LONG-TERM CHARACTERIZATION OF YEARLY DISEASE PRESSURE IN VINEYARDS: CASE STUDY OF THE BORDEAUX REGION FROM 1940 TO 2018

Leslie Daraignes

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Leslie Daraignes. LONG-TERM CHARACTERIZATION OF YEARLY DISEASE PRESSURE IN VINEYARDS: CASE STUDY OF THE BORDEAUX REGION FROM 1940 TO 2018. Agronomy. 2019. hal-03126908

HAL Id: hal-03126908
https://hal.inrae.fr/hal-03126908
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UNIVERSITÉ de BORDEAUX – BORDEAUX SCIENCE AGRO

INSTITUT DES SCIENCES DE LA VIGNE ET DU VIN

RAPPORT de fin de stage

pour l'obtention du

MASTER Science de la Vigne et du Vin
PARCOURS : ŒNOLOGIE ET PROCEDES OU VIGNE ET ENVIRONNEMENT VITIVINICOLE OU MANAGEMENT DES EXPLOITATIONS VITIVINICOLES

LONG-TERM CHARACTERIZATION OF YEARLY DISEASE PRESSURE IN VINEYARDS: CASE STUDY OF THE BORDEAUX REGION FROM 1940 TO 2018

présenté par

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- 2019 -

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MASTER'S THESIS
"Vineyard and Winery Management"

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ACKNOWLEDGMENT

This work was supported by the Laccave project, and co-supervised by UMR SYSTEM (INRA Montpellier) and UMR SAVE (INRA Villenave d'Ornon).

First, I would like to express my gratitude to my daily supervisor Marc Fermaud for the useful guidance, comments, and his general engagement during this internship. I would also like to thanks my co-supervisors from Montpellier for their ideas, guidance and availability throughout this long-distance relationship.

Moreover, I would like to express my deepest gratitude to Lionel Delbac for supplying the long series of plant health reports, his help in retrieving the missing bulletins and complementary resources, and his precious advices throughout the internship.

I would also like to thank the experts who were involved in the acquisition of additional data and validation of results: Marc Raynal, Christian Debord, Bernard Guery.

GLOSSARY

Key-word	**Definition**
Annual reports	Plant health reports (BSV) issued at the end of a growing season. They consist in a summary of the considered growing season (weather, phenological stages, pests, …)
Bio-aggressor	A pathogen or pest that causes damage in the vineyard
BR	Black Rot
BSV	Bulletin de santé du végétal, or plant health report
DM	Downy Mildew
Expertise	What allows an expert to interpret, analyze and/or synthetize his knowledge to make a judgement (EFSA, 2014)
Frequency	See "mean frequency of attack"
GM	Grey Mold
Incidence	Measure the proportion of plants units diseased (or the number diseased) out of the total number of plants observed
Index	Integrated indicator designed in Chapter 2 to represent the epidemics of a given disease. In the study, indexes names consist in the following information: DiseaseName_Index_OriginOfTheData
Index_BSV	In Chapter 2, indexes designed from BSV data for the 2010-2018 period
Index_IFV	In Chapter 2, indexes designed from IFV Data for the 2010-2018 period
Intensity	See "mean intensity of attack"
Mean Frequency of Attack	In the BSV reports, on the 2010-2018 period, MFA, or Mean Frequency of Attack, is defined as the number of affected organs, on the number of observed organs, in the affected plots
Mean Intensity of Attack	In the BSV reports, on the 2010-2018 period, MIA, or Mean Intensity of Attack, is defined as the surface occupied by the disease, on the total surface of all observed organs, in the affected plots
Mean prevalence	In the BSV reports, on the 2010-2018 period, MP, or Mean Prevalence, is defined as the total number of infected plots, on the number of observed plots
PM	Powdery Mildew
Prevalence	General definition: proportion or number of fields with diseased plants. In Chapter 1, on the 1940-2018 period, prevalence is used to characterize the geographical zone of the study (i.e. "local" or "general"). See 3.2.1
Seasonal reports	Plant health reports (BSV) issued during the growing season, often on a weekly basis
TM	Tortricid Moths
Severity	General definition: assessment of the area of plant tissue affected by a disease. In Chapter 1, on the 1940-2018 period, severity is used to characterize the epidemics (i.e. "low", "medium", and "high"). See 3.2.1

ABSTRACT

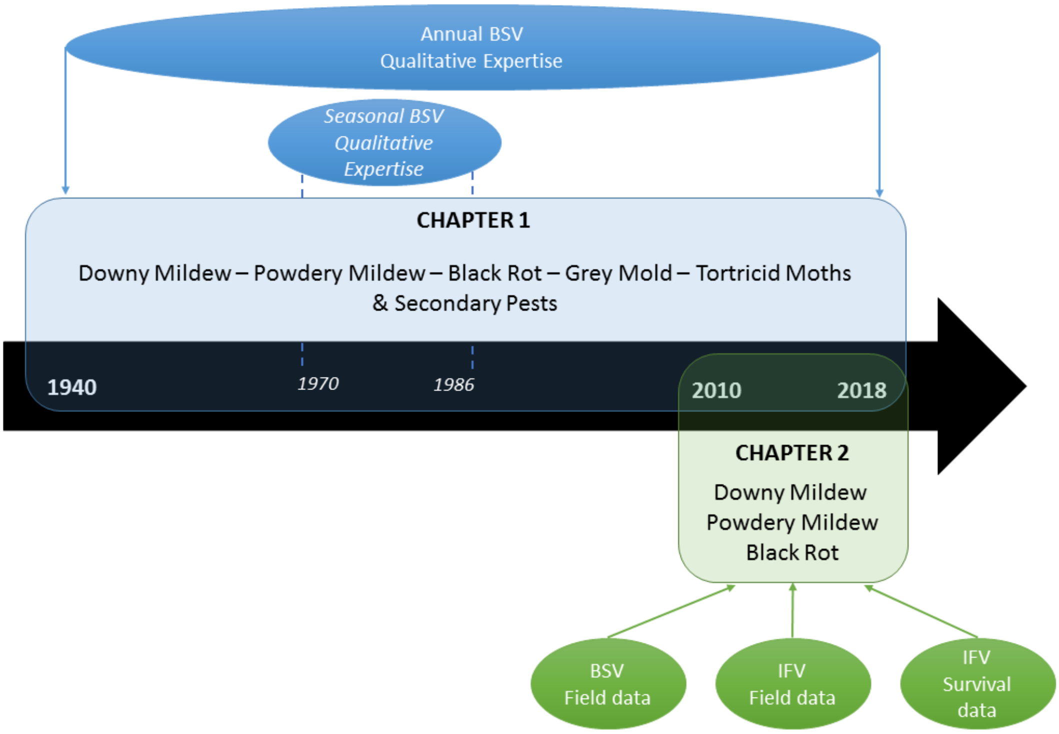


Figure 1. Graphical abstract

Because of their harmfulness, vine pests and diseases can cause quantitative and qualitative losses. In the context of reduction of the use of phytosanitary products, many studies and experiments are carried out to design pest management strategies with fewer negative impacts, while maintaining satisfactory agronomic, social and economic performance for winegrowers. To analyze the impact of a phytosanitary strategy, or a production situation on the performance of these new wine-growing systems of the future, it will be necessary to control the development and damage of pests and diseases on the plots studied. However, it is also necessary to take into account and characterize, in quantitative terms, the regional pressure of pests and diseases and the associated climatic context that partly determines this biotic pressure on a larger scale.

The present study was carried in the context of climate change and its effect on grapevine, in Laccave project. The objective of this framework was to characterize the annual level of exposure to pests and diseases of vineyard by constructing biotic pressure indicators based on the textual data from a long series of plant health reports. It was based on an approach of investigation and clarification of expert knowledge, a process known as elicitation. The characterization was carried out on the Bordeaux region, from 1940 to 2018. Census, extraction, and analyses of the *Bulletins de Santé du Végétal* issued during this period were performed. A digital database was created from the textual information, and was analyzed by designing a semi-quantitative scale adapted to the dataset. As a result, yearly pressure indicators of epidemics of Downy Mildew, Powdery Mildew, Black Rot, Gray Mold and Tortricid Moths were characterized, in vineyards of the Bordeaux region, from 1940 to 2018. In a second part of the study, quantitative data from the plant health reports and a secondary database were used to design a set of indicator based on quantitative data. In both cases, the goal was to propose a comprehensive and replicable scale in order to process and analyze the information contained in the plant health reports.

1. INTRODUCTION

Most of the studies involving the assessment of pests incidence in the vineyard are related to predictive models (e.g. Bregaglio, Donatelli and Confalonieri, 2013) or risks assessments (e.g. Donatelli *et al.*, 2017; Savary *et al.*, 2018). The models use mostly climatic and plant physiological data to investigate their relationships and propose possible outcomes concerning the general physiology of the vine, its susceptibility to diseases. In most cases, the models also include crop yield (Schauberger *et al.*, 2018). However, few studies have analyzed disease data covering long periods of past years. For example, on potato (Zwankhuizen and Zadoks, 2002), wheat (Huerta-Espino *et al.*, 2011), and rice (Savary *et al.*, 1995). The difficulty, in such both historical and epidemiological approaches, is to find a consistent dataset, at a sufficient level of details, and capable of being analyzed by elaborating and/or using reliable disease indexes. The VESPA Project used mining methods to create a resource of datasets available for agricultural studies (Turenne *et al.*, 2015; Roussey *et al.*, 2016). Despite being rather complete in the general agricultural field (e.g. wheat, fruits, …), the database is lacking information about vineyards. Moreover, the goal of this online archive is to propose a census and, at this time, not an in-depth analysis of any dataset. There are also a significant number of field observations and data collections that lies in technical institutes, and which are more or less available or easy to access. Therefore, and to the best of our knowledge, most the data regarding bio-aggressors in the vineyards is left unexploited in the long term, at least for major French viticultural regions, including the Bordeaux area.

In the context of this study, we have chosen to use the collection of *Bulletins de Santé du Végétal* (plant health reports), given the availability of the documents on a large time scale, and the almost continued consistency that this national governmental institution provides. For the Bordeaux region (France), the plant health reports issued by the *Station d'Avertissements Agricoles* (agricultural warning station), are available from 1940 to 2018. National plant health bulletins represent very valuable pieces of information, but have a heterogeneous data format: they are either qualitative or quantitative, with sometimes a combination of both. Another issue is that they do not scale at the same precision, either technical or geographical. Indeed, when looking at the reports issued on spent of about eight decades, it is noticeable that different methods were used to collect, measure, and characterize the information on grapevine pests and diseases. Nowadays, it is a scientific and technical consensus that plant diseases are defined by three main parameters, i.e. frequency, intensity and severity (Seem, 1984; Madden, Hughes and Van den Bosch, 2007). However, such quantified information was not necessarily used to address status of epidemics at the beginning of the XXth century, or at least it was not the way the assessments were transmitted to the vintners. According to Krebs (2014), these reports can be classified as “guesswork”, i.e. pieces of information that a subject-matter specialist is able to provide based on their expertise and experience. In other words, they are based on expert knowledge, and therefore do not specifically refer to explicit numeric values (like frequency and/or intensity) that could be used in a quantitative analysis. As a result, one of the major challenges in this study was the construction of a preliminary semi-quantitative and statistical description of implicit expert knowledge, a process known as elicitation (Hughes and Madden, 2002). To create a comprehensive and easily re-usable scale, iterative and empirical methods were used, and will be presented in this report.

The present study focuses on the vineyards main bio-aggressors, which are encountered at a national level in various proportions (Dubos, 2002; Bois, Zito and Calonnec, 2017, Appendix 1). Accordingly, our efforts were concentrated on the following six major diseases and pest:

Downy Mildew (DM), Powdery Mildew (PM), Black Rot (BR), Gray Mold (GM), and the Tortricid Moths (TM). To the best of our knowledge, this approach constitutes the first trial in designing and elaborating a multipathogens, long term, dataset, from the plant health reports in viticulture. In addition, other pests encountered in the plant health reports are addressed as secondary bio-aggressors in the appropriate section (Chapter 1, 3.2.3).

The main three objectives of this study, focusing on vineyards in the South-West of France and more precisely on the Bordeaux region, are to:

(i) Collect, cense, and extract the data issue from the plant health bulletins, in order to create a comprehensive and a most complete database;

(ii) Create an index capable of providing an overview and classification of the multiple pests pressures observed in the vineyards from 1940 to 2018 (Chapter 1);

(iii) Analyze and compare these results with quantitative data collected regarding the last ten years (Chapter 2).

The present study was carried in the framework of the Laccave project, which proposes to investigate the effect(s) of climate change on grapevines. These results aim to provide a preliminary source of information, in order to: (i) compare them with bio-aggressors data from other wine regions, and (ii) compare them with climatic data. As an output of this study, the final dataset is expected to be used as a reference in further studies linked with climate change. In addition, the database will be used in an analysis of the evolution of cultural practices, taking into account the relationship between cultural practices and biotic pressures (pers. com. Lionel Delbac).

2. LITERATURE REVIEW

2.1. Vineyard's pests and pathogens

The first settlers faced several issues when they attempted to introduce to introduce European grapevines in North America by the Atlantic shore. The climatic conditions were indeed favorable to fungal diseases, and *Vitis vinifera* a disease sensitive plant. The failure of the implantation of a European vineyard in North America was attributed to diseases known today as Downy Mildew, Powdery Mildew, Black Rot, and Phylloxera. At the time, these diseases were unknown to European winegrowers. In the following section, Downy Mildew, Powdery Mildew, Black Rot, Gray Mold, and Tortricid Moths are presented from an historical point of view, in the chronological order of their appearance in France. Information regarding their biology and impacts on the vineyard are presented in Table 1.

Powdery Mildew (PM)

Powdery Mildew was the first American pathogen to be introduced in Europe. The disease was first reported in England in 1845 (Tucker, 1845), then in France in 1848, near Paris. In a few years, epidemics were reported all across the country. Notably, in 1852 and 1853, vineyards of Côtes du Rhône, Provence and Languedoc suffered heavy losses. The following year, a terrible and national epidemic of Powdery Mildew caused the loss of millions of hectolitres of wine, leading to an economic crisis for the wine industry and the migration of viticulturists to major cities or in other countries such as Algeria or Argentina (Geoffrion, 1976; Galet, 1982). After 1855, the discovery that sulfur could be used to fight the disease, and the development of methods for large-scale application, brought the disease under control in France and much of Europe.

Downy Mildew (DM)

From his observations on potato, the German botanist Scheinitz proposed in 1837 a scientific description of the suspected fungi, which he called *Botrytis cana*. It was later revealed that he was referring to a variation of an already known pathogen: *Botrytis cinerea*. In 1863, De Bary proposed the name *Peronospora viticola*, following his observations on the reproductive cycle of the organism. In 1888, Berlese and De Toni observed the production of sporanges and proposed to classify the pathogen in the *Plasmospora* genra. As a result of their work, a new scientific name was appointed, *Plasmospora viticola* (Global biodiversity information facility, 2019). In the current language, the name "*mildiou*" derivate from the English term Mildew, and the pathogen nowadays belong to the Chromista reign.

Following the devastating epidemic of Phylloxera and the introduction of American vines to reconstruct European vineyards by grafting, in 1872, Maxine Cornu expressed his concerns regarding the possible associated introduction of American pathogens. At the time, it was estimated that the beneficial use of rootstocks overcame this risk. Nevertheless, in 1878, the first case of Downy Mildew in France was reported near Coutras (Gironde). In the following fifteen years, massive epidemics were deemed responsible for the loss of about 50% of the French grapevine production. At the beginning of the XXth century, it was reported that the vintages were highly contrasted, with cycle of years of massive loss and years virtually free of disease. Years like 1908, 1910, 1915, 1921, and 1930 were referred to "*Années à mildiou*" in numerous text books (Siriez, Geoffrion and Roussel, 1978).

Black Rot (BR)

Black rot was first identified by Viala and Ravaz in 1885 in the Hérault region. It spread over South-West of France, where it caused important epidemics, notably from 1896 to 1898, and again from 1902 to 1904. Indigenous from North America, Black Rot occurs on portions of Europe, South America, and Asia. It is unknown in Chile, anecdotic in Switzerland, and a quarantined pathogen in Australia (Wilcox, Gubler and Uyemoto, 2015). The disease can poses serious threats in regions with remaining free water, moderate temperatures, and warm weather. Nowadays, the impact of Black Rot in vineyards is mostly controlled by several groups of modern fungicides. However, all cultivar of *Vitis vinifera* appear highly susceptible to the disease. The susceptibility of "fungus resistant" varieties could benefit from investigations, since managements systems tend toward the reduction of the use of pesticides, or the use of such varieties (Delière *et al.*, 2017).

Gray Mold (GM)

The first possible reference to Gray Mold is attributed to Pliny The Elder, back in the Antiquity. From old records, the fungus is believed to have caused multiple crop losses in the Middle Age, notably in the 1310 to 1410 period (Galet, 1982). The name *Botrytis* was appointed by De Bary in 1886, from an Ancient Greek and Latin contraction, meaning "grape disease". *Botrytis cinerea* is a necrotrophic fungus that affects numerous plant species, and is found in vineyards throughout the world. The regions were the disease is the most severe are characterized by moderate temperatures, and rainfall or extended periods of high humidity between veraison and harvest. Yield reductions are often associated with pre or post-harvest berry rot, and sometimes damaged flower clusters early in the season. Quality loss results from the modified chemical composition of diseases berries. Under a certain set of cultivar and weather conditions, Botrytis infections can lead to the development of "noble rot". In the Bordeaux region, the appellation Sauternes is renowned for its production of sweet white wine, consecutive to noble rot.

Tortricid Moths (TM)

Under the appellation Tortricid Moths are considered *Lobesia botrana* (European vine moth; "*Eudémis*"), and *Eupoecilia ambiguella* ("*Cochylis*").

Due to its early appearance and severity of its damage, *Cochylis* was one of the first pest for which there was a need to know its behaviour and biology in order to control it (Galet 1982). In 1740, Charles Bonnet of Geneva gave the first description of the damage caused in the vineyard by a reddish caterpillar. It was then mentioned in 1769 in the Academy of Dijon, then in 1770 in Burgundy under the name of "Mazard". In 1771, following the considerable losses it caused to the vineyards of Champagne, Bourgogne, Beaujolais, Lyonnais and Dauphiné, Abbot Rozier wrote about "*Teigne des grains*" in his "*Mémoire des insectes essentiellement nuisibles à la vigne*". The pest was then mentioned several times, under several names. In 1796, Hubner proposed the first detailed description of the pest, and the name *Tinea ambiguella*. In 1799, damage were reported in Crimea, later in Germany on the Reichenau Island or near Stuttgart, and other places. The insect is a widespread pest across vineyards, although it is considered more as a northern pest, and presents a different economic importance according to the regions where it is found

With the appearance of *Eudémis* on grapevine at the beginning of the XXth century, winegrowers had to control two pests, which fortunately had many common features. At the time of the harvest, it was common to find a lot of caterpillars on the racks or presses. In wet years, the subsequent Botrytis attacks were very serious on the tight-grained grape varieties and made winemaking delicate. The absence, for a very long time, of sufficiently effective insecticides explains the extraordinary outbreaks of the two grapevine moths. The situation was such that in 1911, the French Parliament voted a credit of five million francs for the wine growers of Maine-et-Loire, in the form of free distribution of lead arsenite. In some regions, the noble grape varieties with tight grapes were even pulled out and replaced by less dense hybrids with bunches. The discovery of new insecticides and improvements in treatment equipment have significantly reduced the economic importance of Tortricid Moths since the end of the Second World War.

Nowadays, it is common to observe two annual generations of *Cochylis* (with a possible third), and three generations (with a possible fourth) of *Eudémis*, the third and fourth being particularly present in the vineyards of the South of France. The proportion of the two species is quite variable depending on regions and years. In the Bordeaux region, *Eudémis* is usually more abundant than *Cochylis*. Their respective damages are not of the same importance, and the attacks are very often localized to certain plots (Galet, 1982; Thiéry, 2008). Eggs and butterflies are relatively resistant to insecticides, and it is important to note that their presence in a vineyard does not necessarily imply the appearance of damage. Moreover, as the latter have already done their damage, any late destruction would not be of any interest. Therefore, management strategies relies on young caterpillars, which are more sensitive to insecticides and whose possible damage is more limited.

Table 1. Synthetic presentation of selected vine diseases. The concerned host is Vitis vinifera (harmfulness, susceptibility).

Disease	**Downy Mildew (DM)**	**Powdery Mildew (PM)**	**Black Rot (BR)**	**Gray Mold (GM)**
Causal agent	*Plasmopara viticola*	*Erysiphe or Uncinula necator*	*Guignardia bidwellii*	*Botrytis cinerea*
Biology	Biotrophic Chromista Polycyclic	Obligatory parasitic fungus Polycyclic	Fungus Polycyclic	Necrotrophic fungus Polycyclic
Favorable climatic conditions	Repeated rainfall, temperature between 20 and 25°C	High relative humidity, temperature between 10 and 30°C	Presence of free water	Rainfall at flowering and maturation
Host susceptibility	Over the herbaceous period (max on young organs), and up until veraison for the clusters	Over the herbaceous period. Max between 2-3 leaves separated and setting, and up until veraison for the clusters	All new growth, with ontogenic, age-related resistance (late appearance of symptoms). Maximum susceptibility from bloom to 3-5 weeks after bloom	Mostly at the beginning of the herbaceous period (inflorescences), then after veraison and up until harvest (berries)
Main symptoms	All green parts of the vine: - Young leaves: facies “oil spot” - Inflorescences and young berries: facies “grey rot” - Old berries: facies “brown rot” - Fall leaves: facies “mosaic”	- Young leaves: facies “flag” - Leaves: white then silver-grey colonies on the lower leaf surface, necrosis - Inflorescences: abortion, coulure - Old berries: necrosis	- Leaves: roughly circular and dark-brown lesions, presence of black Pycnidia on the lower surface - Berries: cream colored to brown necrotic spot - End of season: mummies	- Inflorescences: stalk mold - Berries (after veraison): rot, wilting, desiccation. (often from the center of bunches)
Harmfulness	- Decrease of photosynthesis, - Leaf fall - Destruction of tissues - Yield and quality loss	- Diversion of assimilates - Destruction of tissues - Yield and quality loss (coulure, berries fall, …)	- Destruction of tissues - Yield loss	- Diversion of assimilates, production of damaging compounds - Destruction of tissues - Yield and quality loss (rotting berries, blight, rots)

2.2. Avertissements Agricoles – Diseases and pathogens records – Dataset

History of Agricultural warning stations

The *Station d'Avertissements Agricoles du Sud-Ouest* (warning station) was created in 1898, in Cadillac (Gironde), by Cazeaux-Cazalet and Capus. The aim was to provide the agriculturists with information regarding the major diseases at the time, mostly by advising dates of treatments. Growers thus received telegrams regarding ongoing epidemics of pathogens known at the time (i.e. Downy Mildew, Powdery Mildew, Black Rot,…). At the same time, in Montpellier, Houdaille and Ravaz, two professors at *Ecole Nationale d'Agriculture de Montpellier*, created their own regional warning system. As a consequence of a terrible frost on March 26, 1898, they organized a meteorologist service that would provide the local growers with information regarding weather forecasts, frost risks, and general advices for agricultural work. This work is considered as one of the first bases of integrated pest management. Following the success of the reports, the French Parliament created in 1911 a *Service Général de Météorologie Agricole*. In 1914, the service was officially established as *Service d'Avertissements Agricoles et de Météorologie appliquée à l'Agriculture*, and dispatched in several stations across regions of agronomical importance. At the time, the directives were to (i) study the influence of meteorological phenomena on vegetation and the inverse action of vegetation on climates; (ii) contribute to the improvement of agricultural production and study rational protection against bad weather; and (iii) provide, as much as possible, a weather forecasting service and agricultural warnings.

