One acre insectory at Benziger Vineyards. (Photo by Mary Benziger.)

Designing biodiverse, pest-resilient vineyards through habitat management

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Most typical California winegrape production is done in monocultures, that totaled 568,000 acres in 2002 (although this acreage decreased slightly in 2003/2004), an agricultural expansion that is slowly resulting in the simplification of large landscapes. Since the onset of such simplification, farmers and researchers have been faced with a major ecological dilemma arising from the homogenization of vineyard systems: increased vulnerability of uniform, large-scale monocultures to insect pests and diseases, which, in many cases, can cause yield losses.

Expansion of monocultures has decreased abundance and activity of natural enemies due to removal of critical food resources and overwintering sites. Many scientists are concerned that, with accelerating rates of habitat removal, the contribution to pest suppression by biocontrol agents using these habitats will decline. It is possible that many pest problems affecting today's vineyards have been exacerbated by such trends.

About 69 million lbs of active ingredients of pesticides are used annually in California vineyards to counteract such pest pressure, especially diseases as much of the chemical inputs comprise applications of sulfur dust. The environmental impact of such pesticide load can be serious.

Concerned about these problems, many people have proposed options to rectify this habitat decline by increasing the vegetational biodiversity of agricultural landscapes. There are many ways in which increased plant biodiversity can contribute to the design of insect pest-stable agro-ecosystems by creating an appropriate ecological infrastructure within and around vineyards. A key feature of that infrastructure are flower resources which can be provided in the form of cover crops, corridors, or islands.

Adult *Anagrus epos* male, parasite of the grape leafhopper. (Photos by Jack Kelly Clark for UC Statewide IPM Project. ©2000 Regents, University of California.)

When choosing flowering plants to attract beneficial insects, it is important to note the size and shape of the blossoms, because that is what dictates which insects will be able to access the flowers' pollen and nectar. For most beneficials, including parasitic wasps, the most helpful blossoms should be small and relatively open. Plants from the Compositae (sunflower) and Umbelliferae (carrot) families are especially useful.

Timing of flower availability is as important to natural enemies as blossom size and shape. Many beneficial insects are active only as adults and only for short periods during the growing season; they need pollen and nectar during these active times, particularly in the early season when prey are scarce. One of the easiest ways growers can help is to provide beneficials with mixtures of plants with relatively long, overlapping bloom times.

Biodiversity is crucial to crop defenses: the more diverse the plants, animals, and soil-borne organisms that inhabit a farming system, the more

Adult female wasp, *Anagrus epos*. (57x magnification)

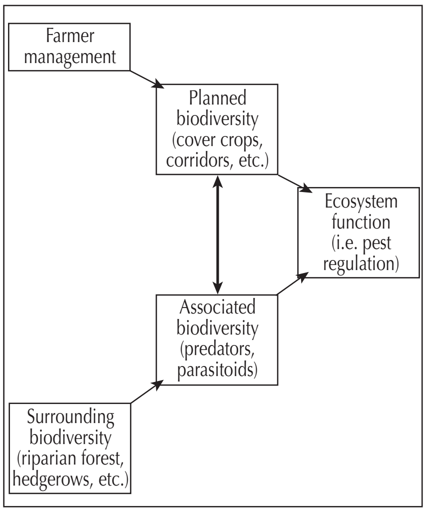

Figure I. Relationship between several types of biodiversity and their role in pest regulation in a diversified vineyard.

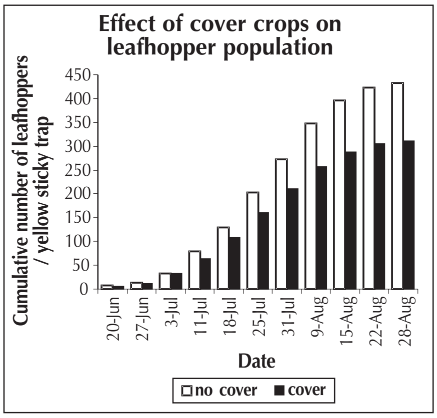

Figure II. Densities of adult leafhoppers *E. elegantula* in cover-cropped and monoculture vineyards in Hopland, CA, during 1997 growing season.

diverse the community of pest-fighting beneficial organisms (predators, parasitoids, and entomopathogens) a farm can support.

