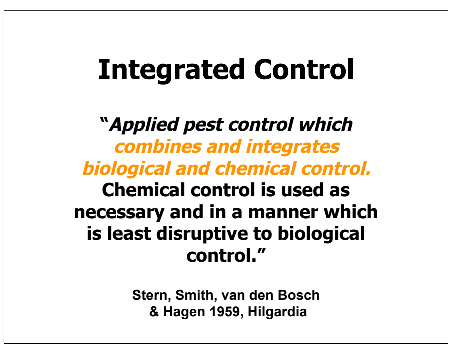
This is a story that I've have told before: in different venues, and to different audiences. However, it is a significant success story, and we had the opportunity to celebrate 50 years of the Integrated Control Concept pioneered by Stern and his colleagues at the last PB-ESA meeting, with my co-author, Steve Naranjo of USDA-ARS, ALARC. We have been working in the cotton-whitefly system for more than 15 years. My goals today are to outline how we are attempting to implement and move this concept forward in Arizona, and to focus in more detail on the chemical and biological control elements of our IPM system. What I think you will see is that much of what we do today in IPM can trace roots back to Stern's very robust ICC.

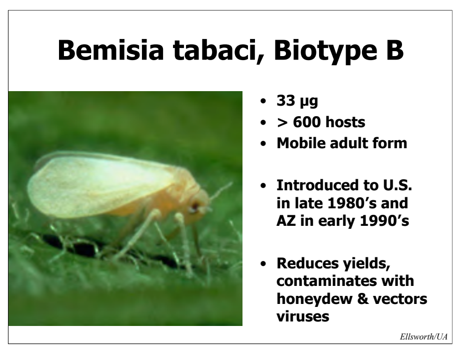
Invited seminar, 1 hr.

The Integrated Control Concept was published by Stern and his Californian colleagues in Hilgardia some 50 years ago. Their experiences were in field crops in California including alfalfa, cotton and safflower. The insights provided in this paper form the conceptual basis for IPM today. If you have not read or re-read this paper recently, I highly recommend it! It is an extraordinary piece with incredible insight into the basic ecology that underpins the control system. We are trying still today to implement many of the ideas brought forward in this work 50 years ago. It is in fact quite humbling to be working in IPM today and realizing just how much they knew back then and how much more we need to do today to fully realize their vision.



At its heart, Stern's ICC boils down to this…

The system that I have worked on ever since arriving in Arizona with Steve Naranjo and others was like a clean slate.



This biotype of Bemisia tabaci was introduced to the U.S. in the late 1980's and invaded AZ in the early 1990's, where it displaced our native A-biotype in a matter of a few years. The native strain was of little practical consequence in cotton, rarely requiring the attention of pest managers. The B-biotype on the other hand was devastating, reducing yields, contaminating agricultural products with honeydew and vectoring viruses.

This is a mobile insect, as is evident in this now famous slide showing "clouds" of whiteflies moving across a newly planted vegetable field in the Imperial Valley of California in the early 1990s. Pressures were so extreme at that time that driving through the valley at that time would actually cloud up your windshield. This was a nearly impossible pest management situation.

The problem starts with the insect, but the driver of this system is what is shown in this micrograph of a cotton thread. While yield losses have always been a potential problem, the real problem is the deposition of honeydew on exposed cotton lint that then is processed, if it can be processed at all, and spun into a thread loaded with these defects. So a 100 million dollar problem starts with honeydew dropping on leaves, and cotton fibers, and finishes with knotted fabrics or yarns. Costly shutdowns of mills for cleaning motivates the marketplace. Marketers play it safe by avoiding buying fiber from whole areas where previous episodes of sticky cotton have occurred. This has a chilling effect on cotton prices locally. [Photo credits: International Textile Center (Lubbock, TX), upper left, Lynn Jech (inset), USDA (wf), pce (remaining)].

Integrated Control

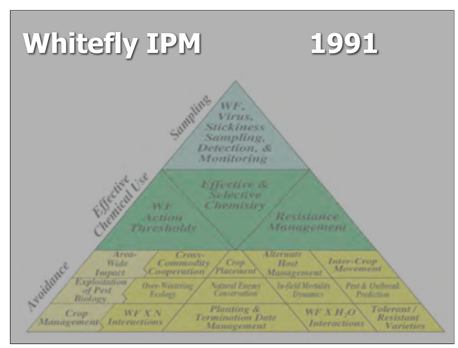
"Integrated control is most successful when sound economic thresholds have been established, rapid sampling methods have been devised, and selective insecticides are available."

Stern, Smith, van den Bosch & Hagen 1959, Hilgardia

The steps for realizing the Integrated Control Concept were very clearly laid out by Stern and colleagues in 1959:

You need economic thresholds, rapid sampling methods, and selective insecticides.

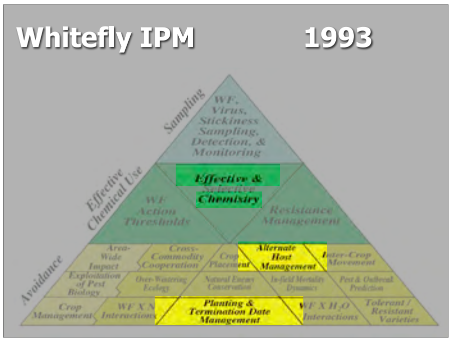
When the whitefly hit us as a brand new and invasive pest of our agroecosystem, we had none of this.



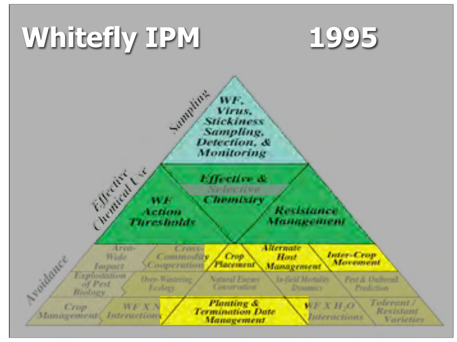
We were starting from nothing in 1991.

The form that our IPM plan takes today was not even conceivable with the severe pressures we were facing and the vast gaps in our knowledge base that were present at the time.

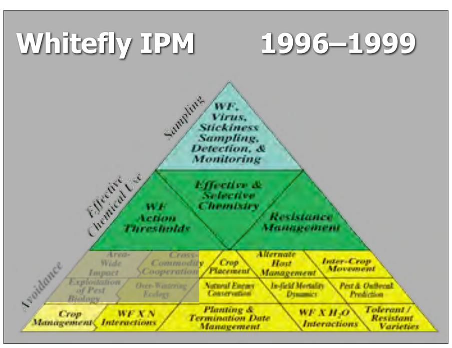
An entire scientific industry mobilized to address the problem, and Steve and I began our collaboration with each other as well as with many other academic and industry stakeholders.



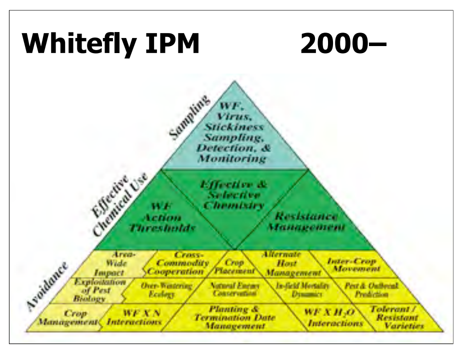
By 1993, we at least had identified some commercial chemistries that could be used to combat this problem. We had some idea of the alternate host interactions that were present in our desert agroecoystem and were faced with telling growers to shorten their season at all costs to avoid major damage from whiteflies.



By 1995, we had major progress in the upper layers of the IPM pyramid, in sampling and chemical use. We were also gaining more insight into the areawide impact of whitefly movement and crop placement.