The organization included a technical committee, a central inspection service and regional stations. In 1922, following the establishment of the national *Office Météorologique*, the *Service d'Avertissements Agricoles* was attached to the *Institut National des Recherches Agronomiques* (national institute of agronomic research), and moved to the Domaine de Grande Ferrade (Villenave d'Ornon, Bordeaux). Its new mission was to focus on research regarding the main crop enemies, and to determine the best cultural techniques to prevent them. In 1935, the Bordeaux station covered the departments of Gironde, Landes, Gers, Lot-et-Garonne, Charente, Charente-Inférieure, Dordogne, and Vienne (Marchal *et al.*, 1936). From 1943 to 2008, the agricultural warnings were managed by the *Service de Protection des Végétaux*, and focused essentially on perennial crops. The reports progressively incorporated annual crops, such as vegetables, maize and colza.

Since 2009, plant health reports known as *Bulletins de santé du végétal* are issued by the *Service Régionaux de l'Alimentation* (SRA1), in collaboration with multiple organisms, notably *DRAAF (Direction Régionale de l'Alimentation, de l'Agriculture et de la Forêt)* and *FREDON (Fédération Régionale de Défense contre les Organismes Nuisibles).* The SRA1 is attached to the *French Ministère de l'Agriculture*, under the *Direction Générale de l'Alimentation* (Agerberg 2011). Nowadays, in the framework of the Ecophyto plan, epidemio-surveillance in French vineyards aims to:

(i) follow diseases and pests that required treatments (e.g. Downy Mildew, Powdery Mildew, Gray Mold, Tortricid Moths), and accordingly propose management strategies that takes into account modeled risks factors;
(ii) follow pests of which the monitoring is regulated by law (i.e. *Flavescence dorée,* submitted to mandatory declaration and treatment);
(iii) follow other bio-aggressors (e.g. viruses) or dieback monitoring (i.e. grapevine trunk diseases).

For the Bordeaux region, monitoring is performed on a network of more than 2 000 plots, consisting in treated ("*parcelles de référence*") and non-treated plots ("*témoins non traités*"). On average, eighteen BSV are issued from mid-March to mid-August each year.

Documents layout, type of information, evolution over time

From the beginning, the warning stations issued regional reports that were sent to the growers at variable intervals. In this study, they are referred to as seasonal reports. According to field observations, and later epidemiological models, the agents proposed strategical and practices advices. The first bulletins were sent to subscribers in the form of telegrams, and consisted in short sentences, mostly advising about the necessity of treatment in the vineyard (
Appendix 3). Progressively, the content of the reports enhanced as research improved, to reach a format of about 2 to 3 pages (Appendix 4).

Since 2009, plant health reports provide farmers with weekly disease risk assessments. The reports are written by regional experts, and are based on available information and translated through their expertise. Several protocols have recently been developed to conduct risk assessments (EFSA, 2011), and the information summarized in the reports originates from several sources, such as field surveys, epidemiological model outputs, and experimental data. Weekly reports are available for free (https://agriculture.gouv.fr/bulletins-de-sante-du-vegetal) for 16 regions of agronomical importance, and send to the producers via email. The exact layout of the reports depends of the crop and the region for which it is issued, with some regions being bigger than others. As an example, the weekly reports for vineyards of the Bordeaux region are issued under the name "*BSV Nord Aquitaine*". They consist in about 10 pages of information regarding: climatic data (last observations and weather forecast on the following week); statements about the general phenological status of the vineyard; a section regarding pathogen and pests epidemics, with general information about biological cycles, field observations, and risks assessments (IFV model, Raynal et al. 2006).

In addition to the weekly reports, annual reports are also available. Regarding vineyards of the Bordeaux region, the first archive that where retrieved was the annual report of the growing season 1943 (UMR SAVE, Lionel Delbac). Since then, annual reports were issued almost every year, at the end of a growing season or the beginning of the next one. They represent the main source of information of the present study (Appendix 2). The period 1970 to 1982 is missing annual reports following relocation of the warning station to another facility (Bernard Guery, pers. comm.). The layout of the annual reports is close to that of seasonal reports, but they review the entire growing season instead of focusing on weekly assessments. They consist in: an inventory of the plot network, a climatic review of the growing season, a phenological status through time of the vineyards, and a review of the biotic and abiotic pressures during the growing season.

2.3. Presentation of the main principles used

In all of the methods of modelling and analysing data, assumptions are made in order to correctly conduct statistical analysis and interpret results (Xu, 2006; Madden, Hughes and Van den Bosch, 2007). Assumptions can be specific to each analytical method, whereas some others are needed in order to generally progress in an analysis. In this study, iterative methods of trials and errors were used. The hypothesis and thoughts processes and will be presented in the method section of each chapter. The main tools and principles used are presented in the following section of the literature review.

Important definitions in plant diseases epidemics

Plant epidemiology is defined as "the science of populations of pathogens in populations of host plants, and the diseases resulting therefrom under the influence of the environment and human interferences" (Kranz, 1990). It involves the disease triangle of host, pathogen, and environment. Environment can be divided as abiotic and biotic components. Abiotic disorders are caused by non-living factors, such as weather conditions, mechanical or chemical injuries, soil, nutrients balance. Abiotic disorders are more likely to occur to several types of plants, and not to spread from plant to plant. On the other hand, biotic stresses or disorders are caused by living organisms, such as fungi, bacteria, insects, or virus. Biotic disorders are more likely to be species dependant, and spread from one plant of a susceptible species to another plant of the same species. Although some symptoms for abiotic and biotic disorders can appear as visually similar, a more precise observation and examination of the surroundings of a symptomatic plant can lead to differentiate the nature of a disorder. In the case of biotic disorders, symptomatic plants are affected by a living organism, which can be directly seen (e.g. Red spider mite), or assessed through its reproductive organs (e.g. Powdery mildew conidia, on the under surface of a leaf). Diseases can affect the visible organs of a plant, or other organs that are far less visible (e.g. white rot in the case of grapevine trunk diseases). The present study focuses on biotic disorders caused by Downy Mildew, Powdery Mildew, Black Rot, Gray Mold, and to a lesser extent pests like Tortricid Moths.

Disease assessment or disease estimation is the starting point in the characterization of an epidemic, and the base for following analyses and interpretation. Plant pathologists have been attempting to obtain quantitative information on disease severity through visual assessment for over a century (Cobb, 1892). Usually, the observer reports an estimate of the area of the specimen that is affected by the disease. The assumption is that the observers make reasonable estimates of the relative affected area by visual inspection, with or without the help of specific lecture grids (Madden, Hughes and Van den Bosch, 2007). In the present study, visual observation is the main method used by the experts to characterize epidemics in the annual plant health reports (EFSA, 2011). The experts used qualitative data (or key-words) during the longest period (1940 to 2018) to express their results in the plant health reports.

Phytopathology is a science defined by some core concepts. Like in any other science, definitions can vary among the authors, and some terms have close meanings and can be misused, voluntarily or not (Seem, 1984; Lilienfeld *et al.*, 2015). For consistency purpose, the following definitions are extracted from the work of Madden, Hughes, and Van den Bosch (2007). Epidemic is defined as "a change in disease intensity in a host population over time and space". Therefore, it is a dynamic process, of which the study involve characterizing rates of change; in population, space, and time. Indeed, epidemics do not exist at the same intensity everywhere at a given time. As an example, in perennial crops, the intensity of a foliar disease tends to increase during the growing season, and will eventually decrease at the end of the season as defoliation occurs.

Incidence is used to measure the proportion of plants units diseased (or the number diseased) out of the total number of plants observed. As there can be different types of plant units, there can be different types of incidence. As an example, one can assess the plant at the organs level, at the whole plant level, or at the field level. According to the definition of the BSV, "**mean frequency of attack**" is a measure of incidence. As a result, in Chapter 2, mean frequency of attack is the number of affected organs, on the total number of observed organs. The term disease prevalence is also a measure of incidence, but it is used at the field level. **Prevalence** is defined as a proportion or number of fields with diseased plants. In the case of our study, disease prevalence refers to the proportion of diseased fields, on the total number of observations (i.e. "*parcelles de reference*") on the BSV/IFV plots networks. In Chapter 1, as explained in more depth in section 3.2.1, the disease prevalence is assigned to a class value (i.e. "local" or "general"). In Chapter 2, as explained in section 4.2.2, according to the source material, mean prevalence is a continuous value, measured at the plot level.

In order to assess the degree of infection of a host, the **severity** can be measured. The term disease severity is used to assess the area of plant tissue affected by a disease. It can be relative or absolute, and is generally expressed as the proportion (or percentage) of host area affected. In Chapter 1, severity is a discrete variable assigned to a class value (i.e. "null", "low", "medium", or "high"). **Intensity**, as a general term, characterizes "the magnitude of disease or infection". However, it can also be used to encompass disease incidence and severity. In the case of our study, and in order to stay true to the original material, the term intensity is used in Chapter 2 in accordance with how it is defined in the BSV. Therefore, the "**mean intensity of attack**" represents the surface of the plant occupied by the disease, on the total surface observed. In other words, severity is a discrete class value in Chapter 1, and intensity is a continuous value measured in Chapter 2, and both refer to the area of the plant infected.

Search for the highest indicator of an epidemics

In order to assess the highest indicator for each of the studied diseases, and throughout the study, information regarding the epidemics was extracted close to veraison. Indeed, veraison represents the period up to where grapes are the most susceptible to Downy Mildew, Powdery Mildew and Black Rot (Calonnec *et al.*, 2004; Rossi, Caffi and Gobbin, 2013; Fermaud *et al.*, 2016). Veraison exact date is year, region, and variety dependant. Nevertheless, in the Bordeaux region, the phenological stage can be estimated to take place around days 200 to 250, i.e. between the end of July and to month of August (Parker *et al.*, 2011; De Cortázar-Atauri *et al.*, 2017). For GM, information regarding the epidemics were extracted close to harvest, as it is the period were grapes express most of the disease symptoms.

Relationships in plant disease epidemics

The data set of Chapter 2 (quantitative date from annual BSV and IFV original data, on the period 2010-2018) consisted in numerous variables regarding the epidemics of DM, PM, and BR. For each of the three diseases, the following information were available: intensity on leaves, intensity on clusters, frequency on leaves, and frequency on clusters, at fifteen and up to twenty two times for each of the eight years. The incidence-severity relationship fall into three categories of analysis: correlation and regression, multiple infection methods, and measurement of aggregation (Seems 1984). In this study, we were able to use correlation and regression analyses in order to characterize this relationships, and transform a large number of variables into a simpler set of variables. Correlation indicates the degree to which two variables are linearly associated, without indicating the nature of the relationship. When the correlation is significant, the similarity of the two variables allows the analyst to use of either one of the values for disease assessment (Gorter, 1974). This process was used in Chapter 2 in order to simplify the use of the many variables available, and was applied to the datasets in 4.2.2 and 4.2.3.

Class scale

When analyzing a large, complex data set, a set of conditions is usually required (Scherrer, 1984). However, disease or pest variables sometimes do not comply with such a series of prerequisites, as the data can be quantitative, qualitative, or a combination of both (Madden, Hughes and Van den Bosch, 2007). Therefore, in order to analyze a long and heterogeneous data set of disease epidemics, transformation is often needed. To this end, methods that allow simultaneous handling of both types of attributes and that do not imply *a priori* assumptions are the most desirable (Savary et al. 1995).

A way to make qualitative variables comprehensible is to encode them into classes (Zwankhuizen and Zadoks, 2002). In order to process qualitative information, a discrete, ordered categorical scale was designed. An **ordered scale** is defined when an ordinal value is given to each measure with respect of the property of interest. The values are only interpretable in terms of their arrangement in a given order, not proportionally to the difference of the values used (Madden, Hughes and Van den Bosch, 2007). In other words, on a scale from 0 to 6 relative to the severity of a disease, a measurement of “3” does reflect a higher severity than a measurement of “2”, but the numerical difference between 3 and 2 has no numerically interpretable meaning. Likewise, the increase in actual severity between scores or 2 and 3 is not necessarily the same as the increase between 1 and 2. In our study, the difference between each grade of the scale is a qualitative measure of “low”, “medium”, or “high”.

Statistical analysis

The process of converting quantitative or qualitative data into an ordered scale is flexible, and the degree of precision and complexity of the analyses depends on the research questions (Xu, 2006). Each analytical method is best suited to answer specific questions, given the nature of the data set. According to Savary et al. (1995), there are no statistical restriction for this process. However, one must be careful of the number of classes regarding the size of the sample when using contingency tables and χ^2 (chi square) tests. In this study, we used contingency tables where the first variable was the severity of a given disease (class scale), and the second variable was the time (on a yearly basis). Such contingency tables, or rank correlation tables, were used in Chapter 1 to propose a first glance at the bivariate frequency distributions. In order to confirm the suggested pattern of the data, χ^2 tests were performed in various conditions. First, a large scale multipest test that used the data from the five main diseases and examined their temporal distribution, and then a series of monopest tests that focused on each of these main pathogens across the entire period of the study (1940 to 2018) or selected periods of time. The null hypothesis was always the independence of the distribution frequency of the two variables. The validity of the χ^2 test relies on the expected sizes of groups, and should generally only be applied to groups with a minimum size. The minimum size varies according the authors (Scherrer, 1984), but Cochran and Snedecor (1971) suggested that the minimum size can be fixed at 1.

Survival curves

Based on the ROC time-dependant curves from the medical field, survival curves were adapted for grapevine Downy Mildew epidemics by Chen et al. (2019). The use of survival representation allows the user to observe the dynamics of the proportion of plots with no symptoms on the chosen organ, over the growing season or multiple seasons. Significant relationship between the proportion of plots with symptomless clusters and the date of appearance of DM on vines was found. According to Chen et al., the earlier the symptoms appeared on bunches, the higher the DM symptoms were on vines. These results could help to understand the dynamics of DM epidemics, showing highly variable incidence across the years mostly attributable to climatic and biological factors (Kennelly *et al.*, 2007; Rossi *et al.*, 2008).

Since 2010, weekly monitoring from untreated sites in Bordeaux vineyards were used to estimate the timing of DM onset, and represent the source material for Chapter 2. The survival function is based on the proportion of symptomless plots and the time of the epidemics appearance, at a given threshold. The binary function characterizes the unaffected (1) versus the affected (0) proportions of plots, and is declined for clusters and leaves. Thresholds are used to characterize the severity of the symptoms; e.g. 5% of bunches affected, 10% of leaves affected. Positive values for given threshold represent the percentage of plots that were asymptomatic below said threshold (i.e. that survived the threshold). In other words, for a threshold of 25% and on grapes, if the value for DM epidemics in 2018 is 8, it means that 8% of the plots do not display at least 25% of DM symptoms on grapes. In other words, 92% of the plots were affected with at least 25% of DM symptoms on grapes, thus marking 2018 a year of high DM pressure. Accordingly, survival curve results are inversely proportional to the studied epidemics.

Structure of the report

The main goal of this study was to create an adequate scale to assess the available data, and be able to represent the pressure of given pests on the vineyards accordingly. The first step was to investigate and synthetize the type of data available. Indeed, on the spent of about eight decades, a lot of data was available, but it did not depict the same information. A common ground was that all bulletins used qualitative terms to describe the epidemics at the vineyard, but those observations were highly dependent of their historical, scientific, and technical contexts. They represent a certain expertise, regarding the available data and knowledge of their respective time.

Chapter 1 will present the design of a semi-quantitative scale created in order to analyze the epidemics of DM, PM, BR, GM, and TM. Data were extracted from plant health reports on the 1940-2018 period. Chapter 2 will present the design of three indexes (Index_BSV, Index_IFV, Index_SC) for epidemics of DM, PM, and BR. Data were extracted from plant health reports and a secondary database on the 2010-2018 period. As the creation of the semi-quantitative scale and indexes was based on methods with preliminary steps and hypothesis, some minors results used to tune the methodology will be presented in the method sections of each chapter (sections 3.1 and 4.1). We consider the main results of this study the presentation and analysis of diseases and pests pressures on the Bordeaux vineyard. Accordingly, they will be presented the results section of their respective chapter (sections 3.2 and 4.2); followed by a respective discussion (sections 3.3 and 4.3). A general discussion on both chapters will be presented in section 5, followed by a general conclusion and proposition of perspectives in section 6. Note that throughout the report, French qualitative and descriptive terms extracted from the plant health reports are reported in italics, in order to quote the original dataset.

3 CHAPTER 1: Historical characterization of diseases and pests pressure in the Bordeaux vineyard from 1940 to 2018.

3.1 Method

3.1.1 Presentation of the dataset

Fist, the collection of seasonal and annual plant health reports issued by the *Service de Protection des Végétaux*, regarding Bordeaux vineyards from 1924 to 2018 were gathered, sorted and registered. A digital database was created by extracting, for each year, information that characterized the epidemics of Downy Mildew, Powdery Mildew, Black Rot, Gray Mold, Tortricid Moths, and any other bio-aggressor mentioned in the reports. This information consisted in original key-words or short sentences regarding each bio-aggressor, and that were used in the reports to describe and characterize their associated epidemics. The years before 1940 were excluded from the analysis, as the reports were either not readable, or incomplete. For the 1940 to 2018 period (i.e. 79 years), information on the epidemics were extracted in priority from the annual plant health report of the year considered. The annual reports consist in information available after harvesting (see 2.3). Additional data from seasonal reports was extracted when necessary and according to their availability (mainly, years 1970 to 1986). Data from seasonal reports were extracted at the time of veraison. To a lesser extent, the last complementary source was the collection of annual national reviews published in Phytoma (three years, 1974, 1976 and 1998). An exhaustive list of the source material used for this chapter is available in Appendix 2.

In order to always assess the maximal pressure of the diseases, and for constancy purposes, the most important epidemics factors were always selected. In accord with the raw material and the database, the study focused on two main characteristics of the epidemics; prevalence and severity. Those terms, according to the source material, and as they are used in this chapter, will be described in the two following sections.

Characterization of the zone of the study and prevalence

In this study, we use the “prevalence” variable to characterize the spread of a given disease within the studied geographical zone. The study focuses on the Bordeaux region, in the Gironde department, in the South-West of France. The reports from the series concerned either the Aquitaine region and its *departements,* or only the Bordeaux region, depending of the year they were issued. Until January 2016, the Aquitaine region was composed of five *departements*: Dordogne, Gironde, Landes, Lot-et-Garonne and Pyrénées-Atlantiques. As a result, the following rules were applied when assessing the prevalence from the database. When the Aquitaine region was addressed, without any precision, it was considered as general. When the *departements* Dordogne, Landes, Lot-et-Garonne and Pyrénées-Atlantiques were mentioned, the information was excluded from the grading. When the Gironde *department* was mentioned, the information was considered as general.

In the Bordeaux region, six sub-regions were identified: Blayais, Entre-deux-mers, Graves, Landais, Libournais, and Médoc. When one and up to three of these sub-regions were mentioned, the information was considered as local. When more than three of the previous sub-regions were mentioned, the information was considered as general. When other Appellations (as defined by the INAO were mentioned, the information was considered as local. When it was mentioned that an epidemics affected a few plots ("*quelques parcelles*" and the likes), historical plots ("*foyers historiques*" and the likes), or non-treated areas ("*parcelles non traitées*" and the likes), they were considered as local outbreaks.

Characterization of the diseases, and severity

For each disease, the severity was assessed according to the main word (or key word) used to describe the epidemics in the annual review. The key words were considered representative of the overall epidemics of a given disease for the concerned year. For example, key words such as "*sain*", "*faible*", or "*pas dangereux*", graded the pressure for a given disease as low. Key words such as "*quelques sorties*", "*des observations*", or "*moyen*" were graded as mean. Key words such as "*dangereux*", "*grave*" or "*explosif*", graded the pressure as high. Those assessments were combined with the prevalence assessment in order to attribute a grade, as described in the following section. Most efforts were made in order not to grade a year solely on its severity or prevalence factor, but rather according to a combination of both, which required the design of the scale presented below.

3.2.1 Construction of the scale

In order to treat the qualitative data, there was a need to create a semi quantitative scale, accepting some arbitrariness of classification. In their study, Zwankhuizen and Zadoks (2002), used a five points scale (0-4) to address the intensity of annual potato late-blight in the Netherlands. This scale was recently used on grapevine for a multipest damage indicator, called Assessment Indicator of Damage in grape Bunches (AIDB), by Fermaud et al. (2016), and a first grading trial was set up by using sixteen (16) of the seventy-nine (79) available reports, arbitrarily picking the years ending in three and eight across the period (e.g. 2018, 2013, 2008, 2003…).. When using this scale, numerous issues emerged, the main one being that the five points scale did not allow to characterize most of the epidemics encountered. Indeed, this scale mixed information regarding severity and prevalence in a way that it was not possible to easily distinguish both information. Consequently, numerous years ended up with the same grade, or were assigned an ambiguous grade. Thus, the AIDB/Zadoks' scale was used as a reference in order to design a new classification, based on the key-words for prevalence and severity, and more suited to our dataset. As a result, a new seven point's scale was designed, and is presented in Table 2. On this scale, prevalence is defined as the geographical dispersion of a disease (local or general), which is characterized in the previous section. The severity is defined by the impact of a disease for a given bio-aggressor (null, low, medium, high), and is characterized in the previous disease section.

Table 2: Semi quantitative scale for main bio-aggressors.

		SEVERITY			
		Nul(le) Null	*Faible* Low	*Modéré(e)* Medium	*Fort(e)* High
PREVALENCE	*Nul(le)* Null	0	-	-	-
	Local(e) Local	-	1	2	3
	Général(e) General	-	4	5	6

Another intermediary scale in six points (0 to 5) was considered for the study. It allowed the ranking to be closer to the reality of an epidemics, as the couple of “local x high” was placed above the couple for “general x low”, thus being closer to the referenced AIDB/Zadoks’ scale (Zwankhuizen and Zadoks, 2002; Fermaud *et al.*, 2016). However, the creation of one more scale point (0 to 6) allowed the present study to easily distinguish the prevalence of an epidemics. Indeed, in this configuration, grades from 1 to 3 instantly depict a local epidemics, whereas grades from 4 to 6 refer to a general epidemics. Moreover, this grading system allowed to distinguish low pressure and high pressure years with better accuracy, i.e. the extreme ends of the scale, which is of the outmost interest.

3.1.2 Statistical analyses

In the study, the response variable was the grade proposed in Table 2. Two types of tests were performed on a monopest basis, and one test on a multipest basis. First, grades for each of the five main bio-aggressors (DM, PM, BR, GM, and TM) over the entire period were compared by using a χ^2 contingency test. Second, grades for each of the five main pathogens were tested over three key time periods of roughly thirty years: 1940 to 1969, 1970 to 1999, and 2000 to 2018. Periods were compared by using χ^2 contingency test, and Fisher’s exact test. Third, bivariate relations between four selected couples of pests were analysed using Spearman’s rank correlation (non-parametric). The couples were selected according to hypotheses that will be presented in the appropriate results section. As the present study relies on qualitative and semi quantitative assessments, results presenting a type I error (α) from 5% up to a threshold of 10% were considered indicative of a trend. Accordingly, tests were carried with both thresholds; 5% ($p=0.05$) and 10 % ($p=0.10$). Contingency tables and χ^2 tests were performed on MS Excel 2013. Fisher’s exact test and Spearman’s correlation were performed with the add-on XL STATS (Addinsoft).

