from 3 to 4.5 (Pasta *et al.*, 2016, p. 94); *Fraxinus excelsior* (green band) growth is favoured by a pH in the range 5-7.5 (Dobrowolska *et al.*, 2011, p. 5); *Corylus avellana* (brown band) between 6.1 and 7.5 (online: Temperature Climate Permaculture, 2013); *Quercus pubescens* (violet band) likes lime-rich soils (Pasta *et al.*, 2016, p. 156); *Pinus uncinata* (not shown) is not particular as to soil type or pH (online: Eagle Lake Nurseries, 2016).

Figure 3.9: *Quercus pubescens* (online: Monumental Trees, 2016)

Figure 3.10: *Fraxinus excelsior* (online: Michigan State University, 2003)

The surge in soil pH in the proximity of the quarry is rampant: the Spearman's Rank correlation coefficient is -0.858, giving it a 99.9%

significance. The soil pH here reaches 9.38 - quite high, considering that it is normally slightly acidic, between 5.5 and 7 (online: University of Vermont, 2003). On both sides the soil pH returns to normal levels, around 7.5, only after 400 m (slightly alkaline because of calcareous substrates). However, the line is less steep on the eastern side, potentially supporting my hypothesis that deposition rates might be here higher (page 17). Notably, the soil pH might have been already quite elevated before the commencement of extractive activities due to the local geology; on the other hand, anthropogenic works may have contributed to a rise.

Figure 3.11: A few *Pinus uncinata* specimens near the San Lorenzo quarry and refinery (in the background) - Site 8 (Gambaro, 2016)

The differences in optimum soil pH may then be one of the causes of the trends in figure 3.14. The graph represents the change in composition of the forest by showing the densities of the tree species described in figure 3.8. Other species identified which were not considered statistically significant are *Malus sylvestris* (European Crab Apple), *Abies alba* (European Silver Fir) and *Acer pseudoplatanus* (Sycamore Maple).

Figure 3.12: *Corylus avellana* (online: Wild Schools, 2016)

The high pH near the quarry means that species like *Fagus sylvatica* and *Fraxinus excelsior* cannot grow in the area. The dominant species is in fact the Mountain Pine (100 stems/ha), a very resistant tree. Its needles probably enable it to reduce dust loading, like Sree Rangasamy *et al.* (1973) found for other plants.

Figure 3.13: *Fagus sylvatica* (Thyssen, 2005)

Pinus uncinata is superseded by *Quercus pubescens* just 100 m westwards (775 stems/ha). We can also observe a surge in Ash densities at -200 m (325 stems/ha), reaching 850

