'PINUS PINEA' L. AND 'PINUS HALEPENSIS' MILLER WITHIN THE UPPER ROCKNATURE RESERVE; PATTERNS OF SURVIVORSHIP AND FUTURE MANAGEMENT

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ABSTRACT

Two species of pine grow within the Upper Rock Nature Reserve in Gibraltar, the stone pine (*Pinus pinea* L.) and Aleppo pine (*Pinus halepensis* Miller). During the drought of 1993 to 1996, many pine trees on the Upper Rock suffered considerably, and mortality was high between both species. With this in mind, we investigate the possibility of differences in both fitness and the rate of mortality between the two species, and find that although the fitness of those pine trees that remain alive does not differ between species (x^2 = 0.55, d.f. = 4, p = >0.05), a far greater proportion of *Pinus pinea* have died as a result of the drought (x^2 = 21.58, d.f. = 1, p = <0.001). *Pinus halepensis* therefore seems better suited to survive in the conditions that prevail within the Upper Rock Nature Reserve, and should be favoured in a pine tree-replanting programme. Furthermore, spatial differences in pine tree mortality on the Upper Rock are also investigated, and conclusions reached on our results are included as part of an action plan for a pine replanting programme.

RESUMEN

Dos especies de pino crecen en la Upper Rock Nature Reserve en Gibraltar, el pino piñonero (*Pinus pinea* L.) y el pino carrasco (*Pinus halepensis* Miller). Durante la sequía del 1993 al 1996, muchos de los pinos de la reserva sufrieron severamente, y mortandad fue alta entre ambas especies. A consecuencia de esto, investigamos la posibilidad que exista una diferencia en la capacidad de sobrevivir y en la mortandad entre nuestras dos especies, y encontramos que no existe diferencia entre la salud de aquellos individuos de las dos especies que siguen vivos (x^2 = 0.55, d.f. = 4, p = >0.05), una proporción mayor de *Pinus pinea* murió como resultado de la sequía (x^2 = 21.58, d.f. = 1, p = <0.001). Entonces, *Pinus halepensis* parece tener una mejor adaptación para las condiciones que existen en la Upper Rock Nature Reserve, y esta especie se debería favorecer en un programa de replantación. A continuación, se investigan diferencias espaciales en la mortandad de los pinos dentro de la reserva, y las conclusiones de nuestra investigación se incluyen dentro de un plan de acción para una repoblación de pinos en el futuro.

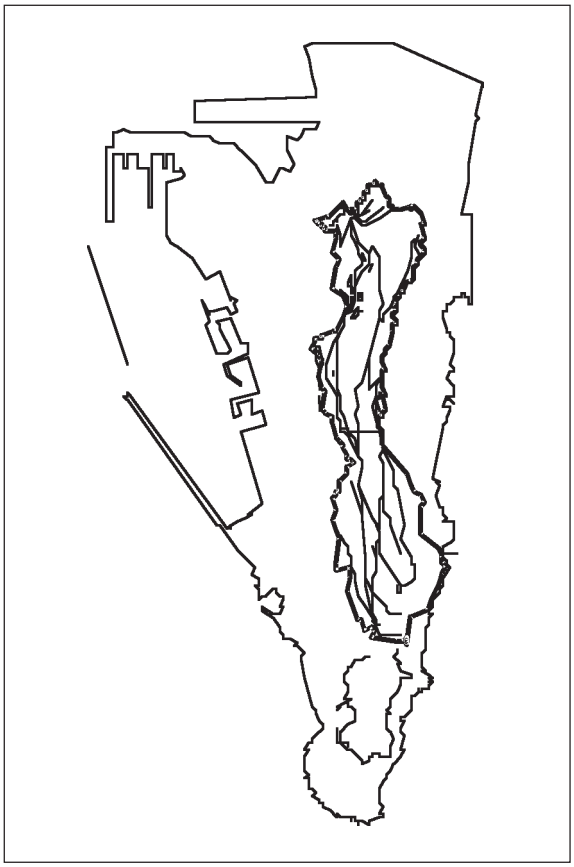


Figure 1. Map showing the location of the Upper Rock Nature Reserve within Gibraltar. The nature reserve is demarcated by the blue boundary.

INTRODUCTION

The western slope of the Upper Rock, Gibraltar, was designated a nature reserve in 1993 under the Nature Conservation Area (Upper Rock) Designation Order, 1993 (L/N 51 of 1993), and has since been known as The Upper Rock Nature Reserve, a protected area that covers roughly 40% of Gibraltar's surface. The location of the Upper Rock Nature Reserve within Gibraltar can be seen in figure 1.

The vegetation on the Upper Rock was once mediterranean woodland (Cortés 1994), but now consists mainly of high maquis, the composition of which is unique in the region (Cortés, in Heath *et al.*, 2002). This is made up largely of *Olea europea*, *Osyris quadripartita*, *Rhamnus alaternus*, *Pistacia lentiscus*, *Pistacia terebrinthus*, *Teucrium fruticans*, *Jasminum fruticans*, *Lonicera implexa*, *Rubia peregrina*, *Ruscus hypophyllum*, *Calicotome villosa*, *Coronilla valentina* and *Genista linifolia*, as well as scattered individuals of *Rhamnus lycioides*, *Quercus coccifera*, *Celtis australis*, *Anagyris foetida*, *Ceratonia siliqua*, *Crataegus monogyna* and *Phillyrea latifolia* (Linares 1994). There is also some garrigue and psuedosteppe within the Upper Rock Nature Reserve, but these habitats are becoming increasingly restricted as a result of the development of the maquis.

