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Habitat management as an integrative strategy for Flavescence dorée: a case study of wild-growing common hazels hosting the alternative vector *Orientus ishidae* (Hemiptera: Cicadellidae)

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Flavescence dorée (FD) is a quarantine grapevine disease associated with FD phytoplasmas (FDp). No curative methods are available for treating FDp-infected grapevines and the mandatory control measures consist of insecticide applications against the main FDp insect vector *Scaphoideus titanus* (Ball 1932) (Hemiptera: Cicadellidae) and the removal of infected grapevines. Despite such systematic control measures, FD has become widespread across numerous European winegrowing areas. Meanwhile, several alternative vectors capable of acquiring and transmitting FDp have been identified and additional host plant species have been found harboring FDp genotypes associated with FD outbreaks. This highlights the importance of extending disease management efforts beyond individual vineyard plots and considering the broader landscape as an element of FD epidemiology. This study examined the potential epidemiological role of the alternative FDp vector *Orientus ishidae* (Matsumura 1902) (Hemiptera: Cicadellidae) and its association with the host plant *Corylus avellana*. A hatching experiment was conducted to confirm the role of *C. avellana* as a host plant for *O. ishidae* in the Swiss southern Alps. Meanwhile, a habitat management (HM) experiment was designed, involving the removal of *C. avellana* resprouts acting as *O. ishidae* host plant and shelter in the surroundings of vineyards. The removal of the *C. avellana* resprouts confirmed to be a good strategy to reduce the *O. ishidae* population in the vineyard and the related risk of exchange of phytoplasma between the wild compartment and adjacent cultivated vineyards. The study concludes by discussing the potential for integrating this HM strategy into conventional FD control methods.

Keywords: grapevine yellows, mosaic leafhopper, phytoplasma management, Southern Switzerland

Introduction

Flavescence dorée (FD) is a quarantine grapevine disease associated with FD phytoplasmas (FDp) belonging to the taxonomic ribosomal subgroups 16SrV-C and 16SrV-D (Lee et al. 1998). FD was first reported in the 1950s in South-western France by Caudwell (1957) and is presently widespread in many European winegrowing areas despite the systematic mandatory control, mainly consisting of insecticide applications against the FDp insect vector *Scaphoideus titanus* (Ball 1932) (Hemiptera: Cicadellidae) and the removal of infected (or just symptomatic, according to the local legislation) grapevines (Tramontini et al. 2020).

In Switzerland, FD was first observed in the southern region of Canton Ticino in 2004, while the presence of the Nearctic leafhopper *S. titanus* had already been reported in the late 1960s (Baggiolini et al. 1968, Schaerer et al. 2007). Although compulsory control measures were quickly implemented, FD spread to almost all the winegrowing areas of the southern Alps within a few years (Jermini et al. 2014). Possible factors explaining the relative lack of success in eradicating FD are—among others—the probable use of uncertified plant material, the potential misapplication of FDp control measures and the role played by secondary epidemiological cycles involving alternative FDp vectors and host plant species (Malembic-Maher et al. 2020, Jarausch et al. 2021, 2023). Even though the epidemic transmission of FDp in vineyards occurs through *S. titanus* (Schvester et al. 1961, Chuche and Thiéry 2014, Gonella et al. 2024a), other Auchenorrhyncha species have resulted infected by several FDp strains (Gonella et al. 2024b). In Southern Switzerland, in

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addition to the alternative FDp vector *Orientus ishidae* (Matsumura 1902) (Hemiptera: Cicadellidae), putative vectors such as *Thamnotettix dilutior* (Kirschbaum 1868) (Hemiptera: Cicadellidae), *Graphocephala fennahi* (Young 1977) (Hemiptera: Cicadellidae), *Japananus hyalinus* (Osborn 1900) (Hemiptera: Cicadellidae), and *Hishimonus hamatus* (Kuoh 1976) (Hemiptera: Cicadellidae) were already found to be infected by FDp, including strains associated to FD outbreaks (Casati et al. 2017, Malembic-Maher et al. 2020, Rizzoli et al. 2021, Belgeri et al. 2021, Oggier et al. 2024). Other known alternative and putative FDp vectors, such as *Dictyophara europaea* (Linnaeus 1767) (Hemiptera: Dictyopharidae), *Phlogotettix cyclops* (Mulsant and Rey 1855) (Hemiptera: Cicadellidae), *Allygus mixtus* (Fabricius 1794) (Hemiptera: Cicadellidae), and *Allygus modestus* (Scott 1876) (Hemiptera: Cicadellidae) apparently do not play a role in the FD epidemiology in this area since they are less common (Filippin et al. 2009, Trivellone et al. 2016, Strauss and Reisenzein 2018, Malembic-Maher et al. 2020, Jarausch et al. 2021). As for host plant species, wild woody species such as *Alnus glutinosa*, *Alnus incana*, *Corylus avellana*, *Salix* spp., and *Ailanthus altissima* have been found to be infected by several FDp strains and may thus potentially act as asymptomatic FDp reservoirs (Arnaud et al. 2007, Mehle et al. 2010, Filippin et al. 2011, Radonjić et al. 2013, Casati et al. 2017, Rizzoli et al. 2021).