3.1.3 Secondary bio-aggressors

By opposition to the main bio-aggressors as assessed previously, the secondary bio-aggressors list consists in all the other pathogens or pests that were mentioned, often in a very limited amount of text, and exclusively in the annual reports. When no annual reports were available, the list was not completed by any other of the sources. The nature of this list was unknown at the beginning of the analysis, and its final version will be presented in the appropriate results section (Table 5).

The secondary bio-aggressors were assessed based on their coverage in the annual reports, according to an occurrence-based scale (Table 3). If the bio-aggressor was not mentioned, the grade was 0. If the bio-aggressor was mentioned, but with no indication regarding its impact on the vineyard (damage), the grade was 1. If the bio-aggressor and its damage on the vineyard were mentioned, the grade was 2. The total number of mentions of each secondary bio-aggressor was assessed on the total number of years studied (i.e. 57 years). Lastly, a visual map was established according to the grades of each bio-aggressor for each year, in order to visualize disease patterns.

Table 3: Scale for secondary pests.

Grade	Mentioned	Damage
0	No	-
1	Yes	Not specified
2	Yes	Yes

3.2 Results

Over the studied period, 1940 to 2018, plant health reports were collected for 75 over 79 years (Appendix 2). On the four years 1940, 1941, 1942, and 1944, annual and seasonal reports were missing. However, we were able to extract information regarding the epidemics of Downy Mildew and, to a lesser extent, of Powdery Mildew and Black Rot, from reports of other years in order to assign a grade to these diseases. The majority of the years were graded using annual plant health reports (57 years over 75). Moreover, 15 years were graded by using seasonal plant health reports (mainly, 1970 to 1986), as no annual reports were issued these years. Lastly, 3 years were graded by using the annual and national reports issued by the journal *Phytoma*.

Monopest results

The distribution for DM, PM, BR, and GM is presented in Figure 2. For DM, PM, and BR, the grades distribution tended to be asymmetric on the left side and towards medium values (around grade 2). For GM, the grades distribution tended to be bimodal, with peaks of grades 3 and 1, followed closely by grades 2 and 4.

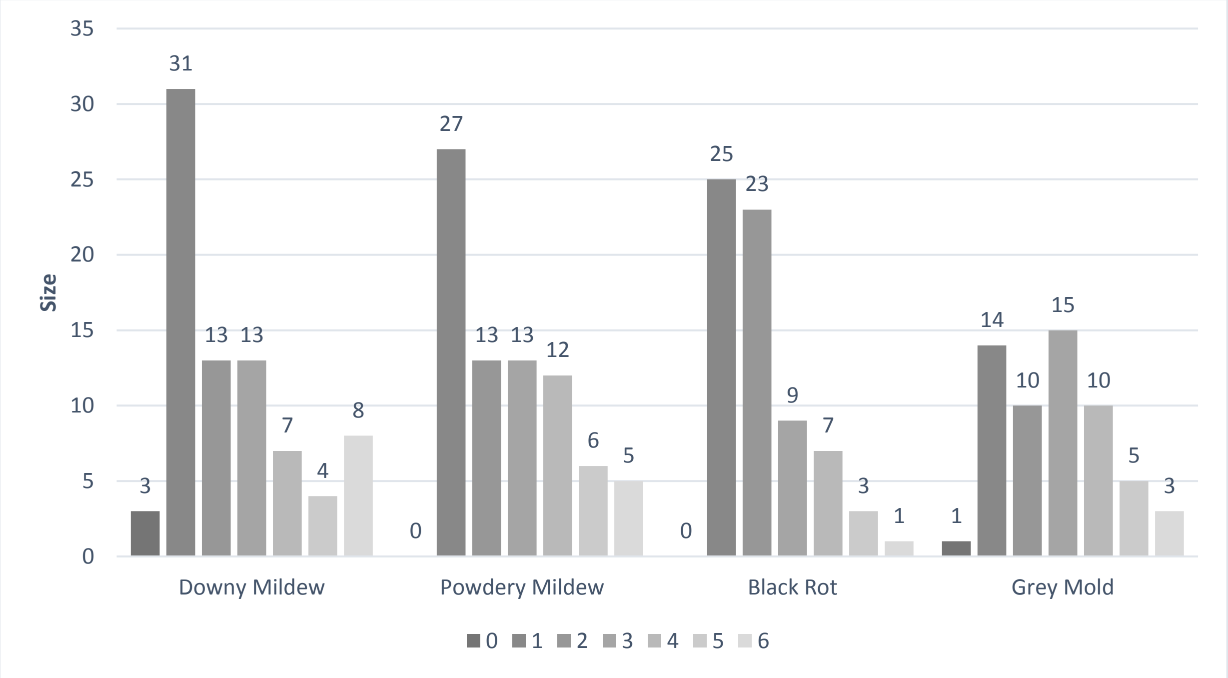


Figure 2. Pressure grades distribution of DM, PM, BR and GM, over the 1940-2018 period.

The pressure grades of each of the four main bio-aggressors (DM, TM, BR and GM), expressed according to the scale presented in Table 2, is presented over the years 1940 to 2018 in figures 3 to 6. Grey bars displays the years where no data was available. According to a χ^2 contingency test, the grades distribution appeared to not be statistically different between each disease and each year (*P*=0.09).

Figure 3 presents the results for Downy Mildew. The entire period of 79 years was covered. In 8 years (1940, 1948, 1977, 1988, 1999, 2000, 2008, and 2018) the Downy Mildew pressure was estimated as high and general across the region (i.e. "*extrêmement virulent et général*", and "*pire de ces dernières années*" in the text). With 10% of its grade being the highest on the scale, Downy Mildew has the highest frequency of very high epidemics of the five main bio-aggressors. The highest pressure years (grade 5 and 6) were represented 12 times (15%) over the period 1940-2018. On the other hand, the pressure was null in 3 years (1972, 1975, 1976), and weak and local (grade 1) in 31 years. For the remaining 33 years, the pressure was estimated as intermediate (grades 2, 3, or 4), which represents 42% of the years considered.

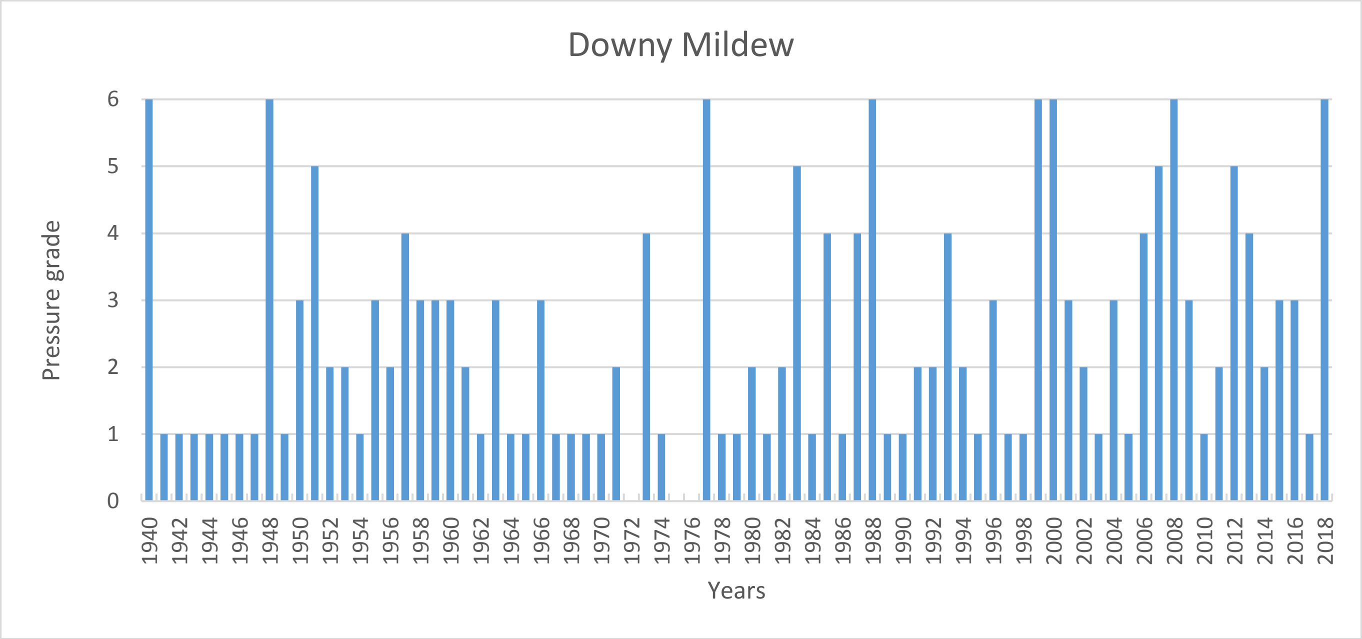


Figure 3. Annual pressure of Downy Mildew (semi-quantitative 0 to 6 scale), in vineyards from the Bordeaux area, from 1940 to 2018. All 79 years of the study are represented.

Figure 4 presents the results regarding Powdery Mildew. A period of 76 years over 79 was documented (96%). In 5 years, the Powdery Mildew (1953, 1954, 1975, 1997, and 1998) pressure was estimated as high and general across the region; which is the second highest frequency over the five main bio-aggressors. The highest pressure years (grade 5 or 6) were represented 11 times (14%) over the period 1940-2018. On the other hand, there was no year in the whole period with an absence of the disease (grade 0). Weak and local (grade 1) epidemics were assessed on 27 years, with the main words used to describe the epidemics being "*pas très important*" and "*faible*". For the remaining 38 years, the pressure was estimated as intermediate (grades 2, 3, or 4), which corresponds to 50% of the considered period.

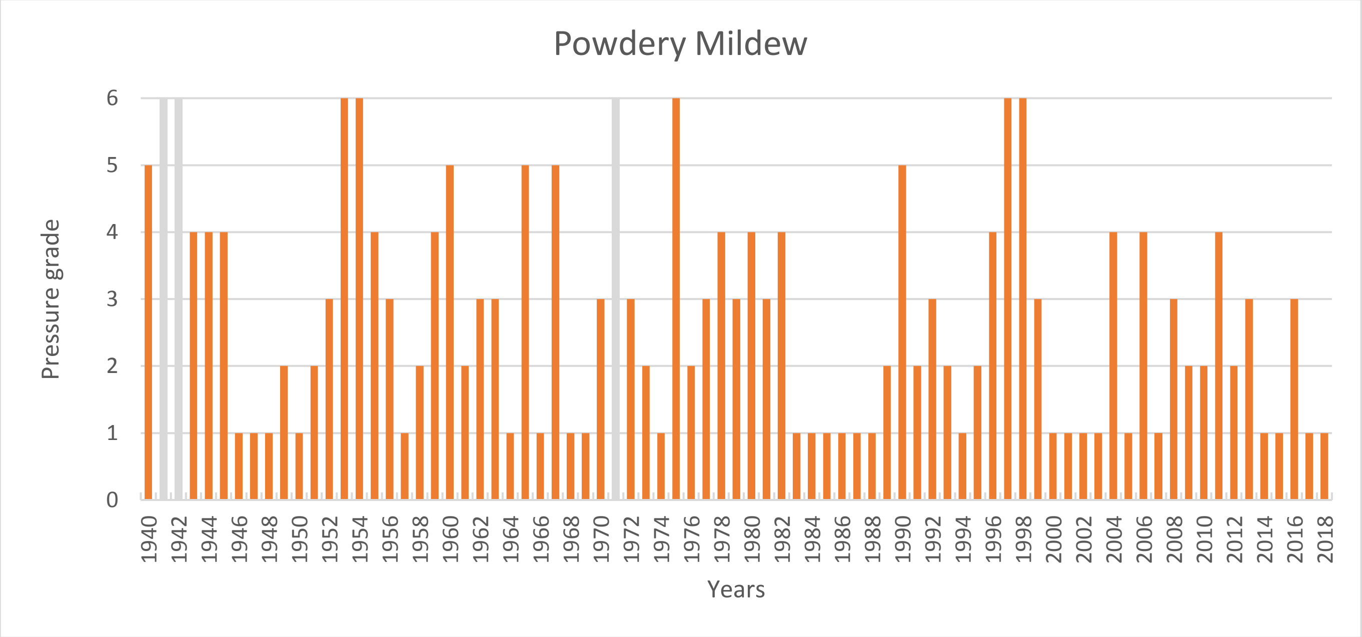


Figure 4. Annual pressure of Powdery Mildew (0 to 6 scale), on vineyards from the Bordeaux area, from 1940 to 2018. Missing years are displayed with a grey bar.

Figure 5 presents the results for Black Rot. A period of 68 years over 79 was covered (86%). In one year (1963), the Black Rot pressure was estimated as high and general across the region and associated with crop loss ("*pertes de récolte importantes*"). This is the lowest frequency of high and general pressure years among the five main diseases. The highest pressure years (grade 5 or 6) were represented 4 times (7%) over the period 1940-2018, which is the lowest of the five main diseases. On the other hand, the pressure was never assessed as null for Black Rot (grade 0). However, there are at least 5 years where the disease was not mentioned in the annual reports, but only on the seasonal reports (1988, 1998, 2006, 2007, and 2009). Weak and local (grade 1) epidemics were assessed in 25 years. For the remaining 39 years, the pressure was estimated as intermediate (grades 2, 3, or 4), which represents 57% of the time, making Black Rot the disease with the most average pressure results.

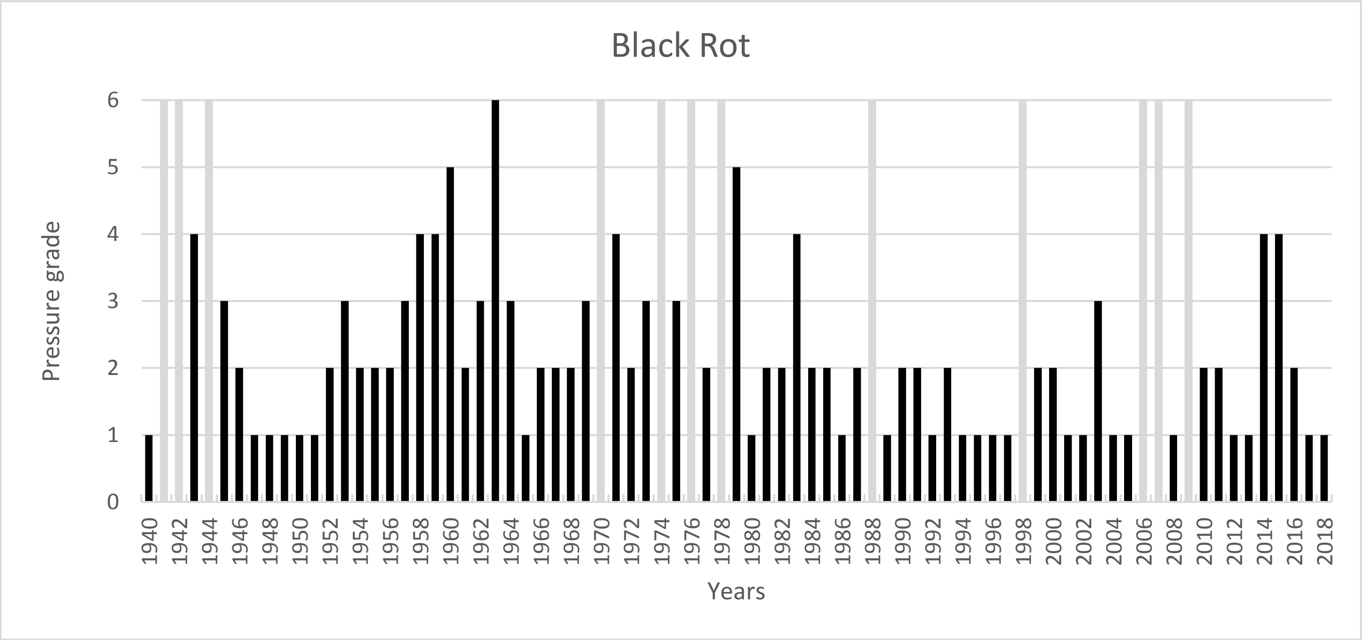


Figure 5. Annual pressure of Black Rot (0 to 6 scale), on vineyards from the Bordeaux area, from 1940 to 2018. Missing years are displayed with a grey bar.

Figure 6 presents the results for Gray Mold. A period of 58 years over 79 was covered (73%), as information regarding GM was the rarest over the five main bio-aggressors. It is important to note that assessments regarding GM were mostly based on treated plots. On 4 years (1960, 1963, 1992, and 2013), the Gray Mold pressure was estimated as high and general across the region; which is the second highest frequency over the five main bio-aggressors, in equal measure with Powdery Mildew. On the other hand, the pressure was null in one year (2016). Low and local (grade 1) epidemics were assessed in 14 years. For the remaining 34 years, the pressure was estimated as intermediate (grades 2, 3, or 4), which represents 59% of the time on the total of data. The highest pressure years (grade 5 or 6) were represented 8 times (14%) over the period 1940-2018.

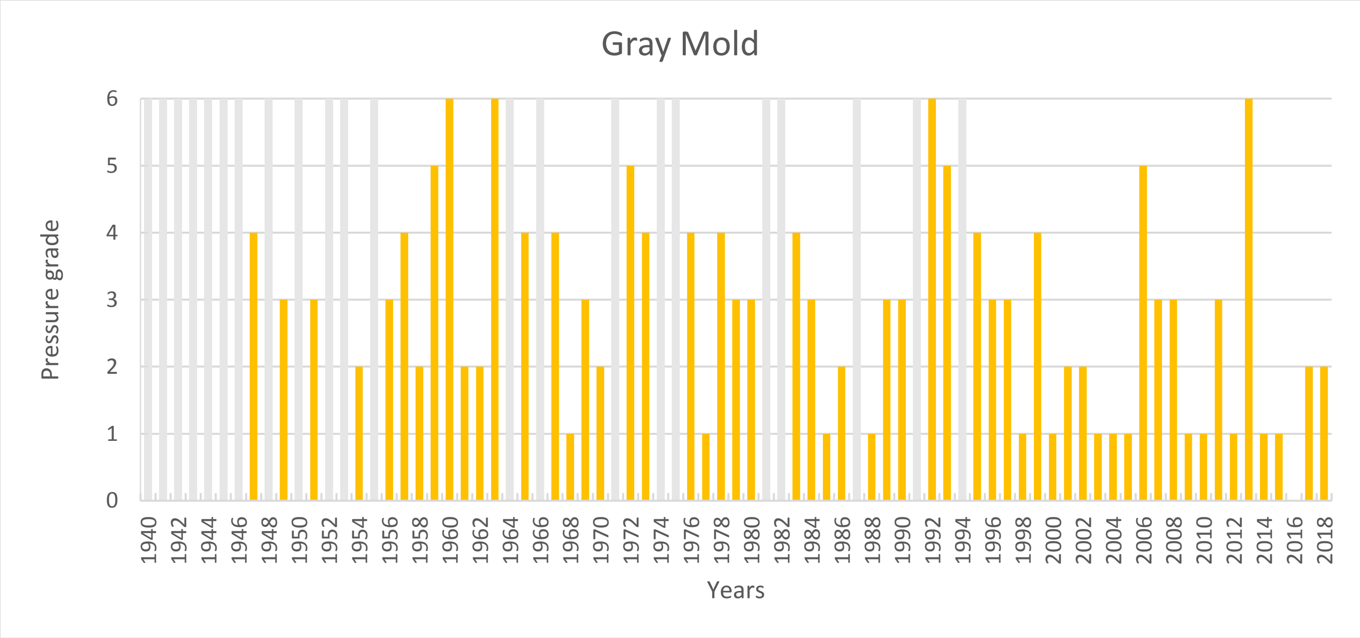


Figure 6. Annual pressure of Gray Mold (0 to 6 scale), on vineyards from the Bordeaux area, from 1940 to 2018. Missing years are displayed with a grey bar.

As information regarding the damage in the vineyard was limited (48% of the data, representing 34% of the whole 1940-2018 period), we chose, at this stage, not to display the results for Torticid Moths. When analysing the data, only 56 years of data were retrieved. Among them, 29 (52%) reported information regarding the population and/or intensity of flights. The information was either qualitative or quantitative, relying on two methods of trapping: sexual or bait attraction. Furthermore, four regions appeared, on a recurring basis, as "*nids à tordeuses*" or "*foyers historiques*" (in 55% of the case). These regions were: Entre-deux-mers, Bergeracois, Sauternais, and Médoc.

Time periods

Distribution analyses were performed over three times periods: 1940-1969, 1970-1999, and 2000-2018. The results are displayed in the form of boxplots on Figure 7.

For Downy Mildew, the first two periods had similar distributions, median, and mode (grade 1) values. However, the distribution and mode tended to increase in the third period (P=0.22);

from grade 1 to a grade of 3. For Powdery Mildew, the first two periods also had similar distributions, median, and mode (grade 1) values. Third period tended to decrease in its distribution (*P*=0.29), as the median grade shifted from 3 to 1, but the mode remained 1. For Black Rot, the shift seemed to occur between the first and second periods, with the last two periods being similar in their grades distribution. The median and mode value of 2 appeared in both the first and the second period, however the range of grades distribution tended to be higher in the first period (*P*=0.32), compared to the first and second periods. On the third period, the mode showed lower grades of 1. For Gray Mold, the first and second periods were similar in both their distribution and median. The mode were grades 4 then 3, for the first and second period, respectively. However, a major shift occurred with the grades during the third period, with a distribution being lower and the mode grade at 1. This is statistically different from the median in the first two periods (*P*=0.02). The trends for DM, PM and BR were not significant, as the grades distribution was independent of the period according to a χ^2 contingency test. However, for GM, the distribution of the grades was dependent of the period. Indeed, the number of null and low grades (0 and 1) attributed to this disease was statistically higher for the period 2000-2018 than the other two periods (Fisher's exact test, *P*<0.05).