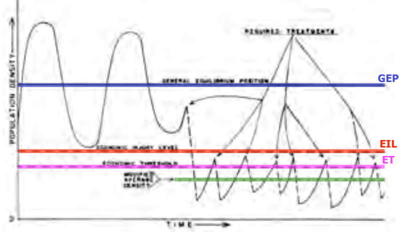
In 1996, we introduced some key selective chemistry that changed everything for us. It enabled a broader base of avoidance tactics, and we were well on our way to stabilizing a previously and seriously destabilized system.



By 2000, we had installed some critical cross-commodity agreements among cotton, vegetable and melon producers and our IPM plan came into full focus. This pyramid metaphor serves as our heuristic representation of whitefly IPM in Arizona cotton. A crucial element added, effective AND selective chemistry, starting in 1996. This continues to be our operational IPM plan. At its simplest, it is just 3 keys to management, Sampling, Effective Chemical Use, and Avoidance. One can break this down further and examine each building block of the pyramid and see an intricate set of interrelated tactics and other advances that have helped to stabilize our management system. However, I will concentrate my comments on those elements relevant to the selectivity of the strategy.

Critical Densities

Stern et al. 1959



Ellsworth/UA

Stern and colleagues developed an enduring set of concepts in their landmark paper, all having to do with critical densities of pest insects and rooted fundamentally in ecology of population regulation. I will not dwell on these aspects as they relate to our whitefly system, except to say that they were critical to our success, too, and covered in the companion presentation by S. Naranjo.

The GEP is an ecological "set-point" for a population that may be, as in our case, be well above a critical injury level, the EIL. In these cases, treatments are regularly required to prevent pest insects reaching the EIL. The level for timing these interventions is known as the economic threshold. After treatment, repeated for a chronic pest, a modified sub-economic density is achieved.

Economic Injury Level

C = Costs; P = Price; D= Damage; K = Damage avoided

$$EIL = C/(PDK)$$

- Stone, J. D., and L. P. Pedigo. 1972. Development and economic injury level for the green cloverworm on soybean in Iowa. J. Econ. Entomol. 65:197-201.
- Norton, G. A. 1976. Analysis of decision making in crop protection. Agro-Ecosyst. 3:27-44.
- Pedigo, L. P., et al. 1986. Economic injury levels in theory and practice. Ann. Rev. Entomol. 31:341-368.

Ellsworth/UA

The EIL is a major concept in IPM; however, it is non-trivial to develop and implement. In fact, it took 13 years after the ICC was published before the very first EIL for an insect pest was published. Various economic theories have been applied to this problem over the years, but even today, there are precious few examples of well-developed, market-sensitive EILs developed in pest management.

Naranjo and others developed an EIL for this system when it was based on broad-spectrum control technologies.

Selective Insecticide

"Chemical control should act as a complement to the biological control."

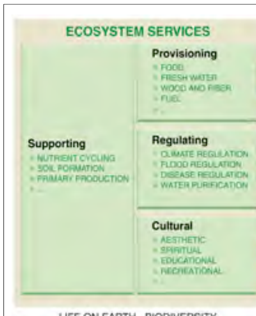
Chemical and biological control… "with adequate understanding, can be made to augment one another."

"An insecticide which while killing the pest individuals spares much or most of the other fauna, including beneficial species, either through differential toxic action or through the manner in which the insecticide is utilized (formulation, dosage, timing, etc.)."

Stern et al. 1959.

Ellsworth/UA

At the heart of Stern's paper, they make several important, simple, and straight-forward statements about chemical control. Namely, chemical control should complement biological control; and the two tactics should be made to augment one another. Within the ICC there is this pervasive idea that an insecticide should kill the target but spare most everything else. Given the times, and given the tools available at the time (DDT, toxaphene), these ideas were rather controversial especially within the agricultural community. Also, much of Stern's hopes for selective insecticides were pinned on the development of new organophosphate and carbamate insecticides! But this idea that there were fauna worth sparing is what was remarkable, an idea that has gained recent momentum…



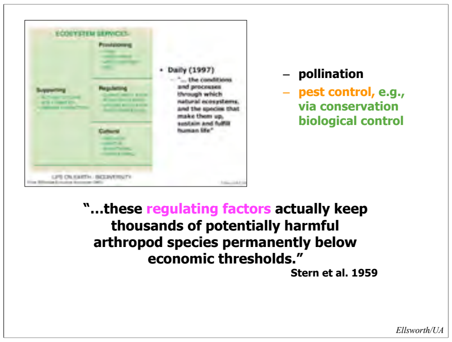
From Millennium Ecosystem Assessment (2005)

- Daily (1997)
  - "… the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life"

Ellsworth/UA

…in the development of the concept of "ecosystem services." Ecosystem services are quite simply defined as those things contained in our ecosystems that sustain our life. Daily's original definition focused on "natural" systems; however, the concept has expanded appropriately to encompass the interrelationships between natural and managed ecosystems.

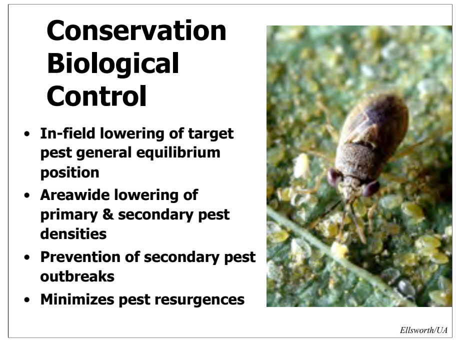
These services are often broken down into categories. Provisioning is an obvious ecosystem service of our agricultural systems; food production from our ecosystems is absolutely essential.



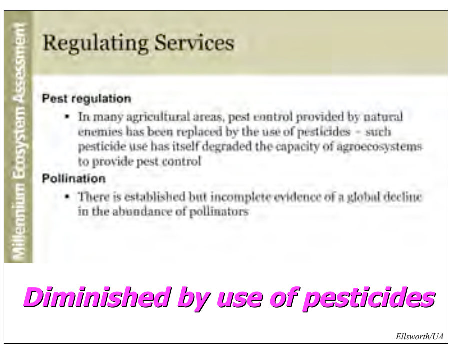
As important as this is now, imagine that Stern and his colleagues recognized this concept more than 50 years ago, by stating…

It is satisfying now as an applied entomologist to see a renaissance in thinking and implementation of these concepts in agroecosystems. But humbling to know that these ideas have been around for 50 years.

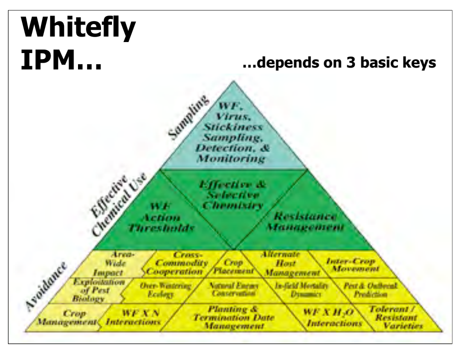
Stern recognized that regulating services are the domain where conservation biological control exists.



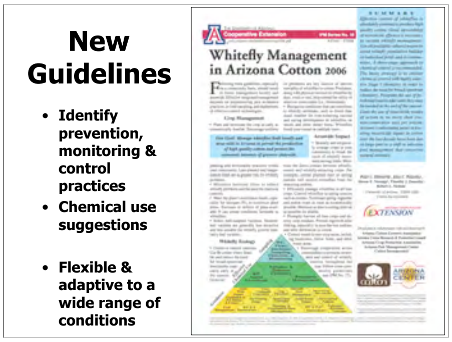
Conservation biological control (CBC) can function to lower the general equilibrium position of the target pest in the field under management, but also of other primary and secondary pests areawide. CBC is often critical to prevention of secondary pest outbreaks and minimization of pest resurgences.



