Biodiversity and management of arthropods in cool-climate vineyards

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Viticulture and oenology are agricultural activities that, in the Mediteranean region, go back to several thousands years. In North America, they evolved very recently, as reported in Pinney (2005). At this time, viticulture is one of the few agricultural activities that is experiencing sustained growth in North America. Because Canada is undoubtedly located in a cool-climate area, viticulture is generally though to be very marginal. Hence, in his masterful 928 pages-book on Wine, Dominé (2008) devoted only 2 pages on Canadian viticulture. However, canadian viticulture has also had tremendous growth in the last 30 years.

Working in cool-climate vineyards poses special challenges. In Canada, the Niagara region in Ontario and the Okanagan valley in British Columbia are clearly leading the wine industry in economic terms and in hectares of planted vines (On - 7163 ha and BC - 3381 ha): this is because they are the warmest regions. Other regions, that have cooler climatic conditions, include southern Quebec (632 ha) and Nova Scotia: nevertheless, these regions have also experienced strong growth. This calls for new information adapted to local agronomic situations. Using Quebec as the focus of a case history, the following text relates the steps involved in entomological research, notably how challenges faced by viticulture practiced in cool-climate regions were addressed.

The context in a nutshell

The American prohibition in the 20’s exerted a strong negative influence on the viticulture industry in North America. As a consequence, little work occurred for decades in all fields related to viticulture. Eventually, action resumed in all canadian provinces in the 70’s. In Quebec, Gilles Rondeau and Joseph Vandal founded the first “Association of amateur wineries” in Charlesbourg in 1979. The vineyard “L’Orpailleur“ planted his first grapevines in 1984. In 1987, the ”Association des vignerons du Québec” (AVQ) was founded. In 1996, the first wines produced in Quebec were for sale at the “Société des Alcools du Québec (SAQ)“, a para-governmental organization that has sales monopoly in Quebec. In 1997, Dubois and Deshaies published their “Guide des vignobles du Québec sur la route des vins“. Up to that point, there had been no research done on protection of vineyards in Quebec.

Challenges

The major challenge of cool-climate viticulture is….climate, as discussed by Lasserre (2001). Because cool-climate viticulture occurs at the edge of the agronomic possibilities, the choice of cultivars and the economics (including research funding) are limited. From a protection point of view, diseases are much more important than entomological problems, as reflected in the number of fungicide sprays done each year against downy mildew (*Plasmopara viticola*), powdery mildew (*Erysiphe necator*) and bunch rot (*Botrytis cinerea*). Our strategy has been basically to protect only vineyards that produce commercially acceptable grapes, irrespective of cultivars ! Basically, the principles of insect management in vineyards are the same as in orchards, as discussed by Kogan and Hilton (2009). However, in contrast to crops such as apples, pears and peaches, grapes are mashed at harvest to produce wine, and therefore cosmetic devaluation of berries by arthropods are irrelevant. Like apple, pear and peach trees, vineplants are perennial plants and their phenological stages (see Bloesch and Viret 2008) offer cues for the timing of pesticide treatments or other interventions. In contrast, vineplants have indefinite growth (i.e. continous production of meristems). The latter feature implies continuous availability of tender tissues, which may favor the residence of some insect populations. Likewise abundant exudates provide food for some insects throughout the season. Finally, the physiology of the berry is peculiar in that, in every berry, cell division and cell expansion occur before the veraison stage and, at the inception of ripening (after veraison) cell expansion is accompanied with increases in sugar content, fruit softness, and color and flavor (Fig. 1; Robinson and Davies 2000). These changes in metabolism are coordinated within each individual berry, and are not synchronized with changes in berries in a given cluster, which results in uneven levels of maturity and size within fruit clusters. Altogether, these features creates opportunities for some insects to thrive.

As agricultural lands devoted to viticulture are relatively small in cool-climate regions, the build-up of entomological problems do not occur at the same pace and intensity compared to well established wine-growing areas.

Research on vineyard protection- a beginning

The first research project formally funded in Quebec vineyard protection was a project concerning the entomofauna of vineyards (Table 1). The story began during a cold afternoon of January 1997, when Charles-Henri de Coussergues (Vignoble L'Orpailleur, Dunham, Qc) and Victor Dietrich (Vignoble Dietrich-Jooss, St-Alexandre, Qc) invited the three of us for an informal discussion about a research project aimed at gaining basic information on the entomofauna of vineyards. In the discussions, we asked for critical but confidential information, namely how many sprays were applied in their vineyards each year and against which insects. de Coussergues and Dietrich agreed to write that information on paper and that information constituted the golden benchmark against which we measured our progress ever since.