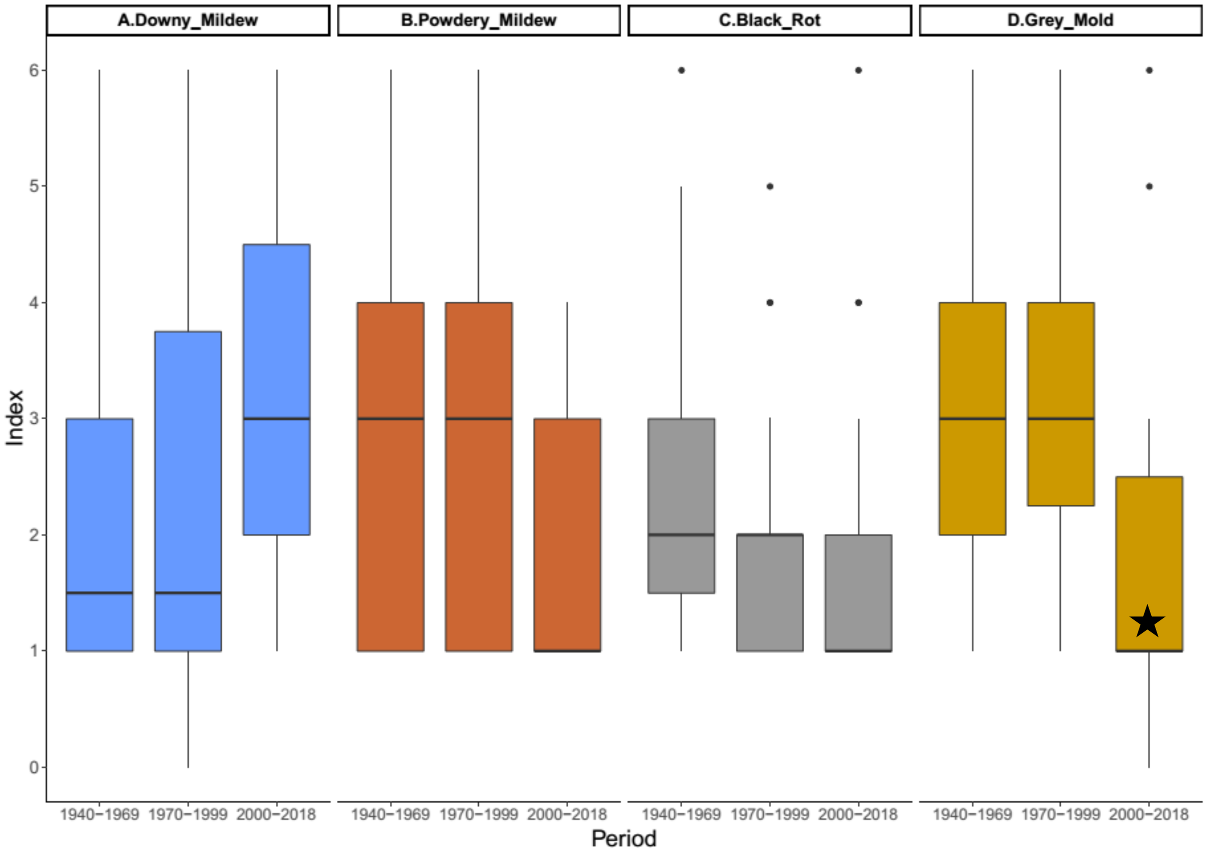


Figure 7. Evolution of the four main diseases pressure grades over three time periods: 1940-1969, 1970-1999, and 2000-2018. The star indicates that the grades distribution of the third period was statistically different than the first and second period for Gray Mold (according to Spearman's correlation test, p<0.01).

Multipests results

Results of Spearman's correlation between four couples of diseases are displayed in Table 4. When no information was available for either one of the disease, the year was took out of the analysis, as showed by number of observations used. For the couples DM*PM, DM*GM, and PM*BR, there was no significant relationship. Although not significant, and as a trend only, severity of the epidemics of Downy Mildew tended to be negatively correlated with epidemics of Powdery Mildew (*P*=0.13). Epidemics of Powdery Mildew were positively correlated with epidemics of Gray Mold, and the relationship was significant (*P*=0.01).

Table 4. Results of Spearman correlation test for the covariation of selected couples of diseases. Bolded P values are statistically significant.

Variables	Spearman	P values	Number of observations
Downy Mildew x Powdery Mildew	-0.174	0.133	76
Downy Mildew x Gray Mold	-0.039	0.771	57
Powdery Mildew x Black Rot	0.102	0.410	68
Powdery Mildew x Gray Mold	0.342	**0.009**	57

Secondary bio-aggressors

The list of secondary bio-aggressors considered (Table 5) consisted in nine pests and six diseases. The number of occurrence of each secondary bio-aggressor is displayed in Figure 8. The analysis of the secondary bio-aggressors was on the spent of 57 years. Vine leafhopper ("*cicadelles*"), red spider mite, and Drosophila were the most mentioned pests over the entire period. The list of secondary bio-aggressors mentioned in the plant health reports (Figure 9) showed pests that were more active at same time periods then others. Red and yellow spider mites where often mentioned between 1958 and 1991, and causing damage (grade 2), but they are absent from the annual plant health reports since 2000. Esca was mentioned for the first time in the 1984 annual plant health report, at the same time of Eutypa dieback, although the later first appeared in the 1979 annual report. Figure 9 also displays the appearance of emerging pests, such as *Flavescence dorée* in 1994, and *Drosophila suzukii* in 2015.

Table 5. List of the secondary bio-aggressors as referenced in the source material, their corresponding translation in English, and name of causing agent.

Name in the text (French)	Name in English	Causing Agent
Anthracnose	Anthracnose	*Elsinoë ampelina*
Araignées jaunes	Yellow spider mite	*Eotetranychus carpini*
Araignées rouges	Red spider mite	*Panonychus ulmi*
Cicadelle pruineuse	Leafhopper	*Metcalfa pruinosa*
Cicadelles	Vine leafhopper	*Empoasca vitis*
Cigarier	Hazel leaf roller	*Byctiscus betulae*
Cochenilles	Vine mealybug	-
Drosophiles	Drosophila	*Drosophila spp*
Erinose	Vine leaf blister mite	*Colomerus vitis*
Esca	Esca	Fungi complex
Eutypiose	Eutypa dieback	*Eutypa lata*
Excoriose	Excoriose	*Phomopsis viticola*
Phylloxera	Grapevine root-aphid	*Daktulosphaira vitifoliae*
Pourriture acide	Sour rot	Fungi and bacteria complex
Cicadelle de la flavescence dorée	Vine leafhopper	*Scaphoideus titanus*

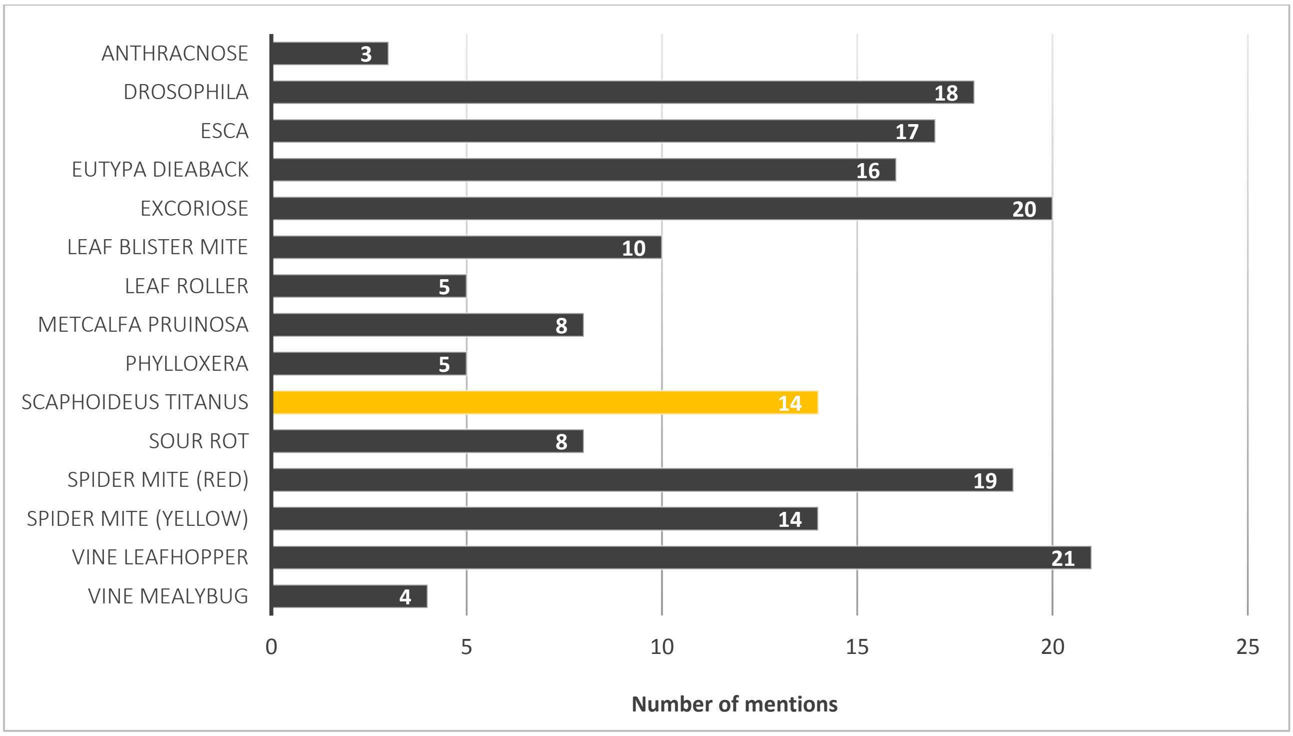


Figure 8. Number of mentions of the secondary bio aggressors in vineyards. Extractions from plant health annual reports of the Bordeaux region, from 1940 to 2018.

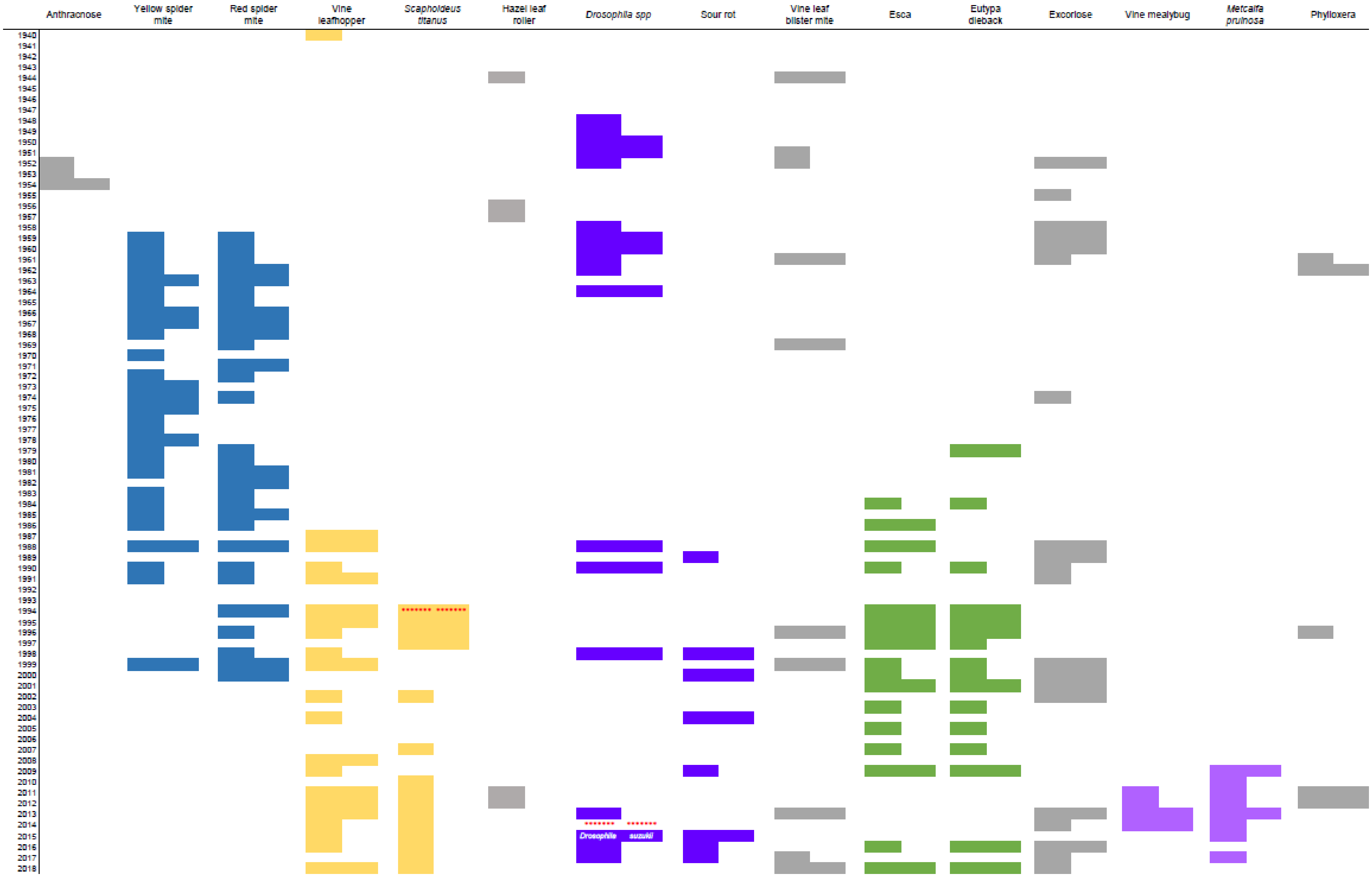


*Figure 9. Occurrence of the secondary bio-aggressors in vineyards of the Bordeaux region, from 1940 to 2018. One case filled is when the bio-aggressor was mentioned in the annual plant health report, with no indication regarding its damage. Two cases filled is when the bio-aggressor was mentioned with damage indication. *** = first appearance of emerging pest.*

3.3 Discussion

The designed semi qualitative scale allowed to characterize annual epidemics Downy Mildew, Powdery Mildew, Black Rot, and Gray Mold, on the spent of 79 years (1940-2018), for the Bordeaux region (Figures 3 to 6). Low and high epidemics were identified at a frequency of 46% over the period. These results were reviewed by three experts: Marc Fermaud (INRA Bordeaux, Gray Mold specialist), Bernard Guery (DRAAF Aquitaine, overall expertise), and Marc Raynal (IFV Bordeaux, Downy Mildew specialist). The specialists agreed, to the best of their respective knowledge, to the exposed results. From Figure 2, it is interesting to note that for each disease and over the entire 1940-2018 period, most of the grades distribution was on the low side of the scale (i.e. highest frequency of grade 1). In the case of Gray Mold however, the grades distribution tended to be bimodal, with peaks of grades 3 and 1, followed closely by grades 2 and 4.

Downy Mildew and Powdery Mildew were mentioned in every available annual report, with Downy Mildew always appearing as the first disease mentioned in the text over the period 1940-2018. Over the four main diseases, DM and PM had the most of the highest grades, suggesting high epidemics. These results are in accord with the observations of Bois, Zito, and Calonnec (2017) at a worldwide level. In the South-West of France, Delbac and Savary (2017) also assessed DM and PM to be the main diseases, as displayed in
Appendix 1. These results demonstrate that whereas years with high Downy Mildew pressure occurred more often than for the other diseases in the Bordeaux region (15% of grades 5 or 6), there were also a several years where the DM pressure was intermediate (42% of grades 2, 3, or 4), or low (39% of grade 1).

In the period 1940-2018, it is interesting to note that Powdery Mildew appeared either in the second or the third place in the layout of the reports, switching with Black Rot, depending on the time period. This trend transpires in Figure 7, where the shift between the two first and the third period is visible. From 1950 to 1980, Black Rot was considered as the second main disease in the Bordeaux vineyard, and prospection bounties were rewarded to vintners who reported the first stained leaf of the season. However, the levels of the BR epidemics were often local and average (57% of the time). Indeed, Black Rot epidemics were mostly indicated in "*foyers historiques*", and associated with abandoned vineyards ("*près des vignes incultes*"). These results are consistent with the study of dynamics of primary inoculum and dispersal patterns of Black Rot by Onesti (2014), which suggested an inoculum dependant disease.

In order to interpret the established semi qualitative scale (Table 1), it should be stressed that the measure of diseases levels allows comparisons of years with respect to a given disease. Indeed, as the relationship between disease injury and yield loss differs depending on the disease considered, analysing the severity of a given bio-aggressor prevents comparison of the actual importance of a disease (Fermaud *et al.*, 2016; Willocquet *et al.*, 2018). In other words, the actual incidence on the vineyard of a "high and general" Downy Mildew epidemics (i.e. "6"), is likely to be more damaging than a "high and general" epidemics of Black Rot. Finally, the data set relying on experts-assessments, and it is impossible at this stage to separate the disease's actual incidence to the technical practices and knowledge of the time it was assessed.

Regarding the three time periods as compared in this study, the choice of the period lengths was arbitrary but guided by some key-points. First, a period of thirty years is likely to be sufficient for statistics elaboration from a climatic point of view (Ouzeau *et al.*, 2014). This is consistent with our wish to further investigate the link between vineyard's bio-aggressors and their evolution through long periods of time. Second, when reading the plant health reports, a shift in practices emerged two times; around the early 70's, with the apparition of new synthetic phytosanitary compounds; and in the 2000-2009 period, when the reports slowly shifted from treatments and applied strategies recommendations to risk assessments. Accordingly, the choice of the three main periods was proposed as followed: 1940-1969, 1970-1999, and 2000-2018. However, this choice is debatable, and further investigations (i.e. different time periods) should be made in order to better qualify them.

Although not significant, some trends can be noted from the evolution of the epidemics across the time periods (Figure 7). The distribution of grades for Downy Mildew tended toward higher grades in the most recent period, compared with the two previous periods, whereas it was the opposite for Powdery Mildew. Indeed, there were four years of high and general epidemics of DM in the last 19 years, and the same number of high and general epidemics in the previous 60 years (Figure 3). For PM, there was no high and general epidemics in the last 19 years, but they appeared five times between 1940 and 1999 (Figure 4). An explanation could be in the weather variations. Indeed, from 1900 and since the 90's, temperatures in France tends toward an elevation of 1°C, with an important yearly variability (Ouzeau *et al.*, 2014). Temperature and humidity requirements for Downy Mildew and Powdery Mildew are different (Galet, 1982; Wilcox, Gubler and Uyemoto, 2015). The maximal temperature for biological activity is considered higher for Powdery Mildew (max 40°C), than it is for Downy Mildew (max 35°C). Therefore, one could expect a highest frequency of PM epidemics in the last 20 to 30 years. However, the opposite was observed in our study, and they were consistent with previous hypothesis based on modelling (Caffarra *et al.*, 2012). These observations could benefit from investigations of the epidemics at a seasonal level. Indeed, the effects of weather conditions on the diseases is variable inside a season, and for each pathogen. Several models exist to forecast disease development, but they all agree on the dependence of the epidemics to complex interactions between temperature, daylight, rainfall, humidity and host development (Donatelli *et al.*, 2017; Savary *et al.*, 2018). As an example, typical years of destructive epidemics of Downy Mildew are years with prolonged cloudy weather, frequent rain events coincident with temperatures around 25°C, and high general humidity (Wilcox, Gubler and Uyemoto, 2015).

In the context of integrated pest management, and more generally the current trend in understanding interactions at a microbial or molecular level (Chaplin-Kramer *et al.*, 2011), we proposed to investigate the relationships between the diseases and pests that were evaluated in this study. Thus, the following couples of pests were selected for investigation of covariation: Downy Mildew x Powdery Mildew (Savary *et al.*, 2009), Downy Mildew x Gray Mold, Powdery Mildew x Black Rot, and Powdery Mildew x Gray Mold. No trend was observed for three of these couples, but the relationship between Powdery Mildew and Gray Mold appeared highly correlated. In cucumber and strawberry, the co-existence of both diseases has been evaluated, and investigations regarding their co management performed (Elad *et al.*, 1998). However, to the best of our knowledge, investigations regarding the co-existence of Powdery Mildew and Gray Mold in vineyard, at the disease level, are limited.

Another relationship of interest is the potential correlation between Gray Mold and Tortricid Moths (Fermaud, 1992). Unfortunately, the limited information regarding the damage caused by Tortricid Moths in the annual plant health reports did not allowed to perform such analysis. Nevertheless, information regarding the populations of Tortricid Moths over the years were available in the reports. The information was mostly qualitative, with indications of the regions or sub-regions were flights were more or less abundant. According to flights information, the repartition of *Lobesia botrana* ("*Eudémis*") in the Bordeaux region appeared to be superior to that of *Eupoecilia ambiguella* ("*Cochylis*") during the 1940-2018 period, which is consistent with previous knowledge (Thiéry, 2008).

Regarding the secondary bio-aggressors, Figure 9 displays their repartition over the 1940-2018 time period, and allows to visualize occurrence patterns. Indeed, it is noticeable that red and yellow spider mites, as well as esca and eutypia dieback tended to have similar distribution patterns. Moreover, two emerging pests were found, in accordance with their date of apparition in France: *Scaphoïdus titanus* and *Drosophila suzukii*, as they appeared for the first time in the region in 1994 (Delbac, 2000) and 2011 (Rouzes *et al.*, 2012), respectively.

4 CHAPTER 2: Characterization of diseases pressure in the Bordeaux vineyard, a focus on 2010-2018.

4.1 Method

4.1.1 Presentation of the dataset

BSV quantitative data were extracted from the annual plant health reports of the growing seasons 2010 to 2018. Qualitative data from Chapter 1 were also extracted from these reports in the same period. IFV field data and survival curves were obtained curtesy of Marc Raynal (IFV Bordeaux) and Christian Debord (IFV Bordeaux). Survival data were extracted from the IFV Epicure database (https://www.vignevin-epicure.com/). BSV and IFV observations originate from a similar network of plots, located in the Bordeaux region. Observations regarding Downy Mildew, Powdery Mildew and Black Rot were available for untreated plots, observations regarding Gray Mold were available for treated plots. Both sources are considered complementary (pers. comm. Marc Raynal). The exact location of the plots is not disclosed.

Both BSV and IFV data sets were analyzed independently. Some common rules were followed, in accordance with the epidemical status of the study: (i) a simple way to model the epidemics of each disease on clusters was sought, using as few parameters as possible; and (ii), in order to assess the highest indicator for each of the studied diseases, information was extracted in priority close to veraison (see Literature review, 2.1). Accordingly, data regarding the diseases were extracted around the end of July and August in the annual BSV in order to design the indexes (Index_BSV). IFV field data were extracted over the entire seasons in order to design the indexes (Index_IFV). However, only the information at veraison was used to characterize a given year through the indexes.

4.1.2 BSV 2010-2018

Parameters used

In the annual reports from 2010 to 2018, and for each of the four main diseases, three important parameters were assessed: Mean Prevalence (MP), Mean Frequency of Attack (MFA), and Mean Intensity of Attack (MIA) (Table 6). In the BSV reports, MP, or Mean Prevalence, is defined in the source as the number of infected plots, on the number of observed plots. MFA, or Mean Frequency of Attack, is defined in the BSV as the number of affected organs, on the number of observed organs, in the affected plots. MIA, or Mean Intensity of Attack, is defined in the BSV as the surface occupied by the disease, on the total surface of all observed organs, in the affected plots. MP, MFA, and MIA were all expressed in percentage, and each of the parameters was available on leaves (-L) and clusters (-C). Only the information regarding non treated plots was used for Downy Mildew, Powdery Mildew and Black Rot. For Gray Mold, the only information available was on treated plots, i.e. “*parcelles de référence*”. For each disease, data were extracted around veraison.

Table 6. Description of the variables used in the design of Index_BSV

Variable	Full name
MP	Mean prevalence
MIA	Mean intensity of attack
MFA	Mean frequency of attack
Variable $_C$	MP, MIA, or MFA, on clusters
Variable $_L$	MP, MIA, or MFA, on leaves

Indexes design

With the objective to combine most of the information in a simple index, and in order to estimate the missing data, relationships between MP, MIA, and MFA were assessed, for each disease independently. First, the correlations of each parameter (MP, MFA, MIA) between organs (e.g. MP on clusters and MP on leaves) were tested. Second, the correlations between each parameter for each organ were tested (e.g. MP on clusters and MFA on clusters). For each disease independently, the variables varied in a similar range, which allowed to combine them and use a regression model as a basis to design the indexes. When missing, data were estimated from the correlations previously established by linear or polynomial regressions (Appendix/Table X). Accordingly, the final indexes for this data are presented in Table 7.