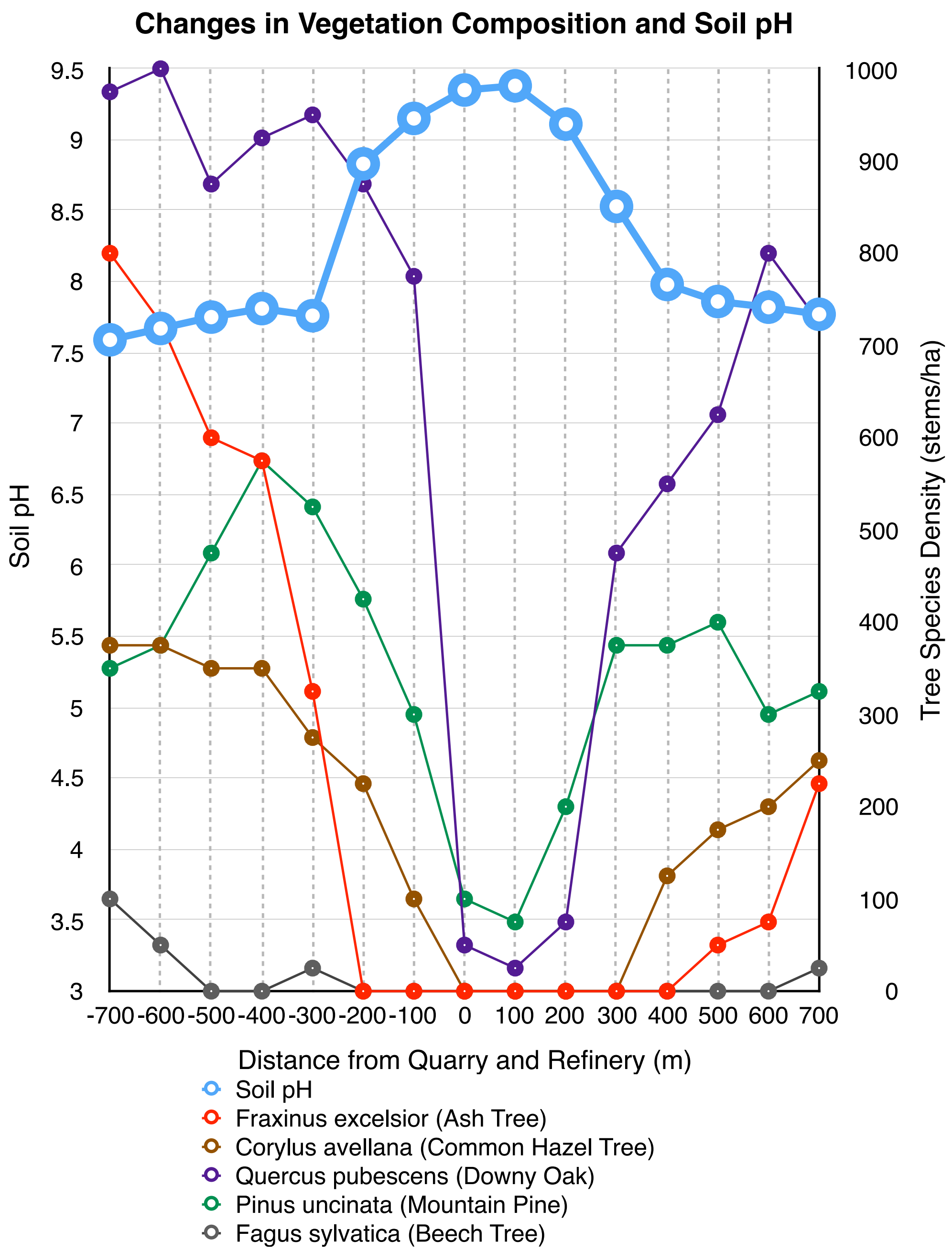

Figure 3.14

stems/ha at -700 m: 1000 m far from the quarry the Downy Oak is in fact rapidly replaced by Ash Trees, probably because of the shift in the local geology. *Corylus avellana* was detected in low but increasing densities as close as 100 m. *Fagus sylvatica* has only a marginal presence, reaching 125 stems/ha at -700 m. All changes in forest composition are delayed on the eastern side because of the factors mentioned above.

The pattern suggests that a secondary ecological succession (figure 3.15) is taking place in the area. This supports my hypothesis of clear cutting (page 16) which could have been the disturbance on the ecosystem instead of a fire (online: Encyclopædia Britannica, 2016). The area around the quarry is in fact dominated by grasses and perennials (figure 3.16), followed by pines, young oaks and shrubs like *Corylus avellana*, then mature oaks being gradually replaced by other hardwood like Ash and Beech. The dates in figure 3.15 are consistent, as the quarry was opened in the 60s.

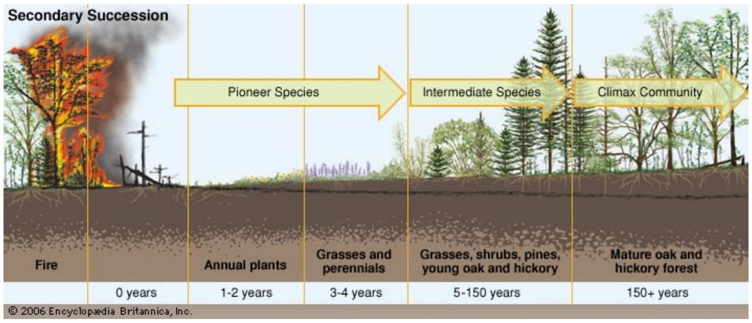

Figure 3.15: The secondary ecological succession is the process by which the structure of a biological community evolves over time after the removal of pre-existing communities by smaller-scale disturbances like fires (online: Encyclopædia Britannica, 2016)