Two species of pine tree occur on the Upper Rock, both introduced to Gibraltar but native to nearby Spain. These are *Pinus pinea* L. (Stone pine) and *Pinus halepensis* Miller (Aleppo pine). *P. pinea* is a tall tree that reaches up to 30m in height. It usually has a straight trunk, with an umbrella-shaped canopy, and can most easily be told from *P. halepensis* by its reddish bark with large scales and rounded cones. *P. halepensis* is generally a smaller tree, reaching about 20m in height, has elongated cones, lacks the large scales of *P. pinea* on it's bark and often has twisted branches and trunk (Linares *et al.* 1996). *P. pinea* is a native of light sandy soils in and around the Mediterranean, such as coastal areas, and is the most common pine in the Campo de Gibraltar, where several woods of this species occur. *P. halepensis* is also native to the Mediterranean and is particularly drought resistant (Humpries *et al.* 1981).

Pine trees were originally planted on the Upper Rock by the garrison, and as such, pines are found mainly on roadsides and pathways. We therefore attempted to investigate the age of the trees by searching through Gibraltar Directories, from the 1880s to the 1930s. Although the exact dates when these trees were planted could not be found, Wolley-Dod (1914) mentions that '…in recent years a considerable number of pines and other trees have been planted on the western slopes.' Growth rings were counted on a number of individuals that had been sawed down once dead, and this did indeed show that most pines on the Upper Rock are between 80 and 100 years old. Those whose rings were counted ranged between 84 and 98 years old. Therefore, most pines were planted on the Upper Rock some time between the 1900s and the 1920s.

A severe drought occurred in the 1990's, from 1993 to 1996. Table 1 shows total annual rainfall data for Gibraltar from 1988 to 2002.

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Jan.	69.7	190.7	136.0	61.4	17.6	71.0	55.3	27.7	482.2	212.0	75.2	70.4	111.2	107.4	24.2
Feb.	54.1	100.6	0.0	95.1	110.9	101.9	83.4	36.3	56.5	0.0	160.4	39.8	0.0	47.6	112.3
Mar.	26.2	22.4	89.8	117.9	42.0	203.6	1.6	20.6	130.3	3.7	53.6	77.1	20.4	1.2	94.4
Apr.	23.3	49.5	132.3	63.6	49.3	99.6	58.3	27.5	122.9	24.1	21.6	32.6	144.6	79.0	67.3
May	18.6	42.3	10.1	3.4	3.0	57.8	22.6	9.7	80.1	38.9	27.0	10.0	43.0	21.0	22.0
Jun.	15.4	1.0	2.3	3.6	146.6	1.2	2.1	26.8	5.1	5.2	4.2	0.0	0.0	0.8	12.8
Jul.	7.8	0.0	0.2	0.0	0.8	0.0	0.6	1.3	0.2	1.8	0.0	1.2	0.0	0.0	0.0
Aug.	0.0	0.0	0.0	2.5	0.0	4.6	0.3	0.0	0.8	1.0	0.0	0.0	0.0	0.0	0.0
Sep.	13.2	14.7	4.9	55.6	15.1	21.6	18.1	8.8	25.0	30.2	30.4	26.8	8.8	39.4	22.0
Oct.	102.4	101.5	76.4	195.3	141.7	158.3	49.4	0.6	58.2	70.0	0.8	149.0	85.7	72.4	204.0
Nov.	263.1	368.8	54.9	66.2	11.1	142.5	62.1	96.8	160.7	230.0	2.4	42.8	90.0	55.4	259.5
Dec.	0.1	556.2	292.3	145.2	112.2	6.8	3.9	357.3	651.8	181.9	64.4	35.2	287.2	306.0	133.0
Total:	593.9	1447.7	799.2	809.8	650.3	868.9	357.7	613.4	1773.8	798.8	440.0	484.9	790.9	730.2	951.5

Table 1. Total annual rainfall in mm for Gibraltar from 1988 to 2002. Total rainfall for each month is also given (data provided by the Gibraltar Met Office)

As can be seen, rainfall from the end of 1993 to the end of 1995 was extremely low. This is illustrated on the graph in figure 2.