The Millennium Ecosystem Assessment, which was completed on a global scale in 2005, concluded that pesticide use was diminishing these regulating services and in fact replacing pest control by natural enemies. It is precisely here where we need selective pesticides more than ever. A well-designed and deployed selective pesticide should fully complement the pest control provided by natural enemies.



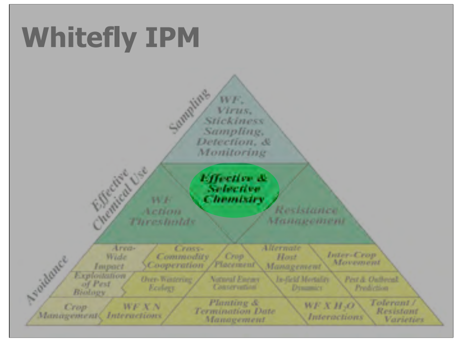
I have been teaching about whitefly IPM to growers from this pyramid metaphor for more than 10 years. But today, I wish to focus on the compatibility between chemical and biological controls that are so important to the ICC and to the success of our IPM plan today.



Steve Naranjo and I have conducted detailed research on this system nearly continuously since their introduction in 1996. They have been continually refined and taught to growers regularly in my Extension program. The guidelines were revised and re-issued in 2006, and I would like to acknowledge our other collaborators, Tim Dennehy (who now works at Monsanto), Bob Nichols of Cotton Incorporated who has helped sponsor much of the work I will review, and John Palumbo our Extension vegetable entomologist.

Within are detailed chemical use suggestions that highlight the effective and selective use of key insecticides.

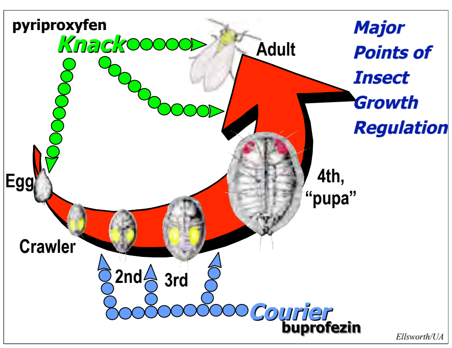
North Carolina State University 13 April 2009



Central to our IPM plan is effective & selective chemistry. Installing and <u>validating</u> this building block of our plan was critical to our strategy.

50 years of the ICC & Moving AZ Forward

North Carolina State University 13 April 2009

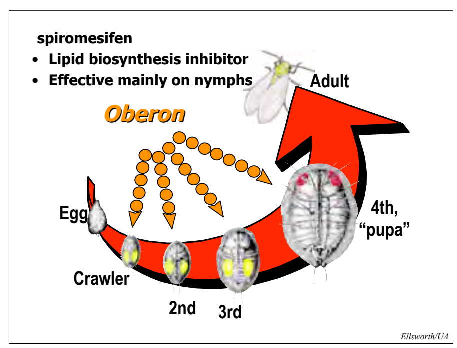


Pyriproxyfen is a juvenoid, a juvenile hormone mimic, that does not kill adults outright -- neither IGR does this -- however, Knack sterilizes adult females and developing eggs prior to blastokinesis. Knack may also prevent metamorphosis. Buprofezin is entirely different chemistry structurally and functionally. It is a chitin inhibitor and as such interrupts the molting of each nymphal instar.

Both of these IGRs are selective in our system, ultimately killing only our target pest, the whitefly.

50 years of the ICC & Moving AZ Forward

North Carolina State University 13 April 2009



Spiromesifen is a lipid biosynthesis inhibitor, also with very little direct adult activity, and major affects on younger nymphs. It was introduced into our system more recently (2005).

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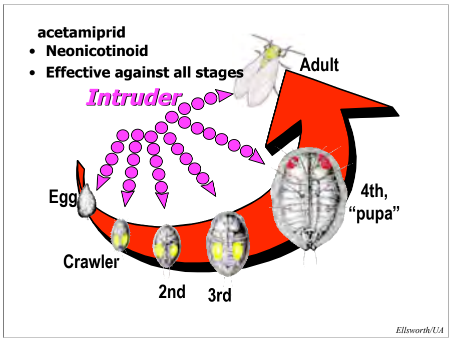
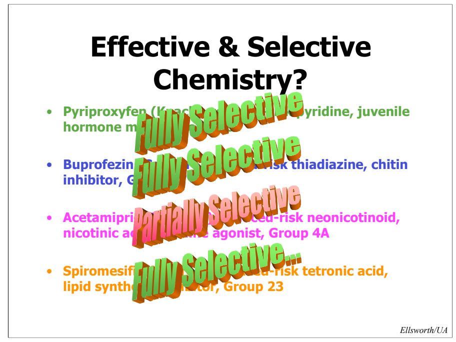
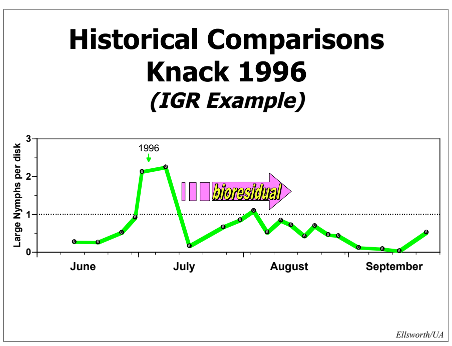


Acetamiprid is arguably biorational, largely through the differential sensitivity of the nicotinic acetylcholine receptor between arthropod and mammalian systems. It, too, came later (2002), but producers have made this the number one whitefly insecticide largely because of its excellent adult activity and acropetal systemic action.

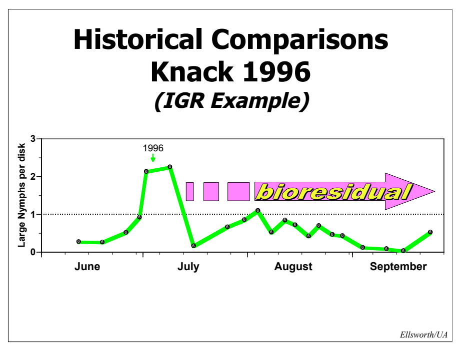


So today these are our 4 best, most effective chemistries. In terms of selectivity, Knack, at least in our system (AZ cotton), is fully selective. Courier (or Applaud), too, is fully selective. Intruder (or Assail, a neonicotinoid), however, is in fact not selective. It is highly effective, but actually will reduce natural enemy densities. Of course, relatively speaking, it is still more selective than the alternatives, pyrethroid mixtures or high rates of endosulfan for example.

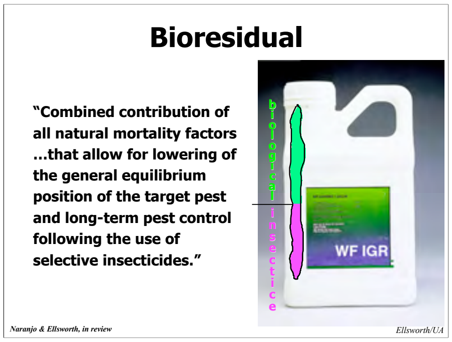
Oberon provides rate-sensitive selectivity, another concept mentioned by Stern et al., where lower, whitefly rates are fully selective, but higher miticidal rates are somewhat less selective.



Our IGRs are the classic example of selectivity in action. We've been running commercial scale demos for years, starting in 1996 with the whitefly IGRs. In this one example with Knack in 1996, we can see that we reached threshold (1 large nymph per disk or 40% infested disks), sprayed, densities continued up for a time, and then the population collapsed. We know from our studies that the chemical effects of Knack last only a few weeks at best, but…



… through the action of predators especially, and other natural sources of mortality, the whitefly population is maintained below threshold well beyond the known period of chemical residual. We term this extended suppressive interval present in a selective system, "bioresidual". We coined this term to better communicate with growers and to accommodate all the mortality processes present in a selective system, not just those related to conservation biological control.



