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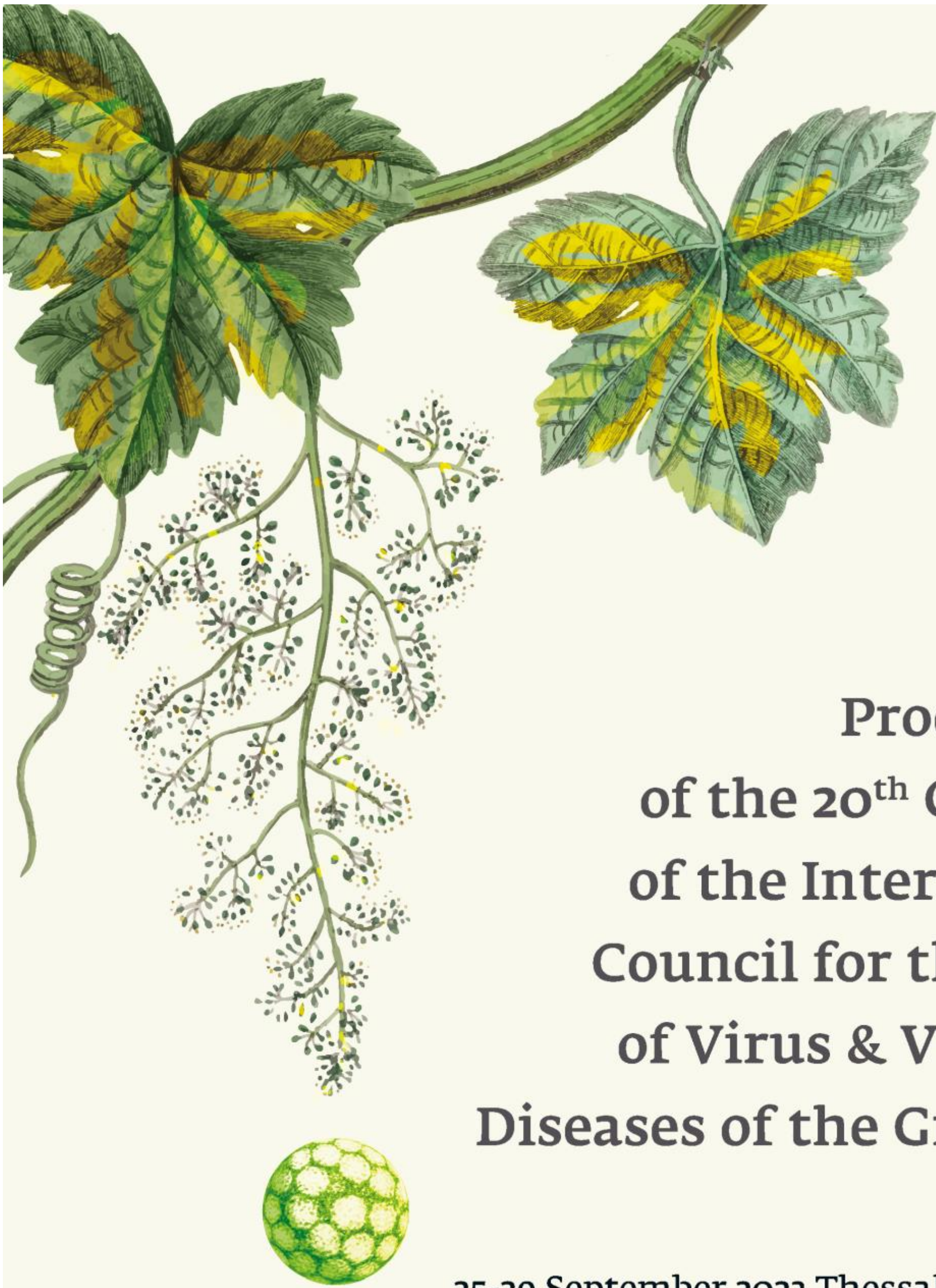

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INTRODUCTION

Flavescence dorée (FD) is a severe disease of grapevine caused by a phytoplasma, epidemically transmitted by the leafhopper *Scaphoideus titanus* in European vineyards (Tramontini et al. 2020). Quarantine FD phytoplasma is controlled by mandatory measures: planting disease-free stocks, annual surveillance of symptoms, removal of infected plants and application of insecticides. Improving FD management strategies has much to gain from the recent advances in both statistical and mechanistic epidemiological modelling (Parnell et al., 2017). Typically, statistical spatial models can be used to identify the agronomical and environmental factors influencing plant pathogen epidemiology. Mechanistic models are able to simulate realistic patterns of epidemic spread and can be used to test the effectiveness of a range of management strategies. Here, both approaches were used to improve our knowledge on FD epidemiology and management. In a first study, we estimated the dispersal distance of FD from two snapshot maps of the FD infectious status in three fields using a mechanistic SIR model coupled with Bayesian inference framework (Adrakey et al., 2023). In a second study, we characterized field and landscape risk factors impacting FD infection in Bordeaux vineyards using spatial statistical models (Adrakey et al., 2022).