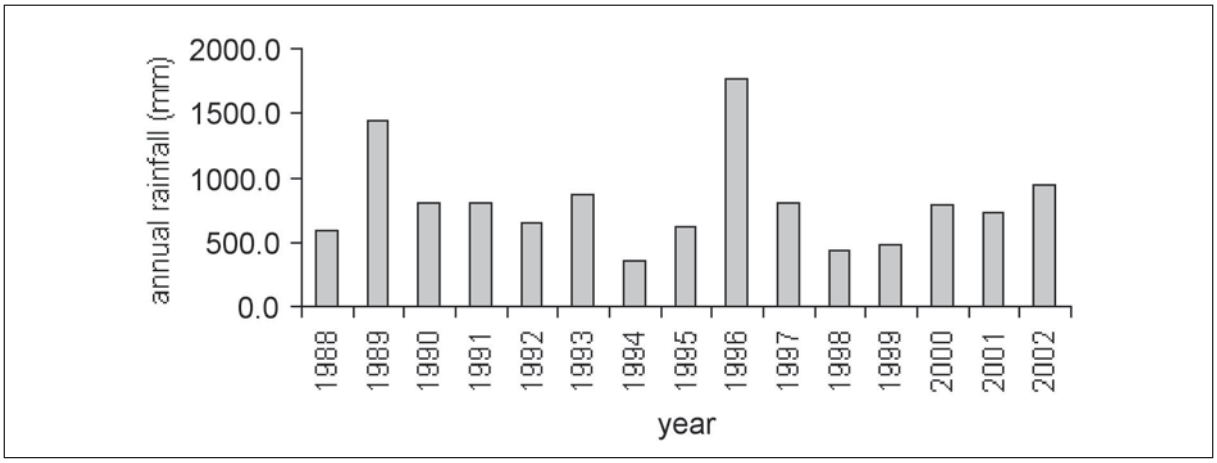


Figure 2. Bar chart showing annual rainfall in Gibraltar, from 1988 to 2002.

During the drought period, the pine tree population of the Upper Rock seems to have suffered dramatically from a lack of water, to the extent that a large number of trees died. As can be seen, 1994 was an exceptionally dry year. There was also a two year period of exceptionally low rainfall during 1998 and 1999, but this seems to have had less of an impact on the pine population of the Upper Rock, given that most of the trees that are found dead today were already dead or dying by then due to the earlier drought (*pers. obs.*). 1995 does not seem, from the bar chart, to have been as dry a year as would be expected during a drought. However, an inspection of the data in table 1 will show that most of the rain recorded during 1995 fell in December, and that month for month 1995 was an even dryer year than 1994. In fact, the data on table 1 shows that the drought began during December 1993 and ended at December 1995, lasting exactly two years. It is our totally

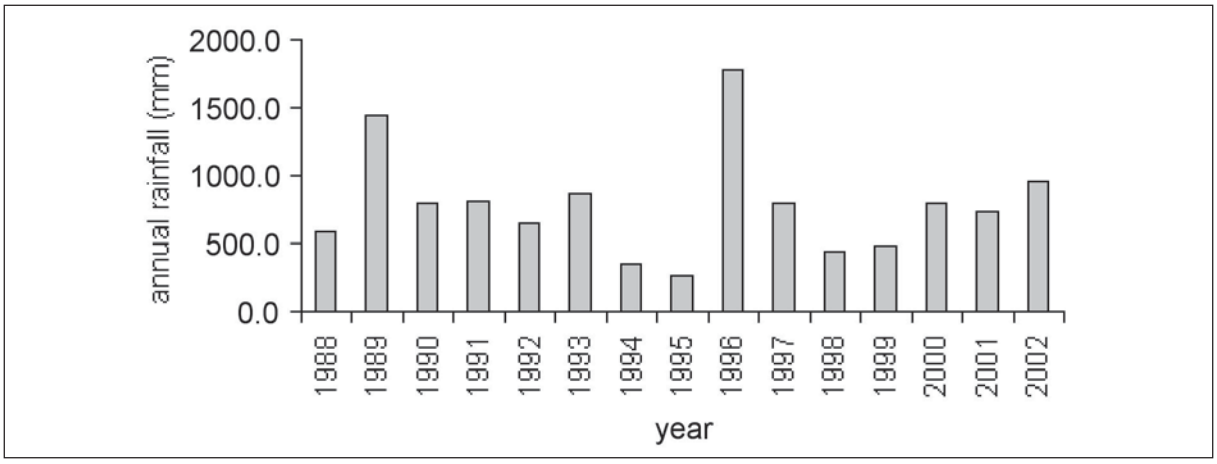


Figure 3. Bar chart showing annual rainfall in Gibraltar, from 1988 to 2002. The December rainfall data of 1993 and 1995 have been switched to show the two-year drought period more effectively.

subjective arbitration of when a year begins and ends that distorts the drought data. Therefore, in order to show the two-year drought more effectively in figure 3, we have changed December 1995's rainfall data for that of 1993, and vice-versa.

It is evident, when the drought period is correlated to the period during which many trees died that these pines probably did not survive due to the 1993-1996 drought. In discussing this, we considered that the drought may have affected our two pine species differently, and that rates of mortality may differ spatially. With this in mind, we decided to investigate pine tree mortality and distribution on the Upper Rock.

METHODS

Since pine trees are distributed mainly along roadsides and pathways and are clearly visible from a distance, trees were observed and counted by walking along the roads and paths of the Upper Rock, and individual pine trees were recorded on maps. Trees were given a score according to the state or 'health' of their canopy by recording an approximate percentage of foliage cover. The scores given are as follows; 0 = dead, 1 = <15% foliage cover of canopy, 2 = 16 – 30% foliage cover, 3 = 31 – 50% foliage cover, 4 = 51 – 69% foliage cover and 5 = 70%+ foliage cover. Once data was collected, several analyses were carried out. These are listed below:

- Maps were produced to show the distribution of both all of the pine trees counted, and live trees alone.
- Proportions of live and dead pine trees were investigated as percentages.
- Since two species of pine tree are found within the Upper Rock, a 2 x 2 chi-square test for differences was used to investigate whether there is a difference in the number of individuals that remain alive of each species. Due to our small sample size (with 1 *d.f.*), Yates's correction was applied to the chi-square test.
- The Upper Rock Nature Reserve was divided into eleven separate areas for the purposes of this study, and pine tree mortality was investigated within each individual site. Three types of analysis were carried out; between-species differences in survivorship, differences in the survivorship of pine trees in the area compared to the Upper Rock as a whole and differences in the survivorship of each species compared to the Upper Rock as a whole.

