Effects of abandonment and salinity over time on plant communities and soil properties in former vineyards in Southern France.

Soil properties and plant community structure in abandoned vineyards

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Abstract

Soil salinity is a crucial and growing problem in our day and age. In Mediterranean regions, the high salinity of agricultural fields has led to the subsequent abandonment of these lands, decreasing economic productivity and social well-being. Once fields are left abandoned for years, the evolution of soil and plant communities provide novel insights for linking ecological and soil sciences, yet are often unstudied. Thus, the purpose of this study was to analyze the effects of abandonment of high salinity farmland on soil characteristics and plant communities at different stages of abandonment. For this, soil properties and plant community characteristics of six abandoned vineyards and a control (current vineyard) were evaluated near Narbonne, France. The groups of plots had a difference of at least 7 years of abandonment between them, and soil and plant communities characteristics in each plot were compared. The study showed that the longest abandoned plots (1986) had the highest ion concentrations (Na^{2+} and K^{+}) and electrical conductivity, and providing a linear correlation confirms these factors are linked over years of abandonment and plant communities. Also, we noticed that species richness tended to decrease over time, and salinity tolerant species remained dominant. Our study concludes that abandonment of agricultural fields is a practice whose effects evolve over time, not necessarily to be naturally recovered and arable again in the future.

Keywords

Salinization, abandoned vineyards, plant community structure, soil properties, soil-plant interactions, Mediterranean.

1. Introduction

Presently, soil salinization is one of the most devastating environmental problems associated with soil degradation, threatening around 932.2 Mha worldwide (1). This phenomenon increases by around 10% annually. The causes range from natural environmental events to the influence of human activities in the agricultural sector. By 2050, the situation could become severe; some estimations predict that more than 50% of arable land will be salinized (2). This threat is most prevailing in arid to semi-arid regions which receive lower levels of rainfall annually, notably southern Europe (3).

A soil is considered saline if it contains a high enough salt concentration to interfere with plant growth, and if saturated paste extract presents an electrical conductivity superior to 4 dSm^{-1} (4). There are two main ways soil salinization is characterized: primary and secondary salinization. Primary salinization depends on the natural conditions of the environment, and it usually occurs when leaching is insufficient to move salts out of the soil (5,6) Secondary salinization comes from anthropogenic activities of which the major drivers are irrigation with saline water (7), use of fertilizers (8), compacted and limited leaching soils (9), or wastewater treatments (10).

Salinity stress has major consequences on plant growth and development by inhibiting seed germination, root length, plant height, fruitification, and photosynthesis (11). Soil salinity will affect almost all aspects of plant development, thus causing lower agricultural productivity and leading to a lower economic return (12). Also, the ability to tolerate saline soils can greatly vary from one plant to another, which is reflected by their physiological responses (13).

When it's no longer viable to cultivate crops on agricultural lands or to adopt any other management practices, they usually fall into abandonment. As a consequence, farmland abandonment is currently a vital land-use change in the Mediterranean region that particularly concerns vineyards in coastal regions dealing with salinity (6,15). Subsequently, the plant communities that colonize follow different trajectories depending on the cultivation legacy and environment of the field. Different stages of abandonment can be characterized through the evaluation of community changes described by functional traits in plants (14). However, it should also be noted that land abandonment can also contribute to the improvement of soil quality. Novara (2017) finds that the restoration of flora and microfauna after abandonment promote litter and organic matter accumulation due to the added biodiversity and mass of the biota (16).

Narbonne, France, is one of the biggest cities in the Aude department (6). The city is near to the Aude river, which has a southern by-pass, La Robine, that flows through Narbonne to the Bage-Sigean and another northern branch that joins the sea (17). Salinization in the Aude region is already an ancient phenomenon caused by the recent and ancient presence of seawater (18,19). This issue has led to the abandonment of a significant amount of agricultural lands. Presently, some farmers in the region manage salinity through the artificial submersion of their lands with fresh water ensuring the leaching of salts (6) but consuming enormous amounts of water every year.

The following study aims to investigate vineyards at multiple stages of abandonment and analyze how the structural properties of soil and plant community traits change over time. In this regard, our following objectives were (i) to better understand the relationship between ecological and pedological processes in abandoned vineyards, (ii) to analyze how salinity changes during the abandonment stage of the field, and (iii) to determine how this change in salinity and age influences plant community structure.