Farmers can enhance biodiversity on their farms by:

1. Increasing plant diversity with crop rotations or with "polycultures" (crop mixes) of cash crops grown on the same vineyard land at the same time;
2. Planting cover crops between vines;
3. Managing vegetation surrounding fields to meet the needs of beneficial organisms;
4. Designing corridors of plants that usher beneficials from nearby forests or natural vegetation to field centers;
5. Selecting non-crop plants grown as strips in fields, whose flowers match beneficials' requirements;
6. Preserve mosaics or islands of native vegetation within or near the vineyards.

All the above strategies provide alternative food (pollen and nectar) and refuge for predators and parasitoids of leafhoppers, mites and lepitodpterous pests, thereby increasing natural enemy diversity and abundance in vineyards.

Biodiversity in vineyards and its function

Biodiversity in vineyards refers to all plant and animal organisms (crops, native vegetation, weeds, livestock, natural enemies, pollinators, and soil flora and fauna) present in and around farms. How diverse the vegetation is within and around a farm, how many cover crops are grown, how close a vineyard is to a forest, hedgerow, meadow, or other natural vegetation, are all factors that contribute to a vineyard's level of biodiversity.

Two distinct components of biodiversity can be recognized in agroecosystems. The first component, *planned biodiversity*, includes the crops and other plants purposely included in a vineyard by a grower. The second component, *associated biodiversity*, includes all soil flora and fauna, herbivores, carnivores, and decomposers, that colonize the agroecosystem from surrounding environments and will thrive in a vineyard, depending on its management and structure. The relationship of both types of biodiversity components is illustrated in Figure I.

Planned biodiversity has a direct function, as illustrated by the bold arrow connecting the planned biodiversity box with the ecosystem function box (Figure I). Associated biodiversity also has a function, but it is mediated through planned biodiversity. Thus, planned biodiversity also has an indirect function, which is realized through its influence on the associated biodiversity.

For example, cover crops enrich the soil which helps vine growth. The direct function of cover crops is to enhance soil fertility and soil structure.

Along with cover crops come wasps (many moving in from riparian forests) that seek out the nectar in the cover crop's flowers. These wasps, in turn, are natural parasitoids of pests that normally attack vines. Wasps are part of the associated biodiversity, some of which live in the riparian vegetation and move from there to vines or cover crops. The cover crops, then, enrich the soil (direct function) and attract wasps (indirect function).

The challenge for growers is to identify the type of biodiversity that is desirable to maintain and/or enhance in their vineyard in order to carry out specific ecological services (such as pest