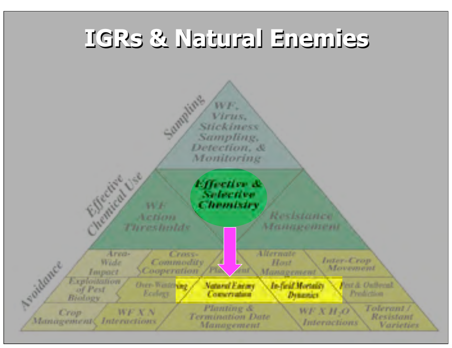
Specifically, we define bioresidual as follows:…

In teaching this concept to growers, I used a familiar icon as a metaphor, the IGR jug. In essence, our work showed that about half of the control interval could be directly attributable to the toxic growth-regulating effects of the IGR, while the other half was due to the biological or ecological sources of mortality that are in place already but are made more effective by the selective reduction of the previously "out of control" host, the whiteflies.

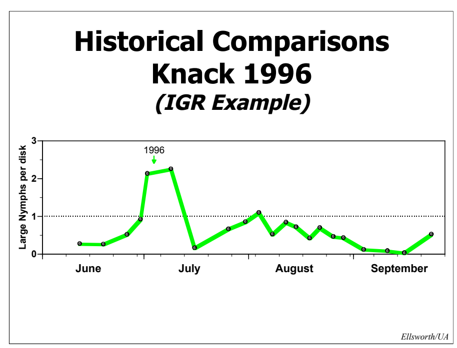
This has been a powerful metaphor for explaining why one might refrain from mixing IGRs with less selective materials. I.e., it is tantamount to dumping out half of the contents of the IGR jug.

Here again, Stern had something to say on the topic…

However, this perhaps represents one of those refinements or small advances we have made in that "bioresidual" is the "natural control" that is possible when a selective insecticide is used, something that Stern did not explicitly write about.

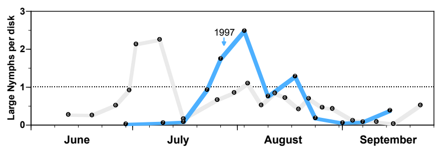


Central to remedial tactics is an effective chemical arsenal. In AZ, we have shown that when selective options are available and effective, huge gains in both target and collateral control can be achieved due to much better natural enemy conservation and other natural mortalities. This ecosystem service is a foundational element of "Avoidance," and one made compatible with the these specific and selective chemical controls in our system.



Returning to our replicated commercial assessments, we can show how durable and predictable the patterns of control are.

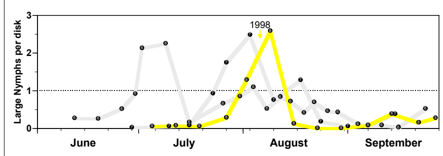
Knack 1997
UTC > 12.8 (9/16)



Ellsworth/UA

Note that starting in 1997, we had replicated UTCs available for the first time. Also, note as I step through each year how the maximal population densities in the UTCs change each year; however, the pattern of control through in our selective system remains consistent.

Knack 1998
UTC > 3.0 (8/10)



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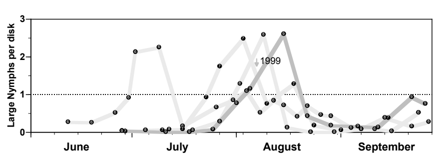
Knack 1999
UTC > 3.3 (8/16)



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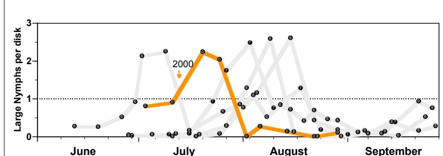
Knack 2000
UTC > 10.6 (8/3)



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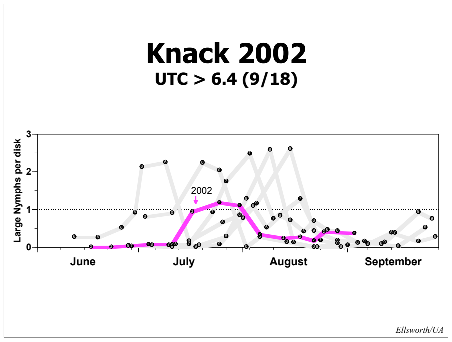
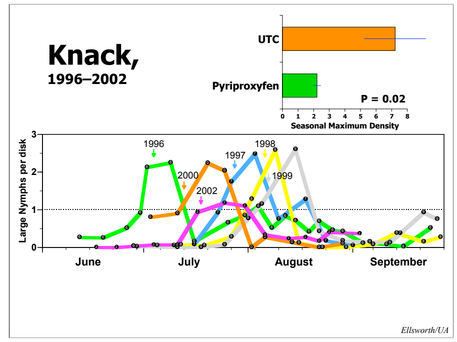
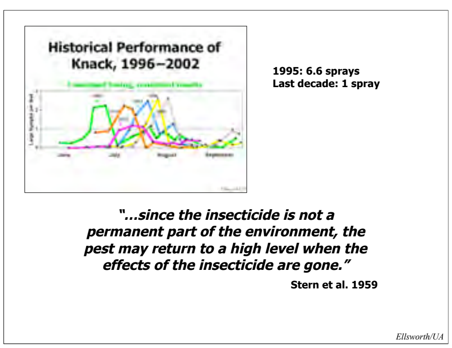




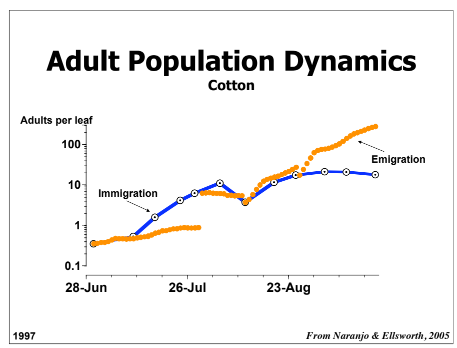
When growers experienced difficulties with this approach, it was almost always due to problems with timing. So I used these demonstrations to show growers that consistent timing of these slower-acting IGRs gives very consistent results.

On average over the last 13 years, growers have sprayed whiteflies in cotton just 1 time per season.

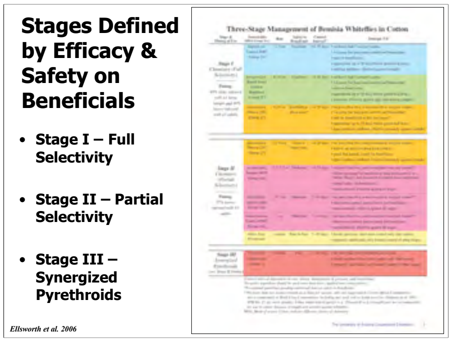
On average over the 5 years of these replicated demonstrations, the IGR regime significantly reduced the maximal seasonal density of large nymphs per disk relative to the untreated controls.



Stern made an observation that is technically true. Insecticides are not a permanent part of the environment, and once gone, pests may return to high levels. However, functionally, IGRs and other selective chemistries in our system have often provided for season-long control of whiteflies in our system. Occasionally, growers spray a second time late in the season.



The reason for this is rooted in the population dynamics in cotton. Here we see the number of adults per leaf in blue in unmanaged cotton. When we run a whitefly simulation model using the identified mortality rates & bio-fixes for each generation studied, we initially see exceptionally good agreement in the predicted adult levels. However, eventually we see that the actual densities of adults track higher than what was predicted. We view this as immigration into the system. In-season, we see very good agreement between the simulations & the actual densities, suggesting residential populations. Still later as cotton approaches physiological senescence (i.e., cut-out), the simulated densities are in excess of what is actually in the cotton field. We view this as emigration from the system. Our control tactics were timed to coincide with these periods of immigration when in-field natural controls were insufficient to prevent economic loss.