2. Materials and Methodology

2.1. Site Description

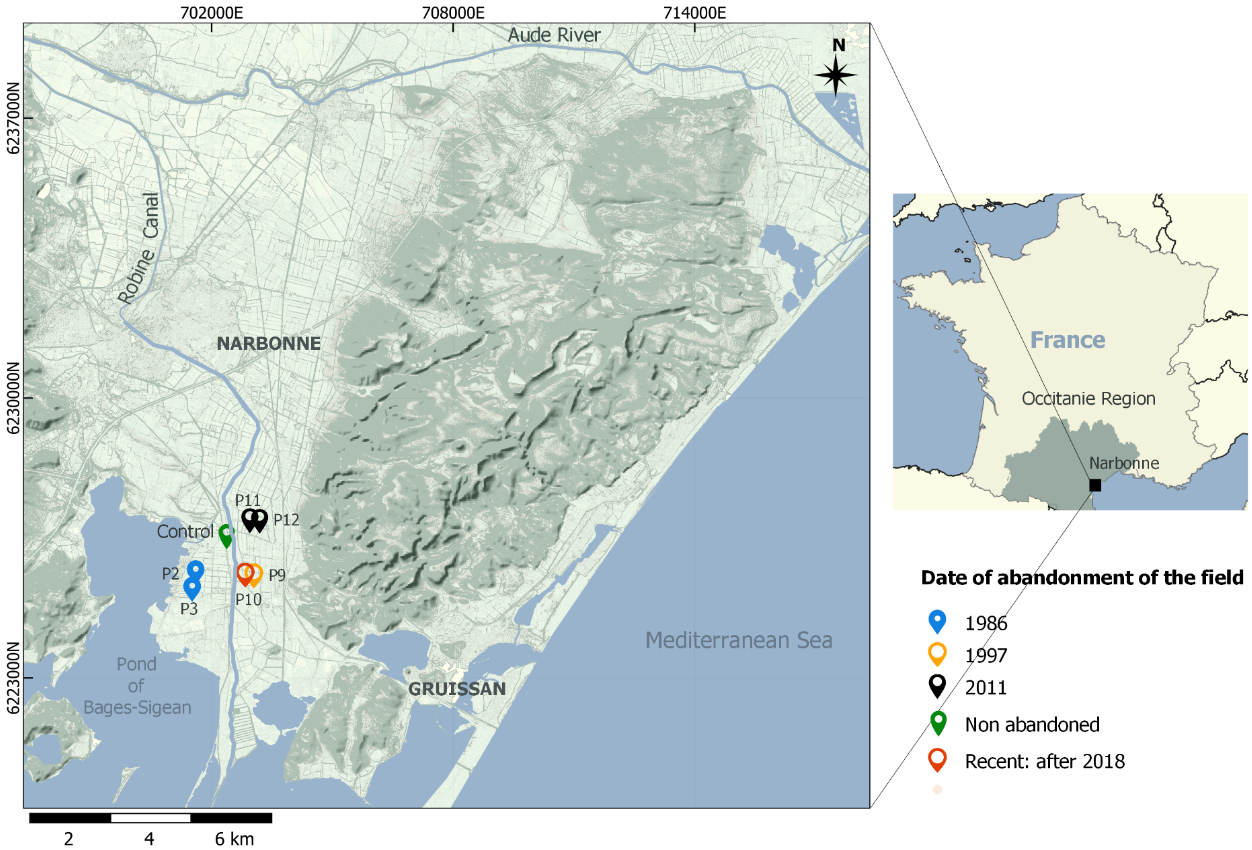

Figure 1. Situation map of the area studied and localization of the plots.

The area studied (**Figure 1**) is located close to the old agricultural farm of the Grand Castelou within Narbonne, a commune in the Occitanie region of France. This is now a protected area on the edge of the Bages-Sigean lagoon owned by the Conservatoire du Littoral since 1984 (17).

In this region, we sampled plots that share the same climatic variables. Average precipitation from 1960 to 2019 is 582 mm/year, and annual evapotranspiration rate for 2020 is 1050 mm (rates since 1960-2019 trend upwards by 3.01 mm/year) (20, 18).

2.2. Sampling

Using online photos (21), we observed that areas in the region first began falling into abandonment during the 60s. It is known that the succession of plants in abandoned fields, especially in a high salinity context, could take several years before significant change is observed (19), therefore the stage of abandonment is crucial to explain vegetation successions (20). However, the succession of plant communities colonizing abandoned fields, as well as the development of soil properties in semi-arid environments, has not been deeply studied and could answer meaningful questions in plant ecology and soil sciences.

The plots selected in Victor Berteloot (2021) were used for characterizing the salinity conditions and hydraulic aspects of the lower Aude plain. The study analyzed aerial photographs from *Géoportail* (Annex 1)*,* a mapping service that contains a function which allows the user to analyze a specific region over time.

According to Walker (2010) (19), a secondary plant succession is usually analyzed over decades. Considering this point, a list of plots and their characteristics was made over the low land of Aude. All the plots selected, using Victor Berteloot (2021), (**Table 1**) have around a difference of 10 years of abandonment between them (with one difference of 7 years). We have also selected a control plot, represented by a non-abandoned vineyard threatened by salinity.

Table 1. List of plots sampled from Victor Berteloot (2021) study to be analyzed. The table contains the given names of each plot (Field), a brief description of the current state of the area (Type), the year when the plot was abandoned (Date of abandonment), and the coordinates of each plot (Coordinates).

Field	Type	Date of abandonment	Coordinates
P2	Salt marsh	1986	43.129927, 3.019709
P3	Salt marsh	1986	43.126151, 3.018571
P9	Intermediary	1997	43.129235, 3.037390
P11	Prairie	2011	43.141589, 3.036236
P12	Prairie	2011	43.141463, 3.039197
P10	Prairie	after 2018	43.129403, 3.034770
Control	Vineyard	Non abandoned	43.138045, 3.029108

By analysis and interpretation of aerial photos, we were able to determine that P2, P3, P9, P11, and P12 are abandoned vineyards. The control is a current vineyard and P10 was a vineyard transformed into grassland for livestock in 2018.