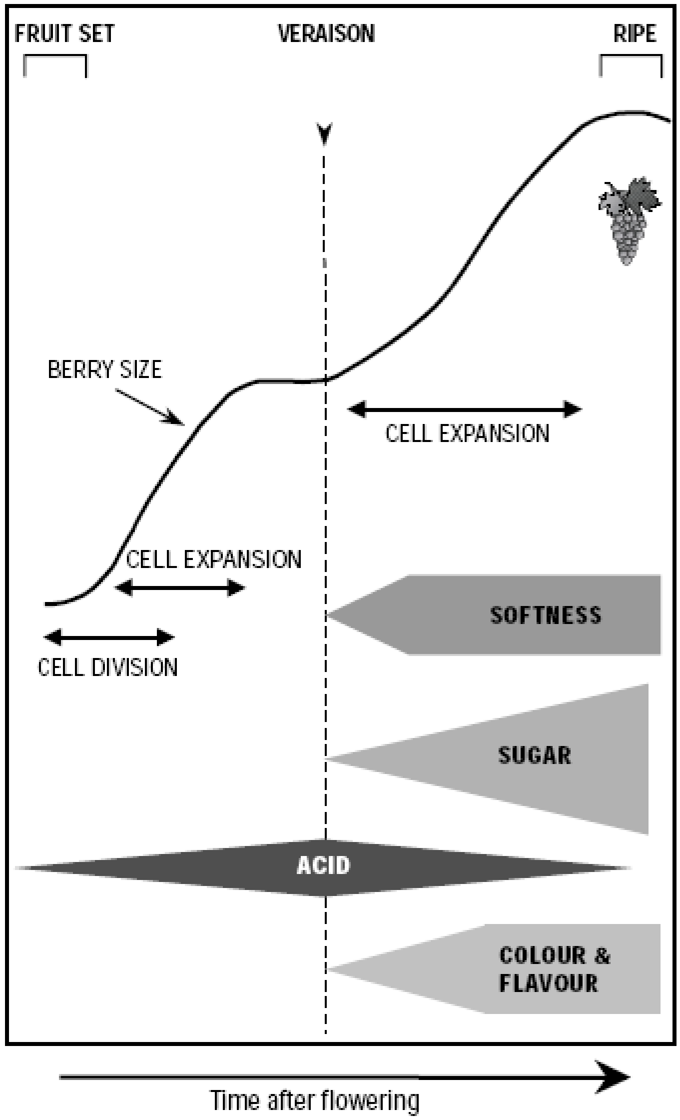

Figure 1. Schematic representation of grape berry development. The curve indicates changes in berry size. The inception of ripening (veraison) is shown by the vertical dashed line. Softening, sugar accumulation, metabolism of organic acids and synthesis of colour and flavour compounds all occur after veraison.

(From Robinson and Davies 2000, with kind permission of S. Robinson)

The first research project, co-funded by the vineyards l'Orpailleur and Dietrich-Jooss, Co-Lab R&D and the MII program of Agriculture and Agri-Food Canada, begun in 1997. The intial concept was to work from the ground up, i.e. from general information concerning arthropod fauna towards more specific subjects as the projects and the situation evolved. It was followed by several research projects in entomology, phytopathology and agricultural engineering (Table 1). We will heferafter focus on entomological issues.

Table 1. Milestones in vineyard protection, from a Quebec perspective

1997

First research project on the entomofauna of vineyards (N. J. Bostanian, C. Vincent, J. Lasnier) co-financed by AAC/ Co-Lab R&D, Orpailleur, Dietrich Jooss.

2000

First research project on phytopathology of vineyards (O. Carisse), co-financed by AAC/ Co-Lab R&D, Orpailleur, Dietrich Jooss.

First field day in viticulture in Quebec. AAC/ Experimental Farm, Frelighsburg , Qc.

2001

First project on spraying techniques in vineyards, (B. Panneton), co-financed by AAC/ Co-Lab R&D, Orpailleur, Dietrich Jooss, Bauge.

First Symposium on insects of vineyards in Canada (C. Vincent, N. J.Bostanian, orgs.), Entomological Society of Canada, Niagara-on-the-Lake, Ont.

First Technical Bulletin on Insects of Vineyards in Quebec. Lasnier, J., M. Trudeau, N. J. Bostanian, C. Vincent, H. Goulet & L. Lesage 2001. Les insectes ravageurs des vignobles au Québec. Downloadable from: http://eduportfolio.org/6644

2002

First series of lectures on viticulture in Quebec, based on original information gathered from research projects.(J. Lasnier, C. Vincent, N. J. Bostanian, O. Carisse) AAC/Saint-Jean-sur-Richelieu, Qc.