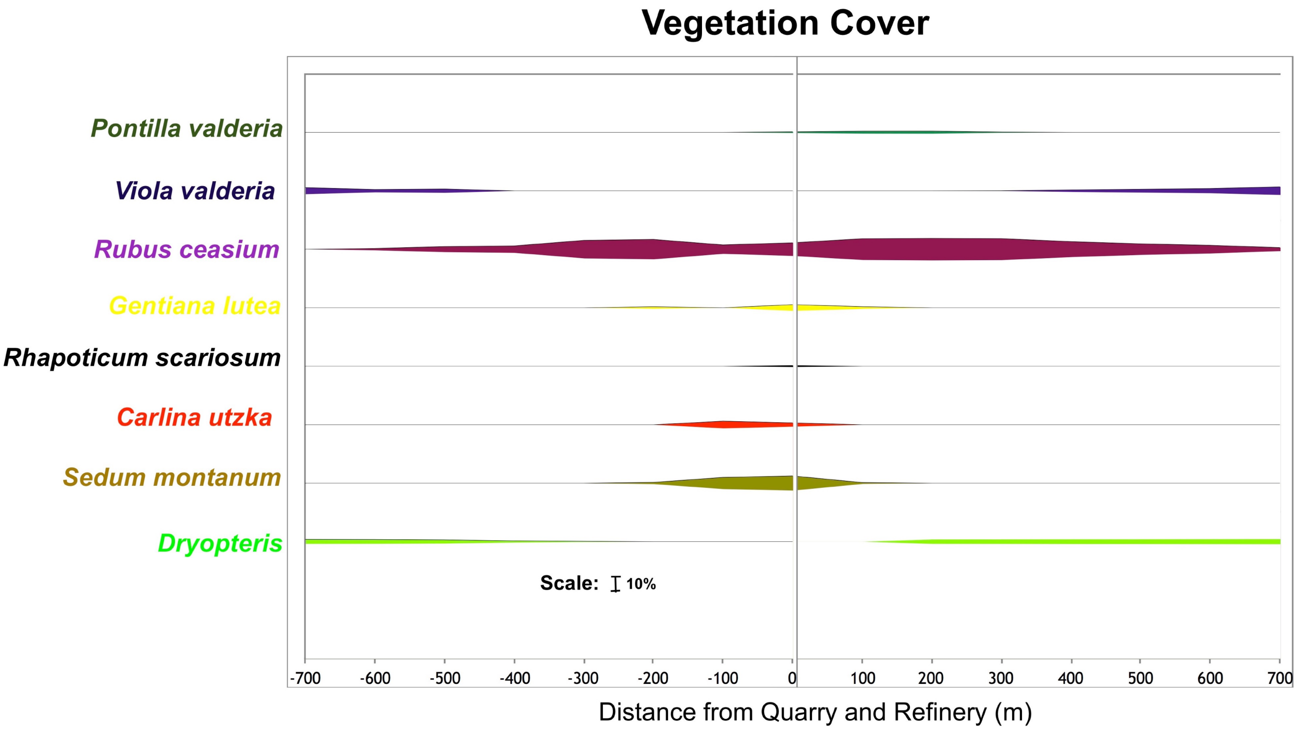

Figure 3.16: The kite diagram shows the trends in vegetation cover

Conclusion

The findings from the river did not prove significant, with the two highest values at the cement plant and refinery of 9.34 and 9.25 respectively (figure 3.1) being not extremely discrepant. They thus cannot be considered damaging for the ecosystem. The calcareous geology must be taken into account as playing an important role in determining such parameters.

The quarry and refinery are instead a source of environmental concern. Not only do these findings confirm Purvis's (1989) and Manning's (1971) theories that limestone dust promotes the excessive growth of plant parasites, fungi and bacteria on tree bark and leaves (figure 3.7), but they also evince a grave thinning out of the forest (figure 3.2), a fall in tree biodiversity (as low as 0.379), *Quercus pubescens* growth inhibition (only 2 m high near the quarry, figure 3.6) and a dramatic change in the vegetation composition (figures 3.14 and 3.16). However, this may not be representative of all limestone quarries in the Gesso valley, since in San Lorenzo the impact is amplified by the refinery.

The strength of this investigation is the great amount of sites where data have been collected which acted as a control - i.e. the trends downstream and at different distances from the quarry. This allowed me to establish correlations and reinforce my analysis.