2.3. Soil measurements

2.3.1. Sampling and Field measurements

To characterize soil chemical properties, we measured ECe, pH, and the specific ion content of Na^+, Ca^{2+}, and K^+. For soil physical properties, we examined the soil organic matter content (OMC) and soil moisture (SM).

We selected samples randomly in four locations in each plot, covering the area homogeneously. Using an auger, we took samples at two depths for each of the four replicates: 0-20 cm, and 20-40 cm, for each spot. After collecting the soil, we tagged and stored them in a plastic bag. The soil was kept in a refrigerator until analysis.

We made an on-field measurement of apparent soil electromagnetic conductivity (ECe) by using an EM38 which gave us two values for each point measured (21). Using the EM38 oriented in a horizontal position (EMh) gave the ECa near the surface (0-0.60m) and using it in the vertical position (EMv) gave measures for a lower depth (0-1.2m) (22).

2.4. Lab analysis

2.4.1. Soil moisture & Organic matter content

To determine soil moisture, we amassed 25g of fresh soil (for each replicate) and left it in an oven for 16 hours at 160º C. After, we weighed the soil again to determine the percentage of massic soil moisture (24).

We took 5g of the dried soil and left it in a hotter oven at 375 °C for another 16 hours. We determined the percentage of organic matter content (OMC) by using the calculation provided by the Centre d’Expertise en Analyse Environnementale du Québec (25) (**Figure 2**):

$$M.O. = \frac{dry\ soil\ weight\ (g) - \ incinerated\ soil\ weight\ (g)}{dry\ soil\ weight\ (g)}$$

Figure 2**.** Organic Matter Content calculation provided by the Centre d'Expertise en Analyse Environnementale du Québec (25).

2.4.2. pH, Ion measurement, & Soil conductivity:

We prepared soil solutions by mixing 10g of dry soil with 50g of water and let it settle for 24h.

For the pH measurement, we used a pHmeter, PHEP HI98121 by Hanna Instruments, calibrated using two different buffer solutions (pH of 4 and 7). Cleaning the pHmeter with distilled water after each sample, we measured the pH of the samples.

For the measurement of EC, (electrical conductivity measured in mS/cm), we followed the same steps as for the pHmeter; however, we used an electrical conductivity meter, Tetracon 925, and a buffer solution of 1431 mS/cm.

To determine Na^{+}, Ca^{2+}, and K^{+} ion content (in ppm), the protocols remained the same using a LAQUAtwin (Horiba). The first step was to clean the tool with distilled water three times and calibrate it with a buffer solution. We measured and recorded the respective ion content values for each replicate by taking the third measurement of our soil solution. After each measurement, we cleaned the tool three times with distilled water.

2.5. Vegetative Measurements

Table 2. Vegetative traits with their descriptions and ecological functions. Measuring these traits will allow us to see changes in plant communities and indications of environmental gradients, like soil properties. (26, 27)

Vegetative Trait	Description	Ecological Function
Canopy height	The shortest distance between the highest photosynthetic tissue and the ground level (27)	Light capture; growth strategy; growth rate; response to climate; competitive ability for light
Species richness and dominant species	Number of species in a given area (28)	Indicator of environmental factors, i.e. soil; ecosystem stability
Soil cover	The percentage of vegetation covering the soil space(28)	Indicator of environmental factors, i.e. soil
Aboveground biomass	Living plant material (29)	Potential Productivity

2.5.1. Sampling and field measures

In each field, we randomly placed quadrats of 1m x 1m to constitute our four replicates (R1, R2, R3, and R4). Inside those quadrats, we placed smaller ones, 0,5 x 0,25 m², in which we collected all the annual plants and annual parts of the perennial plants. The samples were tagged and stored in paper bags which we refrigerated until analysis.

Inside each quadrat, we observed the vegetation to determine the number of species and their specific abundance; a Narbonne floral guide provided by Ph.D. student Victor Berteloot and phone applications, PlantNet (30) and FloraIncognita (31), were used to identify the plant species. The percentage of the species cover was estimated by sight.

2.5.2. Mean Height

To obtain the mean height of the vegetation, we randomly measured the height of four plants in each quadrat using a ruler and calculated the mean in cm.

2.5.3. Litter Score

The litter coverture was classified by a score ranging from 0 to 3 (**Table 3**).

Table 3. Litter Score description. The values go from 0 (no litter at all) to 3 (almost fully covered). Source: made by the authors.

Litter Score	Soil Description
0	No litter on the soil
1	Surface covered < 25%
2	Surface covered > 75%
3	Surface covered < 75%

We estimated a litter score for each replicate in the plots.

2.5.4. Biomass (g/m^2)

We used the envelopes with our plant material collected in the field to determine the dry biomass. We weighed each envelope, left them in the oven at 90°C overnight, and weighed them again. Calculating the difference between them, we obtained the biomass in g/m^2, excluding the weight of the envelopes.