2 x 2 chi-square tests for differences were again used in these analyses. Many of our chi-square tests gave a probability (*p*) value of >0.05. It is customary in such a situation, where more than one test has been carried out, to alter *p* values according to the number of tests used, as the probability of arriving at a figure at random increases with every test. This would render some of our x^2 values insignificant. However, since sample sizes were very small in most cases, it was decided to consider any x^2 value with a *p* value of <0.05 significant for the purposes of our analysis.

- Using the 1-5 fitness scores given to live pine trees, the 'fitness' of those pine trees remaining alive was investigated by calculating the number of individuals that fall into each score as a percentage of the total number of live pine trees left within the Nature Reserve.
- Using the number of individuals recorded in each 'fitness' category, chi-square tests for differences were used to ascertain whether there is, a) a difference between fitness levels recorded for each species and, b) whether this difference remains once dead individuals are eliminated from the analysis.
- In order to illustrate the changing nature of the western slope of the Upper Rock from north to south, and relate this to spatial differences in tree mortality, six west-east intersections of the Rock of Gibraltar were produced and the angle of the slope measured at each one.

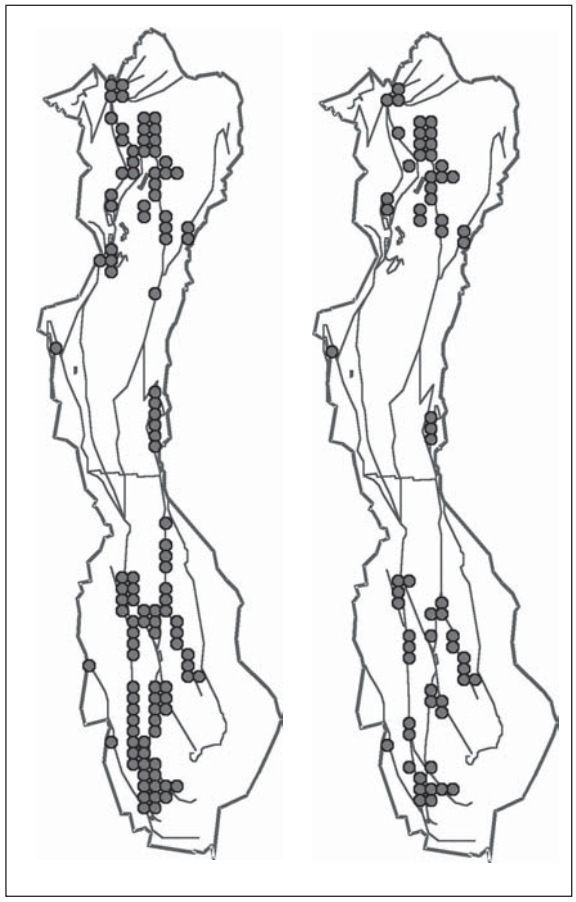


Figure 4. The map on the left shows the distribution of all pine trees within the Upper Rock Nature Reserve, including dead individuals. The map on the right includes only live pine trees.

RESULTS

The results obtained from the analyses described above are given next.

How many pine trees remain alive within the Upper Rock Nature Reserve?

A total of 307 trees of both species were counted within the Upper Rock Nature Reserve, 108 *P. halepensis* and 199 *P. pinea*. Of these, 113 individuals were alive whilst 194 were dead. This means that 63.2% of pine trees found within the Nature Reserve are dead, with only 36.8% alive. This is best illustrated in Fig. 4, which shows a map of all pine trees found on the Upper Rock (including dead individuals) and another map showing the distribution of live pine trees only on the Upper Rock.

Differences between the survivorship of *Pinus pinea* L. and *Pinus halepensis* Miller

The proportions of dead and live trees differ from species to species. Of the 108 *P. halepensis* counted, 59 were alive and 49 were dead, i.e., 54.6% are alive whilst 45.4% are dead. This contrasts sharply with *P. pinea*. Of the 199 individuals of this species counted, 54 were alive and 145 were dead, i.e., 27.1% are alive whilst 72.9% are dead. There is a marked difference in the probability of survival of both species, with *P. halepensis* having a significantly higher survivorship (x^2 = 21.58, *d.f.* = 1, p = <0.001).

Does pine tree mortality differ spatially?

Different areas of the Upper Rock showed differences in the proportion of pine trees dying, and indeed in the proportion of each species dying. The Upper Rock was divided into 11 separate areas for the purposes of this study. Table 2 shows all of our results.