Table 7. Indexes of DM, PM and BR, for BSV dataset.

Disease	Name	Formula	Organs
Downy Mildew	DM_Index_BSV	½ [MIA$_C$ * (MP$_C$*MFA$_C$)]	Clusters
Powdery Mildew	PM_Index_BSV	½ (MIA * MFA$_{CL}$)	Clusters, Leaves
Black Rot	BR_Index_BSV	½ [MIA$_C$ * (MP$_{CL}$*MFA$_C$)]	Clusters

4.1.3 IFV ratings: field ratings and survival curve indices

Two datasets regarding Downy Mildew, Powdery Mildew, and Black Rot were acquired from the IFV network: (i) field data, from disease observations across the growing seasons 2010 to 2018; and (ii) survival data from the plots network, across the same growing seasons. Since these data originated from a different source than the BSV, they were treated independently of the previous dataset. However, the same basic hypothesis regarding the diseases were used to sort the data, and the dates close to veraison where analyzed, as explained in the presentation of the dataset (4.2.1).

4.1.4 Field ratings

Description of the variables.

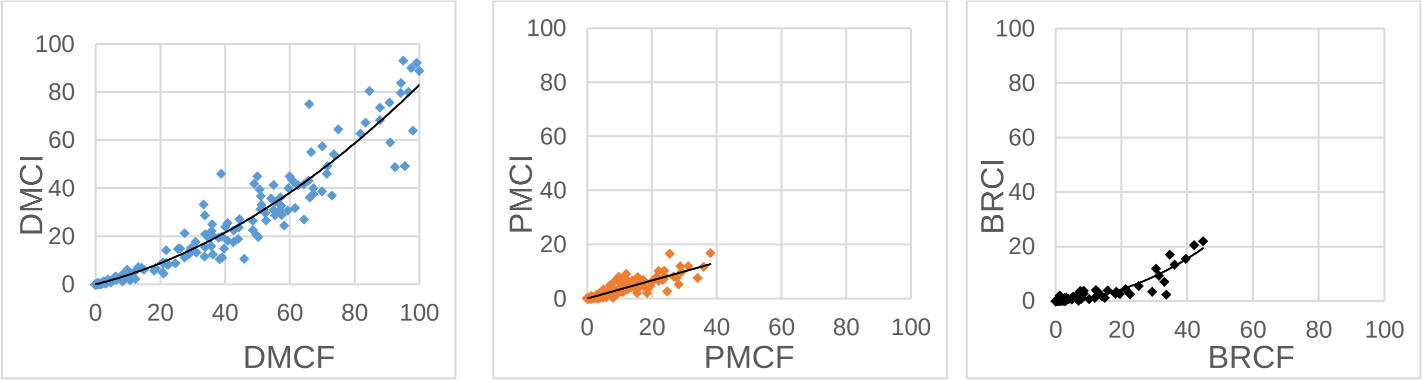
From field assessments, data from clusters (-C) and leaves (-L) frequency (-F) and intensity (-I) of symptoms of Downy Mildew, Powdery Mildew, and Black Rot were collected, on non-treated plots, and over the entire growing seasons 2010 to 2018 (Table 8).

Table 8. Variables description, IFV data 2010-2018

Disease	Variable	Full name
Downy Mildew	DMLI	Downy Mildew Intensity on Leaves
	DMLF	Downy Mildew Frequency on Leaves
	DMCI	Downy Mildew Intensity on Clusters
	DMCF	Downy Mildew Frequency on Clusters
Powdery Mildew	PMLI	Powdery Mildew Intensity on Leaves
	PMLF	Powdery Mildew Frequency on Leaves
	PMCI	Powdery Mildew Intensity on Clusters
	PMCF	Powdery Mildew Frequency on Clusters
Black Rot	BRLI	Black Rot Intensity on Leaves
	BRLF	Black Rot Frequency on Leaves
	BRCI	Black Rot Intensity on Clusters
	BRCF	Black Rot Frequency on Clusters

Indexes design

In order to reduce the number of variables and design integrative indexes, relationships were tested, for each disease independently, as follows. First, correlation between frequency (-F) and intensity (-I) of the symptoms on clusters were established (Figure 10) Second, the intensity relationships between intensity on leaves (-LI) and intensity on clusters (-CI) were investigated (Figure 11).

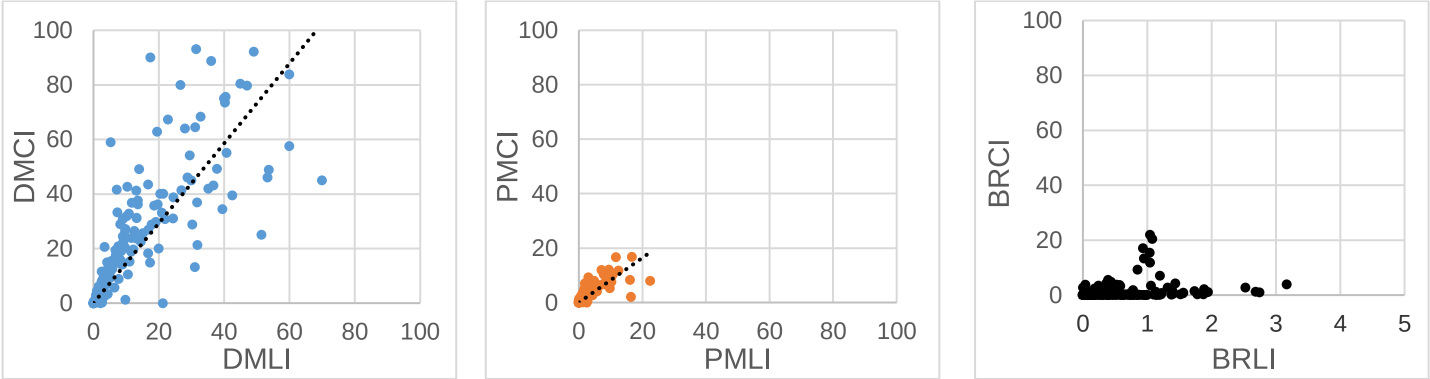


A.1. Frequency x Intensity of DM on clusters.
$R^2 = 0.9403$.
DMCI=(0.0049*DMCF)+(0.344*DMCF)

B.1. Frequency x Intensity of PM on clusters.
$R^2 = 0.845$.
PMCI = (0.3343*PMCF)

C.1. Frequency x Intensity of BR on clusters.
$R^2 = 0.8779$.
BRCI=(0.0088*BRCF)+50.0369*BRCF)

Figure 10. Results of relationships between frequency and intensity on clusters of Downy Mildew (A), Powdery Mildew (B) and Black Rot (C).



A.2. Intensity on clusters x Intensity on leaves of DM.
$y = 1.4643x$
$R^2 = 0.7084$

B.2. Intensity on clusters x Intensity on leaves of PM.
$y = 0.7908x$
$R^2 = 0.6617$

C.1. Intensity on clusters x Intensity on leaves of BR.
No relationship.

Figure 11. Results of relationships between intensity on clusters and intensity on leaves of Downy Mildew (A), Powdery Mildew (B) and Black Rot (C).

Inspection of R^2 values indicated that the regression fit was better when describing the frequency (-F) and intensity (-I), on clusters (-C) only. For this reason, the –CI and –CF parameters were used to design the indexes. Three main relationships were established (Table 9). The indexes were finally used on variables of each disease, on each year, on the veraison period, in order to grade the selected year. The average of each variable at veraison was used for the calculation.

Table 9. Indexes of DM, PM and BR, for IFV dataset.

Name	Formula	Organs	Relationship
DM_Index_IFV	½ ($DMCI_{obs}$ & $DMCI_{cacl}$)	Clusters	$DMCI_{calc}$ = $(0.0049*DMCF^2)+(0.344*DMCF)$
PM_Index_IFV	½ ($PMCI_{obs}$ & $PMCI_{calc}$)	Clusters	$PMCI_{calc} = 0.3343*PMCF$
BR_Index_IFV	$BRCI_{calc}$	Clusters	$BRCI_{calc}$ = $(0.0088*BRCF^2) + (0.0369*BRCF)$

4.1.5 Survival curves

Data for epidemics of Downy Mildew, Powdery Mildew, and Black Rot, on the growing seasons 2010 to 2018, were extracted in the form of survival curves. An example of survival curve is displayed in Appendix X. Data were extracted at week 32 (veraison), on clusters, at a threshold of 10% in intensity. In order to analyze the data, a rank system was established according to the variation domain of each disease. The fixed class break of 10% was picked arbitrarily. For DM, as the variation ranged from 5 to 90, a difference of 10 points between two observations was considered a class break (10% of 100). For PM and BR, as the variation ranged from 50 to 100, a difference of 5 points between two observations was considered a class break (10% of 50).

4.2 Results

4.2.1 BSV indexes

From BSV annual reports 2010 to 2018, 43 observations were used to fit the regression model. The results of DM, PM, and BR epidemics, as calculated by the Index_BSV are showed in Figure 12. BR was non-assessed in 2010 and 2011, because there was no quantitative information in the corresponding annual reports. The variation scale of the indexes were dependant of each disease. DM_Index_BSV was the highest index of the three diseases in 3 years; 2012, 2013, and 2018 (reaching a maximum of 62 points). It was intermediate in 2014, 2016, and 2015 (between 21 and 40). BR_Index_BSV was the second highest index, on 2015 (reaching a maximum of 45 points). Year 2014 was the second highest for BR (36). The other BR indexes were the lowest among all the indexes (from 3 to 15). PM_Index_BSV was at its highest on 2011 (38), and second highest in 2010 (32). It was between 15 and 27 on the 7 other years.

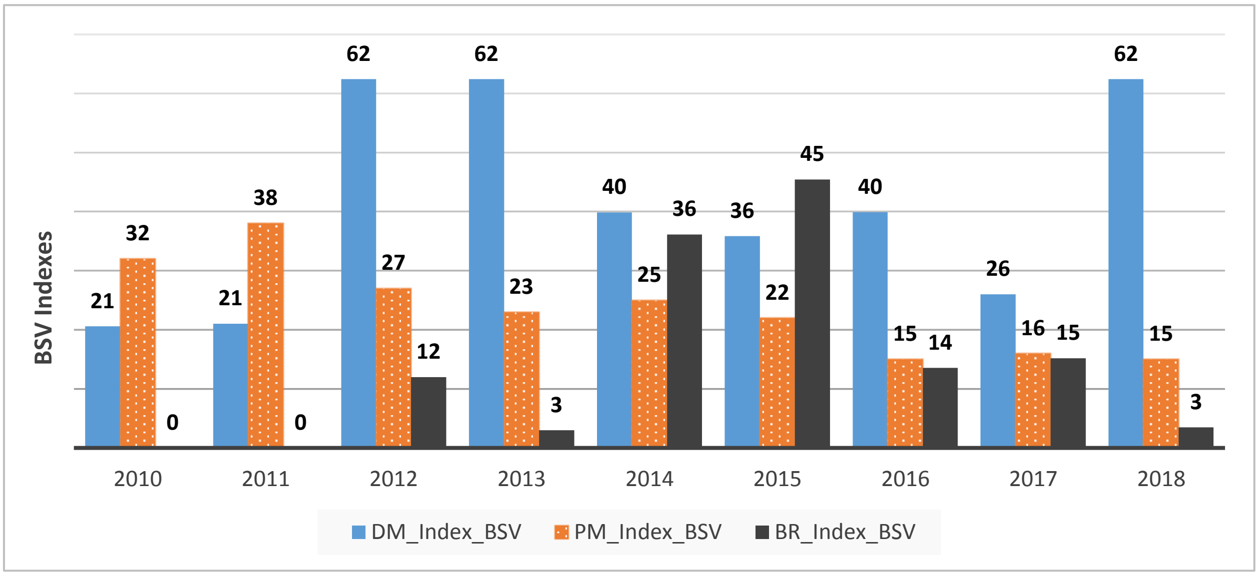


Figure 12. BSV indexes, estimated over the 2010-2018 period, from BSV quantitative data.

4.2.2 Indices IFV

IFV field notations represented 312 data that were used to create the regression model, through organs and variables relationships. For each disease, a strong relationship appeared between intensity and frequency of the symptoms on clusters. It allowed to use either one of the variable (-CF or -CI) in the next steps. From the IFV data, the variation scale of the indexes were dependant of each disease. DM_Index_IFV was the highest index of the three diseases on 3 years; 2012, 2013, and 2018 (i.e. 41, 44, and 64, respectively). It was medium in 2014 and 2016 (between 25 and 35). BR_Index_BSV was the second highest index, on 2015 (15). The other BR indexes were the lowest among all the indexes (from 0 to 4). PM_Index_BSV was at its highest on 2011 (11). It was low on the 8 other years (from 2 to 11).

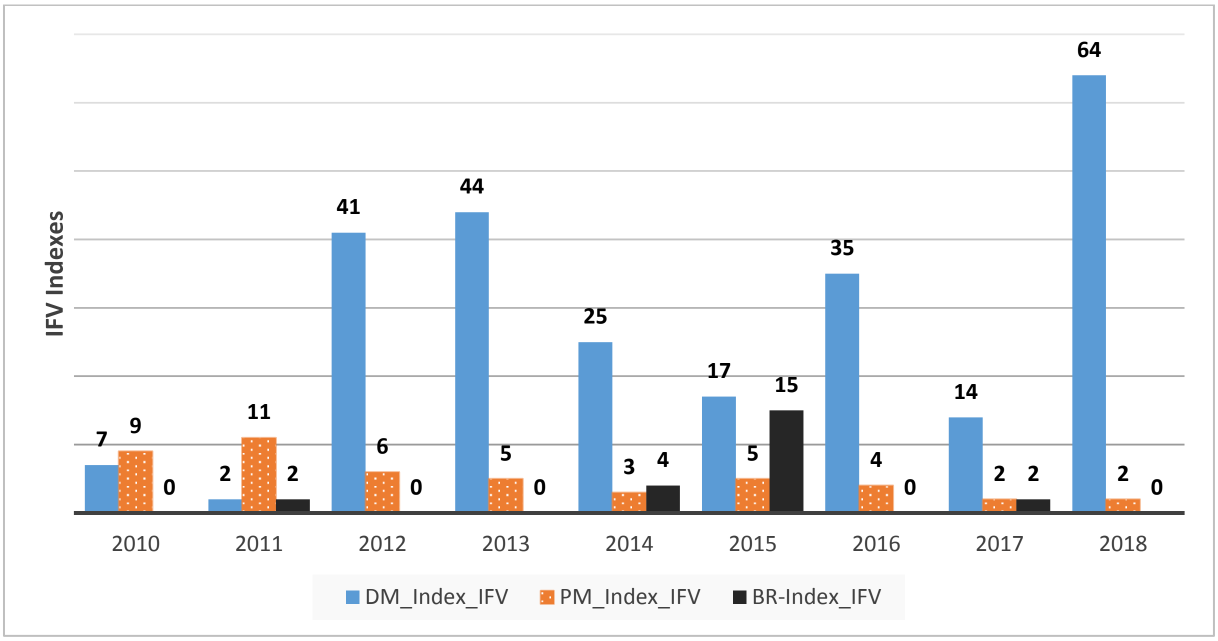


Figure 13. IFV indexes, estimated over the 2010-2018 period, from IFV field notations.

4.2.3 Survival curves

In the case of PM and BR, data from thresholds 5 and 25% did not allow to differentiate the epidemics from each other's. Indeed, at veraison, every untreated plot displayed symptoms above the 5% disease threshold, and data was about the same for every year. On the other hand, PM and BR almost never reached the threshold of 25%. As a result, the 10% threshold was selected for rank analysis (Figure 14).

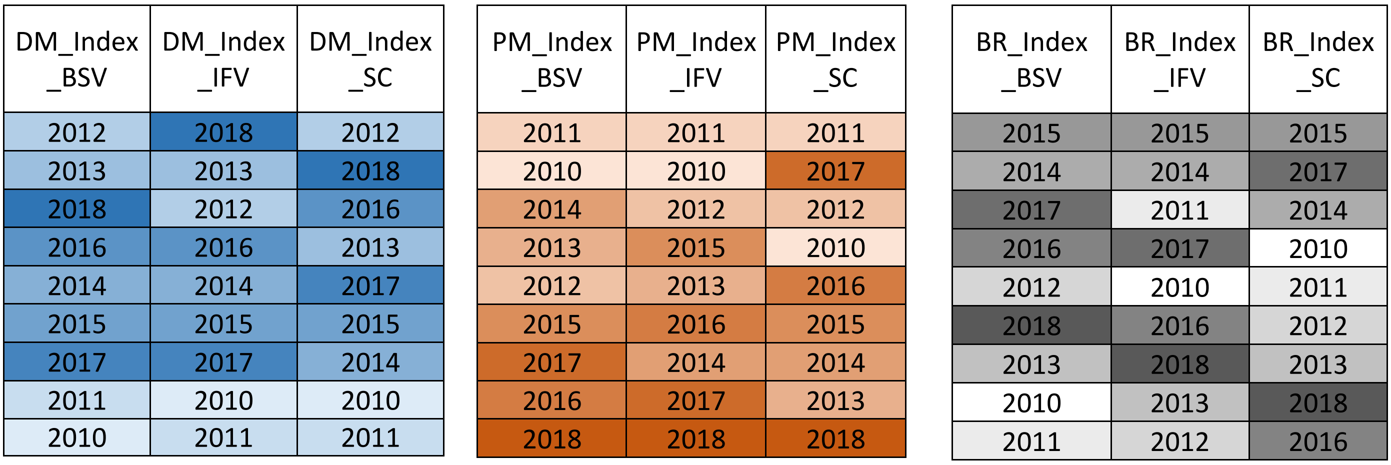
4.2.4 Comparison of the datasets

Years 2010 to 2018 were ranked according to the indexes from the quantitative BSV dataset, IFV field data, and IFV survival curves data. They are ranked in ascending order, from the highest to the lowest epidemics pressure (Figure 14).

For DM, 5 years were ranked the same with both BSV and IFV indexes (2013, 2014, 2015, 2016, and 2017), with the other 4 years being inverted but in about the same rank in both cases. The correlation between DM_Index_BSV and DM_Index_IFV was the highest of the three datasets ($R^2=0.86$; Figure 15 A.1). The correlation between Index_IFV and Index_SC was the highest for DM ($R^2=0.78$; Figure 15 A.2).

For PM, 3 years were ranked the same with both BSV and IFV indexes (2010, 2011, and 2018). The correlation between PM_Index_BSV and PM_Index_IFV was the second highest of the three datasets ($R^2=0.82$; Figure 15 B.1). The correlation between Index_IFV and Index_SC was low ($R^2=0.01$; Figure 15 B.2).

For BR, only the highest two years pressure were ranked the same from BSV and IFV datasets (2014 and 2015). The correlation between Index_BSV and Index_IFV was the lowest ($R^2=0.75$; Figure 15 C.1). There was no correlation between Index_IFV and Index_SC (Figure 15 C.2).



DM_Index _BSV	DM_Index _IFV	DM_Index _SC
2012	2018	2012
2013	2013	2018
2018	2012	2016
2016	2016	2013
2014	2014	2017
2015	2015	2015
2017	2017	2014
2011	2010	2010
2010	2011	2011

A. Downy Mildew

PM_Index _BSV	PM_Index _IFV	PM_Index _SC
2011	2011	2011
2010	2010	2017
2014	2012	2012
2013	2015	2010
2012	2013	2016
2015	2016	2015
2017	2014	2014
2016	2017	2013
2018	2018	2018

B. Powdery Mildew

BR_Index _BSV	BR_Index _IFV	BR_Index _SC
2015	2015	2015
2014	2014	2017
2017	2011	2014
2016	2017	2010
2012	2010	2011
2018	2016	2012
2013	2018	2013
2010	2013	2018
2011	2012	2016

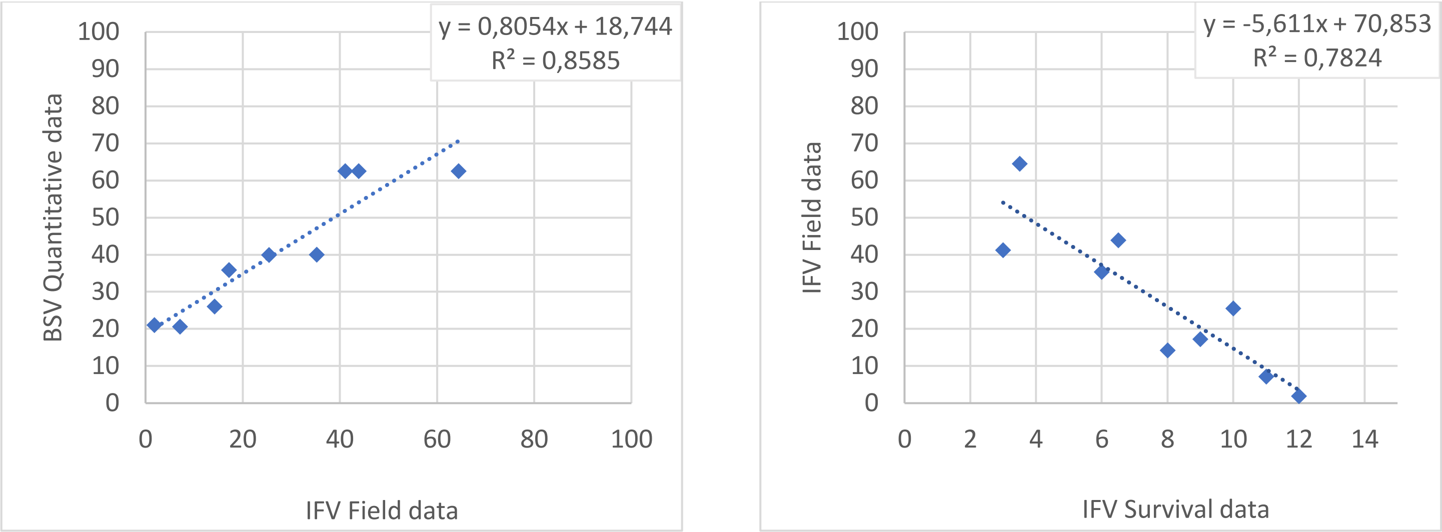
C. Black Rot

	DM	PM	BR	Total
Index_BSV * Index_IFV	5	3	2	10
Index_BSV * Index_SC	2	3	2	8
Index_IFV * Index_SC	3	4	1	7

D. Number of matches between the three indexes.

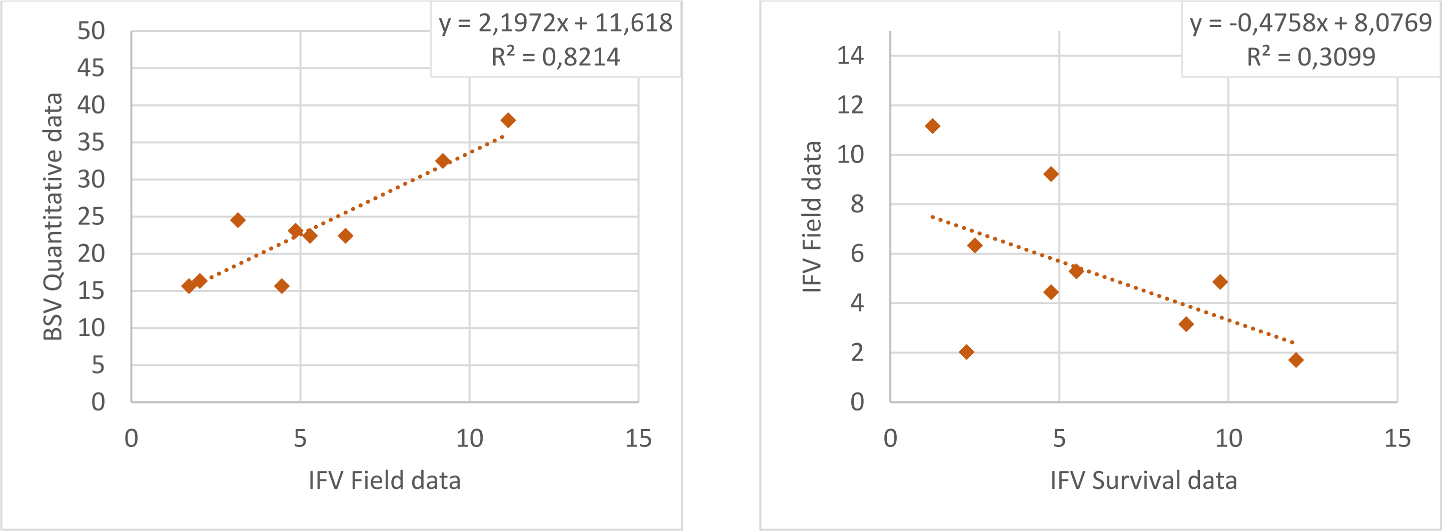
Figure 14. Comparison of the ranking results, from BSV quantitative data, IFV field and, IFV survival curves, for GM, PM and BR. Ranks are established from the each dataset index. Years are ranked in ascending order, from the highest to lower epidemics pressures.

