Fifty years of the integrated control concept: the role of landscape ecology in IPM in San Joaquin valley cotton

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Abstract

In defining the integrated control concept, Stern, Smith, van den Bosch and Hagan described ‘understanding the ecosystem’ as a key underpinning of the concept. In following years, Stern and van den Bosch continued to refine and expand the role of the ecological landscape. They and their colleagues developed cultural practices that took advantage of this understanding to limit the need of pesticide intervention in cotton in the San Joaquin Valley during the 1960s and 1970s. Research and extension activities in the intervening years built upon those fundamental concepts using geospatial tools and analytical techniques to refine current understanding and develop ecological landscape level approaches to manage Lygus hesperus (Knight) in San Joaquin Valley cotton, Gossypium hirsutum (L.) and more recently G. barbadense (L.). The result has been a significant drop in insecticide use against L. hesperus, with less than one application per season during the 1990s and early 2000s.

Keywords: cotton; San Joaquin Valley; Lygus hesperus; ecological landscape; IPM; cultural control; geospatial

1 INTRODUCTION

In their seminal paper ‘The Integrated Control Concept’, Stern, Smith, van den Bosch and Hagan provided the theoretical foundation on which IPM was able to build. So fundamental were their insights that, 50 years later, their principles still guide pest management. Many of the issues facing mid-twentieth-century pest management have still to be addressed in the early twenty-first century. For example, the authors listed three key methods for an insect to become a pest, including (1) human-driven changes to the environment that favor the pest, (2) new invasive species arriving in the agroecosystem and (3) the crop under cultivation having a low tolerance to pest damage.

As a result of using insecticides to deal with agricultural pests, the authors recognized important ‘side effects’ due to the widespread use of insecticides:

- development of resistance to toxics;
- secondary outbreaks;
- resurgence of key pests;
- worker safety;
- pesticide residues on food and fiber;
- litigation as a result of these problems.

These effects are still topics of concern and regulation 50 years later.

To meet the challenges facing pest management in 1959, Stern et al. identified four key factors in integrating biological and chemical control:

- recognition of the ecosystem, that the production of any food and fiber system must be considered in its entirety;
- augmentation of natural enemies, including conservation and augmentation;
- population sampling and prediction, including economic thresholds as decision-triggering mechanisms;
- selective controls, by choosing the least disruptive mode of action, by minimizing the residual effect on natural enemies, by using prescriptive treatments to areas where pests are damaging and by timing to limit the effect of any treatment on natural enemies.

This short review will focus on the influence this seminal paper had on the development of IPM in California cotton through the recognition of the ecosystem. It will discuss developments over the years after its publication with respect to current understanding of the influences of surrounding crop mosaic on cotton insect pest management. In this review, landscape is considered to go beyond individual fields or farms and will focus on the development of landscape-level management approaches for cotton in the San Joaquin Valley of California. For a more thorough review of the state of entomological science with respect to landscape, ecosystem services and area-wide pest management, the reader is directed to Koul et al.2

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2 THE ROLE OF SURROUNDING CROPS IN LYGUS BUG MANAGEMENT

In the 1959 paper, recognition of the ecosystem was focused on ‘the oneness of the environment’ and the integration of the biotic and non-biotic elements of the ecosystem. The role of natural mortality to keep a pest population in check was viewed as a critical element of the biotic ecosystem and recognized for its vulnerability with respect to biological upset through the use of broad-spectrum insecticides. The implication of disturbing natural mortality through undisciplined insecticide use was a motivating factor in the development of economic injury level and economic threshold, the keystones of the integrated control concept.

In the following decade, Stern in particular began to elucidate the key principles of the role of the ecological landscape in pest management within individual fields. He recognized that a long-term solution to managing a key pest must consider larger dimensions than the individual pest, field or farm. He developed management approaches to Lygus species (primarily L. hesperus Knight) in cotton [Gossypium hirsutum (L.)] that work with the surrounding cropping mosaic to mitigate movement into vulnerable cotton. As a landscape ecologist, he developed the following principles for cotton IPM in the San Joaquin Valley:

- In row and field crops, most arthropod populations must rebuild each year.
- Populations must move into a field, and it is the surrounding environment that determines the degree of pest severity.
- Bordering crops and weeds can act as a source or a sink.
- The landscape mosaic has both a spatial and a temporal component.
- Some plants are more ‘preferred’ than others.
- The landscape can be manipulated.