In the specific case of Southern Switzerland, Casati et al. (2017) reported the presence of FDp-infected *C. avellana*, *Salix* spp., and *O. ishidae* specimens. Moreover, Rizzoli et al. (2021) found a high 16SrV-p-infection rate among the *O. ishidae* population collected on infected *A. glutinosa* adjacent to cultivated vineyards, including genotypes associated with FD outbreaks. As a result, FDp alternative epidemiological cycles could be especially significant in Southern Switzerland, where 43.1% of the vineyard boundaries are less than 25 m from the forests (Wyler et al. 2021), which are in turn rich of common hazel shrubs (*C. avellana*; Jutzi et al. 2024), an understory woody species potentially acting as a reservoir of FDp inoculum in the landscape (Casati et al. 2017, Mehle et al. 2019), as well as host plant for the alternative FDp vector *O. ishidae* (Hamilton 1985, Nickel 2010). Thus, the proximity to forested areas may pose a phytosanitary risk to vineyard agroecosystems, especially in heavily forested regions such as Southern Switzerland.

To support the development of a strategy to mitigate the possible role played by the *O. ishidae*—*C. avellana* system as an alternative FDp epidemiological cycle, this study aimed at (i) verifying the suitability of *C. avellana* shrubs as oviposition substrate for *O. ishidae* and (ii) testing the effect of coppicing and removing *C. avellana* shoots from the forests surrounding the vineyards on the *O. ishidae* populations in and outside of cultivated vineyards.

The rationale behind this research is to evaluate the general feasibility of habitat management (HM) as an integrative strategy for reducing the population of the alternative FDp vector *O. ishidae*. Reducing the hazel shrubs hosting population hotspots of this alternative FDp vector may consequently represent an efficient contribution to mitigate the inoculum exchange between wild and cultivated compartments, also considering the FDp infection rates reported for *O. ishidae* in the same study area (Casati et al. 2017, Rizzoli et al. 2021).

Materials and Methods

Study Area

The study area consists of 8 vineyards and the surrounding forested areas distributed along a north-south gradient in the wine groves of Canton Ticino in Southern Switzerland (Fig. 1). The experimental sites were chosen according to the abundance of *O. ishidae* recorded in 2021 in the frame of a survey program based on the use of 10 yellow sticky traps (Rebell Giallo, Andermatt Biocontrol AG, Switzerland; hereafter referred to as yellow sticky traps [YST]) per site, of which 6 YST were hung inside the vineyard and 4 placed in the proximity of target host plants such as *C. avellana* in the surrounding landscape, respectively. For 2 plots (ie, Avegno and Bedano, see Supplementary Table 1), a higher number of YST was available, thus enhancing the resolution of the survey. Inverse distance weighted (IDW) interpolation maps showing *O. ishidae* imago captures from 2021 were generated using ArcMap (release 10.6.1, ESRI) to identify areas of aggregation, also referable to as *O. ishidae* hotspots. A subset of these hotspots was then selected for the manipulation experiments.

For the hatching experiment, only the plot in Arzo was selected due to the consistent number of *O. ishidae* captures and the high abundance of hazel shrubs surrounding the cultivated vineyard. For the HM experiment, 4 out of the remaining 7 sites were chosen for the treatment, while the other 3 acted as control (Fig. 1B, Supplementary Table 1).

Hatching Experiment on Common Hazel Wood

For the hatching experiment, 2 landscape hotspots corresponding to traps L12 and L14 within the plot of Arzo were selected based on *O. ishidae* captures from 2021. A higher probability of egg-laying activity by *O. ishidae* females was assumed to have taken place around traps with higher adult captures in the previous season (ie, 554 imagoes on L12 and 236 on L14, respectively; Fig. 2, Supplementary Table 2). During the vegetative dormancy (ie April 2023), dominant shoots of 2 representative (ie most prominent and well-developed) hazel shrubs were cut and removed in each selected hotspot. The freshly collected shoots were kept separate for each hotspot, trimmed to 0.5 m and grouped according to 3 categories of their original height above ground (ie low = 0 to 1.5 m; medium = 1.5 to 3.5 m; high = 3.5 to 6.5 m), which also corresponded to a decreasing wood diameter class. The sampled wood was then transported to the research facility in Cadenazzo, where the wood samples of each height class were further subdivided by 1 to 2 wood diameter classes according to their size distribution (Table 1). For each final grouping category, the obtained samples were weighed and the total surface area was calculated based on diameter and length.

In May 2023, the wood samples were placed in single rearing cages (160 µm nylon mesh, 120 × 50 × 50 cm, BugDorm, MegaView Science Co. Ltd, Taichung, Taiwan) according to height and diameter category. To avoid egg desiccation, the wood was moistened every other day. The air temperature of the experimental room was recorded every 2 h by means of a data logger (HOBO Pro v2 U23-001, Onset Computer Corporation, Bourne, Massachusetts, USA). As counting eggs directly beneath the bark often results in egg destruction and making species determination challenging, the oviposition was indirectly expressed as freshly hatched nymphs (Chuche and Thiéry