First conference on viticulture organized as part of the "Journées Horticoles", Saint-Rémi, Qc. The proceedings, published under the title: "Vincent, C., J. Lasnier & N. J. Bostanian 2002 (eds.). La viticulture au Québec. Vol. 1, 42 p.", are downloadable from: http://eduportfolio.org/6644

2003

Second series of lectures on viticulture in Quebec, based on original information gathered from research projects.(J. Lasnier, C. Vincent, N. J. Bostanian, O. Carisse) AAC/Saint-Jean-sur-Richelieu, Qc.

2004

Third series of lectures on viticulture in Quebec, based on original information gathered from local research projects. .(J. Lasnier, C. Vincent, N. J. Bostanian, O. Carisse) AAC/Saint-Jean-sur-Richelieu, Qc., in collaboration with the "Comité de recherche de L'Association des Vignerons du Québec".

2005

Series of lectures on viticulture protection in Quebec, delivered in Dunham, St-Eustache, Château Richer, Mirabel, Ste-Pétronille, Frelighsburg. (J. Lasnier, C. Vincent, N. J. Bostanian, orgs.).

Second conference on viticulture organized as part of "La Semaine Horticole", Boucherville, Qc. . The proceedings, published under the title: "Vincent, C., N. J. Bostanian & J. Lasnier 2005 (eds.). La viticulture au Québec. Vol. 2, 53 p.", are downloadable from: http://eduportfolio.org/6644

2007

Third conference on viticulture organized as part of the "Journées Horticoles", Saint-Rémi, Qc. The proceedings, published under the title: "Vincent, C., J. Lasnier & N. J. Bostanian 2002 (eds.). La viticulture au Québec. Vol. 3", are downloadable from: http://eduportfolio.org/6644

2008

Second Symposium on insects of vineyards in Canada (O. Olivier, C. Vincent orgs.), Entomological Society of Canada, Ottawa, Ont.

2009

Inception of a book project entitled "Arthropod Management in Vineyards**"** (N. J. Bostanian, R. Isaacs & C. Vincent eds.), Spinger SBM, NL.

As mentioned earlier, the first project was intended to study the biodiversity of arthropods in Quebec vineyards. Here we will report on some taxa in chronological order of publication, i.e. carabids, curculionids, spiders, and cicadellids. Then, we will treat special issues such as the tarnished plant bug, the mite predator *Anystis baccarum* and the grape berry moth.

Research on arthropod biodiversity in vineyards

Our study of biodiversity aimed at answering basic questions such as: what arthropods species are present in the vineyards ? What are the levels of abundance of some taxa ? Biodiversity work was conducted from 1997 to 1999 at l'Orpailleur (Dunham, Qc) and Dietrich Jooss (Iberville, Qc) vineyards. The populations of arthropods were captured or estimated thanks to a variety of methods, notably by visual estimation, by tapping of clusters over a plastic pot, with pitfall and flight interception traps. A major challenge was to sort out the specimens by given taxa such that they were amenable to identification. To estimate the biodiversity of the arthropod fauna, various statistics were used, i.e. the Shannon index, the evenness index, and the Chao-1 non-parametric estimator of species richness. Identification of thousands of specimens belonging to some taxa were done by professionnal systematists that co-authored scientific papers and are cited in the **Acknowledgements** section below.

Coccinellidae. Coccinellids are an important group of predators found in Quebec vineyards. Twenty species have been collected, including *Coccinella septempunctata* Linné, *Coleomegilla maculata lengi* Timberlake, *Hippodamia convergens* Guérin-Méneville et *Propylaea quatuordecimpunctata* (Linné) (Table 2). Twice more coccinellids were collected at Dietrich-Jooss vineyard. It is difficult for a non expert to identify coccinellid larvae. Some species, such as the adults the multicolored Asian ladybeetle, *Harmonia axyridis* Pallas, have up to 200 color variants on their elytra. The introduced species *H. axyridis* is an aggressive predator that displaced a number of coccinellid predators (Lucas et al. 2007a,b). When crushed with raisins at harvest, adults release pyrazine, a chemical that taints wine.