As part of our IPM program, a 3-stage chemical use plan identifies chemistry based on efficacy and selectivity attributes, with the ultimate goal of exploiting selectivity as much as is possible. It does not mandate a sequence but teaches growers that more selective approaches will create more effective ecosystem services that provide regulation of all pest species.

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Designing and labeling a product as selective or "biorational" is not sufficient to establishing its selectivity. Because it is subject to a specific ecological context, some effort must be made to validate the candidate approach or product in the system of interest. Thus, a product may be fully selective within one environment and catastrophically disruptive in another. Petri dish or similar assays without ecological context are inadequate for establishing the selectivity of a system.

There are several ways to verify and validate an approach as being selective.

50 years of the ICC & Moving AZ Forward

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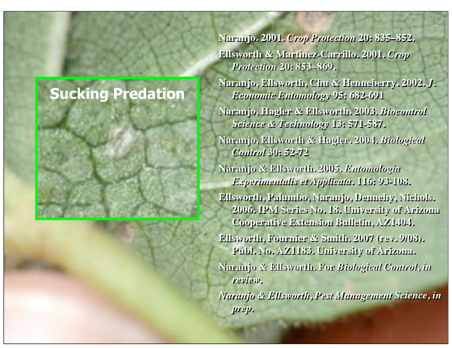

General observation can establish the presence and function of natural enemies. In this example, we can see two of the whitefly's flattened nymphs on the underside of a cotton leaf. Upon closer inspection, however, we can determine that in fact these nymphs are dead and have been evacuated by some kind of sucking predator, probably *Geocoris* or perhaps *Orius*.

The information and data I will share with you comes from a series of studies carried out over many years and published in collaboration with Steve Naranjo (USDA-ARS, ALARC) and others.

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Many of the insights we have developed over the years are the result of extensive life table studies that we have done in cotton. These are not easy things to do in general, but especially mid-summer in Arizona heat. However, the immobility of the nymphal stage has provided us a convenient system whereby we mark the locations of thousands of insects in both managed and unmanaged cotton systems. Then Steve and I monitored the fate of each individual whitefly until death or adult emergence. From these data, we constructed life tables that tell us what mortalities are operational and which ones are most influential in population regulation.

50 years of the ICC & Moving AZ Forward

Thanks to Demonstration Farm

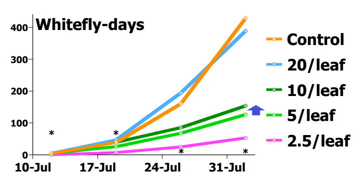
Normally, we say thanks at the end of a presentation or paper. However, I would like to thank the Maricopa Agricultural Center which operates a traditional research farm as well as a rather unique Demonstration Farm, where researchers and extension specialists can do commercial-size experimentation and demonstrate new technologies for our stakeholders. We have run replicated trials as large as 190 acres! And, routinely do assessments on large plots, one third to 5 acres in size. These dimensions are very important when trying to develop insights into population processes of mobile insects.

Thanks to Our Crew!

I would also like to thank the many crews I've had over the years, who have assisted in all phases of this very difficult work. Special thanks to Virginia Barkley, my research technician, who helps keep the crew running smoothly.

Selectivity through Timing

Similar whitefly densities at 5 & 10 / leaf thresholds

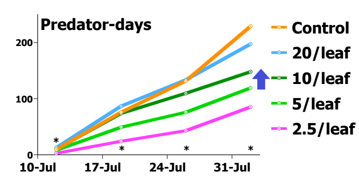


Naranjo, Ellsworth, Chu, Henneberry, J. Econ. Ent. 2002 Ellsworth/UA

Processes and not products *per se* can be selective as well. In this example, we were working with very broad spectrum conventional materials and applying them according to 4 nominal thresholds. Looking at cumulative whitefly-days over time, we can see that there is little difference between the 5 & 10 adults / leaf thresholds. 20/leaf was far too high and gave rise to unacceptable sugar deposits on lint. The 2.5/leaf regime was very aggressive and expensive to maintain. 5/leaf is our current threshold for adults. However,...

Selectivity through Timing

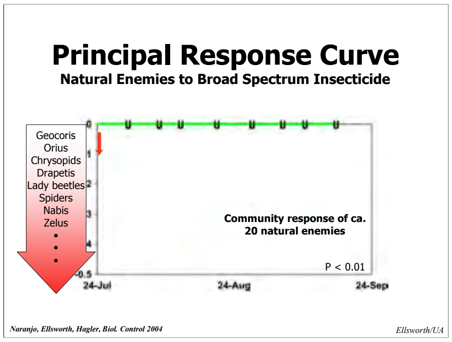
But more predators at 10 / leaf threshold
Predators most influenced by date of first spray



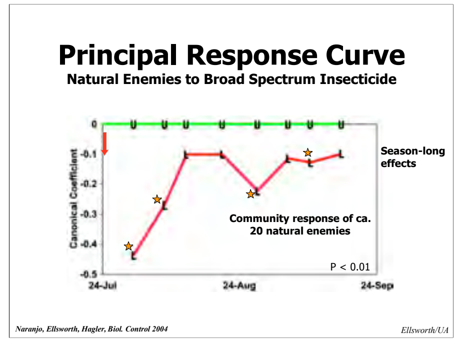
Naranjo, Ellsworth, Chu, Henneberry, J. Econ. Ent. 2002 Ellsworth/UA

Substantially more predators can be found in the 10/leaf threshold relative to the 5/leaf threshold. In fact, in these studies, predators were most influenced by the date of first spray. So a more selective threshold would be one that serves to delay the usage of a broad-spectrum insecticide.

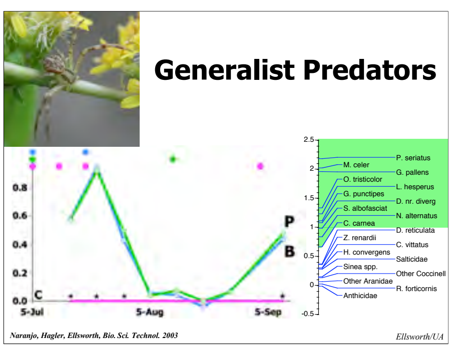
And even broad-spectrum insecticides can be used in a way that increases the functionality of natural enemies.



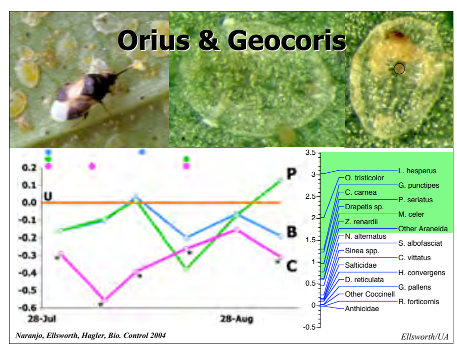
Another way to validate a selective approach is to measure and analyze whole community responses. We used a multivariate, time-dependent, analytic approach that is represented graphically in Principal Response Curves. In this example we can see the green 'U' line representing the UTC as a baseline from which we compare other treatments. Departures from the baseline may be interpreted as density changes in this natural enemy community. The red arrow indicates the timing of a single, very broad spectrum insecticide sprayed to control Lygus in a study that we did several years ago…



…What we see is a dramatic and immediate lowering of the density of these natural enemies in comparison to the UTC. What is more sobering is the duration and significance of this effect, all the way out to 7 weeks post-treatment. These season-long effects have grave consequences in the control of many other primary and secondary pests, as well as Lygus. So having potentially selective options to reduce the risks of natural enemy destruction is quite important to us.