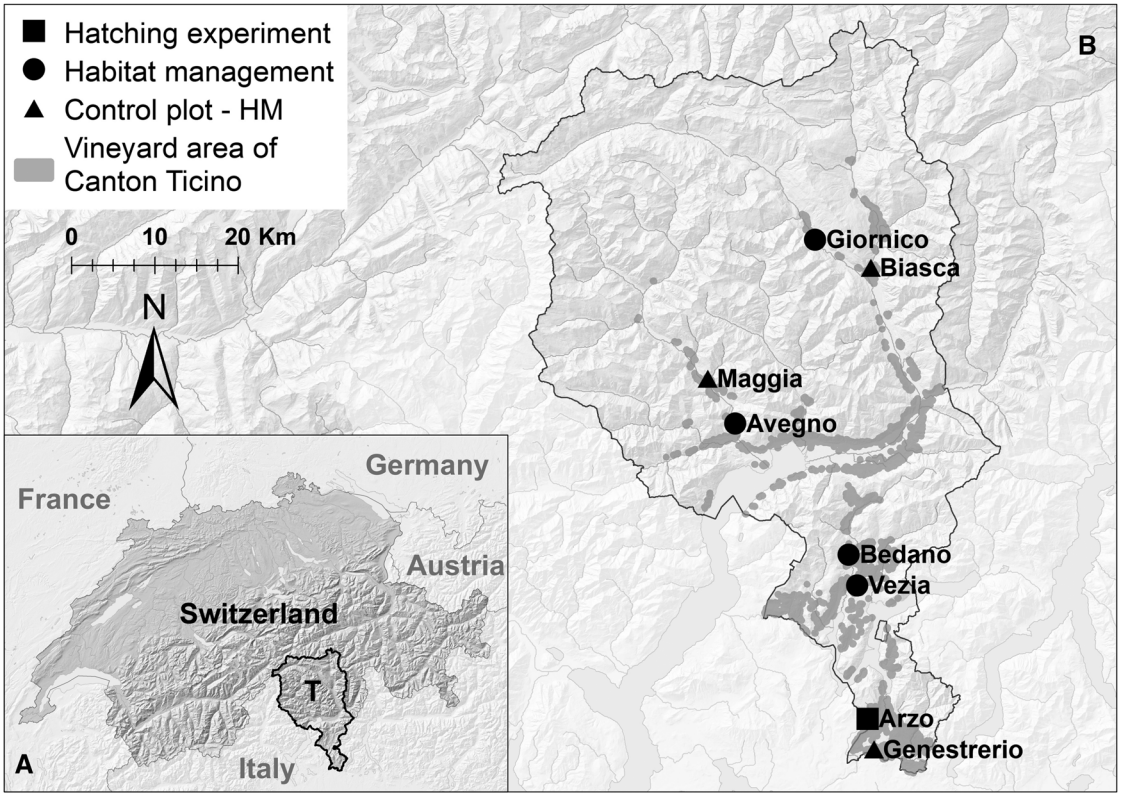

Fig. 1. Geographic distribution of the experimental sites. A) Location of the study area within Switzerland; T: Canton Ticino. B) Black square: site where hazel wood was sampled for the hatching experiment targeting *Orientus ishidae* nymphs; black dot: sites where single hazel shrubs were coppiced and their shoots removed as a HM measure; black triangle: control plots without HM.

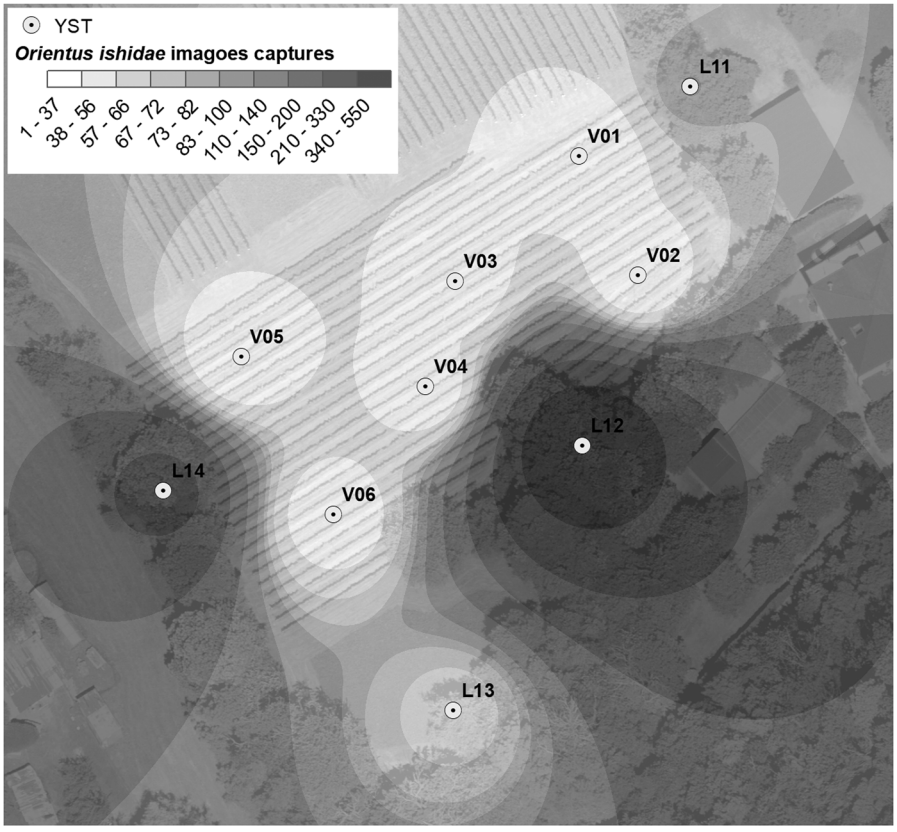

Fig. 2. Inverse distance weighted (IDW) interpolation generated from the *Orientus ishidae* imago captures obtained from yellow sticky traps during the 2021 season in Arzo. *Corylus avellana* wood was sampled in 2023 around landscape traps L12 and L14.