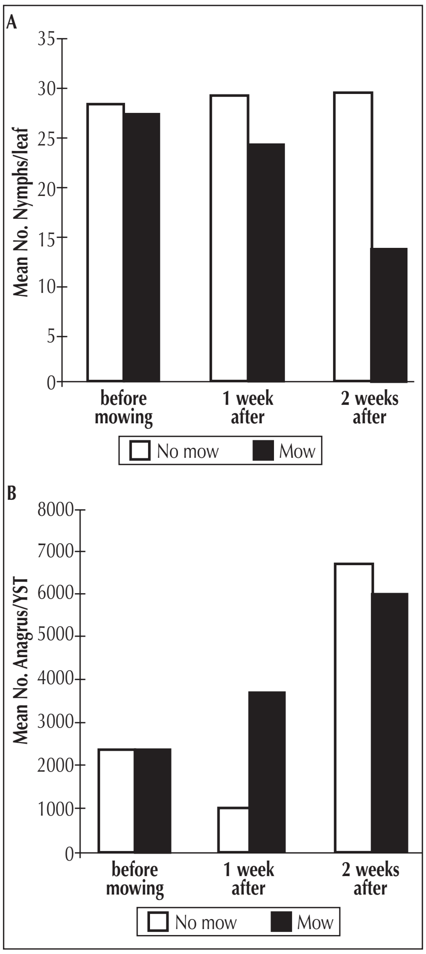

Figure III. A) Effect of cover crop mowing in vineyards on densities of leafhopper nymphs during the 1997 growing season in Hopland, CA. B) Effects of cover crop mowing in vineyards on densities of Anagrus epos during the 1997 growing season in Hopland, CA.

regulation) and then determine the best practices that will encourage such biodiversity. Cover cropping and creation of habitats within vineyards are key strategies.

Enhancing vineyard biodiversity with cover crops

In California, many growers manage resident vineyard floor vegetation or plant cover crops as habitat management to enhance natural enemies. Reductions in mite and grape leafhopper populations have been observed in cover cropped systems.[2,4] But in many cases, such biological suppression has not been sufficient from an economic viewpoint.[3] Usually the problem is that most growers plant winter cover crops and/or allow weedy resident vegetation which are mowed or plowed under at the beginning of the growing season, mainly to avoid competition with the vines for water.

In early summer, these vineyards become virtual monocultures without floral diversity. It is important to maintain a green cover during the entire growing season in order to provide habitat and alternate food for natural enemies, especially in areas affected by grape leafhoppers.

One approach is to sow summer cover crops that bloom early and throughout the season, thus providing a highly consistent, abundant, and well-dispersed alternative food source, and micro-habitats, for a diverse community of natural enemies. Such food supply decouples predators and parasitoids from strict dependence on grape herbivores, allowing an early build-up of natural enemies in the system, which helps keep pest populations at acceptable levels.

Maintaining floral diversity throughout the growing season in a Northern California vineyard near Hopland in the form of summer cover crops of buckwheat and sunflower, the abundance of grape leafhoppers and western flower thrips was substantially reduced as associated natural enemies increased.

During two consecutive years (1996–1997), vineyard systems with flowering cover crops were characterized by lower densities of leafhoppers nymphs and adults (Figure II). Thrips also exhibited reduced densities in cover-cropped vineyards in both seasons.[7]

During both years, general predator populations on the vines were higher in the cover-cropped sections than in the monoculture blocks. Generally, populations were low early in the season, but increased as prey became more numerous as the season progressed. Dominant predators included spiders (mainly salticid [jumping spider] and thomisid species [crab spider], *Nabis* sp. [damsel bugs], *Orius* sp. [Minute pirate bug], *Geocoris* sp. [Big eyed bugs], Coccinellidae [ladybugs] , and *Chrysoperla* sp. [lacewings]).

Although *Anagrus epos* (the most important leafhopper parasitoid wasp), achieved high numbers and inflicted noticeable mortality of grape leafhopper eggs, this impact was not substantial enough. Apparently the wasps encountered sufficient food resources in the cover crops and few moved to the vines to search for leafhopper eggs, especially when eggs are not abundant and despite the presence of leafhopper honeydew. For this reason, alternate tractor row cover crops were mowed to force movement of *Anagrus* wasps and predators into the vines.

Before mowing, leafhopper nymphal densities on vines were similar in all the selected cover-cropped rows. One week after mowing, probably due to increased predation, numbers of nymphs declined on vines where the cover crop was mowed, coinciding with an increase in *Anagrus* densities in mowed cover crop rows. During the second week such decline was even more pronounced (Figure III).

The mowing experiment suggests a direct ecological linkage, as mowing cover crop vegetation forced movement of the *Anagrus* and predators harbored by the flowers, resulting in a decline of leafhopper numbers on vines adjacent to the mowed cover crops (in both years). Timing of mowing must coincide when eggs are present on vine leaves in order to optimize the efficiency of arriving *Anagrus* wasps.