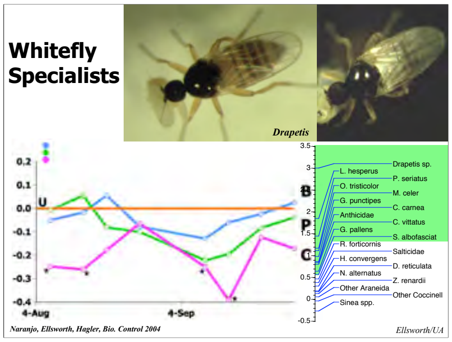


In this PRC, we were working on commercial acreage and could not set-up an UTC. So the baseline in this case is conventional, broad-spectrum chemistry as was common in the early to mid-1990's. The IGRs, (P)yriproxyfen and (B)uprofezin, were generally supporting more natural enemies than the conventional control. Generalist predators often drive these relationships as seen here with *Misumenops celer*, a common crab spider. As seen in the accompanying species wts table, species with weights greater than 0.5 are considered most influential and most reflective of the PRC shown. The large crash seen in the middle of the curve is attributable to two things. Major monsoon-associated storms, and a broad spectrum Lygus spray. Note one spray saved in this study.



In subsequent years, we ran very large scale replicated studies that included an untreated check, the orange baseline. Once again, however, the (C)onventional chemistry suppressed NEs for a period that extended almost the entire season. The IGRs, on the other hand, rarely departed significantly from the UTC line. Sucking predators are very important in our system and *Orius* and *Geocoris* drive this particular PRC.

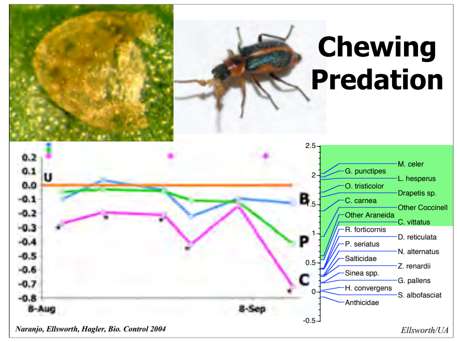
Again one spray saved relative to the conventional regime.



In another example, an unusual predaceous Empidid fly, *Drapetis*, drove the overall PRC. This adult fly, while technically not restricted to whitefly prey, does seem to specialize on feeding on adult whiteflies. A related species is present in Israeli cotton where whiteflies are also a key pest.

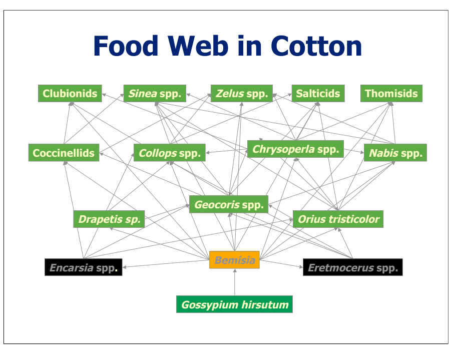
Each time, the two IGRs selectively control the whiteflies while conserving the NE complex.

1998 was an unusual year in that no matter what was sprayed, whitefly populations collapses and no more spraying was needed, even in the conventional regime.

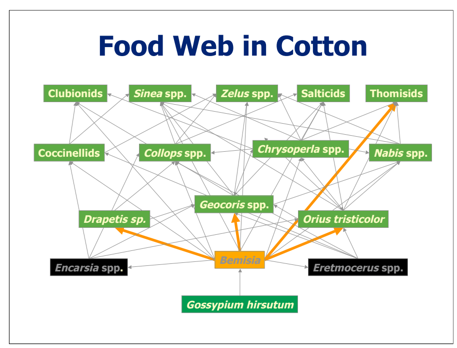


Evidence of chewing predation is rarely seen because it results in the complete removal of the nymphal or egg stage whitefly, unlike what you can see in this picture, where a partial cadaver was left by a predator. While *Hippodamia* is often present in cottonfields early in the season, *Collops* spp. beetles are far more common and more likely to be influential on whitefly dynamics, along with some smaller coccinellids. In this example just one IGR spray was needed to accomplish season long control of whiteflies, and 3 conventional sprays were needed to accomplish similar levels of control.

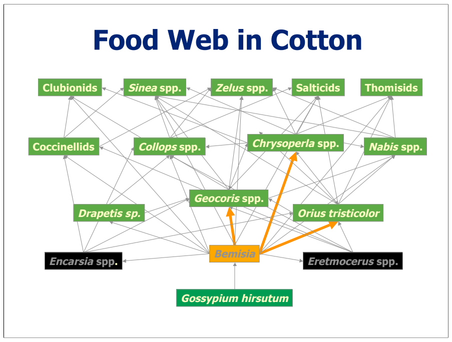
Note, too, that we often see an apparent decline in the IGR lines relative to the UTC. We believe this reflects some weakly density-dependent effects of their being so many fewer whitefly prey to support predators.



The idea that different species dominate the PRC in different years or locations in AZ cotton is a remarkable testament to the complexity of the food web. Certain conditions may favor certain pathways in certain years and other pathways in other years. Yet the same, generally, level of natural mortality is expressed.



Four predators dominated the PRC in this year.



Three species in this year.

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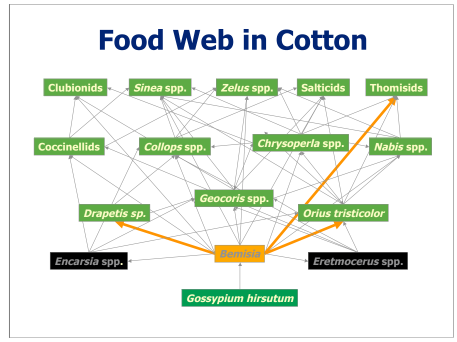

And a different set of 3 species in this year.

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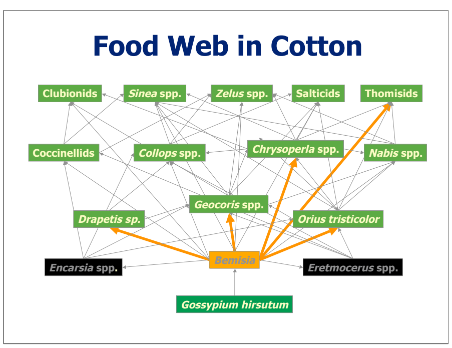

And 5 species dominated the PRC this year.

Other analyses are necessary to better understand how these NEs are functioning.

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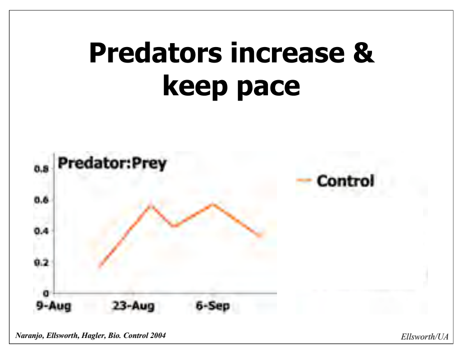

One way to do this is to examine Predator:Prey ratios. In this example, all predators captured in 50 sweeps compared to all whiteflies per leaf in cotton. Here we see that predator numbers increase and stay level relative to prey numbers, which are increasing through this time period.

Recall that this "Control" is producing out-of-control whitefly populations.