Table 1. *Orientus ishidae* hatching events grouped by sampling category, diameter range of sampled material, lateral surface, weight, hatching counts (N_{hat}), hatchings per square meter; hatchings per kilogram. L12 and L14 = *O. ishidae* landscape hotspots in Arzo; L = sampling in low sector (0, 1.5 m), M = sampling in median sector (1.5, 3.5 m), H = sampling in high sector (3.5, 6.5 m), I/II = different diameter ranges of sampled material in the same sector

Category	Sampling height range (m)	Diameter range (cm)	Lateral surface (m^2)	Mass (kg)	Nhat	Nhat/m^2	Nhat/kg	Ratio lateral surface/ mass (m^2/kg)
L12_L_I	(0, 1.5)	(0.6, 2.5)	0.61	2.28	7	11.39	3.07	0.27
L12_L_II	(0, 1.5)	(2.6, 4.3)	0.84	6.32	7	8.36	1.11	0.13
L12_M_I	(1.5, 3.5)	(0.3, 1.9)	0.71	3.72	0	0.00	0.00	0.19
L12_M_II	(1.5, 3.5)	(2.0, 3.9)	0.46	2.62	5	10.96	1.91	0.18
L12_H_I	(3.5, 6.5)	(0.2, 0.4)	0.66	0.95	2	3.03	2.11	0.69
L12_H_II	(3.5, 6.5)	(0.5, 1.0)	0.53	1.09	6	11.29	5.50	0.49
L14_L_I	(0, 1.5)	(2.4, 6.5)	0.91	9.25	32	35.19	3.46	0.10
L14_L_II	(0, 1.5)	(6.6, 9.7)	1.69	25.08	42	24.92	1.67	0.07
L14_M	(1.5, 3.5)	(2.7, 6.6)	1.33	13.83	30	22.52	2.17	0.10
L14_H_I	(3.5, 6.5)	(0.4, 1.9)	2.99	8.20	77	25.78	9.39	0.36
L14_H_II	(3.5, 6.5)	(2.0, 6.3)	1.42	9.75	36	25.34	3.69	0.15

2009, Oggier et al. 2023). To this purpose, 2 potted broad bean plants (*Vicia faba major* "aqua dulce," directly grown from seeds obtained from Sativa Rheinau AG, Switzerland) were added to each cage as nourishment source for the hatching nymphs. The broad bean plants were watered once a week and substituted when needed. The cages were inspected every other day from the start of the experiment up to the observation of the first hatched nymph. Subsequently, the inspection took place daily until the end of June and 3 d a week in July (Mondays, Wednesdays, and Fridays). Newly hatched nymphs were sampled with an electric aspirator (InsectaVac Aspirator, Bio-Quip Products Inc., USA), determined to species level with a stereomicroscope (Günthart and Mühlethaler 2002), and eventually transferred into additional rearing cages provided with 2 potted hazels (*C. avellana* "Corabel," Lubera AG, Switzerland) in order to check the potential of further development of the insects up to imago. The end of the hatching phase was declared after 4 wk of inspections, during which no new hatched nymphs were observed.

Habitat Management

The HM treatment consisted of a unique coppicing in March 2022 (ie during the dormant season) of all hazel shrubs located within a 3-m radius from the YST positions of the selected *O. ishidae* hotspots. The working hypothesis is that by removing such plant material the availability of oviposition substrate and feeding resources for *O. ishidae* in the subsequent seasons would be reduced. The 3-m radius was arbitrarily chosen in order to contain the workload (in average ca. 3 h per treated spot, including the initial measurements and the loading of the wood) and by considering the general spatial arrangement of hazel shrubs in the experimental sites. After the treatment, the coppiced hazel shrubs were left to resprout naturally throughout the entire experimental period of 3 posttreatment seasons. By the end of the experiment, each treated shrub consisted of 15 to 30 new shoots ranging from 0.5 to 2.5 cm in basal diameter and from 0.8 to 2.80 m in height depending on original shrub size, light availability, and competition by the natural forest regeneration. As an internal control at site level, a subset of YST position-hotspots was deliberately left untreated. Such measures were applied in 3 experimental sites (Avegno, Giornico, and Vezia), whereas in Bedano, all woody plants (ie including hazel shrubs) other than chestnut trees were eradicated (ie including root systems) in the frame of an independent restoring action of an abandoned chestnut orchard, thus avoiding any resprout chances for common hazel. As control sites, the 3 plots of Biasca, Genestrerio, and Maggia were left completely untreated (Fig. 1B). Insect monitoring before and after the HM treatment (before = 2021; after = 2022, 2023, and 2024) was performed using YST placed in the same positions.

Statistical Analysis

For the hatching experiment, the embryonic development was calculated as the time needed for egg hatching based on degree-days (DD). DD were calculated according to the formula:

$$\mathrm{DD} = \sum_{i=1}^{n} \frac{\max\left[0, (T_i - T_b)\right]}{12},$$

where n is the number of hours since 1st January, T_i is the temperature measured by the datalogger at hour i (12 readings per day), and T_b is the base developmental threshold temperature, which was set to 5 °C as proposed by Chuche and Thiéry (2009) for *S. titanus*.

Embryonic development between different sampling categories was compared with Kruskal–Wallis rank sum test. Hatching dynamics of *O. ishidae* were evaluated by means of an inverse transformation of the Kaplan–Meyer survival curve and compared with the log-rank and Gehan–Wilcoxon (with Peto modification) tests (Pyke and Thompson 1986, Chuche and Thiéry 2009). Daily hatching variations over time were compared with a Spearman correlation test. For the HM experiment, the efficacy and persistence of the treatment were tested through an unpaired Wilcoxon test comparing *O. ishidae* captures between sampling years and groupings.

All statistical analyses were performed using R (version 4.5.0, R Core Team 2025). ArcGIS (release 10.6.1, ESRI 2011) was used for spatial analysis and mapping renditions.