Table 2. Coccinellid species collected in two vineyards in 1997 and 1998 (From Vincent et al. 2002)

Species	L'Orpailleur	Dietrich-Jooss
Anatis mali (Say)	1	0
Brachiantha ursina (Fabricius)	1	2
Coccinella septempunctata L.	216	270
Coccinella transversoguttata richardsoni Brown	0	1
Coccinella trifasciata perplexa Mulsant	6	0
Coleomegilla maculata lengi Timberlake	89	268
Diomus debilis (LeConte)	1	0
Diomus terminatus Say	10	2
Harmonia axyridis (Pallas)	43	52
Hippodamia convergens Guérin-Méneville	83	181
Hippodamia parenthesis (Say)	18	0
Hippodamia variegata (Goeze)	3	0
Hyperaspis octavia Casey	0	5
Propylaea quatuordecimpunctata (L.)	32	230
Psyllobora vigintimaculata (Say)	4	7
Scymnus ? americanus Mulsant	2	2
Scymnus (Pullus) brullei (Pallas)		1
Scymnus (Scymnus) ? *indianensis* Weise		1
Scymnus (s-g ?) sp.		1
Stethorus punctillum Weise	0	3
Total	**509**	**1026**

Carabidae. Carabids are generally nocturnal and predatory. From 1997 to 1999, 11,435 specimens of ground beetles representing 124 species were captured in pitfall traps at L'Orpailleur and Dietrich-Jooss vineyards (Goulet et al. 2004). Over the 3-year period, the carabid diversity and the number of species (51 and 54) were similar in both vineyards. The most common species were ranked differently in a position that was consistent over the 3-year period: *Chlaenius sericeus* (Forster) and *Clivina fossor* (L.) occurred mainly on the clay loam vineyard, while *Amara latior* (Kirby) and *Harpalus herbivagus* Say on the gravel and sand loam vineyard. Two recently introduced European species, *Harpalus rufipes* (Duftschmid) and *Pterostichus vernalis* (Panzer), became more prevalent between 1997 and 1999 and are likely to affect the rank position at each site. Diversity at the clay loam vineyard was equal to another unsprayed and annually cultivated site on clay in the ecozone.

Spiders. At the onset of our work, the spider fauna of vineyards in northern parts of North America were completely unknown, even though spiders represent important natural enemies to phytophagous insects occurring in vineyards. Weekly pitfall trapping in 1998 and 1999 in two vineyards in southern Quebec yielded over 4,600 spiders belonging to 97 species and 16 families (Bolduc et al. 2005). Spider assemblages (diversity and community composition) were similar between the two vineyards independent of environmental differences. However, some species-specific patterns were noted when the two vineyards were compared. High landscape diversity, including fallow fields and adjacent apple orchards, is hypothesized to account for a higher abundance of certain agrobiont species in one of the vineyards. Phenological data show the most abundant linyphiid species, *Tennesseellum formicum* (Emerton), exhibits high phenotypic variation, and its multivoltine life cycles may be of adaptive importance for vineyards that are frequently disturbed. We also note several other species exhibiting period of peak activity in the spring [e.g., the wolf spiders *Pardosa moesta* Banks and *Trochosa ruricola* (De Geer)] or autumn [e.g., the funnel-web spider *Agelenopsis potteri* (Blackwall)]. Species turnover was high between sample dates, and data on activity and species richness of two guilds (web-building spiders and hunting spiders) indicate that many species that differ in foraging mode are active during all months of the growing season. The diverse ground-dwelling spider fauna in vineyards was therefore well positioned to prey on phytophagous pests, and their populations should be conserved in these agroecosystems.

Curculionidae. Adult weevils were collected using pitfall and flight intercept traps. In total, 3,176 specimens were collected, representing 73 species in three families of Curculionoidea (Bouchard et al. 2005). The family Curculionidae was the most species rich, especially the subfamilies Ceutorhynchinae, Curculioninae, and Entiminae. Four species were known to feed on *Vitis* sp. (Vitaceae) in North America: *Madarellus undulatus* (Say), *Barypeithes pellucidus* (Boheman), *Otiorhynchus ovatus* (L.), and *Otiorhynchus sulcatus* (F.). *O*. *sulcatus* is thought to represent the greatest potential threat because of its abundance in one wineyard and reports on its impact in other wine-making regions in North America. Four species [*Ceutorhynchus oregonensis* Dietz, *Pelenomus waltoni* (Boheman), *Rhinoncus perpendicularis* (Reiche), and *Sphenophorus minimus* Hart] were recorded in Quebec for the first time. A significant number of weevils collected during this study are adventive species associated with agroecosystems of northeastern North America.