Nonetheless there are a few questions which I have not been able to answer. One is the cause of the worsening tree health, particularly in Downy Oaks: I could not establish whether the white colour of the leaves was induced by dust depositions or by the fungus *Erysiphe alphitoides*; either way, because of Manning's findings, this colour is very likely to be caused by the anthropogenic activities.

Another issue is whether the decline in tree density, especially within 200 m from the quarry, is due to a general reduction in growth, pollen germination inhibition (Farmer, 1991, p. 5) and a very high pH (up to 9.38) caused by dust depositions, or rather by a clear cutting in the area which could have triggered a secondary ecological succession (figure 3.15). Despite the lack of data on deposition rates, I surmise that my findings are a result of all these factors combined.

As Bignami *et al.* (1980, pp. 53-55) suggest, a simple way of limiting the spread of this toxic dust would be planting shelterbelts with a density of 300 stems/ha. The location is already suitable as *Pinus uncinata* is excellent for shelterbelts (online: Eagle Lake Nurseries, 2016). This would tackle noise and dusty winds contributing to the health and wellbeing of the community of San Lorenzo.

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Appendices

Appendix I - River Raw Data

Site	River pH	TDS (ppm)
1	7.95	67
2	9.25	92
3	8.86	84
4	8.91	86
5	9.02	88
6	9.06	88
7	9.08	88
8	9.11	88
9	9.34	92
10	9.29	89

Table 1

Appendix II - Quarry and Refinery Raw Data

Site	**Distance (m)**	**Soil pH**	**Humidity**	**Simpson's Diversity Index**	**Nº of Trees affected by *Clematis vitalba***	**Nº of Trees affected by Fungi**
1	-700	7.59	55%	0.725	1	0
2	-600	7.67	54%	0.716	1	0
3	-500	7.75	55%	0.722	2	1
4	-400	7.81	52%	0.722	5	0
5	-300	7.76	50%	0.692	7	0
6	-200	8.83	46%	0.652	8	0
7	-100	9.15	46%	0.599	11	1
8 (Q)	0	9.35	39%	0.447	9	3
9	100	9.38	36%	0.379	4	2
10	200	9.11	45%	0.398	3	2
11	300	8.53	54%	0.494	4	1
12	400	7.98	62%	0.584	2	1
13	500	7.86	70%	0.627	0	0
14	600	7.82	65%	0.59	1	0
15	700	7.77	57%	0.69	0	0

Table 2: Abiotic factors, tree biodiversity and parasites

Tree Density (stems/ha)	***Malus sylvestris* (European Crab Apple)**	***Fagus sylvatica* (Beech Tree)**	***Fraxinus excelsior* (Ash Tree)**	***Corylus avellana* (Common Hazel Tree)**	***Quercus pubescens* (Downy Oak)**	***Pinus uncinata* (Mountain Pine)**
2600	0	100	800	375	975	350
2525	0	50	725	375	1000	375
2300	0	0	600	350	875	475
2425	0	0	575	350	925	575
2100	0	25	325	275	950	525
1725	200	0	0	225	875	425
1350	175	0	0	100	775	300
150	0	0	0	0	50	100
100	0	0	0	0	25	75
275	0	0	0	0	75	200
850	0	0	0	0	475	375
1050	0	0	0	125	550	375
1250	0	0	50	175	625	400
1375	0	0	75	200	800	300
1550	0	25	225	250	725	325

Table 3: Tree densities

Site	1	2	3	4	5	Average (m)	Standard Deviation
1	36.58	32.57	29.36	26.72	29.36	30.92	3.78369131933354
2	29.36	26.72	24.52	32.57	22.66	27.17	3.92177000855481
3	19.66	21.05	22.66	21.05	18.44	20.57	1.59639280880365
4	22.66	24.52	21.05	26.72	22.66	23.52	2.16910580654794
5	26.72	23.52	22.66	26.72	22.66	24.46	2.09634920755107
6	18.44	18.44	16.39	19.66	21.05	18.8	1.72259397421447
7	10.4	8.41	14.03	11.72	9	10.71	2.25569723145638
8 (Q)	1.88	2.82	2.34	2.25	2.53	2.36	0.347606098910822
9	1.97	2.06	1.97	2.34	2.25	2.18	0.16873055443517
10	5.5	5.83	6.18	6.36	4.66	5.71	0.671624895309875
11	6.75	7.17	6.96	8.14	7.4	7.28	0.536031715479598
12	8.41	8.14	9	8.41	9.32	8.66	0.486446297138749
13	10.81	10.02	10.02	11.25	10.4	10.5	0.531366163770333
14	14.03	9.66	14.03	13.38	12.78	12.78	1.81791914011597
15	14.74	15.52	17.35	18.44	17.35	16.68	1.50869148602357