Designing corridors

Several studies indicate that the abundance and diversity of entomophagous (insect-eating bugs) insects within a field is dependent on the plant

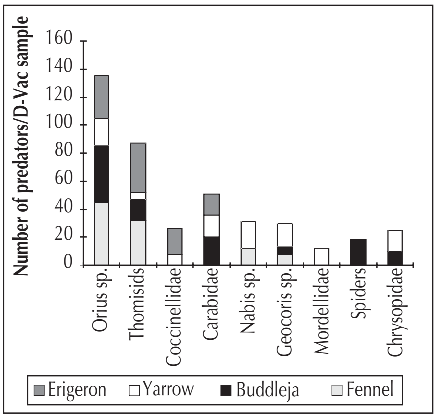

Figure IV. Main predator groups associated with dominant corridor flowering plants (Hopland, CA 1996).

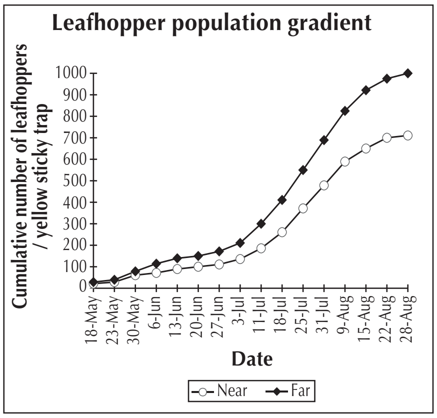

Figure V. Seasonal patterns of adult leafhoppers in vineyard near and far from the corridor (Hopland, CA 1996).

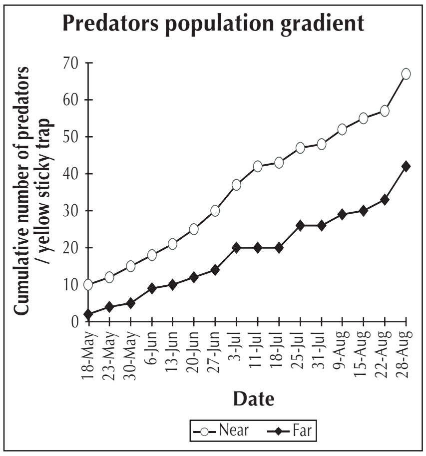

Figure VI. Seasonal patterns of predator catches (numbers per yellow sticky trap) in vineyards as influenced by presence of the corridor (Hopland, CA 1996).