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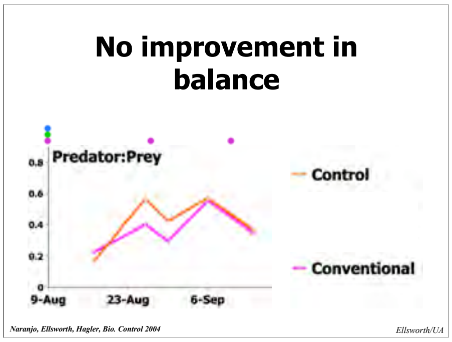
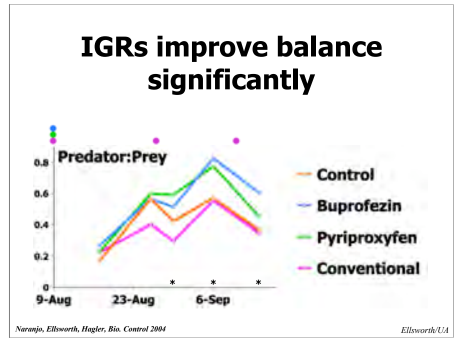


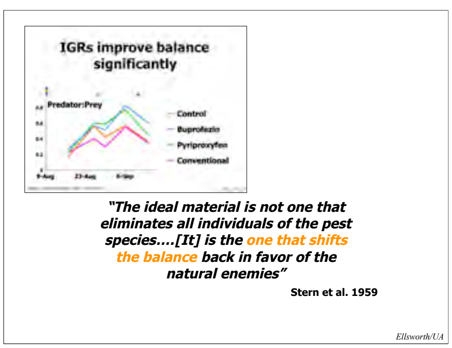
Conventional sprays served to lower prey densities, but predator densities as well. Thus, there is no improvement in the balance.

Recall again that whiteflies are in fact well-controlled by conventional chemistry but required 3 sprays to do so in this example.



IGRs on the other hand not only reduce prey numbers, they conserve existing predator numbers and create a more favorable balance of predators to prey resulting in a more efficient control system that creates collateral benefits in regulation of other pests in the system. Only 1 IGR spray was needed.

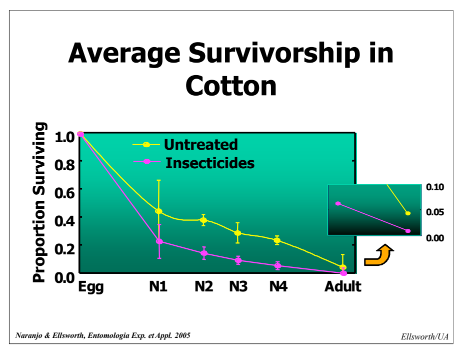
So the question is how are we changing the survivorship of whiteflies when we apply IGRs…



But before we answer that question, we must tip our hat once again to Stern and colleagues…

They saw envisioned an ideal material that we only gained commercial access to some 37 years later. Our Section 18 emergency exemptions for pyriproxyfen and buprofezin in Arizona cotton were the first uses of these materials in U.S. agriculture in 1996.

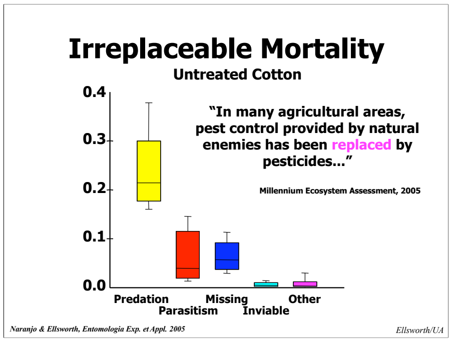
So what does whitefly survivorship look like when we apply IGRs…



Steve and I examined 14 summer generations of whiteflies in cotton and constructed life tables. In untreated systems, whiteflies survived to adult at what appear to be very low rates. Rates that belie the explosive potential of this pest.

When we compare this to systems managed with these selective insecticides, we see what appears to be only a subtly different outcome.

There is a difference in survivorship: the yellow line represents an out-of-control growing population, while the purple represents a well-managed system with collapsing populations. Thus, we are trying to leverage, on average, only about a 4% absolute or irreplaceable change in survivorship by using insecticides.



You can only die once! So even though one mortality factor can act to kill a whitefly like pyriproxyfen killing a large nymph, a predator can come along & then feed directly on the newly dead cadaver. Math allows us to estimate which factors are more "irreplaceable" or indispensible in untreated cotton & thus infer which ones are most important in controlling the insect populations. For whiteflies in cotton, predation is by far the most important mortality factor. This is WHY selectivity of the IGRs is so key. The remaining factors are not nearly as important. Incidentally, despite major changes, if not, wholesale species replacements over the last decade, parasitoids exert very little irreplaceable mortality. Here, too, a portion of 'missing' is due to chewing predation. This is where we need selectivity in chemistry. This cuts to the heart of the criticism made in the recent global ecosystem assessment.

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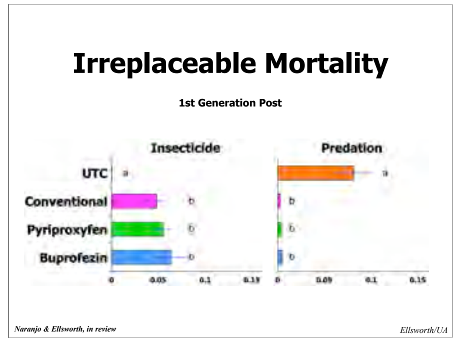

We examined patterns of irreplaceable mortality in selective vs. conventional systems. The two major sources of mortality are "insecticide" and predation. No insecticide-related mortality was measured in the UTC, but similar levels for each compound used in the first generation exposed to the sprays. Predation, however, was significantly higher in the UTC. Even though predation is present in the IGR regimes, it is less irreplaceable because of the insecticidal action of the IGRs. Recall that you can only die once. IGRs are most certainly killing whiteflies; however, predators are also feeding on these whiteflies.

If we advance our time step to the next generation, ca. 3-6 weeks later…

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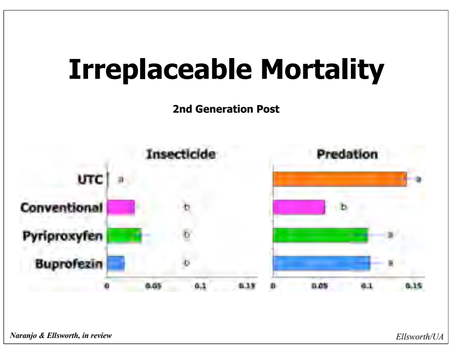

Looking at the next time course, i.e., the 2nd generation after initiating sprays, we see that rates of insecticidal mortality are still present where insecticides are used, but lower than before. Residues are diminished. Irreplaceable mortality due to predation, however, grows substantially in the IGR regimes, but much less so in the conventional regime. These levels of irreplaceable mortality in the IGR regime are very similar to what can be seen in the UTC.

Thus, the bioresidual effect is starting to exert influence over the population, because predators in particular were selectively conserved in the IGR system.

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Convincing an industry that used to spray 10-15 times per season with broad-spectrum chemistry that natural enemies can be part of the fabric of their control system is a difficult. Pictures do tell a story, however.

Peter Asiimwe, our current graduate student, is trying to understand the relative contribution of NEs and irrigation to the control dynamics of *Bemisia*. Last year, we had plots where NEs were chemically excluded by using a common Lygus insecticide. These broad-spectrum sprays released whiteflies from the natural control possible in the rt hand figure. The result was very sticky and sooty cotton. The left side was never sprayed at all.