Chrysomelidae. Using pitfall and flight interception traps, a total of 3,078 leaf beetles representing 59 species were collected, with 31 of these species found in both vineyards, 8 found exclusively at the L'Orpailleur vineyard, and 19 found only at the Dietrich-Jooss vineyard (Lesage et al. 2008). The higher abundance and species richness found at Dietrich-Jooss was associated with plants growing on the edges of a creek. *Longitarsus rubiginosus* was the dominant species at Dietrich-Jooss, whereas *Chaetocnema minuta*, *C. denticulata*, and *C. concinna* were the major dominant species at L'Orpailleur. The two grape flea beetles, *Altica chalybea* Illiger and *A. woodsi*

Isely that had large populations in the two vineyards in 1996 were completely absent during the survey. Only *Systena frontalis* was found; the adults fed on the grape foliage. Companion species accounted for more than 66% of the captured specimens, although they represented less than 33% of the species diversity. These species were mostly associated with weeds growing inside the vineyards, and almost 66% of these species had been introduced from Europe. Finally, transient species accounted for more than 66% of the leaf beetle diversity, but represented less than 33% of captured chrysomelids.

Cicadellidae. Up to 60 cicadellid species were found in Quebec vineyards (Bostanian et al. 2003). They were assigned to four categories, i.e. 1) species strickly associated with grapevine; 2) species using grapevines as secondary hosts; 3) species associated with weeds inside the vineyard; and 4) species associated with neighboring vegetation of the vineyard. Among the species strickly associated with grapevine, five species, the eastern grape leafhopper, *Erythroneura comes* (Say); the grapevine leafhopper, *Erythroneura vitis* (Harris); the threebanded leafhopper, *Erythroneura tricincta* Fitch; the Virginia creeper leafhopper, *Erythroneura ziczac* Walsh; and *Erythroneura vitifex* Fitch, were captured in very low numbers. Phytoplasmas were recently found in vineyards of Canada (Olivier et al. 2009). For a discussion of cicadellids in respect to their capacity of carrying or vectoring phytoplasmas in vineyards, see Saguez et al. (this volume).

Management of arthropods

In retrospect, the passage from biodiversity survey to activities more focused on specific entomological issues has been rather smooth, chiefly because most of our projects were co-funded by commercial vineyards. A general paper concerning phytophagous insects of Quebec vineyards was published by Bostanian et al. (2003). Briefly, the arthropod fauna in Quebec vineyards was qualitatively and quantitatively different than that of neighboring Ontario and New York State. We hypothesized that a colder winter climate in addition to the agronomic activity of earthing up around the vines in autumn to protect the roots from freezing in winter contributed to low numbers of pests, such as the grape berry moth, *Endopiza viteana* Clemens (Lepidoptera: Tortricidae). From 1997 to 1999, the density of this pest approached, in one of the vineyards, the action threshold recommended in New York State. However, in subsequent years, population levels of the grape berry moth rose enough to warrant initiation of a study by F. Besadia, enrolled in a Ph. D. program at the Université du Québec à Montréal.

The tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), has been a cause of concern. Few papers have been published on the system tarnished plant bug/grapevine (*Vitis vinifera*). From 19th century documents, it has been inferred that *L. lineolaris* may have economic impact in vineyards, notably in Missouri. Crosby and Leonard (1914) observed *L. lineolaris* feeding on *V. vinifera*. Jubb et al. (1979) reported that *L. lineolaris* was the most abundant mirid in Pennsylvanian vineyards and they concluded that, because of its appearance late in the season, its effect on grape production was negligible. By tapping over flower/fruit clusters, Bostanian et al. (2003) sampled nymphs and adults of *L. lineolaris* throughout the growing season on three cultivars (Cayuga White, de Chaunac and Seyval blanc) in Quebec vineyards. In laboratory experiments coupled with histological studies, Fleury et al. (2003, 2006) demonstrated that nymphs and adults of *L. lineolaris* can cause minor histological damage to buds and berries when allowed to feed for 1 hour at early phenological stages (from bud burst, i.e. B stage of Baillod and Baggiolini 1993) to closure (L stage)) of *V. vinifera*. The status of tarnished plant bug in vineyards has yet to be established.

Modeling

In biodiversity studies, 60 cicadellids species were found in Quebec vineyards (Bostanian et al. 2003). Although the abundance of cicadellids was relatively low between 1998-2000, phytoplasmas were later found in Canadian vineyards (see Saguez et al.- this volume). This translated into a greater need to develop a tool to optimise resources needed to estimate cicadellid populations (Bostanian et al. 2006). Because the development of leafhopper nymphs and feeding injury is closely tied to temperature, a model driven by the accumulation of degreedays was developed to predict leafhopper cumulative abundance at 5, 50, and 95% levels in vineyards. The model was based on 22 data sets collected over 7 year in three vineyards in southern Quebec. It was based on the cumulative abundance of nymphs of the eastern grape leafhopper *(Erythroneura comes* (Say)); the grapevine leafhopper (*Erythroneura vitis* (Harris)); the threebanded leafhopper (*Erythroneura tricincta* Fitch); the Virginia creeper leafhopper (*Erythroneura ziczac* Walsh); and *Erythroneura vitifex* Fitch. The lower threshold temperature for development was 8ºC. Paired *t*-tests and the forecasting efficiency confrmed the validity of the model. The model indicated that monitoring for leafhoppers in vineyards should be initiated at 630 DD (5% cumulative abundance) and terminated at 1,140 DD (95% cumulative abundance). Maximum abundance would be between 850 and 860 DD (50% cumulative abundance) calculated from 1 March.