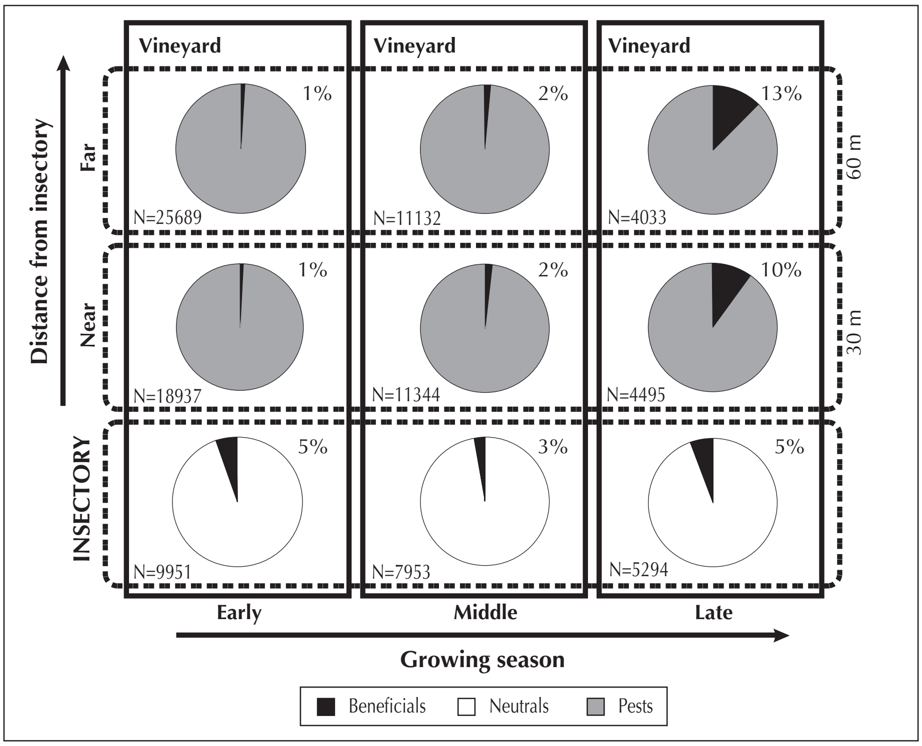

Figure VII. The proportion of beneficials, neutral, and pestiferous insects (insects that feed on or exert damage to vines) in the island, and in the vineyard at various distances from the island as the season progressed (N = total number of insects caught in yellow sticky traps, % = proportion of beneficial insects).

species composition of the surrounding vegetation, and also on the spatial extent of its influence on natural enemy abundance, which is determined by the distance to which natural enemies disperse into the crop.

The role of riparian habitats and especially of wild blackberry patches near vineyards in enhancing the effectiveness of *A. epos* in parasitizing the grape leafhopper is well known.

Based on this knowledge, researchers established that French prunes adjacent to vineyards could also serve as overwintering sites for *A. epos* and found higher leafhopper parasitism in grape vineyards with adjacent prune tree refuges.[8] However, the effect of prune refuges is limited to only a few vine rows downwind and *A. epos* exhibited a gradual decline in vineyards with increasing distance from the refuge. This poses an important limitation to use of prune trees, as the colonization of grapes by *A. epos* is limited to field borders leaving the middle rows of the vineyard void of biological control protection.

To overcome this limitation, the owners of an organic farm near Hopland, CA, established a 600-meter corridor containing at least 65 flowering species, which was connected to a riparian forest and cut across the vineyard. The idea was that such a corridor would serve as a biological highway for movement and dispersal of predators and parasitoids (especially *Anagrus* wasps) into the center of the vineyard.

Movement by natural enemies from nearby habitats to disperse readily within crops, theoretically enhances the speed with which a numerical aggregative response to pest foci may take place.

Data collected within the corridor in the 1996 and 1997 growing seasons showed that species such as *Chrysoperla carnea*, *Orius* sp., *Nabis* sp., *Geocoris* sp., and several members of the families Coccinellidae, Syrphidae (hover flies), Mordellidae, and some species of thomisid spiders, to be predators commonly found on flowers of the dominant corridor plants such as fennel (*Foeniculum vulgare*), yarrow (*Achillea millefolium*), *Erigeron annuus* and *Buddleja* spp.

Certain predator species moved from the riparian forests, using the resources of the corridor as they were continuously found associated with specific flowering plants (Figure IV), and many of them moved into the adjacent vineyard.

The flowering sequence of various plants species provided a continual source of pollen and nectar, and a rich and abundant supply of neutral insects (non-pestiferous herbivores) for the various predator species, thus allowing the permanence and circulation of viable populations of key predator species within the corridor.

In both years, adult leafhoppers exhibited a clear population density gradient reaching lowest numbers in vine rows near the corridor and increasing in numbers towards the center of the field. The highest concentration of adult and nymphal leafhoppers occurred after the first 20 to 25 rows (30 to 40m) downwind from the corridor (Figure V). A similar population and distribution gradient was apparent for thrips. In both years, thrip catches were substantially higher in the central rows than in rows adjacent to the corridor.

The abundance and spatial distribution of generalist predators in the families Coccinellidae, Chrysopidae, Nabidae, and Syrphidae was influenced by the presence of the corridor which channeled dispersal of insects into adjacent vines (Figure VI). Predator numbers were higher in the first 25 meters adjacent to the corridor which probably explains the reduction of leafhoppers and thrips observed in the first 25 vine rows near the corridor.