MATERIALS AND METHODS

Spatially explicit mechanistic SIR model. In 3 adjacent fields situated near Bordeaux (France) and planted with 5961 stocks of Merlot and Cabernet-Sauvignon, FD symptomatic and removed plants were precisely mapped in 2018 and 2019. A larger area of 300 m radius around the target fields was also monitored from 2014 to 2018 by recording FD-infected fields and the number of infected plants per field, without their exact location. A spatial SIR (Susceptible, Infected, Removed) model with a discrete time step of one year was used to describe the probability of infection of each plant in the focal fields. The model considered a time varying rate of primary infection, differences in cultivar susceptibility for secondary infection and a dispersal kernel representing the statistical distribution of the infected hosts after inoculum dispersal from a focal plant source. Model inference relied on data augmentation with a Bayesian approach that accounts for the missing information related to plants removed before the initial survey in order to construct the full trajectory of the epidemic.
Spatial statistical model. Between 2012 and 2016, GDON des Bordeaux organization monitored and georeferenced grapevine fields in the Bordeaux vineyard (area of 347 districts and 84000 ha), with 10 % achieved each year. A geographic information system was designed by collating the characteristics of the 34581 fields inspected over 5 years: FD-infection status, date of survey, altitude, organic or conventional practice, area, age, density of plantation and cultivar, the later extracted from the Casier Viticole Informatisé (CVI) (Fig 1). Landscape characteristics obtained from the CVI and land cover map were expressed as percentages of urban, forest, vineyard areas, vineyards with Merlot or with organic practice in radii from 50 to 5000 m around each field. The effects of these field and landscape factors on the probability that a field is infected by FD were estimated using spatial generalized linear models fitted with INLA (Integrated Nested Laplace Approximation) method.

RESULTS AND DISCUSSION

FD dispersal distance. Bayesian model inference first suggested that heavy-tailed dispersal kernels, characterized by frequent long-distance dispersal events, best fit the spread of FD. On average, 50%

(resp. 80%) of new infection occur within 10,5 m (resp. 22,2 m) of the source plant (Adrakey et al., 2023). These values are in agreement with estimates of the flying capacity of *S. titanus* using mark-capture techniques (Lessio et al. 2014). Simulations of simple removal scenarios using the fitted model predicted that the disease still spread over years despite complete removal of symptomatic plants, suggesting that cryptic infections hamper FD management. Future efforts should explore whether strategies relying on reactive removal of plants in determined buffers can improve FD management.

Effects of field and landscape factors on FD infection. Our analysis first highlighted the importance of the monitoring period with a probability of FD detection 4 times higher in September than in August. At field scale, altitude and cultivar choice were the main factors affecting FD infection (Fig 1). The odds ratio of FD infection in fields of the susceptible Cabernet Sauvignon, Cabernet Franc, or Muscadelle were twice those in fields of the less susceptible Merlot. Field infection was also affected by the field's immediate surroundings within a circle of 150 to 200 m radius corresponding to landscapes of 7 to 12 ha. In particular, the probability of FD infection increased with the proportions of forest and urban land and with the proportion of susceptible cultivars, demonstrating that the cultivar composition at landscape scale impacts FD epidemiology. The satisfactory predictive performance of the model for identifying districts with a prevalence of FD detection of >10% of the fields suggests that it could be used to target areas in which future surveys would be most valuable.

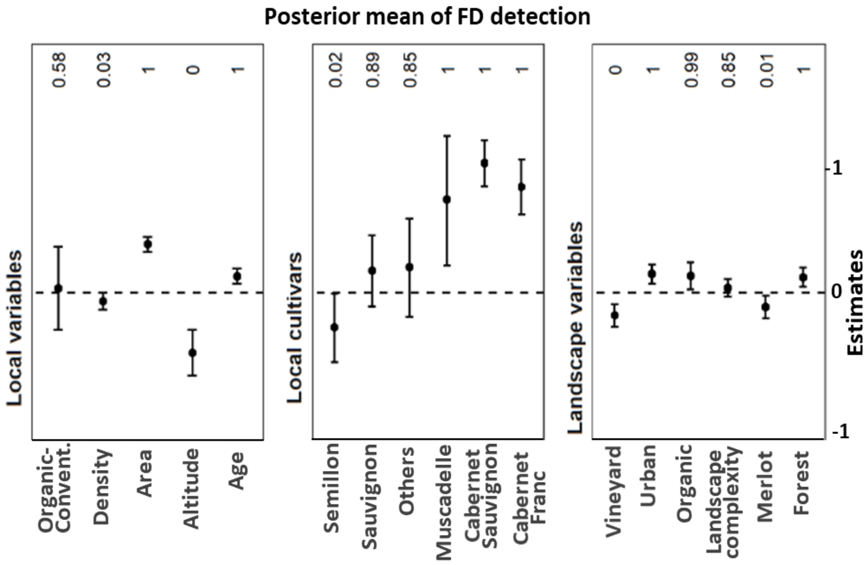

Fig 1: Effects of the local and landscape explanatory variables. For each variable, the posterior mean (dots) and 95 % credible intervals (solid lines) are displayed, together with the posterior probability of the effect being positive. The dashed lines correspond to the value 0. For estimating the local effect of cultivars, the poorly susceptible Merlot was chosen as the reference (value 0).

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