Toxicological studies

In Canada, vineyards represent a small market niche for compagnies that produce or market pesticides. As there is ca. 50 pesticides registered for use in vineyards in Canada, much remains to be done. Our research on toxicological effects of pesticides focused on two arthropod species, i.e. a potential insect pest (*Lygus lineolaris*) that is an important pest on several crops in North America, and an important mite predator (*Anystis baccarum*).

***Lygus lineolaris*.** Toxicological studies were carried out with tarnished plant bug adults and nymphs collected from three mixed vegetation strips adjacent to orchards and vineyards along the St Lawrence valley: the Niagara Peninsula (Ontario), Dunham (Quebec) and La Pocatière (Quebec). Assays were done in the laboratory by confining adults in glass vials coated with dried residues. The estimated LC_{50} values for the three populations varied from 11.2 to 16.8 $\times 10^{-5}$ g/L for azinphos-methyl and from 0.8 to 1.4 $\times 10^{-5}$ g/L for cypermethrin (Fleury et al. 2007). A possible explanation for this susceptibility to insecticides is that very low selection pressure (i.e. reduced number of insecticide treatments) is exerted on *L. lineolaris* in the context of the diversified agricultural landscapes encountered in eastern Canada: this allows movements of adults from treated to non-treated areas.

***Anystis baccarum*.** Predacious mites are vital for the success of integrated pest management programs for phytophagous mites in vineyards. Most of these programs are either based on conservation and augmentation or the rearing and massive releases of different species of phytoseiids. *Anystis baccarum* (L.) (= *Anystis agilis* (Banks)) is a common predatory mite recently identified in apple orchards and in vineyards of Quebec, Canada. Found on agricultural crops grown from temperate to sub-tropical regions. It is a voracious generalist, fast-moving, large orange-red mite that feeds on any prey that it can overpower. A laboratory with the following insecticides: methoxyfenozide (Interprid® 2F), acetamiprid (Assail® 70WP), thiamethoxam (Actara® 25WG), imidacloprid (Admire® 24%), spinosad (Tracer® 44.1%), λ-cyhalothrin (Warrior® T), and carbaryl (Sevin® XLR) showed that residues of λ-cyhalothrin, and carbaryl were very toxic to *Anystis baccarum* in Petri dish bioassays. The field rate of λ-cyhalothrin is 0.0184 g a.i./L, which is 26 fold the estimated LC50 (0.0007 g a.i./L) for this predator. The field rate for carbaryl is 1.960 g a.i./L which is 784 fold the estimated LC_{50} (0.0025 g a.i./L). The renaining five insecticides, evaluated were non-toxic (Laurin and Bostanian 2007a, Bostanian and Laurin 2008).

Laboratory tests with fungicides showed that dry residues of sulfur (Microscopic Sulphur® 92 WP), captan (Maestro® 80 DF), kresoxim-methyl (Sovran® 50 WG), metiram (Polyram® 80 WP), boscalid (Lance® 70 WDG) and myclobutanil (Nova® 40 WP) were harmless to *A. baccarum* adults. In contrast, dried residues of mancozeb (Dithane® M-45) was moderately toxic at the field rate and the LC_{50} was estimated at 1.88 g a.i./L (1.2-fold the field rate) (Laurin and Bostanian 2007b). These findings were only part of the toxicity attributes of these fungicides, since only effects on adults were studied. Once a reliable rearing technique for *A. baccarum* is developed, effects on immatures, fecundity and egg hatch would be evaluated to complete our understanding of the effects of these fungicides on this predator.

Grape berry moth. *Endopiza viteana* is an important pest of vineyards in Ontario and New York State. The number of larvae enumerated per 100 clusters by direct counting over 1997-1999 totalled to 7 larvae in the L'Orpailleur vineyard and 24 larvae in the Dietrich-Jooss vineyard. If we assume that 1 larva per cluster could damage the cluster in late July, then the density of larvae in the Dietrich-Jooss vineyard was in 1999 at the action threshold recommended for New York State, that is, 3% damaged clusters in late July. Later, larval populations of the grape berry moth were observed in much higher abundance, prompting work by F. Bensadia, a graduate student at the Université du Québec à Montréal.