SITE	SPECIES				TOTAL		
	Pinus halepensis		*Pinus pinea*				
	Live	Dead	Live	Dead	Live	Dead	Total
Martin's Path	6	7	0	15	6	22	28
Mediterranean Road	3	1	1	22	4	23	27
Queen's Road	9	2	8	41	17	43	60
Cave Branch Road	9	20	0	0	9	20	29
O' Hara's Road	5	4	7	12	12	16	28
St. Michael's Rd (Lower)	6	9	2	8	8	17	25
St. Michael's Rd (Upper)	0	3	0	10	0	13	13
Spur Battery Road	2	0	1	10	3	10	13
Signal Station Road	5	0	29	17	34	17	51
Cable Car Area	0	0	2	4	2	4	6
Governor's Lookout	14	3	4	6	18	9	27
Total	**59**	**49**	**54**	**145**	**113**	**194**	**307**

Table 2. Table showing the number of *Pinus halepensis* and *Pinus pinea* found within the Upper Rock. Results have been divided up into 11 separate areas, and we have also recorded whether the trees are alive or dead.

P. halepensis showed a higher survivorship than *P. pinea* in most cases, and at no site did *P. pinea* show a significantly higher rate of survival than *P. halepensis*. Our findings on each area are given below:

- Martin's Path – Pine trees in this area showed no significant difference to the overall proportion of trees found alive (x^2 = 2.02, *d.f.* = 1, p = >0.05). Survivorship of *P. pinea* is significantly lower than average along Martin's Path (x^2 = 4.10, *d.f.* = 1, p = <0.05).
- Mediterranean Road – With only 4.3% of *Pinus pinea* surviving, the survivorship of this species is significantly lower along this road than within the Upper Rock as a whole (x^2 = 4.59, *d.f.* = 1, p = <0.05). At 14.8%, a significantly lower proportion of both species of pine tree have survived along Mediterranean road than in the whole of the Upper Rock (x^2 = 4.35, *d.f.* = 1, p = <0.05).
- Queen's Road – Survivorship of both species combined along Queen's road does not differ significantly from that of the Upper Rock as a whole (x^2 = 1.23, *d.f.* = 1, p = >0.05).
- Cave Branch Road – Only individuals of *Pinus halepensis* were found along this road, a lower proportion of which remain alive (at 31%) when compared to the whole of the Upper Rock (x^2 = 4.19, *d.f.* = 1, p = <0.05).

- O'Hara's Road – Survivorship of both species does not differ from that of the Upper Rock (x^2 = 0.18, *d.f.* = 1, *p* = >0.05).
- St. Michael's Road (Lower) – There is no significant difference between the proportion of trees found dead along this road and that of the Upper Rock as a whole (x^2 = 0.38, *d.f.* = 1, *p* = >0.05).
- St. Michael's Road (Upper) – All of the pine trees found along this stretch of road were dead. It is therefore no surprise that the proportion of dead trees along this road (at 100%!) is significantly higher than that of the Upper Rock as a whole (x^2 = 5.87, *d.f.* = 1, *p* = <0.05).
- Spur Battery Road – The proportion of trees of both species found dead along this road did not differ significantly from the proportion found within the Upper Rock (x^2 = 0.51, *d.f.* = 1, *p* = >0.05).
- Signal Station Road – at 63%, a much higher proportion of *Pinus pinea* remain alive along this road than within the Upper Rock as a whole (x^2 = 19.93, *d.f.* = 1, *p* = <0.001). The proportion of both species that remain alive is also much higher than within the whole of the Upper Rock, at 66.7% (x^2 = 14.9, *d.f.* = 1, *p* = <0.001).
- Cable Car Area – only individuals of *Pinus pinea* were observed along this part of the Upper Rock, a similar proportion of which remained alive to the rest of the Upper Rock (x^2 = 0.02, *d.f.* = 1, *p* = >0.05).
- Governor's Lookout – at 66.7%, a much higher proportion of pine trees survived around Governor's Lookout than within the whole of the Upper Rock (x^2 = 8.07, *d.f.* = 1, *p* = <0.01).

We can arrive at some conclusions from these findings, and these are given later.

***Pine* tree 'fitness' within the Upper Rock Nature Reserve**

Although 36.8% of pine trees within the Nature Reserve remain alive, not all of these are in a healthy condition. From the individuals that remain alive, the following fitness scores were recorded: 1 = 6 (5.3%), 2 = 40 (35.4%), 3 = 38 (33.6%), 4 = 24 (21.2%), 5 = 5 (4.4%). As can be seen, only 4.4% of pine trees achieved the highest score, and 74.3% were deemed to have a canopy foliage cover of less than 50%. This means, in fact, that many of the pine trees that remain alive within the Nature Reserve are not in a good condition, and extremely few are in prime condition. However, does 'fitness' (as measured by our 0-5 scale) differ between the two species found within the Nature Reserve? Table 3 gives scores recorded for both species at each of the eleven sites, together with the totals.