This review will focus on the developments since the integrated control concept was introduced and subsequent progress to IPM in cotton in the San Joaquin Valley. It will consider how this principle within the integrated control concept has been refined by Stern and colleagues and developed further over the past 50 years.

3 EXAMPLES OF STERN’S CONTRIBUTION TO IPM AT THE LANDSCAPE SCALE AND SUBSEQUENT PROGRESS

3.1 Strip cutting alfalfa

In San Joaquin Valley cotton, the importance of the idea that Lygus bugs or western tarnished plant bug move in and out crops emerged in the early 1960s. The concept of source and sink in a landscape means that Lygus bugs build on multiple plant hosts including crops, weeds present in crops and resident vegetation outside crops, and, as the hosts become unsuitable, move to other neighboring crops. As cotton has one of the longest crop development times for a field crop, it is available as a sink for a longer period for Lygus coming from surrounding crops that are harvested earlier. Stern recognized that alfalfa, Medicago sativa (L.), grown for forage played a unique role in regional Lygus bug population development by providing a preferred and perennial habitat. In addition, alfalfa hay is a crop that is grown not for the reproductive portion (e.g. seeds, fruit or lint) but for the vegetative contribution (hay, forage). Thus, alfalfa forage is not allowed to senesce, but rather is removed from the field before it reaches reproductive senescence, suddenly changing a suitable habitat to an unsustainable habit. Thus, preserving alfalfa habitat as strips during monthly harvests could mitigate Lygus bug movement from an alfalfa source to a cotton sink.

Stern et al. described the value of strip cutting alfalfa to limit the movement of Lygus bugs into bordering cotton. This approach could ‘shepherd’ Lygus bugs between cut and uncut sections of an alfalfa hay field, and they thus could be prevented from moving en masse to bordering cotton fields. This approach was formalized in a later technical publication in which the authors pronounced:

The grower, faced with rising production costs at all levels, must decide if he will rely completely on insecticides to fight Lygus and accept the financial burden or if he will look for another method of control . . . . In attacking the Lygus problem, chemicals are used when absolutely necessary; but first a major change must be made in farm practices to keep Lygus out of cotton.

The strip-cutting approach reached a high point in the late 1960s but was limited in use after the 1970s. This decline was due to two major factors. First, in-field management of Lygus bugs in cotton was improved by reducing applications of broad-spectrum insecticides for cotton bollworm. In addition, Lygus management decisions were based on population densities that were related to whole-plant fruit analysis, e.g. Lygus to square ratio, providing more quantifiable decision-making. The second major factor was lack of convenience in managing split fields, which required different irrigation and harvesting schedules.

To overcome these problems, a simplified strip harvest system was introduced in the 1990s. In this approach, growers were asked to leave only a few strips in the field. Based on three years of data, it was found that Lygus bugs would aggregate in uncut strips, tripling their density compared with populations before harvest in the same field. Very little movement of Lygus bugs into adjacent cotton was noted. Additionally, hay could be blended between older and newer strips with minimal impact on quality, an important consideration to hay producers. In these studies there were no differences in retention of Lygus bugs when 2.5% or 10% of the field was left uncut. Growers are encouraged to leave at least 2.5% and to place these strips strategically in order best to minimize movement into cotton. Growers developed various strategies, including leaving strips only on the side of the hay field next to cotton, or framing the field with uncut strips, or leaving strips at each irrigation check. In some cases, growers found it useful to leave uncut strips around their solid-set sprinkler lines, saving labor costs and providing habitat for Lygus bugs (Fig. 1). The concept of leaving as many uncut strips as possible in an alfalfa field during the months of May, June and July was widely practiced in the early 2000s and incorporated into the UC Pest Management Guidelines for Cotton. In a 2000 survey of IPM use by California cotton growers, 51% of respondents who used non-affiliated pest control advisers (PCAs) reported that they ‘manage Lygus in surrounding alfalfa by strip cutting’. A non-affiliated PCA was defined as a person providing IPM service but connected to sales of pesticide products, and also included PCAs hired directly by the farm. In this survey, 98% of respondents reported using one or more PCAs on their ranch.