Table 4: *Quercus pubescens* height

Site	1	2	3	4	5	Average (m)	Standard Deviation
1	2	2.1	2.3	1.9	1.6	1.98	0.258843582110896
2	1.35	1.5	1.4	1.2	1.25	1.34	0.119373363863133
3	1.05	0.9	1.2	0.95	0.87	0.99	0.133902949930164
4	1	1.15	1.1	1.2	1.05	1.1	0.0790569415042095
5	1	1.1	1.3	1.2	0.9	1.1	0.158113883008419
6	0.9	0.85	0.84	0.9	1.2	0.94	0.149063744753713
7	0.57	0.37	0.46	0.64	0.41	0.49	0.11247221879202
8 (Q)	0.3	0.2	0.25	0.22	0.24	0.24	0.0376828873628335
9	0.15	0.17	0.19	0.18	0.19	0.18	0.0167332005306815
10	0.35	0.27	0.29	0.3	0.32	0.31	0.0304959013639538
11	0.4	0.35	0.45	0.44	0.42	0.41	0.0396232255123179
12	0.5	0.56	0.47	0.48	0.52	0.51	0.0357770876399967
13	0.71	0.6	0.58	0.66	0.67	0.64	0.0531977443130816
14	0.8	0.7	0.78	0.77	0.75	0.76	0.0380788655293196
15	1	0.9	0.95	0.93	0.96	0.95	0.0370135110466435

Table 5: *Quercus pubescens* girth

Site	1	2	3	4	5	Average (m)	Standard Deviation
1	1.9	1.5	2.3	2	1.6	1.86	0.320936130717624
2	2	2.2	1.5	1.7	3	2.08	0.580517010948
3	10	7.8	8	9.9	9.2	8.98	1.03537432844358
4	5.6	6.8	7	4.9	6.2	6.1	0.866025403784439
5	1.1	3.5	2.6	2.3	2.2	2.34	0.861974477580398
6	5.4	2.6	2.8	3.7	2.5	3.4	1.21449578014911
7	5.13	2.8	2.75	3.2	4	3.58	1.0025617187984
8 (Q)	10	20	15	12	23	16	5.43139024560011
9	25	17	20	15	11	17.6	5.27257053058563
10	10	9	12	15	14	12	2.54950975679639
11	5.5	9	6.7	8	7.8	7.4	1.33977610069743
12	6	5	5.4	3	6.9	5.26	1.45189531303052
13	9	4.5	4.9	5.4	6	5.96	1.78969271105405
14	3.4	3.7	4.1	4.55	4.2	3.99	0.447772263544762
15	2	3	4	4.1	2.9	3.2	0.868907359849138

Table 6: *Quercus pubescens* nearest neighbour

Distance (m)	***Potentilla valderia***	***Viola valderia***	***Rubus caesius***	***Gentiana lutea***	***Rhaponticum scariosum***	***Carlina utzka***	***Sedum montanum***	***Dryopteris***
-700	0	11.3	0	0	0	0	0	7.8
-600	0	4.9	3.3	0	0	0	0	7.5
-500	0	6.7	9.6	0	0	0	0	6.4
-400	0	0	12	0	0	0	0	3.1
-300	0	0	30.9	0	0	0	0	1.3
-200	0	0	34.1	3.8	0	0	3	0
-100	0	0	15.4	0.1	0	12.4	20.1	0
0	2	0	22.6	10.9	2.7	6.6	25.2	0
100	4.5	0	36.5	4	0	0	2.4	0
200	4.7	0	37.8	0	0	0	0	7.7
300	1.2	0.4	36.9	0	0	0	0	7.9
400	0	3.5	26.6	0	0	0	0	8.2
500	0	5.8	19.1	0	0	0	0	8.3
600	0	8.1	14	0	0	0	0	8.6
700	0	14	6	0	0	0	0	8.9

Table 7: Vegetation Cover (%)