SITE	*P. halepensis*						*P. pinea*					
	0	**1**	**2**	**3**	**4**	**5**	**0**	**1**	**2**	**3**	**4**	**5**
Martin's Path	7	0	2	2	2	0	15	0	0	0	0	0
Mediterranean Road	1	0	0	1	2	0	22	0	1	0	0	0
Queen's Road	2	0	1	6	2	0	41	1	4	3	0	0
Cave Branch Road	20	1	4	3	1	0	0	0	0	0	0	0
O'Hara's Road	4	0	1	3	1	0	12	2	3	2	0	0
St. Michael's Rd (Lower)	9	1	1	2	2	0	8	0	1	1	0	0
St. Michael's Rd (Upper)	3	0	0	0	0	0	10	0	0	0	0	0
Spur Battery Road	0	0	0	0	2	0	10	0	0	1	0	0
Signal Station Road	0	0	2	0	2	1	17	1	5	9	10	4
Cable Car Area	0	0	0	0	0	0	4	0	0	2	0	0
Governor's Lookout	3	0	14	0	0	0	6	0	1	3	0	0
Total	**49**	**2**	**25**	**17**	**14**	**1**	**155**	**4**	**15**	**21**	**10**	**4**

Table 3. Pine tree 'fitness' scores (as given in the methods section) within 11 separate areas of the Upper Rock Nature Reserve, together with overall scores for the whole of the Nature Reserve.

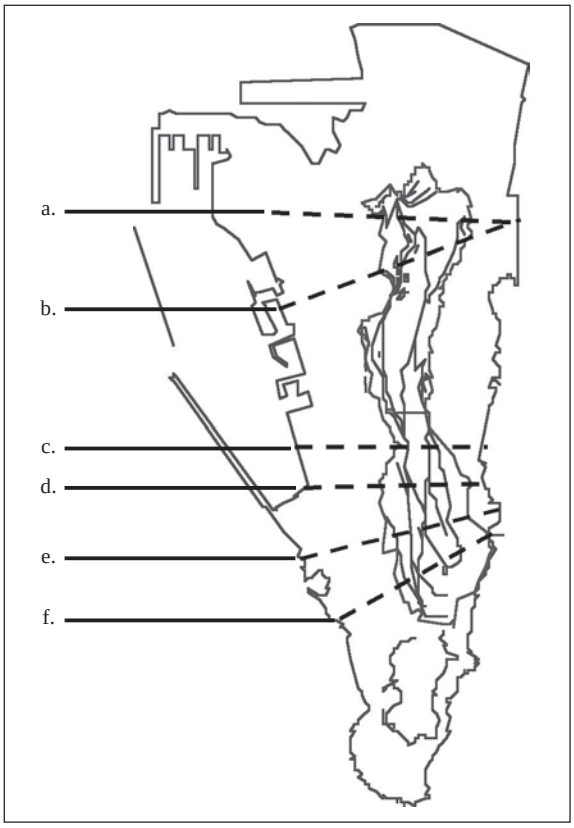


Figure 5. Map of Gibraltar, showing the lines of intersection at which west-east sections of the Rock have been produced. These are labelled a., b., c., d., e. & f.

Using species totals, a chi-square test showed that there is a significant difference between the distributions of individuals of both species across our 'fitness' scores (x^2 = 18.00, *d.f.* = 5, p = <0.01). However, it is plain to see when looking at the number of individuals under each 'fitness' score that the largest discrepancy between both species occurs at the number of individuals that are dead (45.4% of *P. halepensis*, 72.9% of *P. pinea*). This first chi-square test was probably, therefore, skewed by this large discrepancy between the number of individuals in the '0' category, and may tell us little about differences in live tree 'fitness' between both species. With this in mind, a second chi-square test was carried discarding the '0' category. This showed that there is no significant difference between the fitness of live populations of *P. halepensis* and *P. pinea* (x^2 = 0.55, *d.f.* = 4, p = >0.05).

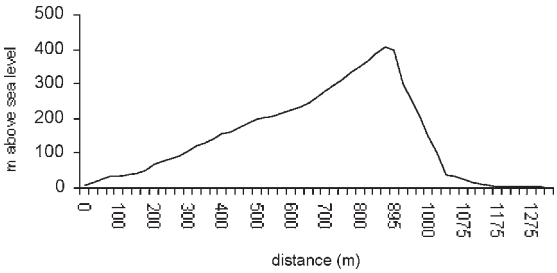
The western slope of the Upper Rock Nature Reserve

The angle of the western slope of the Upper Rock, that which constitutes the Upper Rock Nature Reserve, changes from south to north. The southern slopes are extremely steep, but these become progressively less steep as we move towards the northern end of the Nature Reserve. Six diagrams of cross-sections of the Upper Rock show the changing angle of the slope from north to south. These correspond roughly to our eleven sites, and are shown in Figures 5 & 6.

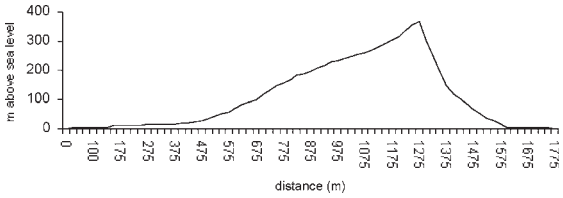
Many of our eleven sites cut through more than one of our six intersections of the Rock, and so a correlation between angle of slope and pine tree survivorship cannot be carried out. However, it is plain to see that the angle of the slope at the southern end of the Upper Rock Nature Reserve is markedly steeper than that at the northern end, with slope angles ranging between averages of 18º and 25º at our northern sites, and between 35º and 39º at our southern sites. It is also evident from our results that the two sites at which pine trees have done best, Governor's Lookout and Signal Station Road, occur towards the northern end of the Upper Rock. There may therefore be a relationship between slope steepness and pine tree survivorship, with pine trees doing better on slopes that are less steep. This may be due to the possibility of two factors; that run-off of water is less drastic on these slopes, and that soil depth is greater. These two factors may aid the continued growth and health of pine trees within the Nature Reserve.