3.2 Interplanting alfalfa and cotton

Stern et al. recognized the importance of diversifying the landscape to attract Lygus bugs to a more preferred host than cotton. They suggested placing strips of alfalfa in a cotton field to...
alternative to Lygus bug management with insecticides. Strips of cowpea, 30 feet wide, were placed on the upwind edge of cotton fields to catch the ‘drifting’ Lygus bugs from bordering fields and concentrate them in the cowpea strips. Data demonstrated that little or no spill-over of Lygus bugs occurred beyond ten rows of adjacent cotton. If the grower was uncomfortable with the population density of Lygus bugs in the buffer strip, prescriptive insecticide applications could be made over the strip and adjacent cotton. This reduced the amount of land being treated from 160 acres (average production unit in this area) to less than 10 acres.

This ‘snow-fence’ concept or buffer strip was easily accepted by many of the growers in the BIFS project because of the ease of management and the ability to use the buffer strip to concentrate and then optionally apply insecticide to the strip to kill Lygus bugs. Providing flexibility to a farmer’s complex production schedule was key to acceptance of this approach. One drawback was the limited amount of buffer strips a farmer would incorporate, as every row of buffer crops was a lost row of cotton production. The limitation was the break-even point between lost cotton production and cost of whole-field applications. However, only 4 – 5% of respondents reported using buffer strips to attract Lygus and natural enemies, regardless of PCA affiliation.10

3.3 Preventing movement from neighboring crops
Mueller and Stern15 provided definitive evidence that managing Lygus bugs in safflower (Carthamus tinctorius L.) before the adults move into cotton is a cost-effective pest management approach. This approach was unique in several ways: first they recognized that safflower was a major source of early-season Lygus bugs into cotton, and second that Lygus bugs could be managed as immature insects and prevented from leaving safflower as adults. Sevacherian et al.16 published their model for timing insecticides against Lygus bugs in safflower, using insect phenology predictions based on degree-day models.

This timing for Lygus bug control in safflower was very successful and was used wherever safflower and cotton coexisted in the landscape. In some areas, large landholders got together to manage the safflower on a regional basis. For many years, cotton growers would seek permission from other farmers to treat safflower at the cotton growers’ expense. This system worked very well and focused broad-spectrum insecticide use away from cotton, preserved natural enemies early in the cotton fruiting cycle and limited large-scale movement of Lygus bugs.

Until recently, safflower was produced only in widely scattered locations. Acreage of safflower has currently increased as the demand for plant oils has increased owing to higher biofuel demands on other oil crops. The authors recently tested the validity of the approach, some 30 years since its inception, and found the recommendations to be valid (unpublished data). In the 2000 survey of cotton IPM practices, between 39% and 45% of growers responded that they ‘manage Lygus in neighboring crops such as safflower to mitigate migration’.10

3.4 Evaluating the risk of Lygus bugs to cotton on the basis of regional analysis
Stern and his colleagues recognized the source and sink relations within the cropping mosaic in which cotton is embedded. Their description4,11,15 of Lygus bug population dynamics remains the basis for the landscape paradigm practiced in IPM cotton in California. Lygus bugs can overwinter within the San Joaquin
Valley as well as outside the Valley, and their population densities build on crops and weeds in late winter and spring until these plants begin to senesce, at which time the Lygus population is forced to move. As cotton is one of the longest maturing field crops, it is available as a sink for Lygus bugs during the summer after most other annual crops have been removed from the landscape, beginning as early as June. In some cases, Lygus bugs move into fall lettuce, resulting in the need for chemical intervention, but more frequently they move into remaining cotton, causing little threat until they move to overwintering sites to start the annual cycle again.

In the late 1970s, Stern began annual surveys of Lygus bug build-up in spring, in order to offer a projection of the potential threat in any given year. He would survey a number of weed hosts in cultivated and uncultivated areas inside and on the periphery of the San Joaquin Valley. These surveys have been conducted annually by the present author since 1983. In most years, external sources are not a primary threat; only in rare years is this the case, when rainfall patterns provide sufficient moisture to allow summer annual weed hosts to remain through May. In one field study, Kellogg's tarweed (Hemizonia kelloggii Greene) and adjacent cotton were surveyed from May until July. It was found that, while tarweed provided an important habitat for Lygus bugs, cotton adjacent to tarweed had lower Lygus bug population densities than weedy onion fields or non-bearing almond orchards bordering the cotton. The reason for this observation is not completely understood; it is most likely related to the biology and phenological development of Lygus bugs, the state of the population structure and the propensity for pre-reproductive adults to move from stressed to more vigorous growing habitats.