Results

Hatching Experiment

O. ishidae nymphs were observed in all categories of the wood samples collected in Arzo, except for the shoots collected around trap position L12 in the height range of 1.5 to 3.5 m

and with a shoot diameter of 0.3 to 1.9 cm (Table 1). In general, the number of hatching events (N_{hat}) observed for wood categories sampled around position L12 was consistently lower than for L14 (ie standardized for m² of lateral surface, 7.51 ± 4.87 N_{hat}/m² for L12 and 26.75 ± 4.88 N_{hat}/m² for L14, respectively; Fig. 2). The absolute and relative highest number of nymphs per kilogram of sampled wood was observed in the height range of 3.5 to 6.5 m and the shoot diameter of 0.4 to 1.9 cm of L14 (ie 9.39 N_{hat}/kg). The highest number of hatchings per lateral surface was also observed in L14 but in the height range of 0.0 to 1.5 m and the shoot diameter of 2.4 to 6.5 cm (ie 35.19 N_{hat}/m²). Overall, sampling height and related diameter class did not show any significant effect on nymph hatching abundance.

Hatching started at the end of May at 687.14 DD, while the last hatching nymph was observed at the beginning of July at 1,633.61 DD. The embryonic development between sample categories was not significantly different (Kruskal–Wallis: $\chi^2 = 5.2$, $P > 0.05$). Nonetheless, the overall egg hatching period (HD) varied widely, particularly when considering the 2 hotspots, L12 and L14, which had HD values of 14.6 ± 3.9 d and 37.0 ± 7.9 d, respectively (Table 2).

For the comparison of the hatching dynamics, hatching events for the sampling classes related to hotspot L12 were pooled due to the low number of nymphs observed in the individual classes (hereinafter referred to as L12_pooled). The hatching dynamics based on the inverted Kaplan–Meyer survival curve were not significantly different and showed weak to moderate correlations across sample categories (log rank: $\chi^2 = 11$, Gehan–Wilcoxon: $\chi^2 = 7.1$, $P \geq 0.05$, Fig. 3, Table 3). Hatching peak was reached between 4 and 21 d after the first observed nymph (Supplementary Fig. 1). Regarding nymphal

Table 2. Embryonic development time of *Orientus ishidae* expressed as degree-days and days for the different sampling categories

		Degree-days				Days
Category	*N*	ED_{dd_min}	ED_{dd_max}	ED_{dd_mean} ± SE	DDA	HD
L12_L_I	7	759.55	1,191.26	925.95 ± 55.03	431.71	21
L12_L_II	7	759.55	1,041.66	893.97 ± 46.07	282.11	14
L12_M_II	5	748.28	955.48	853.39 ± 39.74	207.19	11
L12_H_I	2	823.50	1,116.65	970.08 ± 146.57	293.15	15
L12_H_II	6	785.52	1,015.26	909.52 ± 45.75	229.74	12
L14_L_I	32	687.14	1,308.05	926.28 ± 28.42	620.90	30
L14_L_II	42	687.14	1,633.61	935.98 ± 27.97	946.47	44
L14_M	30	728.72	1,270.08	943.65 ± 23.12	541.37	27
L14_H_I	77	728.72	1,588.75	1,005.42 ± 20.97	860.03	41
L14_H_II	36	728.72	1,630.89	988.32 ± 41.82	902.18	43

L12 and L14 = *O. ishidae* landscape hotspots in Arzo; L = sampling in low sector (0, 1.5 m), M = sampling in median sector (1.5, 3.5 m), H = sampling in high sector (3.5, 6.5 m), I/II = different diameter ranges of sampled material in the same sector. *N* = number of hatched nymphs, ED_{dd_min} and ED_{dd_max} = degree-days accumulated at the first and last hatching, respectively, ED_{dd_mean} = mean accumulated degree-days, DDA = degree-days accumulated between first and last hatching, SE = standard error, HD = hatching period duration in days. L12_M_I was excluded since no hatching events were observed in this category.

Table 3. Spearman correlation table for daily hatchings of *Orientus ishidae* related to wood samples collected around the landscape traps L12 and L14 in Arzo ($n = 35$)

	L12_pooled	L14_L_I	L14_L_II	L14_M	L14_H_I
L14_L_I	0.36*	1.00	-	-	-
L14_L_II	0.17	0.33	1.00	-	-
L14_M	0.50*	0.50*	0.31	1.00	-
L14_H_I	0.60**	0.31	0.31	0.56**	1.00
L14_H_II	0.14	0.21	0.22	0.14	0.22

Significance levels:
*$P < 0.05$.
**$P < 0.01$.