2.5.5. Statistical analysis

Plots were selected according to the year of their abandonment: P2 and P3 (1986), P9 (1997), P10 (2018), P11 and P12 (2011), and the control (currently a managed vineyard). For each plot, 4 soil samples were collected and 4 vegetation analyses were conducted. Sampling locations for soil and vegetation were determined at random.

Statistical tests were conducted using the software ‘R’ (32) to test our hypotheses (Annex 2). First, we checked the normality and homogeneity of our data by conducting the Shapiro-Wilk test and Bartlett’s test. Since the results showed that the data was not parametric, we decided to use a Kruskal-Wallis test to compare plots according to all the variables. After the Kruskal-Wallis test, a Dunn’s *post hoc* test was made to highlight the differences between groups of two.

As for linear correlations, we used the Pearson correlation formula. We crossed data for the date of abandonment of each plot and all plant and soil data. We also ran linear correlations to see if salinity affects plant community traits.

By performing these statistics, we wanted to characterize the evolution of plant characteristics and soil properties in response to the two gradients: stage of abandonment and salinity.

3. Results

3.1. Soil 0 - 20 cm

For the Kruskal-Wallis test (**Table 4**), soil moisture, conductivity, Na^+, and K^+ content showed statistical differences among themselves, but not OMC, pH and Ca^{2+}. The plot P3 in soil moisture differed significantly from P11 ($p=0.0058$) and P12 ($p=0.0181$). As for EC, P2 ($p=0.0357$), P3 ($p=0.0089$) and P9 ($p=0.0265$) showed significant differences from the control. Similarly, for Na^+ content, P2 and P3 differed from the control ($p=0.0265$, $p=0.0228$) and P11 ($p=0.0265$, $p=0.0228$) and for K^+ content, P2 ($p=0.0376$) and P3 ($p=0.0119$) showed significant differences when compared with P12.

We noticed that, in general, the plots that were abandoned for the longest time showed significant differences between the recently abandoned and not abandoned. Furthermore, it is possible to identify an ascending or descending order among the values when looking at the order of abandonment (P2/P3 ➡ P9 ➡ P11/P12 ➡ Control), even if the values were not significantly different.

Table 4. Soil layer from 0 - 20 cm was analyzed in the region of Grand Castelou in Narbonne, France. The parameters studied were soil moisture (%), organic matter content (g), pH, EC (mS/cm) and ion content (Ca^{2+}, Na^{+}, K^{+}) in ppm. The plots were vineyards previously abandoned in 1986 (P2 and P3), 1997 (P9), 2011 (P11 and P12), 2018 (P10), and the control, a current vineyard. Median (IQR).

Soil 0 - 20 cm							
Plot	**Soil Moisture (%)**	**OMC (g)**	**pH**	**EC (mS/cm)**	**Ca2+ (ppm)**	**Na+ (ppm)**	**K+ (ppm)**
P2	6.34 (0.58) ab n=4	3.4 (0.55) a n=4	7.99 (0.08) a n=4	2185 (1008) b n=4	53.50 (19) a n=4	960 (940) b n=4	46 (22.50) b n=4
P3	9.08 (3.45) b n=4	4.71 (0.47) a n=4	7.80 (0.21) a n=4	2510 (1008) b n=4	91 (14.20) a n=4	965 (82.5) b n=4	55.50 (9.25) b n=4
P9	5.45 (0.71) ab n=4	4.16 (1.08) a n= 4	7.94 (0.11) a n=4	1801(1125) b n=4	43 (29.80) a n=4	530 (332) ab n=4	28.50 (7.25) ab n=4
P11	3.78 (0.66) a n=4	2.05 (1.93) a n=2	7.78 (0.062) a n=4	364 (49.50) ab n=4	115 (12.50) a n=4	44.5 (9) a n=4	19.50 (2.50) ab n=4
P12	4.11 (0.53) a n=4	0.40 (1.38) a n=3	7.88 (0.12) a n=4	456 (90.20) ab n=4	66.50 (7) a n=4	140 (12.50) ab n=4	16 (4) a n=4
P10	5.90 (0.77) ab n=4	0.2 (1.1) a n=4	7.78 (0.12) a n=4	868 (69.20) ab n=4	92 (50.20) a n=4	235 (12.5) ab n=4	18.50 (1.75) ab n=4
Control	5.32 (0.69) ab n=4	4.22 (0.69) a n=4	7.86 (0.05) a n=4	263 (120) a n=4	115 (16) a n=4	46 (7.25) a n=4	22.50 (6.25) ab n=4

Medians followed by different letters in the same column differ at the 5% significance level when compared using the Dunn's *post hoc* test; n = number of replicates per plot.

Confirming what was possible to identify in the tables, a negative linear correlation between the year of abandonment of some plots and EC (*R=-0.75, p=3.7e-06*), Na^{+} (*R=-0.81, p=1.5e-07*) and K^{+} (*R=-0.8, p=3.1e-07*) content was found (**Figure 3**). The lines describe increasing ion content over time after abandonment, as well as the EC in the area.