From the comparison of the datasets (Figure 14), and correlation tests between them (Figure 15), a final ranking of epidemics of Downy Mildew, Powdery Mildew, and Black Rot, over the 2010-2018 period, was proposed (Figure 16). It is issued from a consensus between results of Index_BSV and Index_IFV, as they presented the highest correlation. For DM, 2018, 2013, and 2012 had the same DM_Index_BSV. However, according to DM_Index_IFV, 2018 had a higher epidemics than 2013, itself higher than 2012. The same procedure was used for establish a final ranking, according to the index that allowed to differentiate the years.



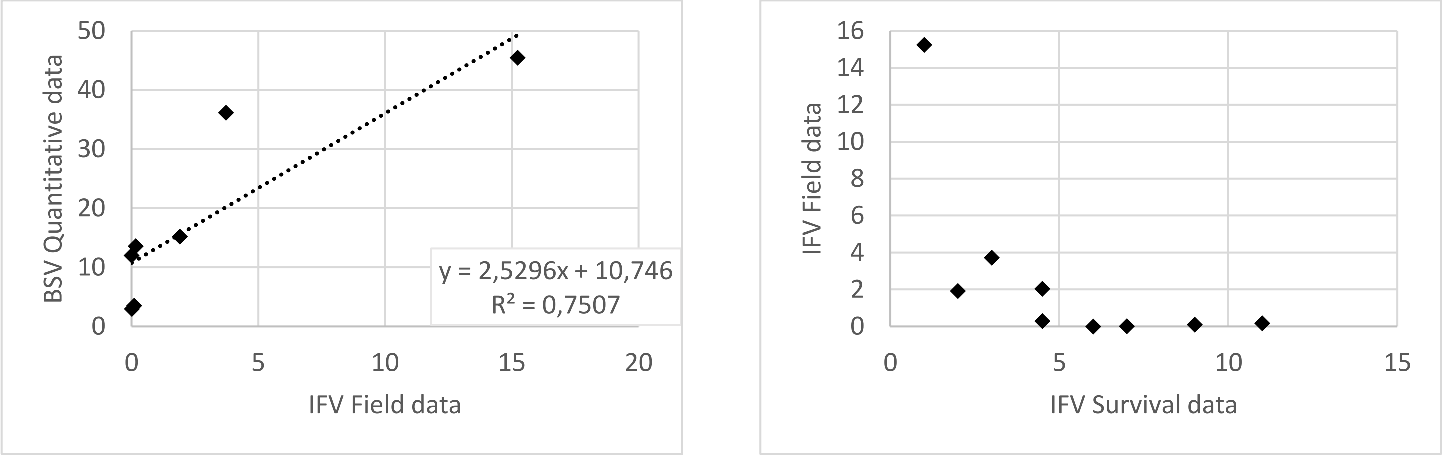
A.1.Correlation between DM_Index_IFV and DM_Index_BSV.

A.2.Correlation between DM_Index_IFV and DM_Index_SC.



B.1.Correlation between PM_Index_BSV and PM_Index_IFV.

B.2.Correlation between PM_Index_IFV and PM_Index_SC.



C.1.Correlation between BR_Index_BSV and BR_Index_IFV.

C.2.Correlation between BR_Index_IFV and BR_Index_SC.

Figure 15. Comparisons between three sets of data for the period 2010 to 2018: IFV survival, IFV field, and BSV quantitative data, for GM, PM and BR.

DM	2018	2013	2012	2016	2014	2015	2017	2011	2010
PM	2011	2010	2012	2014	2013	2015	2017	2016	2018
BR	2015	2014	2017	2016	2012	2013	2018	2010	2011

Figure 16. Proposed ranking of the DM, PM, and BR epidemics of the years 2010-2018, according to the correlation between Index_BSV and Index_IFV.

4.3 Discussion

The best correlations between the datasets were found between BSV quantitative data and IFV field observations (Figure 13). This result is in accord with the origin of the data, as both datasets originate from a shared number of the same untreated plots. Moreover, the correlation between BSV and IFV data allowed to propose a ranking of the 2010-2018 years, for DM and PM epidemics, according to their respective indexes (Figure 14).

The indexes established in this study were based on the data from specific datasets. As a result, the exact formula of their linear or non-linear regression model may not fit every data set. Despite this, the relationships assessed tended to be coherent with other studies, notably regarding the different range of epidemics of each disease and dual epidemics between organs (Donatelli et al. 2017; Savary et al. 1995; Savary et al. 2009). The purpose of this work was to point the preliminary hypothesis that should be fulfilled, and propose a guideline in order to assess the epidemics of DM, PM and BR through the context of BSV and IFV data. As a result, the hypothesis and decisions to conduct the indexes can be summarized as follow: (i) when a lot of quantitative information is available, simplification was sought; (ii) in order to conduct a reliable simplification, relationships between the data, at the organ and variables level were tested (i.e. frequency, intensity, and prevalence); (iii) if a 1 for 1 ratio appeared for a couple of variables, the average of these variables was used onward; (iv) if regression was possible between variables, the formula was used to fit the data to a model, and (v) the final index relied on both modeled data and field observations.

In the indexes construction, the goal was to integrate different key epidemiological variables into the design of indexes to characterize epidemics of Downy Mildew, Powdery Mildew, and Black Rot. Although the indexes ended up as pretty similar in their construction, the different analyses showed that each disease had its own pattern, notably in terms of their respective intensity and frequency distribution (Figure 9). When assessing the correlation between clusters and leaves symptoms' frequency and intensity for each disease, differences in their respective ranges also appeared (Figure 9). These observations are consistent with previous studies (McRoberts, Hughes and Madden, 2003; Savary *et al.*, 2009), and represents the challenge when trying to assess a multipest environment (Donatelli *et al.*, 2017). Moreover, a strong correlation between clusters and leaves symptoms' frequency and intensity was established for Downy and Powdery Mildew, on BSA and IFV data, as displayed in Figure 13. These observations are consistent with the study of Savary et al. (2009), were they determined parabolic patterns between clusters and foliage epidemics for DM and PM. From BSV quantitative data, the relationships between frequency and intensity on clusters for DM and BR (Figure 9, A.1 and C.1) show progressive increases of intensity with increasing frequency. The same can be said for PM, but giving the shorter range in both measurements, the relationship does not appear as clearly. In the case of BSV data, however, the available measurements were truncated of the values of zero, which could furthermore impact the assessed relationships.

The intensity displays the percentage of host surface affected by a given disease, and is therefore considered more precise than the measure of the frequency, which indicates the number of affected organs (Madden, Hughes, and Van den Bosch 2007). When given the choice (1 for 1 ratio), the intensity of the symptoms was selected over their frequency for further analysis. However, it was suggested that frequency was more adapted than intensity when studying an expert-based dataset. In his thesis, "*Impact du changement climatique sur la pression des ravageurs et parasites dans les vignes de Champagne et Bourgogne*", Sebastien Zito, PhD student at Université de Bourgogne, chose to rely on the measure of frequency to assess ten years of epidemics in the vineyard (pers. comm., unpublished work). The results of this work are not available at the moment, but the team is known to work on long-term datasets (Labbé *et al.*, 2019).

The negative correlation between the index from the survival curves (Index_SC) and the two other datasets is consistent with the binary nature of survival studies (Figure 5), as they indicates the percentage of asymptomatic plots (Chen et al. 2019). In our study, survival curves were not used in order to observe a temporal variation, as the data was set to week 32 (veraison). The goal was to link the survival rate at this fixed point in time with the severity of an epidemics. To this end, we chose not to use time as a parameter, as our time of reference was always veraison. Moreover, it could be interesting to investigate the dynamics of vineyard diseases and compare their yearly profiles, as since then the IFV survival curves tools was improved with data regarding epidemics of Powdery Mildew and Black Rot.

5. GENERAL DISCUSSION

In Chapter 1, we were able to successfully differentiate years with high epidemics *versus* years with low epidemics pressure, for four major vineyard diseases that are Downy Mildew, Powdery Mildew, Black Rot, and Gray Mold, on the spent of almost eight decades, in the Bordeaux area. It was possible to extract and display which were more local or general, and to give an evaluation of their dangerousness (Figures 2 to 6). In terms of dangerousness, another point that this study highlighted is that the reports are dependant of the context (historical, scientific, and technical) they were produced. Thus, their interpretation should take into account the information they propose with relativity. This observation is in accord with the studies of Wallsten et al. (1986) and Chen et al. (2019).

In order to properly assess expert's opinions, EFSA recommend the use of probabilistic expert elicitation (EFSA 2014), in the context of risk management. However, to the best of our knowledge, there are not guidelines to assess the reliability of past expert's statements. In the context of the plant health reports, some important factors need to be taken into account when using the database. First, the vocabulary used at different time periods is not necessarily equivalent: experts are writing about the same things, but not using the same words to describe it. Second, plant health reports are not scientific papers, and their accuracy cannot be compared to that of peer reviewed scripts. Indeed, the initial goal of these reports were not to give quantitative information regarding the epidemics, but to warm the agriculturists about risks, in accordance with the knowledge of their time. In order to analyze such dataset, we chose to use a semi-quantitative scale, based on the work of Zwankhuizen and Zadoks (2002) and Fermaud et al. (2016) (see 3.2). Qualitative systems for risk assessment often use ordered categorical labels, such as "low", "medium" and "high", in order to simplify the message. Usually, the inputs and calculations are reduced to a manageable set of judgements. In our case, the goal was to reduce the number and diversity of key words used in the reports to describe the epidemics into computable qualitative data. Thus, the rating logic ought to be transparent and easy to apply. The scale proposed in Chapter 1 allows to easily distinguish local *versus* general epidemics (i.e. local for grades 1 to 3, general for grades 4 to 6), and their severity.

On the other hand, qualitative and quantitative interpretations can be difficult to compare. According to Cox, Babayev, and Huber (2005), two types of errors can occur when dealing with qualitative risks: (i) reverse rankings, i.e. the assignment of a higher qualitative risk rating to situations that have arbitrarily a small quantitative risk, and vice-versa; and (ii) uninformative ranking, or frequently assigning the same ratings to risks that differ by many orders of magnitude. In our study, we have chosen to focus on two of the most relevant epidemiological factors that were available from the reports: prevalence and severity, and to give a higher weight to the prevalence in the semi-qualitative grading system (Chapter 1, Table 1). However, as seen in the literature review, even those two terms of prevalence and severity do not have a simple definition. Prevalence, frequency, or incidence are often misused in each other's place, despite each word having a specific definition (Madden, Hughes, and Van den Bosch 2007; Seem 1984). In this context, the process of extracting and treating this information represents a bias itself, one we can choose to accept or not. Qualitative rating systems are often considered inaccurate, and they do not provide the same level of information than quantitative ratings (Cox, Babayev, and Huber 2005). Nevertheless, it is the role of the experimenter to assess if the level of the information that their database provides is adapted to their research question.

In order to reinforce the observations made in Chapter 1, we proposed in Chapter 2 to focus on reports from the last eight years, as they introduced quantitative data. A second and third dataset were also obtained from the IFV database, regarding untreated plots, from field notations and survival curves, regarding the same period and location. These datasets were used (Chapter 2) to compare with the previous analysis (Chapter 1). The goal was to assess the epidemics in Bordeaux vineyards main diseases through different but complementary datasets, in order to give an overall picture. In order to compare the three datasets, transformation in indexes was performed (see 4.2), and resulted in independents year rankings (Figure 13). Regarding epidemics of Downy Mildew, Powdery Mildew, and Black Rot, it was shown in Chapter 2 that indexes designed from the 2010-2018 BSV were highly correlated with the indexes of IFV field notations. The correlation was less successful with the indexes designed from IFV survival curves (4.3.4; Figure 5). At the end of the comparison, we proposed a ranking of Downy Mildew, Powdery Mildew, and Black Rot epidemics the 2010-2018 period, based on a consensus between the two most correlated indexes (Figure 14). In the case of Black Rot, the presented ranking was mostly extracted from the BR_Index_BSV assessments, as it was the only index that allow a differentiation between years.

It should be stressed that in our study, data were collected over several years, and that part of the variability of the assessed relationships could be related to the yearly variations of the epidemics. Moreover, at this stage, it is not possible to distinguish environmental or practices factors that could have impacted the observed measurements and associated relationships. To this end, analysis of climatic and agronomic data, crossed with the created database, is of the outmost interest. A more in-depth evaluation of viticultural practices could be of great interest over such a long period. To this end, the seasonal plant health reports were identified as a possible source of information.

6. CONCLUSION AND PERSPECTIVES

During this internship, the census, extraction, and analysis of information contained in a long series of annual and seasonal *Bulletins de Santé du Végétal* were performed. A digital database was created. It proposes in a single excel file data on epidemics of Downy Mildew, Powdery Mildew, Black Rot, Gray Mold, Tortricid Moths and other pests that occurred in vineyards of the Bordeaux region, from 1940 to 2018, based on annual plant health reports. Over the entire period, key-words and key sentences were extracted from the reports in order to characterize the epidemics. From 2010 to 2018, quantitative data of prevalence, frequency and intensity were also extracted from the annual plant health reports.

In order to analyze the qualitative data, a semi-quantitative scale was created (Chapter 1). This scale will now be tested on plant health reports from the Hérault region. A collection of *Bulletins de Santé du Végétal* of the last twenty years regarding this region was indeed recently compiled by Nathalie Smits (UMR SYSTEM). If the method developed during this internship is efficient on plant health reports from another region, it could be used to record, compile, and analyze this type of dataset at regional levels, and later, at a national level. Moreover, plant health reports are also issued in other countries, such as Uruguay and Brazil (Roussel, 1986). Given the recent rise of meta analyses and evolution in the processing of big data, new digital methods could also be implemented in order to investigate the vast information that is contained in the *Bulletins de Santé du Végétal.*

In the framework of the LACCAVE project, analysis on long-term epidemiological data are of the outmost interest. Indeed, in regard with climatic data, they can lead to the study of climate change from an historical and epidemiological point of view.

The study of the long series of reports allowed a glimpse at technical and scientific practices of their respective time. We think that the seasonal *Bulletins de Santé du Végétal* could be used to investigate the evolution of viticulture practices, from the beginning of the XXth century to this date.

REFERENCES

Agerberg, J. (2011) ‘Rapport final de l’étude de faisabilité du développement et de la valorisation d’une base de données sur l’évolution des pressions biotiques dans les parcelles agricoles’, p. 66.

De Bary, A. (1863) ‘Recherches sur le développement de quelques champignons parasites’, *Annales des Sciences Naturelles de Botanique*, 4(20), p. 148.

Bois, B., Zito, S. and Calonnec, A. (2017) ‘Climate vs grapevine pests and diseases worldwide: The first results of a global survey’, *Journal International des Sciences de la Vigne et du Vin*. pp. 133–139. doi: 10.20870/oeno-one.2016.0.0.1780.

Bregaglio, S., Donatelli, M. and Confalonieri, R. (2013) ‘Fungal infections of rice, wheat, and grape in Europe in 2030-2050’, *Agronomy for Sustainable Development*, 33(4), pp. 767–776. doi: 10.1007/s13593-013-0149-6.

Caffarra, A. *et al.* (2012) ‘Modelling the impact of climate change on the interaction between grapevine and its pests and pathogens: European grapevine moth and powdery mildew’, *Agriculture, Ecosystems and Environment*, 148, pp. 89–101. doi: 10.1016/j.agee.2011.11.017.

Calonnec, A. *et al.* (2004) ‘Effects of Uncinula necator on the yield and quality of grapes (Vitis vinifera) and wine’, *Plant Pathology*, 53, pp. 434–445. doi: 10.1111/j.1365-3059.2004.01016.x.

Chaplin-Kramer, R. *et al.* (2011) ‘A meta-analysis of crop pest and natural enemy response to landscape complexity’, *Ecology Letters*, 14(9), pp. 922–932. doi: 10.1111/j.1461-0248.2011.01642.x.

Chen, M. *et al.* (2019) ‘Timing of grape downy mildew onset in bordeaux vineyards’, *Phytopathology*, 109(5), pp. 787–795. doi: 10.1094/PHYTO-12-17-0412-R.

Cobb, N. A. (1892) ‘Contributions to an economic knowledge of the Australian rusts (Uredineae)’, *Agricultural Gazette of New South Wales*, 3, pp. 44–48.

Cochran, W. G. and Snedecor, G. W. (1971) *Méthodes statistiques. Translation by H. Boelle et E. Camhaji*. Association de Coordination Technique Agricole.

De Cortázar-Atauri, I. G. *et al.* (2017) ‘Grapevine phenology in France: From past observations to future evolutions in the context of climate change’, *Oeno One*, 51(2), pp. 115–126. doi: 10.20870/oeno-one.2016.0.0.1622.

Cox, L. A., Babayev, D. and Huber, W. (2005) ‘Some limitations of qualitative risk rating systems’, *Risk Analysis*, 25(3), pp. 651–662. doi: 10.1111/j.1539-6924.2005.00615.x.

Delbac, L. (2000) *Epidémiologie de la flavescence dorée de la vigne. Détection du phytoplasme et dynamique de population de Scaphoideus titanus ball. en Gironde*.

Delbac, L. and Savary, S. (2017) *Incidence moyenne des principaux champignons aériens de* *la vigne dans les régions viticoles françaises (évaluée sur 25 années)*. Available at: http://ephytia.inra.fr/fr/C/6998/Vigne-Champignons-pathogenes (Accessed: 5 June 2019).

Delière, L. *et al.* (2017) 'Cépages résistants : la vigne contre-attaque !', *Phytoma*, 708, pp. 34–37.

Donatelli, M. *et al.* (2017) 'Modelling the impacts of pests and diseases on agricultural systems', *Agricultural Systems*, 155, pp. 213–224. doi: 10.1016/j.agsy.2017.01.019.

Dubos, B. (2002) *Maladies cryptogamiques de la vigne. les champignons parasites des organes herbacées et du bois de la vigne*. Collection Féret.

EFSA Panel on Plant Health (2011) 'Guidance on the environmental risk assessment of plant pests', *EFSA Journal*, 9(12), pp. 1–121. doi: 10.2903/j.efsa.2011.2460.Available.

Elad, Y. *et al.* (1998) 'Management of powdery mildew and gray mold of cucumber by Trichoderma harzianum T39 and Ampelomyces quisqualis AQ10', *Biocontrol*, (43), pp. 241–251.

Fermaud, M. (1992) ' Transmission of Botrytis cinerea to Grapes by Grape Berry Moth Larvae ', *Phytopathology*, p. 1393. doi: 10.1094/phyto-82-1393.

Fermaud, M. *et al.* (2016) 'New multipest damage indicator to assess protection strategies in grapevine cropping systems', *Australian Journal of Grape and Wine Research*, 22(3), pp. 450–461. doi: 10.1111/ajgw.12238.

Galet, P. (1982) *Les maladies et les parasites de la vigne. Tome II. Les parasites animaux*. Montpellier: Paysan du Midi.

Geoffrion, R. (1976) 'L'Oïdium de la vigne: historique et méthodes de lutte', *Phytoma, la défense des cultures*, pp. 15–25.

Global biodiversity information facility (2019) *Plasmopara viticola (Berk. & M.A.Curtis) Berl. & De Toni, 1888, Species 2000 & ITIS Catalogue of Life*. Available at: https://www.gbif.org/fr/species/141904289 (Accessed: 11 September 2019).

Gorter, G. M. A. (1974) 'Methods of Assessing Cucurbit Powdery Mildew (Sphaerothecajuliginea) In Terms of Fungicide Evaluation', 70(January), pp. 7–9.

Huerta-Espino, J. *et al.* (2011) 'Global status of wheat leaf rust caused by Puccinia triticina', *Euphytica*, 179(1), pp. 143–160. doi: 10.1007/s10681-011-0361-x.

Hughes, G. and Madden, L. V. (2002) 'Some methods for eliciting expert knowledge of plant disease epidemics and their application in cluster sampling for disease incidence', *Crop Protection*, 21(3), pp. 203–215. doi: 10.1016/S0261-2194(01)00087-4.

Kennelly, M. M. *et al.* (2007) 'Primary infection, lesion productivity, and survival of sporangia in the grapevine downy mildew pathogen Plasmopara viticola', *Phytopathology*, 97(4), pp. 512–522. doi: 10.1094/PHYTO-97-4-0512.

Kranz, J. (1990) ‘Epidemics, Their Mathematical Analysis and Modeling: An Introduction’, pp. 1–11. doi: 10.1007/978-3-642-75398-5_1.

Krebs, C. J. (2014) *Ecological Methodology, 3rd ed., Addison-Wesley Educational Publishers, Inc.* doi: 10.1007/s007690000247.

Labbé, T. *et al.* (2019) ‘The longest homogeneous series of grape harvest dates, Beaune 1354&ndash;2018, and its significance for the understanding of past and present climate’, *Climate of the Past Discussions*, pp. 1–33. doi: 10.5194/cp-2018-179.

Lilienfeld, S. O. *et al.* (2015) ‘Fifty psychological and psychiatric terms to avoid: A list of inaccurate, misleading, misused, ambiguous, and logically confused words and phrases’, *Frontiers in Psychology*, 6(August), pp. 1–15. doi: 10.3389/fpsyg.2015.01100.

Madden, L. V, Hughes, G. and Van den Bosch, F. (2007) *The study of plant disease epidemics*. Edited by American Phytopathological Society. doi: https://doi.org/10.1094/9780890545058.

Marchal, P. *et al.* (1936) *Annales de épiphyties et de phytogénétique*. Edited by M. de L’Agriculture. Paris: Imprimerie Nationale.

McRoberts, N., Hughes, G. and Madden, L. V. (2003) ‘The theoretical basis and practical application of relationships between different disease intensity measurements in plants’, *Annals of Applied Biology*, 142(2), pp. 191–211. doi: 10.1111/j.1744-7348.2003.tb00242.x.