Technology transfer

Before the inception of our activities, Quebec viticulturists totally relied on published material from various sources, notably from neighboring Ontario and New York State, to manage insect pests. As we generated new information and, within the limits allowed by our research contracts, we organized a series of events to disseminate knowledge as events unfolded (Table 1). As early as 2000, a field day focusing on vititulture was organized at the Agriculture and Agri-Food Canada experimental farm of Frelighsburg. In 2001, the first Technical Bulletin on Insects of Vineyards in Quebec was available on the web (Lasnier et al. 2001). We organized a series of lectures at Saint-Jean-sur-Richelieu (Lasnier et al. 2002, 2003, 2004). As part of larger horticultural events, we organized three conferences and published their Proceedings through the web (Vincent et al. 2002, 2005, 2008). In 2005, a series of 9 field workshops and 9 conferences were given in six localities of Quebec (Table 1- Lasnier et al. 2005). We also took scientific leadership in organizing two Symposia on the entomology of vineyards in the context of the Entomological Society of Canada at Niagara-on-the-Lake (2001) and Ottawa (2008) (Table 1). As of October 2009, a Technical Bulletin and a Book on Arthopods of vineyards are in preparation.

Concluding remarks- the future

From a meeting in a cold January afternoon in 1997 to the present, much has been accomplished in protection of vineyards in Quebec. First, research allowed to determine the diversity and abundance of arthropod species in Quebec vineyards. Second, contractual research facilitated agreements about research priorities. Third, several technology transfer events ensured that research results were valued as much as possible. Fourth, the quantities of insecticides used has dropped to ca. 50% of those used before 1997. In closing, much remains to be done in Quebec viticulture, especially if the hypothesis of global warming is true. Admitedly, this should improve climatic conditions such that new vine cultivars could be cultivated, but it will also likely change the dynamics of entomological problems.

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References

Bloesch, B. & O. Viret 2008. Stades phénologiques repères de la vigne. Rev. Suisse Viti. Arbor. Horti. 40(6): 1-4.

Bolduc, E., C.M. Buddle, N. J. Bostanian & C. Vincent 2005. The Ground-Dwelling Spiders (Aranae) of two vineyards in Southern Quebec. Env. Entomol. 34: 635-645.

Bostanian, N. J., G. Bourgeois, C. Vincent, D. Plouffe , M. Trudeau & J. Lasnier 2006. The Population Dynamics of Leafhoppers in Quebec Vineyards. Env. Entomol. 35:1477-1482.

Bostanian, N. J., Vincent, C., G. Goulet, L. LeSage, J. Lasnier, J. Bellemare & Y. Mauffette 2003. The Arthropod Fauna of Quebec Vineyards, with particular reference to phytophagous species. J. Econ. Entomol. 96: 1221-1229.

Bostanian, N.J. & M.-C. Laurin 2008. Effects of ten pesticides to *Anystis baccarum* (Acari: Anystidae). Working group ″Pesticides and beneficial organisms″. WG Meeting 2007, 10-12 October 2007, Berlin-Dahlem, Germany. IOBC/wprs Bulletin 35: 96-100.

Bouchard, P., L. Lesage, H. Goulet, N. J. Bostanian, C. Vincent, A. Zmudzinska & J. Lasnier 2005. Weevil (Coleoptera: Curculionoidea) diversity and abundance in Quebec vineyards. Ann. Entomol. Soc. Am. 98: 565-574.

Crosby, C.R. & M.D. Leonard. 1914. The tarnished plant-bug. Agricultural experiment station of the college of agriculture. Department of Entomology. Cornell University. Bulletin 346: 462-525.

Dominé, A. 2008. Le Vin, h.f Ullmann (Tandem Verlag Gmbh), Paris, 928 p.

Dubois, J. M. & L. Deshaies 1997. Guide des vignobles du Québec sur la route des vins. Les Presses de l'Université Laval, Québec, Qc, 297 p.

Fleury, D., J. Paré & C. Vincent 2003. Identification histologique des lésions causées sur l'inflorescence de *Vitis vinifera* L. (Vitacées) par *Lygus lineolaris* (Palisot de Beauvois) (Heteroptera: Miridae). Rev. Cytol. Biol. Vég. 26: (1/2):8-18.

Fleury, D., J. Paré, C. Vincent & Y. Mauffette 2006. Feeding impact of *Lygus lineolaris* (Heteroptera: Miridae) on *Vitis vinifera*: a behavioural and histological study. Can. J. Bot. 84: 493-500.