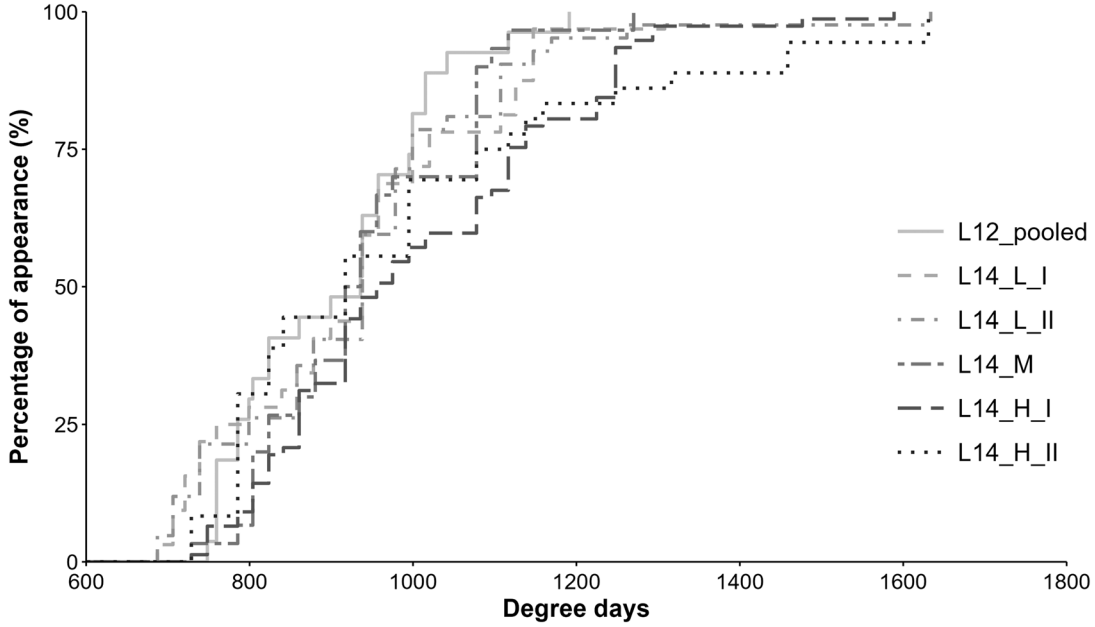

Fig. 3. Cumulative percentage of *Orientus ishidae* hatchings by degree-day (inverted Kaplan–Meyer) for the various sampling classes. Hatching events belonging to hotspot L12 were pooled (summed) due to the low number of hatchings observed. L12 and L14 = landscape trap locations in Arzo plot; L = sampling in low sector (0, 1.5 m), M = sampling in median sector (1.5, 3.5 m), H = sampling in high sector (3.5, 6.5 m), I/II = different diameter ranges of sampled material in the same sector.

survival and development to imago stage, of the 232 nymphs successfully sampled after hatching, 41% ($n = 95$) were able to complete their development to the adult stage, with a female to male ratio of 0.73.

Habitat Management

In the first year after the HM treatment (2022), the abundance of *O. ishidae* in HM sites significantly decreased compared to untreated control sites (Fig. 4, Supplementary Table 3). Interestingly, the reduction was observed also in untreated YSTs positions within all 4 treated HM sites. In the second and third posttreatment years (2023, 2024), the *O. ishidae* population slightly increased in the treated positions. Nonetheless, such an increment was not sufficient to reestablish the pretreatment population level (Table 4).

The decrease in *O. ishidae* population observed after the third post-management year (2024) in the treated positions ranged from −75% (Avegno) to −82% (Vezia). However, the highest decrease was observed in Bedano with the orchard restoration project (−86%). For the untreated positions within HM sites, the decrease after 3 seasons ranged from −21% (Avegno) to −67% (Giornico). In contrast, in the control sites, during the

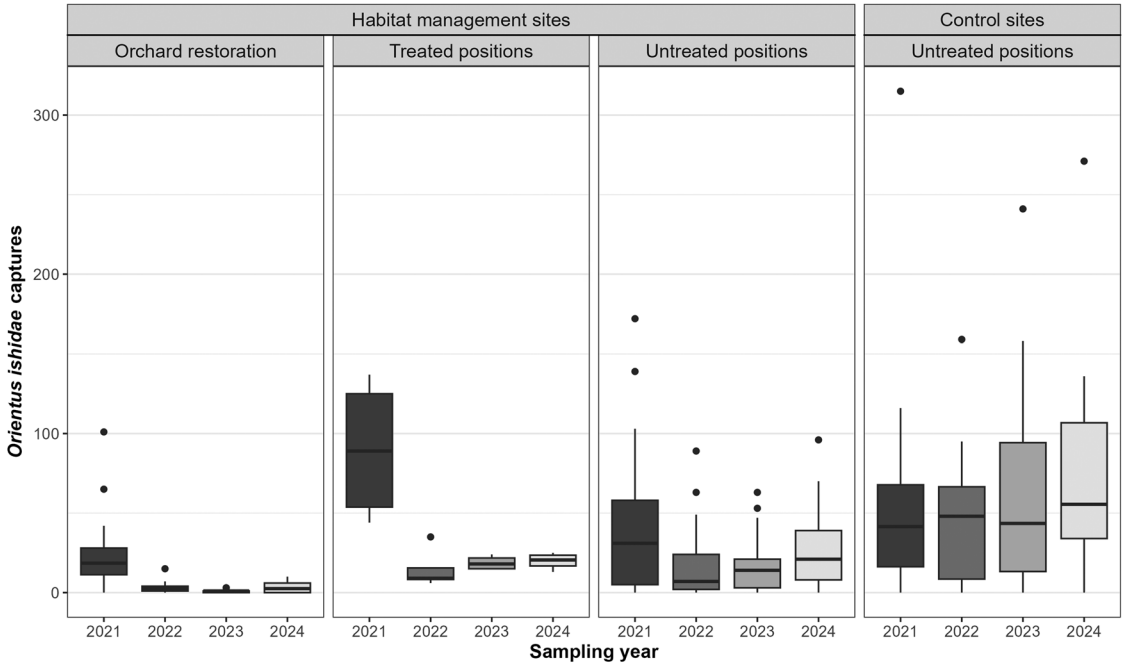

Fig. 4. *Orientus ishidae* total captures grouped by site type, treatment category and sampling year.
Boxplots with distribution of *Orientus ishidae* total captures from the traps placed in the landscape surrounding vineyards.