However, Stern and his colleagues did not have the benefit of the geospatial analytical tools and computational power available in recent years. Through a series of studies it has been possible to develop risk maps based on crop maps and the propensity of crops to develop Lygus bug populations, as well as utilizing satellite imagery to improve predictions of overwintering weed cover. One of the striking results has been that, the more alfalfa present in an area, the fewer reported Lygus bug treatments there are in cotton. Alfalfa, as observed by Stern et al., plays a key role as a sponge for absorbing Lygus bugs in a landscape while acting as a temporary source when alfalfa is harvested. Goodell and Lynn-Patterson noted that alfalfa abundance, alfalfa proximity to cotton and distance between alfalfa fields all play a role in landscape level movements (Fig. 2). A landscape of many alfalfa fields can ensure that suitable temporary habitat is available to absorb any Lygus bugs moving from recently cut fields, as uncut fields are always nearby to cut fields and available to act as a sink. Having alfalfa near cotton assures that alternative ‘sinks’ are available into which reproductive Lygus settle. In Fig. 2, a desired arrangement would occur in the upper right ‘quadrant’ of the figure. This is an area in which alfalfa is abundant, proximal and well distributed.

One outcome of this knowledge was acceptance by a large farming company that implemented landscape ‘engineering’. By introducing alfalfa onto the ranch to absorb Lygus bugs on their upwind border, gathering their own internal Lygus bug sources (alfalfa seed) into larger blocks and isolating them from cotton, Lygus bug pressure was reduced and substantial insecticide savings gained (Grewal M, private communication, 2001).

At present, Arizona, California and Texas are engaged in the USDA-CSREES Risk Avoidance, Mitigation and Prevention (RAMP) grant, which in part is dedicated to increasing current understanding of Lygus bug source across three very different landscapes. This 4 year undertaking has already developed extensive geo-based datasets which are being analyzed to quantify the ‘strength’ of different crops as sources and the distance at which they can influence Lygus bug management in cotton, based on earlier analysis by Carrière et al.

4 CONCLUSIONS
The role of the ecological landscape in IPM is well represented in many fields such as precision agriculture, geospatial analysis of pest outbreaks, influence of crops on pest density and biological control, to name a few. However, the pragmatic landscape planning that Stern introduced has been less widely studied or implemented.

An important lesson that Stern and his colleagues demonstrated is that the landscape setting in which cotton or other crop is embedded plays a substantial role in defining and developing the IPM system for that crop setting. There have been major shifts in land use in the San Joaquin Valley over the past decades, with cotton declining from 1.4 million acres in the 1980s to under 300 000 acres in 2008. This shift from a cotton-dominated landscape to cotton fields being fragmented, isolated from each other and influenced by non-cotton neighbors brings a new dimension to IPM. This shift is evident when comparing cotton distribution in 2000 compared with 2008 (Fig. 3) in the west side of Fresno County, California. In this area, during 2008 there was a large increase in safflower acres planted, which went beyond the capacity of cotton growers to manage, resulting in continued Lygus movement into cotton fields during several weeks of critical fruit formation. Even with multiple applications of insecticides, losses caused by Lygus bugs in the area were as great as many had ever experienced, owing to landscape-induced outbreaks. Understanding the role of the landscape in which an IPM program was developed is critical when substantial changes occur over a period ranging from a few years to a decade.

As cotton acres decline, other crops become more dominant. In the San Joaquin Valley, almonds and corn have increased substantially on land that once was occupied by cotton. In...
almonds, the concept of a crop-dominated landscape is being recognized as an important component in the development of sustainable IPM programs where the influence of almond orchard proximity to pistachio orchards influences the degree of damage caused by navel orangeworm, Amyelois transitella (Walker).24

Like cotton, safflower and Lygus bugs, the relationship between almond, pistachio and navel orangeworms offers insights into the development of landscape-level pest management approaches.

As another example, silage corn has dramatically increased in the San Joaquin Valley, and, with it, there has been an increase in an insect-vectored disease, corn stunt, caused by Spiroplasma kunkelii (Whitcomb et al.) and the corn leafhopper, Dalbulus maidis (DeLong and Wolcott).25 Summers (private communication, 2009) is continuing to develop landscape-level models that explain this disease and pest increase relative to increased dominance of corn in the landscape and shifts in other cultural practices.

The shifting landscape in which any crop now exists dictates how the existing IPM system is refined and serves as a reminder that those principles of ‘integrated control’ developed a half-century ago are as relevant now as they were in 1959.

REFERENCES