Fleury, D., N. J. Bostanian, C. Vincent & Y. Mauffette 2007. The intrinsic residual toxicity of two insecticides on three field populations of *Lygus lineolaris* collected along the St. Laurence vally in eastern Canada. Pest Man. Sci. 63:495-499.

Goulet, H., L. LeSage, N. J. Bostanian, C. Vincent & J. Lasnier 2004. Diversity and seasonal activity of ground beetles (Coleoptera: Carabidae) from two vineyards in southern Quebec. Ann. Entomol. Soc Am. 97: 1263-1272.

Jubb, G.L. Jr., E.C. Masteller & A.G. Jr Wheeler. 1979. Survey of arthropods in vineyards of Erie County, Pennsylvania: Hemiptera-Heteroptera. Environ. Entomol. 8: 982-986.

Kogan, M. & R. J. Hilton 2009. Conceptual Framework for Integrated Pest Management (IPM) of Tree-Fruit Pests pp. 1-31 *in* Aluja, M., T. C. Leskey & C. Vincent 2009 (Eds.). Biorational Tree-Fruit Pest Management, CABI, Wallingford, U.K., 295 p.

Lasnier, J., M. Trudeau, N. J. Bostanian, C. Vincent, H. Goulet & L. Lesage 2001. Insect pests of grapevine in Quebec. Technical Bulletin downloadable from: http://eduportfolio.org/6644

Lasserre, F. 2001. L'essor du vignoble au Québec. Histoire de climats et de goûts », *Cybergeo : European Journal of Geography.* Document 190, Downloadable from: http://www.cybergeo.eu/index3747.html

Laurin, M.-C. & N. J. Bostanian 2007a. Laboratory studies to elucidate the residual toxicity of eight insecticides to *Anystis baccarum* (Acari: Anystidae). J. Econ. Entomol. 100: 1210-1214.

Laurin, M.-C. & N. J. Bostanian 2007b. Short-term contact toxicity of seven fungicides on *Anystis baccarum*. Phytoparasitica 35: 380-385

Lesage, L., P. Bouchard & H. Goulet 2008. Leaf beetle diversity and abundance in two Quebec vineyards (Coleoptera, Chrysomelidae). Nouvelle Revue d'Entomologie 25 (1): 3-16.

Lucas, E., C. Vincent, G. Labrie, G. Chouinard, F. Fournier, F. Pelletier, N. J. Bostanian, D. Coderre, M.-P. Mignault & P. Lafontaine 2007a. The multicolored Asian ladybeetle

Harmonia axyridis (Coleoptera: Coccinellidae) in Quebec agroecosystems ten years after its arrival. Eur. J. Entomol. 104 : 737-743.
Lucas, E., G. Labrie, C. Vincent & J. Kovach 2007b. The Multicoloured Asian Ladybeetle *Harmonia axyridis* - beneficial or nuisance organism ? pp. 38-52 *in* Vincent, C., M. Goettel & G. Lazarovits 2007 (eds.). Biological Control: a global perspective. Case Histories from around the world. CABI Publishing, Wallingford, U.K., 440 p.
Olivier, C. Y, D.T. Lowery, L. W. Stobbs, C. Vincent, B. Galka, J. Saguez, L, Bittner, R. Johnson, M. Rott, C. Masters & M. Green 2009. First report of Aster yellow phytoplasmas (*Candidatus* phytoplasma *asteris*) in Canadian Grapevines. Plant Dis. 93: 669.
Pinney, T. 2005. A History of Wine in America, From Prohibition to the Present, University of California Press, Berkeley and Los Angeles, CA, 532 p.
Robinson, S. P. & C. Davies 2000. Molecular biology of grape berry ripening. Australian J. Grape Wine Res. 6: 175-188.
Vincent, C., N. J. Bostanian, J. Lasnier, H. Goulet, L. LeSage & M. Trudeau 2002 Insectes bénéfiques des vignobles du Québec, pp. 29-32 *in* Vincent, C., J. Lasnier & N. J. Bostanian 2002 (eds.). La viticulture au Québec, Vol. 1, 42 p. Downloadable from: http://eduportfolio.org/6644
Vincent, C., J. Lasnier & N. J. Bostanian 2002 (eds.). La viticulture au Québec, Vol. 1, 42 p. Downloadable from: http://eduportfolio.org/6644
Vincent, C., N. J. Bostanian & J. Lasnier 2005 (eds.). La viticulture au Québec, Vol. 2. 53 p., Downloadable from: http://eduportfolio.org/6644