Onesti, G. (2014) *Studies on inoculum dynamics of Guignardia bidwellii, causal agent of grape black-rot*. Università Cattolica del Sacro Cuore.

Ouzeau, G. *et al.* (2014) *Le climat de la France au XXIe siècle, Direction générale de l’Énergie et du Climat*. doi: 10.1038/098127b0.

Parker, A. K. *et al.* (2011) ‘General phenological model to characterise the timing of flowering and veraison of Vitis vinifera L.’, *Australian Journal of Grape and Wine Research*, 17(2), pp. 206–216. doi: 10.1111/j.1755-0238.2011.00140.x.

Raynal, M. *et al.* (2006) ‘Epicure , a geographic information system applied on downy and powdery mildew risks of epidemics on the Bordeaux vineyard’, (June), pp. 3–5.

Rossi, V. *et al.* (2008) ‘A mechanistic model simulating primary infections of downy mildew in grapevine’, *Ecological Modelling*, 212(3–4), pp. 480–491. doi: 10.1016/j.ecolmodel.2007.10.046.

Rossi, V., Caffi, T. and Gobbin, D. (2013) ‘Contribution of molecular studies to botanical epidemiology and disease modelling: Grapevine downy mildew as a case-study’, *European Journal of Plant Pathology*, 135(4), pp. 641–654. doi: 10.1007/s10658-012-0114-2.

Roussel, C. (1986) ‘Une technique française qui s’exporte: les avertissements agricoles en uruguay’, *Phytoma, la défense des cultures*, (381), pp. 10–12.

Roussey, C. *et al.* (2016) *Gestion Sémantique des Bulletins de Santé du Végétal dans le projet Vespa*.

Rouzes, R. *et al.* (2012) ‘Une nouvelle drosophile (Drosophila suzukii) en vignoble bordelais’, *Union Girondine des vins de Bordeaux,* pp. 36–42.

Savary, S. *et al.* (1995) ‘Use of Categorical Information and Correspondence Analysis in Plant Disease Epidemiology’, *Advances in Botanical Research,* 21(C), pp. 213–240. doi: 10.1016/S0065-2296(08)60014-2.

Savary, S. *et al.* (2009) ‘Analysis of nonlinear relationships in dual epidemics, and its application to the management of grapevine downy and powdery mildews’, *Phytopathology,* 99(8), pp. 930–942. doi: 10.1094/PHYTO-99-8-0930.

Savary, S. *et al.* (2018) ‘Concepts, approaches, and avenues for modelling crop health and crop losses’, *European Journal of Agronomy,* 100, pp. 4–18. doi: 10.1016/j.eja.2018.04.003.

Schauberger, B. *et al.* (2018) ‘Yield trends, variability and stagnation analysis of major crops in France over more than a century’, *Scientific Reports,* 8(1). doi: 10.1038/s41598-018-35351-1.

Scherrer, B. (1984) *Biostatistique*. Edited by G. Morin. Université du Québec à Montréal.
Seem, R. C. (1984) ‘Disease Incidence and Severity Relationships’, *Annual Review of Phytopathology,* 22(1), pp. 133–150. doi: 10.1146/annurev.py.22.090184.001025.

Siriez, H., Geoffrion, R. and Roussel, C. (1978) ‘Le mildiou de la vigne: un sicèle de lutte et des progrès décisifs’, *Phytoma, la défense des végétaux,* pp. 5–23.

Thiéry, D. (2008) ‘Les tordeuses nuisibles à la vigne’, in *Les ravageurs de la vigne*. Editions Ferret, Bordeaux, pp. 214–246.

Tucker (1845) ‘The Gardeners’ chronicle and agricultural gazette’.

Turenne, N. *et al.* (2015) *Open Data Platform for Knowledge Access in Plant Health Domain : VESPA Mining.*

Wallsten, T. S. *et al.* (1986) ‘Measuring the Vague Meanings of Probability Terms’, *Journal of Experimental Psychology: General,* 115(4), pp. 348–365. doi: 10.1037/0096-3445.115.4.348.

Wilcox, W., Gubler, W. and Uyemoto, J. (2015) *Compendium of grape diseases, disorders, and Pests. Second Edition.* American Phytopathological Society.

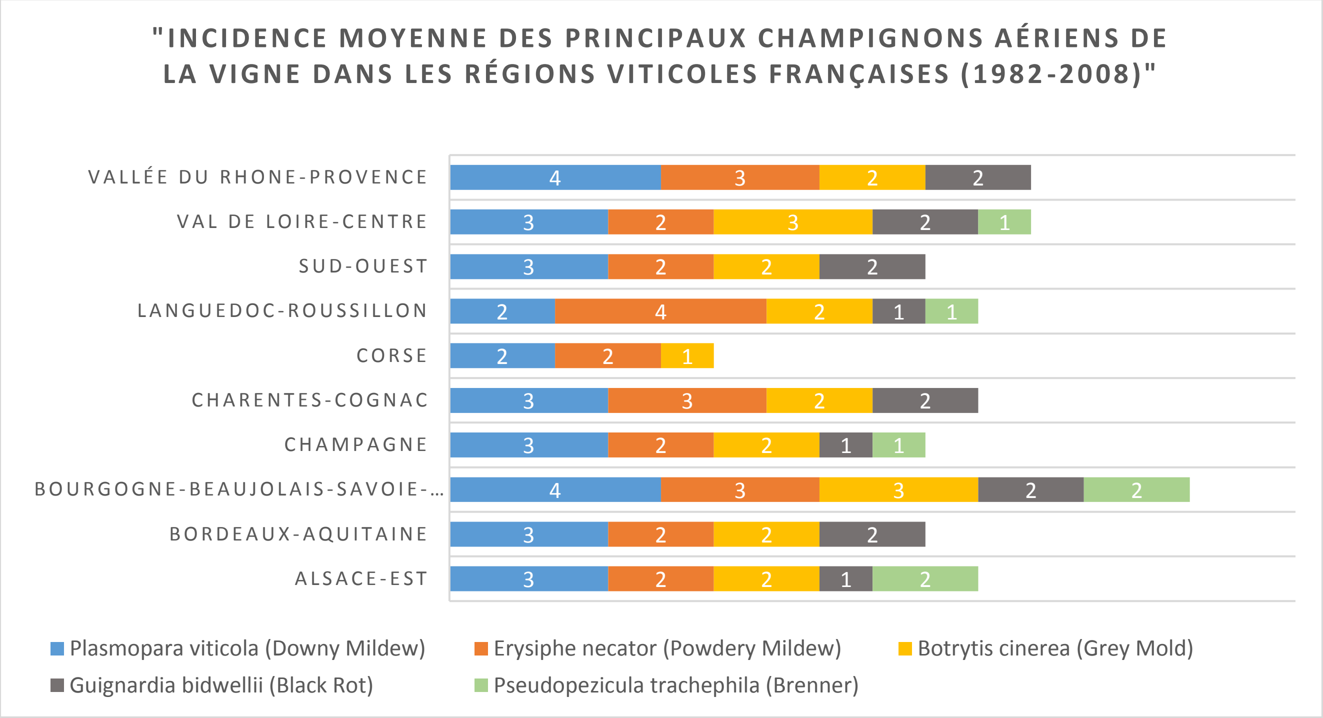
Willocquet, L. *et al.* (2018) ‘Reverse modelling to estimate yield losses caused by crop diseases’, *Plant Pathology,* 67(8), pp. 1669–1679. doi: 10.1111/ppa.12873.

Xu, X. (2006) ‘Modelling and interpreting disease progress in time’, in *The Epidemiology of Plant Diseases,* pp. 215–238. doi: 10.1007/1-4020-4581-6_8.

Zwankhuizen, M. J. and Zadoks, J. C. (2002) ‘Phytophthora infestans’s 10-year truce with Holland: A long-term analysis of potato late-blight epidemics in the Netherlands’, *Plant Pathology,* 51(4), pp. 413–423. doi: 10.1046/j.1365-3059.2002.00738.x.

APPENDICES

Appendix 1. Mean incidences of main pathogenic fungi affecting French vineyards, by regions. Adapted from Delbac and Savary, 2017. Original data available at http://ephytia.inra.fr/fr/C/6998/Vigne-Champignons-pathogenes



Appendix 2. Exhaustive census of source material: annual and seasonal plant health reports, Phytoma.

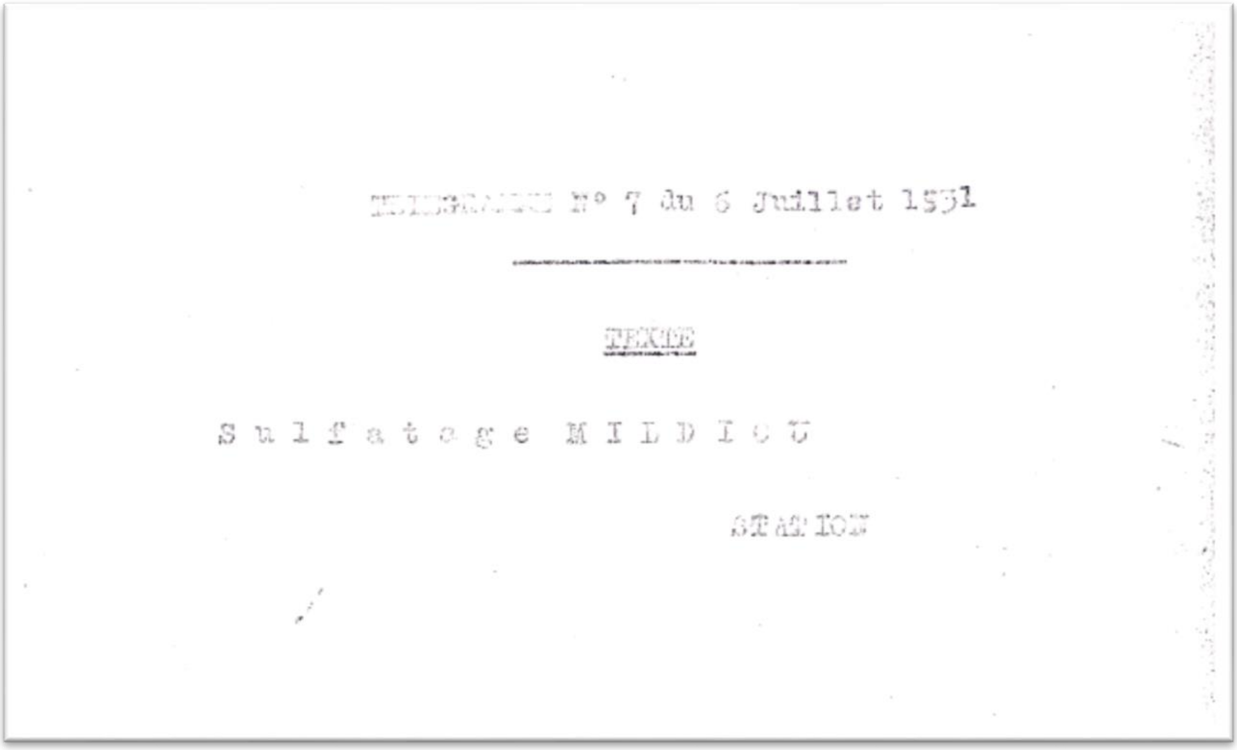
	Report's number	Report's title	Issued by	Station's name	Region	Number of pages	Date	Edition	Format	Authors
1940	na	Missing	na	na	na	na	na	na	na	na
1941	na	Missing	SPV	na	na	na	na	na	na	na
1942	na	Missing	SPV	na	na	na	na	na	na	na
1943	none	Evolution des maladies pendant la saison 1943	SPV	Avertissements Agricoles du Sud-Ouest	Sud-Ouest	1	na	Vigne	Annual review	C. Roussel ; J. Bruneteau
1944	na	Missing	na	na	na	na	na	na	na	na
1945	none	Résumé de l'évolution des maladies et des insectes (pour la vigne et les arbres fruitiers) pendant la saison 1945	SPV	Avertissements Agricoles du Sud-Ouest	Sud-Ouest	1	na	Vigne	Annual review	C. Roussel ; J. Bruneteau
1946	6	Résumé de l'évolution des maladies et des insectes pendant la saison 1946	SPV	Avertissements Agricoles	Sud-Ouest	2	05/11/1946	Vigne	Annual review	C. Roussel ; J. Bruneteau
1947	5	Résumé de l'évolution des maladies et des insectes pendant la saison 1947	SPV	Avertissements Agricoles	Sud-Ouest	1	na	Vigne	Annual review	C. Roussel ; J. Bruneteau
1948	20	Résumé de l'évolution des maladies et des insectes pendant la saison 1948	SPV	Avertissements Agricoles	Sud-Ouest	1	26/10/1948	Vigne	Annual review	C. Roussel ; J. Bruneteau
1949	none	Résumé de l'évolution des maladies et des insectes pendant la saison 1949	SPV	Avertissements Agricoles	Sud-Ouest	1	08/12/1949	Vigne	Annual review	C. Roussel ; J. Bruneteau
1950	none	Résumé de l'évolution des maladies et des insectes pendant la saison 1950	SPV	Avertissements Agricoles	Sud-Ouest	1	15/11/1950	Vigne	Annual review	C. Roussel ; J. Bruneteau
1951	na	Résumé de l'évolution des maladies et des insectes pendant la saison 1951	SPV	Avertissements Agricoles	Sud-Ouest	2	31/10/1951	Vigne	Annual review	C. Roussel ; J. Bruneteau
1952	na	Résumé de l'évolution des maladies et des insectes pendant la saison 1952	SPV	Avertissements Agricoles	Sud-Ouest	2	05/11/1952	Vigne	Annual review	C. Roussel ; J. Bruneteau
1953	5	Evolution des maladies et des insectes pendant la saison 1953	SPV	Avertissements Agricoles	Sud-Ouest	2	14/11/1953	Vigne	Annual review	C. Roussel ; J. Bruneteau
1954	5	Evolution des maladies et des insectes pendant la saison 1954	SPV	Avertissements Agricoles	Sud-Ouest	2	25/10/1954	Vigne	Annual review	C. Roussel ; J. Bruneteau
1955	5	Evolution des maladies et des insectes pendant l'année 1955	SPV ; Ministère de l'Agriculture	Station d'Avertissements Agricoles du Sud-Ouest	Sud-Ouest	2	29/10/1955	Vigne	Annual review	C. Roussel ; J. Bruneteau
1956	5	Evolution des maladies et des insectes pendant l'année 1956	SPV ; Ministère de l'Agriculture	Station d'Avertissements Agricoles du Sud-Ouest	Sud-Ouest	3	22/12/1956	Vigne	Annual review	C. Roussel ; J. Bruneteau
1957	4	Evolution des maladies et des insectes pendant l'année 1957	SPV ; Ministère de l'Agriculture	Station d'Avertissements Agricoles du Sud-Ouest	Sud-Ouest	3	12/10/1957	Vigne	Annual review	C. Roussel ; J. Bruneteau
1958	4	Evolution des maladies et des insectes pendant l'année 1958	SPV ; Ministère de l'Agriculture	Station d'Avertissements Agricoles du Sud-Ouest	Sud-Ouest	2	na	Vigne	Annual review	C. Roussel ; J. Bruneteau
1959	4	Evolution des maladies et des insectes pendant l'année 1959	SPV ; Ministère de l'Agriculture	Station d'Avertissements Agricoles du Sud-Ouest	Sud-Ouest	4	21/10/1959	Vigne	Annual review	C. Roussel ; J. Bruneteau
1960	3	Bulletin technique : Evolution des maladies et des insectes pendant l'année 1960	Régisseur de recette de la Protection des Végétaux	Edition de la station de Bordeaux	Bordeaux	4	Dec 1960	Vigne	Annual review	C. Roussel ; J. Bruneteau
1961	15	Bulletin technique : Evolution des maladies et des insectes pendant l'année 1961	Régisseur de recette de la Protection des Végétaux	Edition de la station de Bordeaux	Bordeaux	4	Dec 1961	Vigne	Annual review	C. Roussel ; J. Bruneteau
1962	27	Bulletin technique : Evolution des maladies et des insectes pendant l'année 1962	Régisseur de recette de la Protection des Végétaux	Edition de la station de Bordeaux	Bordeaux	4	Dec 1962	Vigne	Annual review	C. Roussel ; J. Bruneteau
1963	39	Bulletin technique : Evolution des maladies et des insectes pendant l'année 1963	Régisseur de recette de la Protection des Végétaux	Edition de la station de Bordeaux	Bordeaux	4	Dec 1963	Vigne	Annual review	C. Roussel ; J. Bruneteau
1964	51	Bulletin technique : Evolution des parasites de la vigne pendant l'année 1964	Régisseur de recette de la Protection des Végétaux	Edition de la station de Bordeaux	Bordeaux	2	Dec 1964	Vigne	Annual review	C. Roussel ; J. Bruneteau
1965	62	Bulletin technique : Evolution des parasites de la vigne en 1965	Régisseur de recette de la Protection des Végétaux	Edition de la station de Bordeaux	Bordeaux	2	Nov 1965	Vigne	Annual review	C. Roussel ; J. Bruneteau
1966	75	Bulletin technique : Evolution des parasites de la vigne en 1966	Régisseur de recette de la Protection des Végétaux	Edition de la station de Bordeaux	Bordeaux	2	Dec 1966	Vigne	Annual review	C. Roussel ; J. Bruneteau
1967	87	Bulletin technique : Evolution des parasites de la vigne en 1967	Sous-régisseur d'avances et de Recettes, Direction Départementale de l'Agriculture	Edition de la station Aquitaine	Aquitaine	2	Dec 1967	Vigne	Annual review	C. Roussel ; J. Bruneteau
1968	99	Bulletin technique : Evolution des parasites de la vigne en 1968	Sous-régisseur d'avances et de Recettes, Direction Départementale de l'Agriculture	Edition de la station Aquitaine	Aquitaine	2	Dec 1968	Vigne	Annual review	C. Roussel ; J. Bruneteau

1969	111	Bulletin technique : Evolution des maladies de la vigne en 1969	Sous-régisseur d'avances et de Recettes, Direction Départementale de l'Agriculture	Edition de la station Aquitaine	Aquitaine	2	Dec 1969	Vigne	Annual review	C. Roussel ; M. Large
1970	na	Bulletins techniques	Sous-régisseur d'avances et de Recettes, Direction Départementale de l'Agriculture	Edition de la station Aquitaine	Aquitaine	6	July and August 1970	Vigne	Periodic report	C. Roussel ; M. Large
1971	132	Bulletin technique : la situation sanitaire du vignoble	SPV, Sous-régisseur d'avances et de Recettes, Direction Départementale de l'Agriculture	Edition de la station Aquitaine	Aquitaine	2	Sept 1971	Vigne	Annual review	C. Roussel ; J. Touzeau
1972	142, 143, 144	Bulletins techniques	SPV, Sous-régisseur d'avances et de Recettes, Direction Départementale de l'Agriculture	Edition de la station Aquitaine	Aquitaine	6	July to September 1972	Vigne	Periodic report	na
1973	154, 155	Bulletins techniques	SPV, Sous-régisseur d'avances et de Recettes, Direction Départementale de l'Agriculture	Edition de la station Aquitaine	Aquitaine	5	July to August 1973	Vigne	Periodic report	na
1974	none	Manifestations des ennemis des cultures au cours du second semestre 1974	Phytoma, la défense des végétaux	None, page 28	National	1	Jan 1975	All cultures	Annual review	R. Teissier
1974 bis	18, 20, 21, 22, 23	Bulletins techniques	SPV, Sous-régisseur d'avances et de Recettes, Direction Départementale de l'Agriculture	Edition de la station Aquitaine	Aquitaine	5	July to September 1974	Vigne	Periodic report	na
1975	45, 46, 48, 49	Bulletins techniques	SPV, Sous-régisseur d'avances et de Recettes, Direction Départementale de l'Agriculture	Edition de la station Aquitaine	Aquitaine	4	July to August 1974	Vigne	Periodic report	na
1976	na	La sécheresse et la situation phytosanitaire	Phytoma, la défense des végétaux	None, page 25	National	1	Nov 1976	All cultures	Annual review	R. Teissier
1976 bis	72, 73, 74	Bulletins techniques	SPV, Sous-régisseur d'avances et de Recettes, Direction Départementale de l'Agriculture	Edition de la station Aquitaine	Aquitaine	3	July to August 1976	Vigne	Periodic report	na
1977	none	Bulletin technique spécial vigne : les problèmes phytosanitaires au vignoble en 1977	SPV, Sous-régisseur d'avances et de Recettes, Direction Départementale de l'Agriculture	Edition de la station Aquitaine	Aquitaine	2	08/12/1977	Vigne	Annual review	M. Large
1977 bis	103, 104, 105, 106, 107, 108, 109	Bulletins techniques	SPV, Sous-régisseur d'avances et de Recettes, Direction Départementale de l'Agriculture	Edition de la station Aquitaine	Aquitaine	7	June to August 1977	Vigne	Periodic report	C Roussel ; M. Large
1978	19, 20, 21, 22, 23, 24, 25, 26	Bulletins techniques	SPV, Sous-régisseur d'avances et de Recettes, Direction Départementale de l'Agriculture	Edition de la station Aquitaine	Aquitaine	8	July to September 1978	Vigne	Periodic report	M. Large
1979	18, 19, 20, 21, 22, 23, 24	Bulletins techniques	SPV, Sous-régisseur d'avances et de Recettes, Direction Départementale de l'Agriculture	Edition de la station Aquitaine	Aquitaine	7	July to September 1979	Vigne	Periodic report	M. Large
1980	20, 21, 22, 23, 24, 25	Bulletins techniques	SPV, Sous-régisseur d'avances et de Recettes, Direction Départementale de l'Agriculture	Edition de la station Aquitaine	Aquitaine	6	July to September 1980	Vigne	Periodic report	M. Large
1981	21, 22, 23, 24, 25, 26, 27	Bulletins techniques	SPV, Sous-régisseur d'avances et de Recettes, Direction Départementale de l'Agriculture	Edition de la station Aquitaine	Aquitaine	7	July to September 1981	Vigne	Periodic report	M. Large
1982	21, 22, 23, 24, 25, 26, 29	Bulletins techniques	SPV, Sous-régisseur d'avances et de Recettes, Direction Départementale de l'Agriculture	Edition de la station Aquitaine	Aquitaine	7	July to October 1982	Vigne	Periodic report	A. Gravaud
1983	2	Bulletin technique : Bilan de la campagne viticole 1983	SPV, Ministère de l'Agriculture	Edition générale Aquitaine	Aquitaine	4	25/01/1984	Vigne	Annual review	A. Gravaud
1984	18, 19, 20, 21,	Bulletins techniques	SPV, Ministère de l'Agriculture	Edition générale Aquitaine	Aquitaine	8	July to August 1984	Vigne	Periodic report	A. Gravaud