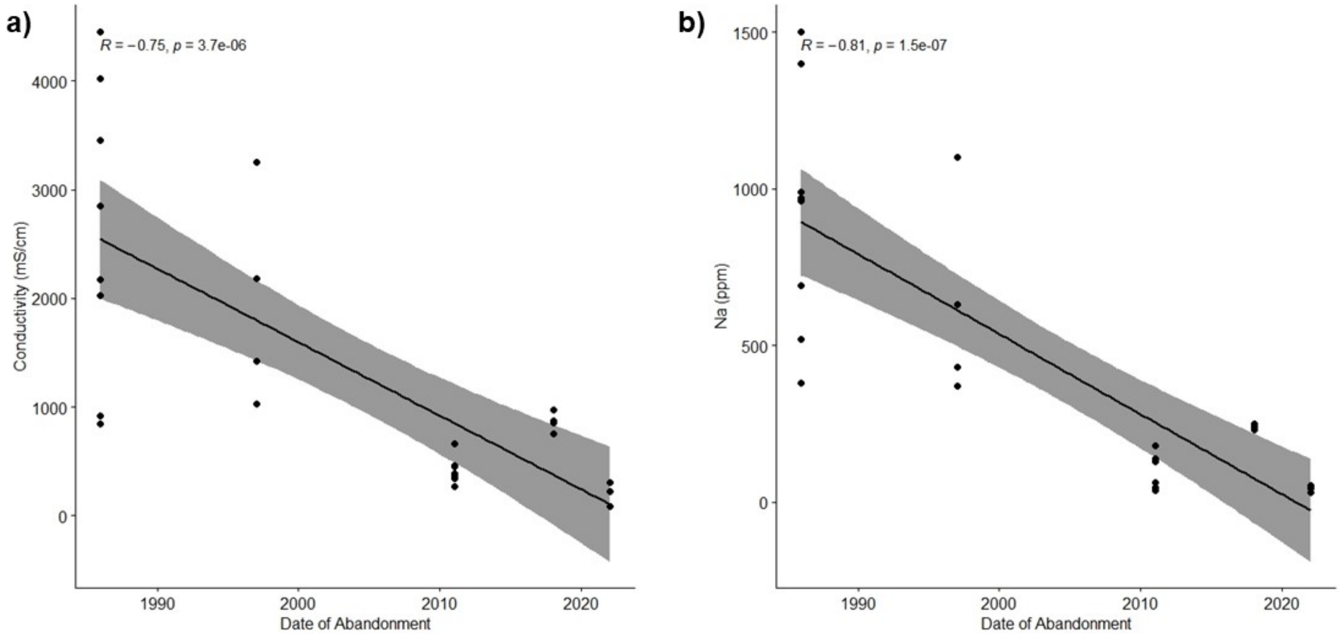

Figure 3. a) EC (mS/cm) and **b)** Na^{+} (ppm) content evolution over time in the first layer (0 - 20 cm) of the fresh soil region of Grand Castelou in Narbonne, France. R = Pearson's correlation test; p = *p-value* for the T-test between variables.

3.2. *Soil 20 - 40 cm*

Running a Kruskal-Wallis test on the 20 - 40 cm depth (**Table 5**), we found significant differences within plots for soil moisture, pH, EC, $Na^{+,}$ and K^{+}. Soil moisture from P11 differs significantly from P2 (*p=0.0064*) and P3 (*p=0.0039*). The pH from the control plot differs significantly from P3 (*p=0.0103*). For EC, the control differs significantly from P2 (*p=0.0444*), and P11 differs significantly from P2 (*p=0.0082*), P3 (*p=0.0246*), and P9 (*p=0.0286*). Results from Na^{+} ion content showed that the control plot differed significantly from P2 (*p=0.0167*), P3 (*p=0.0069*), and P9 (*p=0.0476*). And results from K^{+} ion content showed that P11 differs significantly from P2 (*p=0.0130*) and P3 (*p=0.0178*), and P10 differs significantly from P2 (*p=0.0470*).

In this data, we see trends that show many significant differences occur between plots abandoned more recently, P2 and P3, and those abandoned much later, P10, P11, and P12. Also, note that the second layer of the soil follows the same patterns as the first layer.

Table 5. Soil layer from 20 - 40 cm was analyzed in the region of Grand Castelou in Narbonne, France. The parameters studied were soil moisture (%), organic matter content (g), pH, EC (mS/cm) and ions content (Ca^{2+}, Na^{+}, K^{+}) in ppm. The plots were vineyards previously abandoned in 1986 (P2 and P3), 1997 (P9), 2011 (P11 and P12), 2018 (P10), and the control, a current vineyard. Median (IQR).
Medians followed by different letters in the same column differ at the 5% significance level when compared using the Dunn's *post hoc* test; n = number of replicates per plot.