The presence of the corridor was associated with the early vineyard colonization by *Anagrus* wasps but this did not result in a net season-long prevalence in leafhopper egg parasitism rates in vine rows adjacent to the corridor. Despite the fact that the vineyard had a flowering cover crop, the proportion of eggs parasitized tended to be uniformly distributed across all vine rows in both blocks. Eggs in the center rows had slightly higher mean parasitization rates than eggs located in rows near the corridor.

Anagrus does not have the same pollen and nectar needs that many other general predators and parasitic wasps have and apparently does not need a diversity of hosts (neutral insects) for its population to be maintained, constituting an exception in this regard. Despite the fact that *Anagrus* is a key leafhopper regulator, the habitat manipulations herein described aid in building a whole beneficial insect complex which confers stability to the vineyard.

Creating flowering islands as a push-pull system for natural enemies

One good way to start integrating vineyard management and conservation of natural enemies is to develop a farm design, recognizing the reality that not all parts of a farm can be managed to maximize conservation objectives, such as habitat enhancement for beneficial arthropods.

Creating habitat on the least productive parts of the farm to concentrate natural enemies is a smart way to use and beautify marginal lands or less productive areas in the vineyard such as a ridgetop, a swale, etc. This is the biodynamic approach used at Benziger Family Estate (Glen Ellen, CA), where an island of flowering herbaceous annuals and perennials was created at the center of a vineyard and which acts as a push-pull system for natural enemy species.

The island has been planted with a mix of herbaceous plants, which provides flower resources from early April to late September to a number of herbivore insects (neutral non-pestiferous insects and pollinators), and associated natural enemies. The island acts as a source of pollen, nectar, and neutral insects which serve as alternate food to a variety of predators and parasites, including *Anagrus* wasps, a prevalent parasitoid in this vineyard (Figure VII).

During the 2004 season, sampling revealed that the island was dominated by neutral insects that forage on the various plants, but also served as food to natural enemies which, starting in early June, slowly built up in numbers in the adjacent vineyard as the season progressed.

Catches in yellow sticky traps placed inside the island and at various distances within the vineyard, suggest that many natural enemies moved from the island into the vineyard (up to 60 meters). *Orius* sp. and Coccinellids are prevalent colonizers at the beginning of the season, but later syrphid flies and *Anagrus* wasps start dispersing from the island (insectory) into the vineyard (Figure VIII).