DISCUSSION

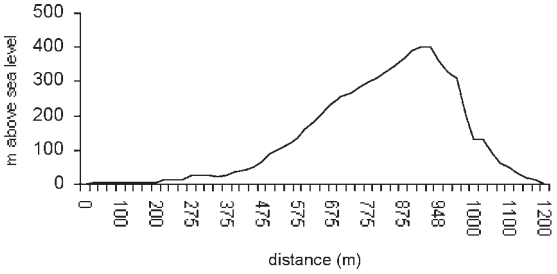
It can be seen from our results that pine tree mortality does not occur at random within the Upper Rock Nature Reserve; rates of mortality differ between our two species, and patterns of mortality differ spatially. Furthermore, it is evident, given that a very large number of trees on the Upper Rock died during or immediately after the drought period of the mid 1990s, that rainfall is a factor that determines pine mortality. Other factors that may affect the health of pines are not deemed to



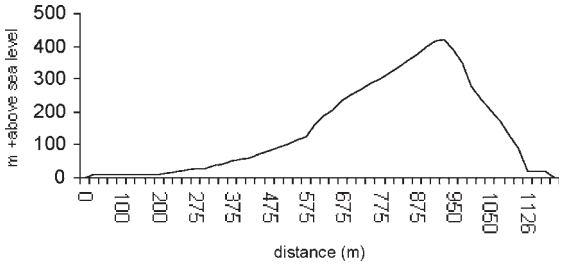
A. The angle of the slope at this intersection is, on average, about 18º. The angle at Governor's lookout, where most of the pines at this intersection grow, is about 5º.



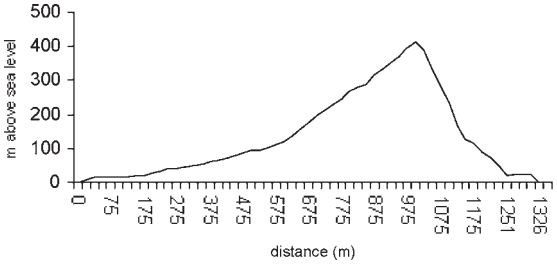
B. The angle of the slope at this intersection is steeper than the previous, at about 25º.



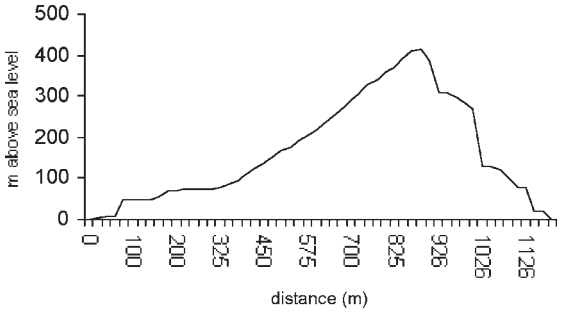
C. The angle of the slope at this intersection is far greater than the previous two, at about 35º.



D. The angle of the slope at this intersection is about 36º.



E. The angle of the slope at this intersection is about 39º.



F. The angle of the slope at this intersection is about 38º.

Figure 6. West-east sections of the Rock, showing the angle of the western slope of the Rock at different positions from north to south.

have contributed significantly to tree mortality during this period. For example, the pine processionary moth (*Thaumetopoea pityocampa*), although common in Gibraltar, has never occurred in high enough densities to cause serious damage to pines, as frequently happens in pinewoods in the neighbouring area. Also, it can be argued that the basic nature of the soil on the Upper Rock Nature Reserve favours *P. halepensis* and not *P. pinea*, yet if this were the primary factor, then it would be difficult to explain how many of these trees survived in an apparently healthy state for more than 80 or 90 years.

Another factor to consider is why these trees were affected at this point in time. If they have been around for more than 80 or 90 years, then it seems highly likely that one or more droughts comparable to that of the mid 1990s will have occurred during these trees' lifetime. Why then did the trees perish during this period? A factor that may have affected pine trees on the Upper Rock is the large increase in traffic along all roads over the 1990s. It is not unreasonable to assume that pollution emanating from car exhaust may have affected and weakened trees (particularly since most pines are found along or close to the road), further exposing them to the effect of the drought. What is certain is that pine trees, and more specifically *P. pinea*, are very sensitive to pollution (Quezel 1977; Cortés 1979). Furthermore, the situation may be aggravated during years of low rainfall, when an increased volume of solids originating from car exhaust may accumulate on trees.

Our findings on pine fitness and mortality within the Upper Rock Nature Reserve are discussed next, in relation to their significance to pine tree management on the Upper Rock Nature Reserve.

Are Pine Trees Important to the Upper Rock Nature Reserve?

Before deciding whether or not to recommend the replanting of pine trees in the Nature Reserve, we must examine the role that pine trees have played within the Upper Rock and whether their presence is important.