Table 4. *Orientus ishidae* total captures (tot) and differences (Δ) between sampling years, YST = number of yellow sticky traps used for monitoring purposes

				Captures				Difference between years				
Type		Plot ID	YST	tot_{2021}	tot_{2022}	tot_{2023}	tot_{2024}	Δ_{22-21}	Δ_{23-22}	Δ_{24-23}	Δ_{23-21}	Δ_{24-21}
Habitat management sites	Treated positions	Avegno	2	165	15	36	41	−150	21	5	−129	−124
		Giornico	1	57	9	15	13	−48	6	−2	−42	−44
		Vezia	1	137	35	24	25	−102	−11	1	−113	−112
	Orchard restoration	Bedano	28	653	85	25	94	−568	−60	69	−628	−559
	Untreated positions	Avegno	12	577	94	153	453	−483	59	300	−424	−124
		Bedano	7	165	115	92	76	−50	−23	−16	−73	−89
		Giornico	3	183	75	88	61	−108	13	−27	−95	−122
		Vezia	3	156	152	86	77	−4	−66	−9	−70	−79
	Vineyard	Avegno	15	109	31	46	60	46	15	14	15	−49
		Bedano	14	63	12	5	8	5	−7	3	−7	−55
		Giornico	6	31	32	20	25	20	−12	−5	−12	−16
		Vezia	6	41	24	14	17	14	−10	3	−10	−24
Control sites	Untreated positions	Biasca	4	202	275	277	314	73	2	37	75	112
		Genestrerio	4	123	86	102	151	−37	16	49	−21	28
		Maggia	4	460	244	424	473	−216	180	49	−36	13
	Vineyard	Biasca	6	5	5	2	8	2	−3	6	−3	3
		Genestrerio	6	2	1	2	2	2	1	0	1	0
		Maggia	6	37	30	15	10	15	−15	−5	−15	−27

same timespan the population generally increased (+55% in Biasca, +23% in Genestrerio, and +3% in Maggia).

Regarding the *O. ishidae* population caught on YST hung in vineyards, a significant decrease was observed in HM sites, with overall reductions ranging from −19% (Giornico) to −87% (restored chestnut orchard in Bedano) 3 yr after the treatment (Fig. 5). In control sites, populations in the vineyards remained stable in Biasca and Genestrerio while they decreased in Maggia (−73%).

Discussion

Hatching Experiment

The hatching experiment unequivocally confirmed the role of *C. avellana* as a host plant for *O. ishidae* in the study area. The absence of significant differences in hatching rates across wood samples varying in size suggests that *O. ishidae* does not exhibit any preference when ovipositing on hazel shrubs. This is supported by the comparable embryonic development and hatching dynamics between the different height and wood diameter categories. The ability of *O. ishidae* nymphs to develop to the adult stage under suboptimal conditions (such as high peak temperatures during the experiment) might indicate a remarkable level of adaptability to changing climatic conditions and resilience to extreme heat waves. The significant differences in hatching densities between the 2 selected hotspots L12 and L14 in Arzo may origin from the higher number of existing hazel shrubs in correspondence of trap L12 and further diverging egg-laying conditions in the field that are difficult to factorize.

From a methodological point of view, the experience gained from rearing *O. ishidae* individuals originating from wood sampled in the wild could be useful for FDp acquisition and transmission experiments requiring a considerable number of specimens. Using previous data on *O. ishidae* adult captures, hazel wood can be selectively sampled from specific locations with reasonable confidence that enough nymphs will be present for further experiments. This could enable parallel experiments involving *S. titanus* and *O. ishidae* hatching from grapevine and hazel wood collected directly on site, without relying on the more time-consuming nymph collection from the wild.

Habitat Management

The results obtained in this study show a good efficacy of the proposed HM interventions on hazel shrubs in decreasing the populations of the alternative FDp vector *O. ishidae*. Reductions in insect population were achieved not only in the immediate vicinity of the treated positions where hazel shoots were removed, but throughout the whole site (Fig. 4). The populations slightly recovered during the 3 yr posttreatment, probably due to the newly resprouted shoots from the treated hazel individuals but remained far lower than before coppicing. This indicates that a single coppicing on hazel shrubs has a lasting impact over time and may thus represent a sustainable integrative approach for reducing *O. ishidae* populations without requiring repeated implementations on a yearly basis. Indeed, targeting common hazel could be an additional and very effective strategy for the control of such an alternative FDp vector. Considering that common hazel is highly widespread over the study area and is commonly present in the understory and at the edge of forests adjacent to cultivated vineyards (Jutzi et al. 2024), potential impacts on the entomofauna are expected to be negligible. In terms of practical implementation, coppicing hazel shrubs is also easier and economically cheaper than sylvicultural interventions on other plant species such as *A. glutinosa* which can harbor FDp genotypes and host *O. ishidae* (Malembic-Maher et al. 2020, Rizzoli et al. 2021, Jarausch et al. 2025).