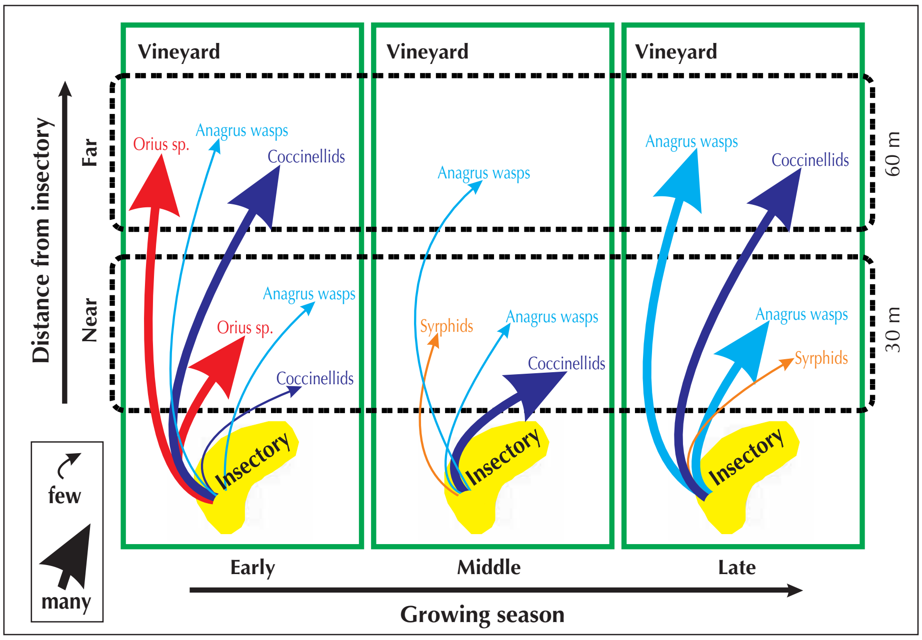

Figure VIII. Dispersal of *Anagrus* wasps and generalist predators from the island into the vineyard.

Parasitization of leafhopper eggs by *Anagrus* wasps was particularly high on vines near the island, with parasitization levels decreasing towards the center of the vineyard away from the island (Table I), a trend not observed at the Hopland corridor vineyard interface.

Planting flower strips (such as Alyssum) that go from the island into a vineyard, could be tried as an effective strategy to pull beneficials deeper into a vineyard and thus overcome the push-effect of the island which confines natural enemy activity to adjacent vine rows.

Conclusions

A key strategy in sustainable viticulture is to enhance biodiversity at the landscape and field level through the use of cover crops, corridors, and various habitats. Emergent ecological properties develop in such diversified vineyards, allowing them to function in a self-regulating manner.

The main approach in ecologically-based pest management is to increase agroecosystem diversity and complexity as a foundation for establishing beneficial interactions that aid in keeping pest populations in check.

Diverse and complex vineyards may be harder to manage, but when properly implemented, habitat management leads to establishment of the desired type of plant biodiversity and a unique ecological infrastructure necessary for attaining optimal natural enemy diversity and abundance.

Current knowledge of which plants are the most useful sources of pollen, nectar, habitat, and other critical needs is far from complete. Clearly, many plants encourage natural enemies, but scientists have much more to learn about which plants are associated with which beneficials, and how and when to make desirable plants available to target organisms. Because beneficial's interactions are site-specific, geographic location and overall farm management are critical variables. ■

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ACTION PLAN

To design an effective plan for successful habitat management, in accordance with the proven principles of ecologically-based pest management, first growers should gather as much information as they can. Growers should make a list of the most economically important pests and their associated natural enemies in the vineyard and find out:

1. What are the pest's food and habitat requirements?
2. What factors influence pest abundance?
3. When do pests build in the crop and when do they become economically damaging?
4. What are the most important predators, parasites, and pathogens?
5. What are the primary needs of those beneficial organisms?
6. Where do these beneficials overwinter, when do they appear in the field, where do they come from, what attracts them to the crop, how and when do they build up in the crop, and what keeps them in the field?
7. When do the beneficials' critical resources (nectar, pollen, and alternative hosts and prey) appear and how long are they available? Are alternate food sources accessible nearby and at right times? Which native annuals and perennials can compensate for critical gaps in timing, especially when prey are scarce?

Once growers have a thorough knowledge of the characteristics and needs of key pests and natural enemies, they are ready to design a habitat management strategy specific for their vineyard. A few guidelines need to be considered when implementing habitat management strategies:

1. Select the most appropriate plant species;
2. Determine the most beneficial spatial and temporal arrangement of such plants, within and/or around the fields;
3. Consider the spatial scale at which the habitat enhancement operates (such as field or landscape level);
4. Understand the predator-parasitoid behavioral mechanisms influenced by the habitat manipulation;
5. Anticipate potential conflicts that may emerge when adding new plants to the agro-ecosystem. (For example, while blackberries may increase populations of *Anagrus epos*, a parasitoid of the grape leafhopper, they may also host *Xylella fastidiosa*, the bacterium that causes Pierce's disease, as well as a disease vector, the blue-green sharpshooter.)
6. Develop ways in which the added plants do not upset other agronomic management practices, and select plants that have multiple effects, such as improving pest regulation while at the same time contributing to soil fertility and weed suppression.

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