Pine trees undoubtedly give character to the Nature Reserve; they have over the years lent an aesthetic appeal to the Upper Rock, and in particular it's roadsides. Their large canopies, when the majority of pine trees were healthy, provided ample shade for drivers and walkers, and this was particularly important during the summer months when temperatures regularly exceed 30ºC. Likewise, pine trees provide shade to picnickers in the Governor's Lookout area, and also stabilise the soil on the sides of the roads.

These trees are also beneficial to some of the wildlife of the Nature Reserve. Within the Upper Rock, the pine processionary moth (*Thaumetopoea pityocampa*) is obviously only found on pine trees, and the buprestid beetle *Buprestis* (*Buprestis*) *magica* is found on *P. halepensis*. Some of the birds that use the Upper Rock also show an association to pine trees. For example, wintering firecrests (*Regulus ignicapillus*) are almost always found on pine trees, whilst booted eagles (*Hieraaetus pennatus*) [a species which is afforded the SPEC category of 3 and is deemed 'Rare' by BirdLife International (Tucker & Heath 1994)] regularly roost in pine trees during the post-nuptial migration, when prolonged easterlies produce large concentrations of this species on the northern shore of the Strait. Similarly, pine trees are frequently used by passerine migrants such as *Phylloscopus* warblers, and in particular the western Bonelli's warbler (*Phylloscopus bonelli*), and also the spotted flycatcher (*Muscicapa striata*) and the pied flycatcher (*Ficedula hypoleuca*) amongst others.

It seems, therefore, that pine trees have had an important role to play in the Nature Reserve, and that some form of pine tree replanting would be beneficial to the Upper Rock. However, this should be restricted to sites at which these trees were originally planted, and their present range within the Nature Reserve should not be extended. Rather, broad-leaved trees that are known to have occurred on the Upper Rock prior to it's deforestation or that occur on nearby limestone mountains should be used in any aforestation programme, as these are known to harbour a higher biodiversity. Such species could include carob (*Ceratonia siliqua*), narrow-leaved ash (*Fraxinus angustifolia*), round-leaved oak (*Quercus rotundifolia*), Algerian oak (*Quercus canariensis*) and possibly nettle tree (*Celtis australis*) (although the use of this last species must be looked into, as it may not in fact be native to this region). This is currently being considered, and recommendations will be published in due course (Perez & Bensusan, *in prep.*).

PINE TREE REPLANTING

Given the proportion of pine trees found within the Upper Rock Nature Reserve that are dead, it is obvious that an intensive replanting programme is necessary if a pine tree population, which has been characteristic of the Upper Rock over the years, is to continue existing. Some lessons can be learnt from the analysis above, and the following points should be taken into account when replanting pine trees on the Upper Rock:

- Given that there is no significant difference between the 'fitness' of live trees of both species, the only important factor to consider in a replanting programme is the difference in survivorship between both species. *Pinus halepensis* is better adapted to environments such as that found on the Upper Rock than *P. pinea*. This is shown by the much higher proportion of *P. halepensis* that survived the severe drought of 1994 – 1996, as is evident from our analysis. Therefore, in any replanting programme, *P. halepensis* and not *P. pinea* should be used. If any P. pinea are to be used, then these should be planted along and around Signal Station Road (on the northern end of the Rock), where survivorship for this species was highest.
- Pine trees seem to do particularly badly along the road that leads upwards from St. Michael's Cave, Mediterranean road and Cave branch road. It is not surprising that these three sites are located towards the southern end of the Nature Reserve, as the slope is steeper in this area and therefore one would expect a lower depth of soil and greater runoff of water here. In fact, it can be seen clearly from the maps in Fig. 4 that the southern end of the Upper Rock has lost many more pine trees than the northern end. These areas should therefore be avoided in a pine tree-replanting programme.
- Pine trees do especially well along Signal Station road and around Governor's Lookout, probably because the slope is less steep at these sites than along most of the Upper Rock. In the event of a tree-replanting programme, a special effort should be made to repopulate these two sites with a good number of trees, as these are most likely to survive here.
- Many pine trees that are currently found in a live state within the Upper Rock Nature Reserve are not in a good condition. A replanting programme should therefore be quite intensive, as many of the trees that remain alive can perhaps be expected to die in the near future. This should include areas where a good number of pine trees still remain alive.
- It is recommended that pine trees should be planted only in areas where they were originally planted, with broad-leaved trees planted elsewhere in the event of an aforestation programme.

DEAD PINE TREES

A total of 194 dead pine trees can be found on the Upper Rock. It is the authors' opinion that these should be left where they are, as they provide a habitat for a large diversity of invertebrates, as well as hibernating reptiles. If any dead tree poses a danger (e.g., if it overhangs a road precariously), then this should be felled and left lying in the same spot where it grew. This will not only provide a habitat for wildlife but also enrich the soil in the decaying process. Dead pine trees within the Nature Reserve are quickly attacked by wood-boring invertebrates, such as the termite *Reticulitermes lucifugus*, and beetles of the families Buprestidae and Cerambycidae. This accelerates the decomposition of dead trees.

Although dead pine trees could be seen by some as a fire hazard, they are not any more of a hazard than any dead or live tree within the Nature Reserve. In fact, live pine trees burn for a longer period of time due to their resinous nature. Dead pine tree removal should not, therefore, be justified through these means.

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