	Soil 20 - 40 cm						
Plot	**Soil Moisture (%)**	**OMC (g)**	**pH**	**EC (mS/cm)**	**Ca2+ (ppm)**	**Na+ (ppm)**	**K+ (ppm)**
P2	5.82 (0.39) b n=4	0.395 (0.16) a n=4	7.8 (0.077) ab n=4	3608 (4455) c n=4	51 (35.50) a n=4	860 (990) b n=4	57.50 (20) c n=4
P3	6.04 (0.83) b n=4	0.365 (0.35) a n=2	8.04 (0.08) b n=4	2080 (426) ac n=4	49 (11.80) a n=4	835 (168) b n=4	58.50 (3.5) bc n=4
P9	4.36 (0.19) ab n=4	0.49 (0.53) a n=4	7.86 (0.23) ab n=4	1918 (817) ac n=4	36.5 (46) a n=4	505 (330) b n=4	28 (9.75) abc n=4
P11	2.19 (0.28) a n=4	1.01 (0.39) a n=3	7.68 (0.11) ab n=4	334 (82.80) ab n=4	105 (12.50) a n=4	90.5 (30.8) ab n=4	9.5 (3.5) a n=4
P12	5.06 (1.24) ab n=4	0.92 (0.84) a n=4	7.73 (0.14) ab n=4	666 (340) abc n=4	70.50 (12) a n=4	285 (150) ab n=4	11 (1.5) abc n=4
P10	3.72 (0.91) ab n=4	1.01 (0.52) a n=4	7.82 (0.11) ab n=4	608 (150) abc n=4	68 (24.80) a n=4	245 (102) ab n=4	11 (4.25) ab n=4
Control	4.36 (0.56) ab n=4	1.28 (0.47) a n=4	7.5 (0.12) a n=4	454 (65.20) a n=4	130 (22.50) a n=4	43.50 (9.75) a n=4	24 (3.75) abc n=4

3.3. Vegetation

3.3.1. Plant Characteristics

The Dunn test did not show significant differences between the different plots in terms of number of species, plants height, litter score, soil coverage by plants or dry biomass (**Table 6**). However, the species cover varies up to 66% between the plot with the smallest species cover (P2, mean species cover = 15%) and the one with the highest (P11, mean species cover=92,5%), and a Kruskal-Wallis test shows a significant difference between the various plot (*p = 0.0319*).

When observing the evolution of the number of species in a plot over time (**Figure 4**), the general trend shows a decrease of the number of species with the years of abandonment (even if the error bars are not all disjointed). The plots abandoned after 2010 (P10, P11 and P12) have significantly more species than the ones abandoned before 1990 (P2 and P3). A linear regression (**Figure 5.b**) shows a correlation (*R= 0.54, p=0.0062*) between the number of species in a plot and the length of its abandonment.

Similarly, the number of species decreases with increase of Na^+ content in the soil (**Figure 5.a**), and Na^+ ion content increases with the length of abandonment (**Figure 5.b**).

Table 6. Vegetation was analyzed in squares of 1m² in the region of Grand Castelou in Narbonne, France. The parameters studied were the number of species, vegetation median height (cm), litter coverage (litter score), percentage of vegetation covering soil (soil coverage and the dry biomass produced in 0,5 x 0,25 m². The plots were vineyards previously abandoned in 1986 (P2 and P3), 1997 (P9), 2011 (P11 and P12), 2018 (P10), and the control, a current vineyard. Median (IQR).

Plot	Number of Species	Height (cm)	Litter Score	Soil Coverage (%)	Dry Biomass (g/m²)
P2	2 (0.5) a n=4	29.8 (12.0) a n=4	0.5 (1.5) a n=4	0.15 (0.238) a n=4	374 (173) a n=4
P3	4 (0.25) a n=4	56.3 (16.4) a n=4	2 (0.25) a n=4	0.625 (0.225) a n=4	291 (160) a n=4
P9	4.5 (1.75) a n=4	38.3 (22.1) a n=4	1.25 (0.75) a n=4	1 (0.075) a n=4	311 (221) a n=4
P11	5.5 (1.25) a n=4	51 (13.1) a n=4	2.5 (1) a n=4	0.925 (0.085) a n=4	157 (46.2) a n=4
P12	4.5 (1) a n=4	30.3 (9.17) a n=4	0.25 (0.75) a n=4	0.325 (0.175) a n=4	107 (43.3) a n=4
P10	4.5 (2) a n=4	56.7 (44.2) a n=4	1.5 (1.25) a n=4	0.775 (0.462) a n=4	319 (453) a n=4

Medians followed by different letters in the same column differ at the 5% significance level when compared using the Dunn's *post hoc* test; n = number of replicates per plot.