	22, 23, 25, 26									
1985	28	Bulletin technique : Bilan phytosanitaire du vignoble aquitaine en 1985	SPV, Ministère de l'Agriculture	Edition générale Aquitaine	Aquitaine	4	14/11/1985	Vigne	Annual review	A. Gravaud
1986	19, 20, 21, 22, 23, 24, 26, 27	Bulletins techniques	SPV, Ministère de l'Agriculture	Edition générale Aquitaine	Aquitaine	8	July to September 1986	Vigne	Periodic report	A. Gravaud
1987	23	Bulletin technique : Bilan phytosanitaire vigne 1987	SPV, DRAF Aquitaine	Station d'Avertissements Agricoles d'Aquitaine	Aquitaine	4	18/11/1987	Plantes pérennes	Annual review	P. Tisse ; A. Gravaud
1988	23	Bulletin technique : Vigne	SPV, DRAF Aquitaine	Station d'Avertissements Agricoles d'Aquitaine	Aquitaine	4	07/11/1988	Plantes pérennes	Annual review	A. Gravaud
1989	22	Bulletin technique : Bilan phytosanitaire 1989	SPV, DRAF Aquitaine	Station d'Avertissements Agricoles d'Aquitaine	Aquitaine	8	05/10/1989	Plantes pérennes	Annual review	A. Gravaud
1990	21	Bulletin technique : Bilan phytosanitaire 1990	SPV, DRAF Aquitaine	Station d'Avertissements Agricoles d'Aquitaine	Aquitaine	10	27/10/1990	Plantes pérennes	Annual review	A. Gravaud
1991	13, 14, 15, 16, 17	Bulletins techniques	SPV, DRAF Aquitaine	Station d'Avertissements Agricoles d'Aquitaine	Aquitaine	5	July to September 1991	Plantes pérennes	Periodic report	na
1992	2	Bulletin technique	SPV, DRAF Aquitaine	Station d'Avertissements Agricoles d'Aquitaine	Aquitaine	7	22/01/1993	Plantes pérennes	Annual review	na
1993	20	Bulletin technique : Bilan phytosanitaire de la campagne 1993, 1ère, 2ème et 3ème parties	SPV, DRAF Aquitaine	Station d'Avertissements Agricoles d'Aquitaine	Aquitaine	11	4/11/1993 ; 11/11/1993 ; 12/01/1994	Plantes pérennes	Annual review	na
1994	1	Bulletin technique : Bilan phytosanitaire	SPV, DRAF Aquitaine	Station d'Avertissements Agricoles d'Aquitaine	Aquitaine	5	14/01/1995	Plantes pérennes	Annual review	na
1995	19 ; 2	Bulletin technique : Bilan phytosanitaire vigne 1995, 1ère et 2ème parties	SPV, DRAF Aquitaine	Station d'Avertissements Agricoles d'Aquitaine	Aquitaine	6	05/11/1995 ; 27/02/1996	Plantes pérennes	Annual review	na
1996	20	Bulletin technique : Bilan 1996, 1ère et 2ème parties	SPV, DRAF Aquitaine	Station d'Avertissements Agricoles d'Aquitaine	Aquitaine	7	07/11/1996 ; 28/01/1997	Plantes pérennes	Annual review	na
1997	18 ; 20 ; 1	Bulletin technique : Bilan phytosanitaire 1ère et 2ème parties + Bulletin technique Plantes pérennes	SPV, DRAF Aquitaine	Station d'Avertissements Agricoles d'Aquitaine	Aquitaine	8	29/09/1997 ; 07/10/1997 ; 23/01/1998	Vigne	Annual review	na
1998	523	Bilan phytosanitaire de la campagne 1998	Phytoma, la défense des végétaux	na	National	1	na	na	Annual review	na
1999	21 ; 1	Bulletin technique des Stations d'Avertissement Agricoles	SPV, DRAF Aquitaine	Station d'Avertissements Agricoles d'Aquitaine	Aquitaine	6	17/12/1999 ; 20/01/2000	Vigne	Annual review	na
2000	25	Bulletin technique : Bilan de l'année 2000	SPV, DRAF Aquitaine	Station d'Avertissements Agricoles d'Aquitaine	Aquitaine	3	20/12/2000	Vigne	Annual review	na
2001	1	Bulletin technique : Bilan phytosanitaire 2001 dans le vignoble aquitain	SPV, DRAF Aquitaine, FREDON Aquitaine	Station d'Avertissements Agricoles d'Aquitaine	Aquitaine	3	10/01/2002	Vigne	Annual review	na
2002	1	Bulletin technique : Bilan phytosanitaire 2002 dans le vignoble aquitain	SPV, DRAF Aquitaine, FREDON Aquitaine	Station d'Avertissements Agricoles d'Aquitaine	Aquitaine	4	15/01/2003	Vigne	Annual review	na
2003	21	Bulletin technique : Bilan climatique et phytosanitaire 2003	SPV, DRAF Aquitaine, FREDON Aquitaine	Station d'Avertissements Agricoles Aquitaine	Aquitaine	3	27/11/2003	Vigne	Annual review	na
2004	22 ; 23	Bulletin technique : Bilan National	SPV, DRAF Aquitaine, FREDON Aquitaine	Station d'Avertissements Agricoles Aquitaine	National	8	26/10/2004 ; 25/11/2004	Vigne	Annual review	na
2005	na	Bilan Aquitaine vigne Campagne 2005	SRPV Aquitaine	na	Aquitaine	8	13/12/2005	Vigne	Annual review	Guillaume Girard
2006	23 ; 25	Bulletin technique : La situation du vignoble aux vendanges + Maladies du bois : bilan régional	SPV, DRAF Aquitaine, FREDON Aquitaine	Station d'Avertissements Agricoles Aquitaine	Aquitaine	10	12/10/2006 ; 14/12/2006	Vigne	Annual review	na
2007	19 ; 20	Bulletin technique : Bilan	SPV, DRAF Aquitaine, FREDON Aquitaine	Station d'Avertissements Agricoles Aquitaine	Aquitaine	8	12/10/2007 ; 14/11/2007	Vigne	Annual review	na
2008	19	Avertissements agricoles	SRPV, FREDON	Station d'Avertissements Agricoles Aquitaine	Aquitaine	5	25/09/2008	Vigne	Annual review	na
2009	22	Bulletin de santé végétale	SRPV, DRAAF Aquitaine, FREDON Aquitaine	Station d'Avertissements Agricoles Aquitaine	Aquitaine	5	17/12/2009	Vigne	Annual review	na
2010	22	Bulletin de santé du végétal : Bilan de campagne 2010	Chambre d'Agriculture de la Gironde, Chambre d'Agriculture de la Dordogne, DRAAF Aquitaine	Various partners (38)	Aquitaine	15	21/12/2010	Vigne	Annual review	D. Graciet ; F. Ballouhey
2011	21	Bulletin de santé du végétal : Bilan de campagne 2011	Chambre d'Agriculture de la Gironde, DRAAF Aquitaine	Various partners (39)	Aquitaine	14	20/12/2011	Vigne	Annual review	D. Graciet ; J. Lurton
2012	21	Bulletin de santé du végétal : Bilan de campagne 2012	Chambre d'Agriculture de la Gironde, DRAAF Aquitaine	Various partners (40)	Aquitaine	14	13/11/2012	Vigne	Annual review	D. Graciet ; A. Betbeder
2013	22	Bulletin de santé du végétal : Bilan de campagne 2013	Chambre d'Agriculture de la Gironde, DRAAF Aquitaine	Various partners	Aquitaine	15	12/11/2013	Vigne	Annual review	D. Graciet ; M. Lasserre
2014	22	Bulletin de santé du végétal : Bilan de campagne 2014	Chambre d'Agriculture de la Gironde, DRAAF Aquitaine	Various parnters	Aquitaine	22	16/12/2014	Vigne	Annual review	D. Graciet ; M. Lasserre

2015	24	Bulletin de santé du végétal : Bilan de campagne 2015	Chambre d'Agriculture de la Gironde, DRAAF Aquitaine	Various parnters	Aquitaine	25	08/12/2015	Vigne	Annual review	D. Graciet ; E. Laveau
2016	24	Bulletin de santé du végétal : Bilan de campagne 2016	Chambre d'Agriculture de la Gironde, DRAAF Aquitaine	Various parnters	Aquitaine	22	23/11/2016	Vigne	Annual review	D. Graciet ; E. Laveau
2017	20	Bulletin de santé du végétal Nouvelle-Aquitaine : Bilan de campagne 2017	Chambre d'Agriculture de la Gironde, DRAAF Aquitaine	Various parnters	Nord Aquitaine (24/33/47)	22	05/12/2017	Vigne	Annual review	D. Graciet ; E. Laveau ; F. Ballouhey
2018	19	Bulletin de santé du végétal Nouvelle Aquitaine : Bilan de campagne 2018	Chambre d'Agriculture de la Gironde, DRAAF Aquitaine	Various parnters	Nord Aquitaine (24/33/47)	20	18/12/2018	Vigne	Annual review	D. Graciet ; M. H. Martigne

Appendix 3. Seasonal plant health report of July 6th, 1931. The telegram was issued by the Service Régional de Protection des Végétaux.



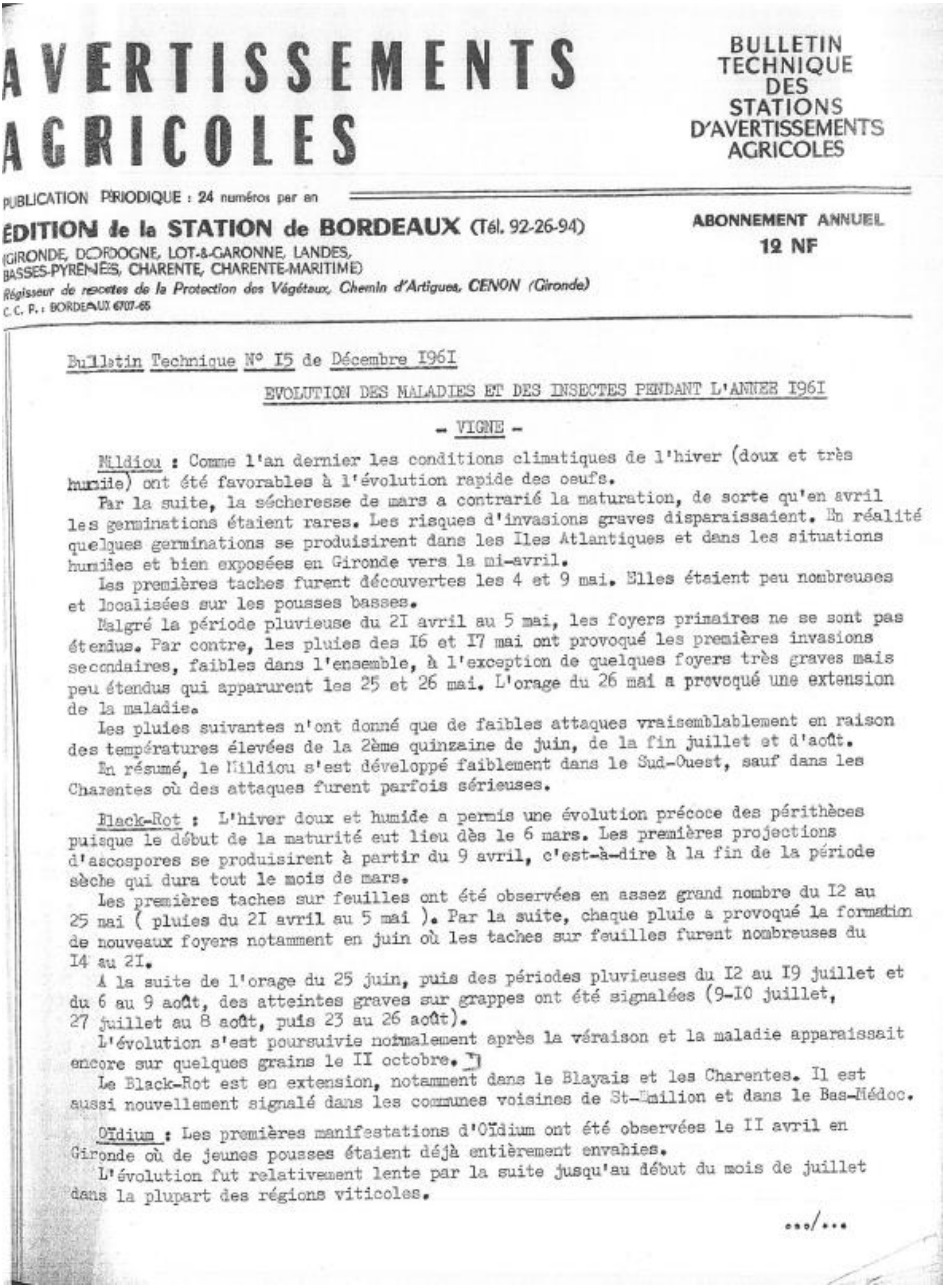
TELEGRAMME N° 7 du 6 Juillet 1931

TEXTE

Sulfatage MILDIOU

STATION

Appendix 4. Annual plant health report of the year 1961, vineyard edition, in the Bordeaux region.



AVERTISSEMENTS AGRICOLES

BULLETIN
TECHNIQUE
DES
STATIONS
D'AVERTISSEMENTS
AGRICOLES

PUBLICATION PÉRIODIQUE : 24 numéros par an

ÉDITION de la STATION de BORDEAUX (Tél. 92-26-94)
(GIRONDE, DORDOGNE, LOT-&-GARONNE, LANDES,
BASSES-PYRÉNÉES, CHARENTE, CHARENTE-MARITIME)
Régisseur de recettes de la Protection des Végétaux, Chemin d'Artigues, CENON (Gironde)
C. C. P. : BORDEAUX 6707-65

ABONNEMENT ANNUEL
12 NF

Bulletin Technique N° I5 de Décembre I96I

EVOLUTION DES MALADIES ET DES INSECTES PENDANT L'ANNEE I96I

- VIGNE -

Mildiou : Comme l'an dernier les conditions climatiques de l'hiver (doux et très humide) ont été favorables à l'évolution rapide des oeufs.

Par la suite, la sécheresse de mars a contrarié la maturation, de sorte qu'en avril les germinations étaient rares. Les risques d'invasions graves disparaissaient. En réalité quelques germinations se produisirent dans les Iles Atlantiques et dans les situations humides et bien exposées en Gironde vers la mi-avril.

Les premières taches furent découvertes les 4 et 9 mai. Elles étaient peu nombreuses et localisées sur les pousses basses.

Malgré la période pluvieuse du 2I avril au 5 mai, les foyers primaires ne se sont pas étendus. Par contre, les pluies des I6 et I7 mai ont provoqué les premières invasions secondaires, faibles dans l'ensemble, à l'exception de quelques foyers très graves mais peu étendus qui apparurent les 25 et 26 mai. L'orage du 26 mai a provoqué une extension de la maladie.

Les pluies suivantes n'ont donné que de faibles attaques vraisemblablement en raison des températures élevées de la 2ème quinzaine de juin, de la fin juillet et d'août.

En résumé, le Mildiou s'est développé faiblement dans le Sud-Ouest, sauf dans les Charentes où des attaques furent parfois sérieuses.

Black-Rot : L'hiver doux et humide a permis une évolution précoce des périthèces puisque le début de la maturité eut lieu dès le 6 mars. Les premières projections d'ascospores se produisirent à partir du 9 avril, c'est-à-dire à la fin de la période sèche qui dura tout le mois de mars.

Les premières taches sur feuilles ont été observées en assez grand nombre du I2 au 25 mai (pluies du 2I avril au 5 mai). Par la suite, chaque pluie a provoqué la formation de nouveaux foyers notamment en juin où les taches sur feuilles furent nombreuses du I4 au 2I.

A la suite de l'orage du 25 juin, puis des périodes pluvieuses du I2 au I9 juillet et du 6 au 9 août, des atteintes graves sur grappes ont été signalées (9-I0 juillet, 27 juillet au 8 août, puis 23 au 26 août).

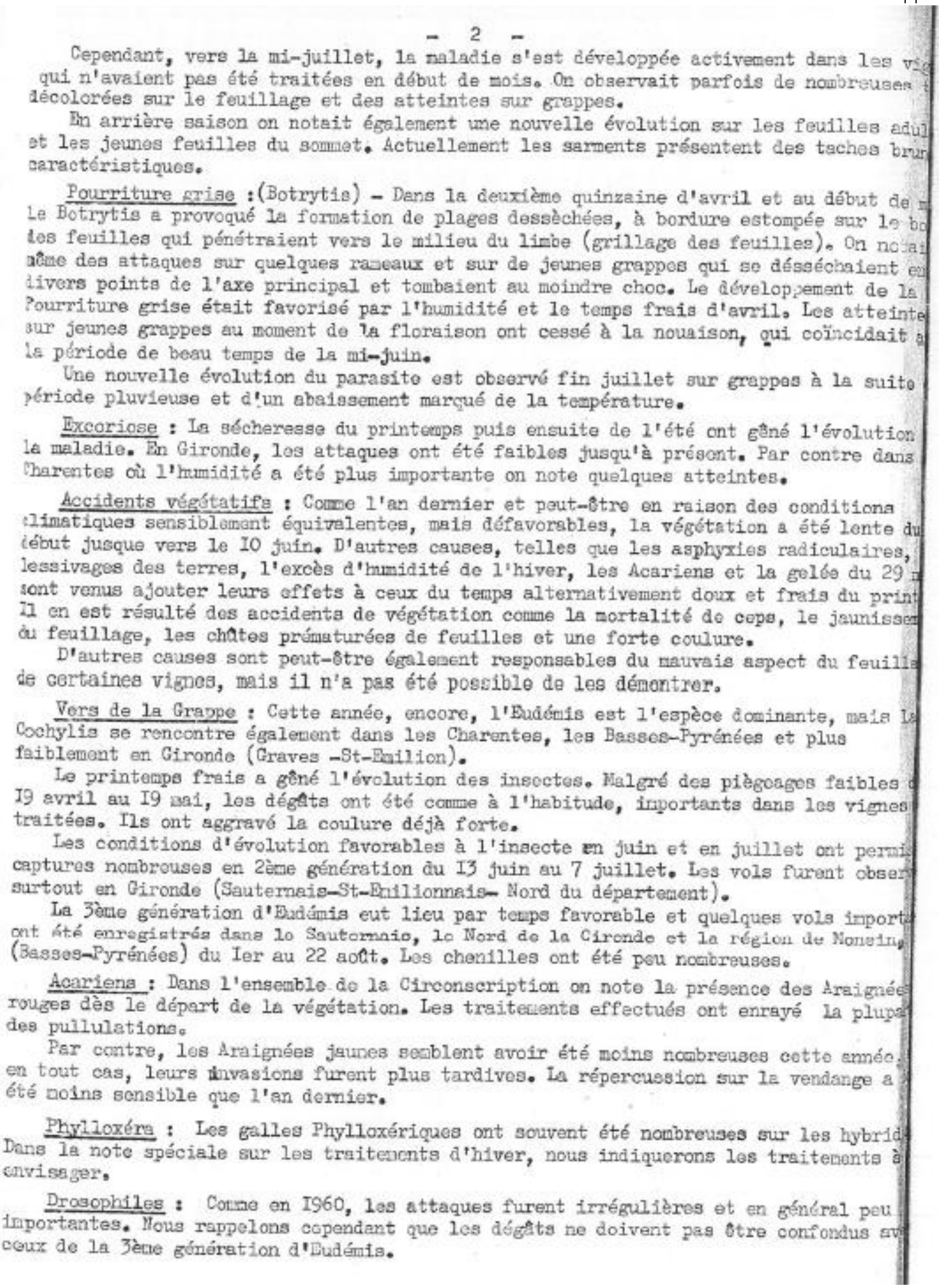
L'évolution s'est poursuivie normalement après la véraison et la maladie apparaissait encore sur quelques grains le II octobre.

Le Black-Rot est en extension, notamment dans le Blayais et les Charentes. Il est aussi nouvellement signalé dans les communes voisines de St-Emilion et dans le Bas-Médoc.

Oïdium : Les premières manifestations d'Oïdium ont été observées le II avril en Gironde où de jeunes pousses étaient déjà entièrement envahies.

L'évolution fut relativement lente par la suite jusqu'au début du mois de juillet dans la plupart des régions viticoles.

.../...



- 2 -

Cependant, vers la mi-juillet, la maladie s'est développée activement dans les vi qui n'avaient pas été traitées en début de mois. On observait parfois de nombreuses décolorées sur le feuillage et des atteintes sur grappes.

En arrière saison on notait également une nouvelle évolution sur les feuilles adul et les jeunes feuilles du sommet. Actuellement les sarments présentent des taches bru caractéristiques.

Pourriture grise :(Botrytis) - Dans la deuxième quinzaine d'avril et au début de m Le Botrytis a provoqué la formation de plages desséchées, à bordure estompée sur le bo des feuilles qui pénétraient vers le milieu du limbe (grillage des feuilles). On notai même des attaques sur quelques rameaux et sur de jeunes grappes qui se désséchaient en divers points de l'axe principal et tombaient au moindre choc. Le développement de la Pourriture grise était favorisé par l'humidité et le temps frais d'avril. Les atteinte sur jeunes grappes au moment de la floraison ont cessé à la nouaison, qui coïncidait a la période de beau temps de la mi-juin.

Une nouvelle évolution du parasite est observé fin juillet sur grappes à la suite période pluvieuse et d'un abaissement marqué de la température.

Excoriose : La sécheresse du printemps puis ensuite de l'été ont gêné l'évolution la maladie. En Gironde, les attaques ont été faibles jusqu'à présent. Par contre dans Charentes où l'humidité a été plus importante on note quelques atteintes.

Accidents végétatifs : Comme l'an dernier et peut-être en raison des conditions climatiques sensiblement équivalentes, mais défavorables, la végétation a été lente du début jusque vers le 10 juin. D'autres causes, telles que les asphyxies radiculaires, lessivages des terres, l'excès d'humidité de l'hiver, les Acariens et la gelée du 29 sont venus ajouter leurs effets à ceux du temps alternativement doux et frais du print Il en est résulté des accidents de végétation comme la mortalité de ceps, le jaunisse du feuillage, les chûtes prématurées de feuilles et une forte coulure.

D'autres causes sont peut-être également responsables du mauvais aspect du feuill de certaines vignes, mais il n'a pas été possible de les démontrer.

Vers de la Grappe : Cette année, encore, l'Eudémis est l'espèce dominante, mais la Cochylis se rencontre également dans les Charentes, les Basses-Pyrénées et plus faiblement en Gironde (Graves -St-Emilion).

Le printemps frais a gêné l'évolution des insectes. Malgré des piègeages faibles 19 avril au 19 mai, les dégâts ont été comme à l'habitude, importants dans les vignes traitées. Ils ont aggravé la coulure déjà forte.

Les conditions d'évolution favorables à l'insecte en juin et en juillet ont permi captures nombreuses en 2ème génération du 13 juin au 7 juillet. Les vols furent obser surtout en Gironde (Sauternais-St-Emilionnais- Nord du département).

La 3ème génération d'Eudémis eut lieu par temps favorable et quelques vols import ont été enregistrés dans le Sauternais, le Nord de la Gironde et la région de Monein, (Basses-Pyrénées) du 1er au 22 août. Les chenilles ont été peu nombreuses.

Acariens : Dans l'ensemble de la Circonscription on note la présence des Araignée rouges dès le départ de la végétation. Les traitements effectués ont enrayé la plupa des pullulations.

Par contre, les Araignées jaunes semblent avoir été moins nombreuses cette année, en tout cas, leurs invasions furent plus tardives. La répercussion sur la vendange a été moins sensible que l'an dernier.

Phylloxéra : Les galles Phylloxériques ont souvent été nombreuses sur les hybrid Dans la note spéciale sur les traitements d'hiver, nous indiquerons les traitements à envisager.

Drosophiles : Comme en 1960, les attaques furent irrégulières et en général peu importantes. Nous rappelons cependant que les dégâts ne doivent pas être confondus av ceux de la 3ème génération d'Eudémis.