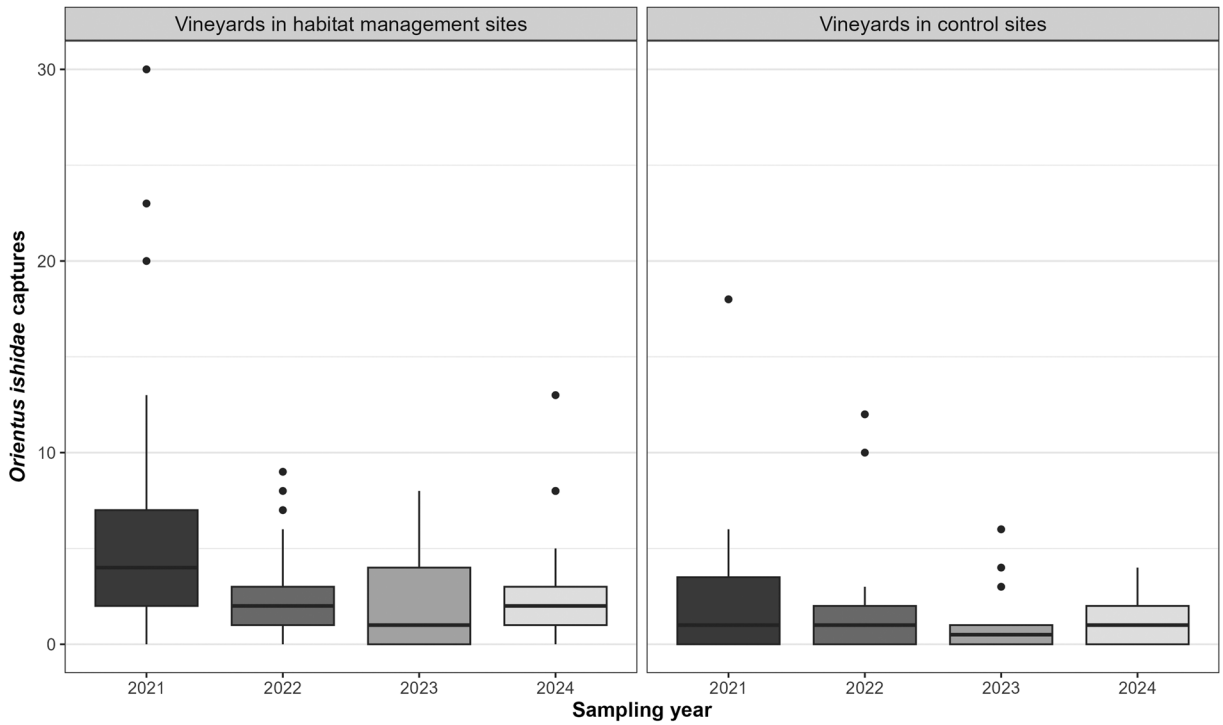

Fig. 5. *Orientus ishidae* total captures in vineyards grouped by site type and sampling year.
Boxplots with distribution of *Orientus ishidae* total captures from the traps placed in the vineyard canopy.

Particularly in relation to FD epidemiology, incorporating common hazel into an HM strategy could provide significant additional benefits in mitigating potential FDp infections originating from the wild and spreading into vineyards. In fact, earlier works in the same study area found identical FDp strains in *C. avellana* and *O. ishidae* which are compatible with both *S. titanus* and grapevine and thus trigger FD outbreaks (Casati et al. 2017, Malembic-Maher et al. 2020). Moreover, *O. ishidae* specimens sampled from gone-wild grapevines (ie surviving and now free-living vines in formerly cultivated and now abandoned plots) were recently found infected with the genetic profile commonly isolated from cultivated vineyards and *S. titanus* (*map* genotype M54, Oggier et al. 2024). Thus, since hazel may act as an intermediary inoculum reservoir between natural FDp sources such as *A. glutinosa*, as well as an additional vector habitat, HM could be of great importance, especially in areas where disease eradication or avoidance is the primary objective. In the specific case of Switzerland, besides for Canton Ticino where the disease is endemic, this could be of key importance for other winegrowing regions of the country, where FD is either present in several FD-infested hotspots or so far absent (Agroscope 2024). Additionally, HM could most likely be scaled up, especially in agroecosystems where vineyards are embedded in areas of differing land-use, as is the case for Southern Switzerland (Wyler et al. 2021). This could create further opportunities for several secondary benefits, such as a biodiversity-enhancing forest edge structure and a targeted neophyte control in the interface between vineyards and the forest edge.

The role of landscape as a habitat for FDp vectors and as an uncontrolled source of FDp inoculum has so far been overlooked, with mandatory control measures focusing on vineyards (and ideally on nurseries) only (Gonella et al. 2024a, 2024b). This calls for a more comprehensive disease management approach that considers not only gone-wild grapevines and alder stands but also hazel shrubs. All of these components can be widely present in forests adjacent to cultivated vineyards and may act as important inoculum reservoirs and habitats for FDp vectors (Lessio et al. 2014, Casati et al. 2017, Rizzoli et al. 2021, Oggier et al. 2023, 2024). In addition, when considering the supposed efficiency and sustainability of control measures, eliminating hazel shrubs may be far less cost-intensive than treating gone-wild grapevines spread over wide forested areas and alder trees.

In conclusion, this study conceptualized and tested a straightforward and minimally invasive HM strategy to effectively reduce the population of the alternative FDp vector *O. ishidae*. In light of the obtained results, this approach could well be added to the classic mandatory control measures and to other HM approaches such as rogueing gone-wild grapevines, while promoting more sustainable and environmentally friendly approaches to disease management, especially in vineyard plots surrounded by forest areas. To further support the implementation of HM strategies and measure its overall impact on FD management, further studies should consider FDp infection rates in insect and plant specimens. Transmission trials involving *O. ishidae*, hazel shrubs and grapevine could also be an additional argument for the application of HM.

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Supplementary Material

Supplementary material is available at *Journal of Economic Entomology* online.

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Conflicts of Interest

None declared.

Data Availability

Data are available at https://www.doi.org/10.16904/envidat.447.

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