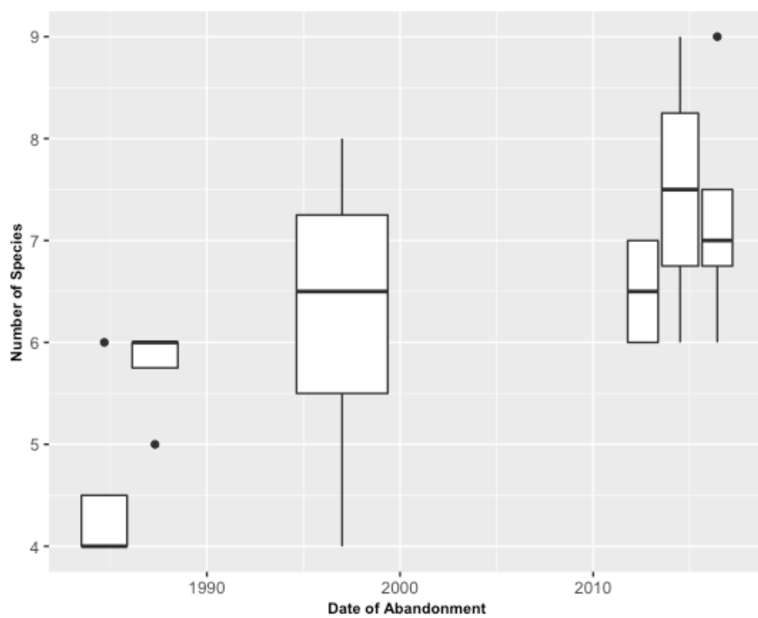

Figure 4. Number of species changes over time in abandoned vineyards. Boxplots represent the mean and quartile of the number of species found in four squares of 1m² randomly placed in each plot (former vineyards P2 and P3, P9, P11, and P12 and P10; respectively abandoned in 1986, 1997, 2011, and 2018.

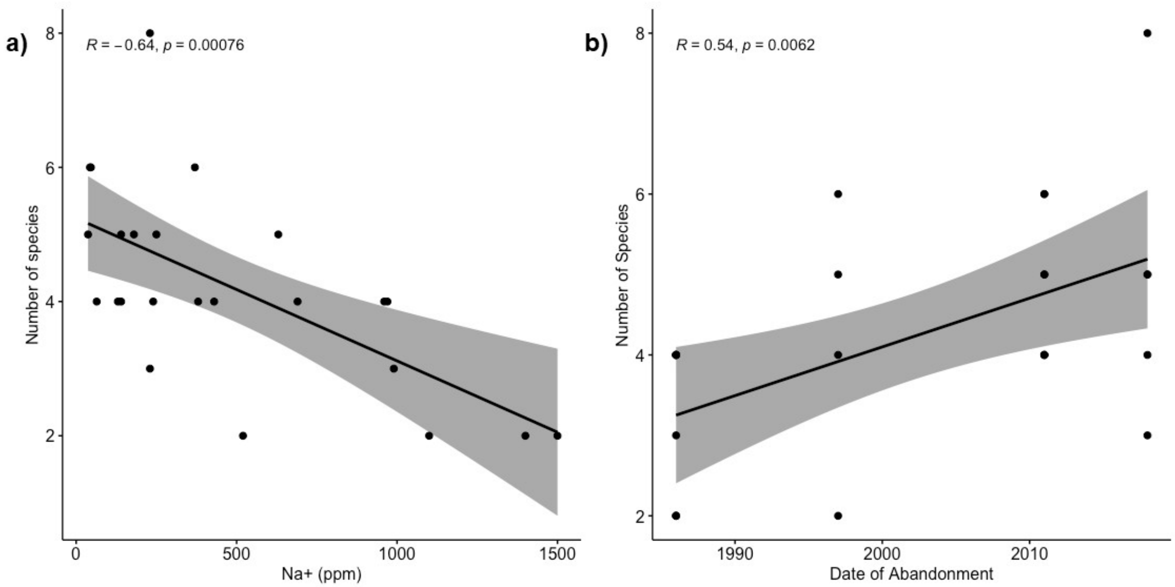

Figure 5. Number of species progression according to **a)** Na+ content and **b)** over time in the first layer (0 - 20 cm) of the fresh soil region of Grand Castelou in Narbonne, France. R = Pearson's correlation test; p = *p-value* for the T-test between variables.

3.3.2. Species Distribution

More than 30 species were identified in the whole area. Their distribution between the different plots varies, and the main plant identified in a plot is different in each of the 6 plots studied. The number of species and their relative occupation of a plot also varies between the different dates of abandonment; in the oldest abandoned vineyards (**Table 7.a** and **7.b**) there are fewer species (3 species present in more than 10% of the plot) than in the more recently abandoned (**Table 7.d**).

Table 7. The main species present and their respective abundance in the samples taken from vineyards abandoned in **a)** 1986, **b)** 1997, **c)** 2011, and **d)** 2018. Species were identified in squares of 1m² in the region of Grand Castelou in Narbonne, and the percentages are a mean of four squares. Only species present in more than 10% of the area are represented in the tables.

a)

Plot (1986)	*Salicornia europaea*	*Puccinellia festuciformis*	*Juncus subulatus*	*Juncus gelardi*
Plot 2	79.25%	14.25%	0.00%	0.00%
Plot 3	21.75%	1.25%	35.00%	30.00%

b)

Plot (1997)	*Salicornia europaea*	*Puccinellia festuciformis*	*Atriplex littoralis*
Plot 9	21.25%	23.75%	47.50%

c)

Plot (2011)	*Bromus diandrus*	*Avena fatua*	*Micropyrum tenellum*	*Helminthotheca echioides*	*unknown poaceae*	*Tragopodon dubius*	*Aster tripolium*
Plot 11	46.75%	20.80%	0.25%	12.80%	0.00%	0.40%	0.00%
Plot 12	0.00%	0.00%	13.75%	0.50%	22.50%	14.50%	18.25%

d)

Plot (2018)	*Lotus corniculatus*	*Plantago coronus*	*unknown poaceae*	*Lotus glabei*	*Phragmites australis*
Plot 10	23.00%	15.00%	15.00%	11.75%	10.00%

4. Discussion

Salinity in Narbonne, France arose after the region was flooded by salt water from the mediterranean sea, and as a result, farmers currently manage the salinity using artificial flooding with fresh water (6). Our results try to characterize the temporal progression of soil properties and plant communities in abandoned fields after management practices to control salinity have stopped.

To preface, it was observed that soil factors like pH and Ca^{2+} didn't differ significantly across plots. This indicates that soil types are homogenous within our study region. Similar Ca^{2+} levels affirm that the soils of the region originate from calcareous sediments.

One of the objectives set by this study was to better understand how salinity changes during abandonment. In this sense, Na and EC, strong indicators of saline soils (33), drastically increased in plots abandoned in the ’80s when comparing them with plots abandoned recently. They also showed a negative linear correlation, meaning that the Na^+ content and the electrical conductivity progressed during abandonment over the years. One explanation could be that once a field is abandoned, management practices to regulate the salinity of the soils are discontinued, and the lands are left to reestablish. Studying our data shows that abandoned fields will not always lead to a productive regeneration of the lands, i.e. returning to an arable state.

Plant communities' succession in abandoned fields depends on the local characteristics of the environment, such as soil quality, climatic conditions and human activity. As seen from our data, plant colonization starts with the spontaneous recovery of the land by plants, first with graminoid vegetation and then with a specialization of more halophytic species. However, in semi-arid environments plant colonization and succession can be very slow (34,35), and literature has shown that changes in perennial vegetation could take decades (36). Thus, time after abandonment is decisive to explain and identify plant communities changes in some areas (28,37). In arid landscapes, EC and ion content are factors that determine the path of vegetation changes over time (39,40). Moreover, the literature also identifies soil salinity and soil moisture as major factors explaining vegetation distribution in those areas (41,42). Analyzing plant-soil interactions, it was evident that the increase in salinity over time indicates a decrease in the number of species in formerly abandoned vineyards (**Figure 5**). In this way, it is possible that the rise of salinity over time influences the selection of salt-tolerant species, reducing species richness in the area. This possibility is reinforced by the fact that in plots P2 and P3 (the oldest former vineyards), the dominant species, *Salicornia europaea, Juncus* spp., and *Atriplex littoralis* are characterized as highly salt-tolerant species[26].

Moreover, knowing that soil moisture is essential to the terrestrial hydrological cycle, a significant decrease will lead to a drop in evapotranspiration (45). Soil moisture and evapotranspiration are particularly important to the processes regulating energy, water, and carbon (46). In this sense, evapotranspiration can also be correlated with biodiversity (47). We identified that the plots abandoned for the longest periods of time had also the lowest values of soil moisture, which could be another factor that explains the drop in the number of species once the vineyards were abandoned. This assumption is however a possible speculation of the trends in our data.

Among the indications of plant species data, we were hoping to see a gradual shift in vegetation. In other words, certain species would be present in multiple stages of abandonment, linking the plots to illustrate a gradient of species distribution. In literature, studies show that community composition suggests a trajectory that reveals how certain stages of abandonment describe transitional periods in vegetation when changing from one ecosystem to another (28,47). Yet, it's possible a longer, more precise study would need to be conducted in order to see these trends.

5. Conclusion

This study brings together two fields of research that are often explored separately in the scientific community. As soil scientists, it is easy to make the judgment that soil properties influence vegetative traits, but an ecologist would propose the contrary. However, a well-rounded researcher would conclude that the interactions between these elements cannot be so easily described as simple cause and effect, but rather as a complex cycle of interactive influences.

Our investigation showed that over time salinity, characterized by our EC and Na+ content findings, increased marginally. We believe this change in salinity may account for the changes identified in plant communities over time, resulting in less species richness and diversity. The dominant species went from a diverse, more graminoid vegetation to more dominance by halophytic shrubs.

To conclude, plant communities are influenced by the salinity and the abandonment stage of the land it belongs to. Therefore, with more precise studies we could imagine a simpler way to characterize the degree of abandonment of a field and to understand its current condition by looking at the vegetation present. This could lead to developments in the process of rehabilitation and conservation of abandoned lands.

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7. Annex

7.1. Interactive map to visualize the localization of the plots:

https://www.google.com/maps/d/edit?mid=1WvWkQMNoQ4WSV88bZOA1-eTJDtL4gEBf&ll=43.163814946672446%2C3.058098591210925&z=11

7.2. Link to data and code: https://github.com/cchancellor/JRL-SOIL-2022/blob/fb01a3255e4ced218da8564f7bb425cdc4d93020/SoilSalinityTeamCodeAnalysis.R

7.3. Team Mascot (that made this work come true)

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9. Supplementary Material

Unpublished work:

18. Projet S.A.L.I.N – Salinisation des Aquifères LIttoraux de la Narbonnaise. 2021;106.