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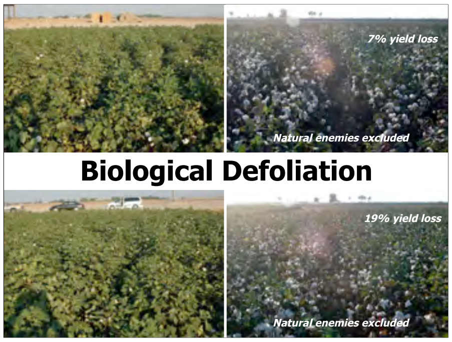
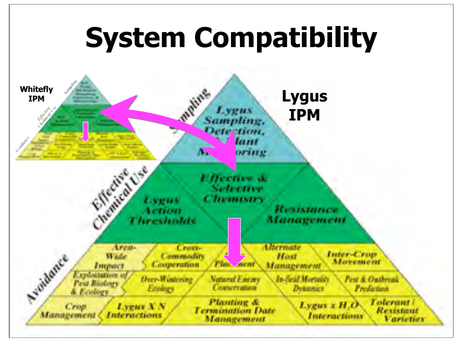


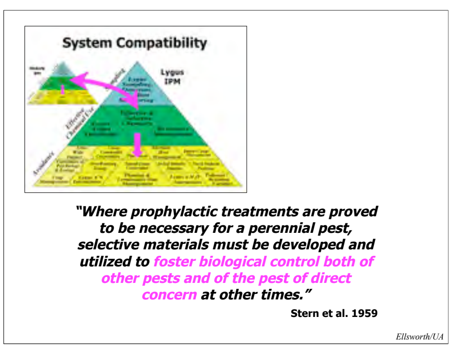
Regardless of irrigation regime, there were major losses to whiteflies where NEs were excluded. These paired pictures were shot on the same day (two weeks after the ones shown on the previous slide) and show cotton that was biologically defoliated by this sucking pest. The cotton on the left was never sprayed for any pest and also had commercially unacceptable whitefly levels but at much lower densities than in the exclusion plots.

This example stresses the interactions of our control systems for Lygus and whiteflies. That is, no matter how selective our control system is for whiteflies, if growers are spraying for Lygus or other pests with broad-spectrum materials, selective advantages may be lost.

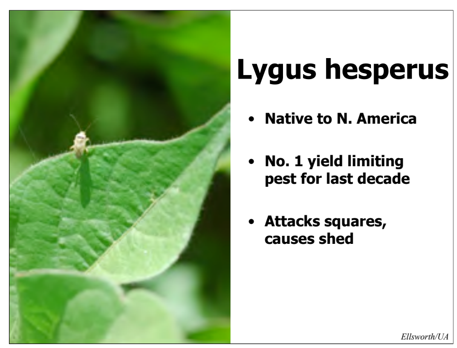


Thus, our whitefly IPM system needs to be complementary with our other pest management systems…

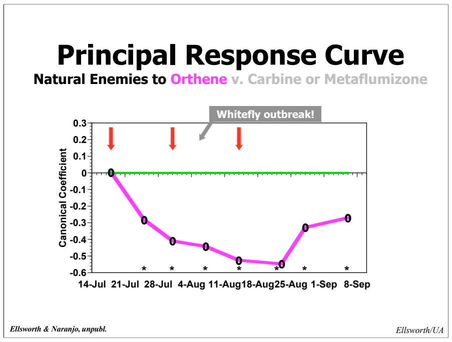
Not surprisingly, the same key set of elements are necessary for management of Lygus. For decades, we have had "effective" control chemistry for Lygus, but no selective or biorational options until very recently.



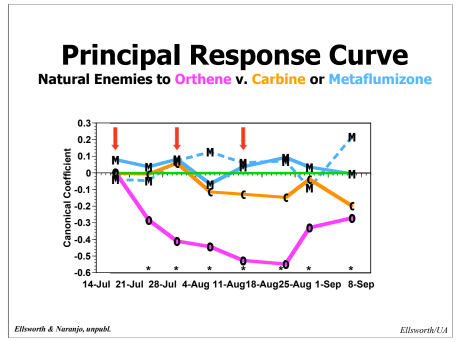
Once again, these ideas are not new ones. Stern and colleagues wrote about this as well…



Lygus bugs have become our number one pest since about 1997, ever since more selective components of our system became available, specifically Bt cotton for PBW control and the IGRs for whitefly control. This mirid attacks squares and causes them to shed. Compatibility and integration of controls with this pest are very important.



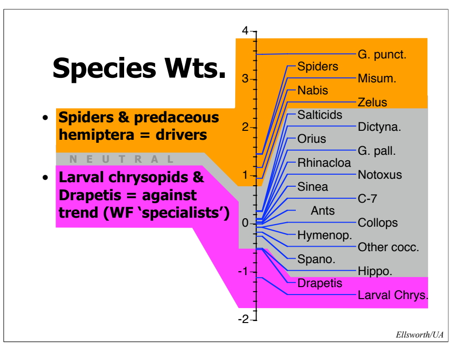
In our 2006 study, we did repeated (every other week) sprays (for a total of 3) of Lygus control chemicals. First, we can see that Orthene (acephate) predictably lowers the densities of the natural enemy community very significantly and for the duration of the season. Interestingly, 2006 was a historic low in whitefly pressure. Yet, shortly after the 2nd spray, we noted a severe and uncontrollable whitefly outbreak in these large plots (1/3 A) of Orthene. Effectively, we had damaged the natural enemy community that otherwise maintains whiteflies at very low densities. The UTC and candidate compounds had no whitefly resurgences.



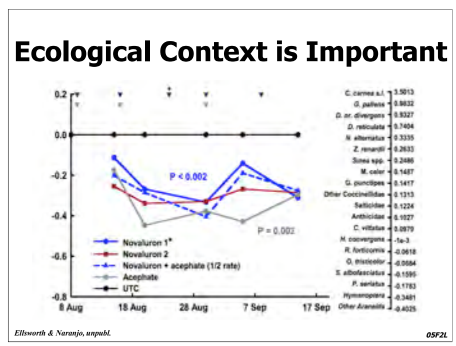
Carbine or flonicamid (orange line) showed no significant declines in the NE community. Metaflumizone at its maximum rate and for two different formulations (blue lines) also had no impact on the NE community.

And neither compound suffered from whitefly resurgence.

So we are on our way to development of the last biorational or selective building block of our cotton IPM system. Carbine has been registered in AZ since late 2006 (first major commercial uses in 2007).

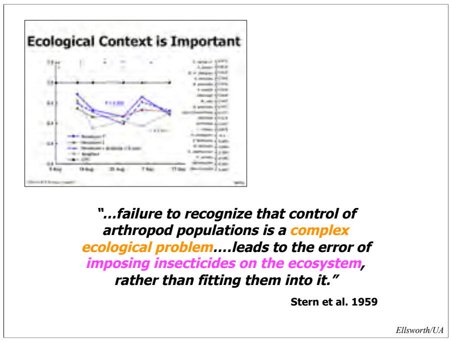


…Strong positive (>0.5) weights indicate species that tracked very closely the relationship depicted previously. Strong negative (<0.5) weights indicate individual species that actually exhibit a reversal of trend shown. In this experiment, we saw that spiders and predaceous hemiptera were driving the system. That is they were the subject of the large decline in the Orthene plots yet conserved in the others. Interestingly, the Orthene plots had an abundance of larval lacewings and Drapetis (an empidid, predaceous fly), each in response to the whitefly resurgence; I.e., they followed the pest!



Ecological context is critical to understanding the selective potential of any approach. Novaluron, ostensibly an insect growth regulator, is actually quite a broad spectrum chitin inhibitor. In some systems, it may perform selectively. However, by these measures and in our ecological context (the AZ cotton system), it is no more selective than acephate, whether used alone or in combination two to four times. [Novaluron1* indicates that only this trt received the 3rd spray.]

Novaluron is registered as Diamond in AZ but never recommended for whitefly or Lygus control. Additionally, pyriproxyfen has been disruptive in some other systems, especially via the destruction of some coccinellid predators in some citrus systems (S. Africa & California).



Stern saw this ecological context and wrote with great clarity:

Probably every agricultural system has witnessed a period where insecticides were imposed on the system rather than fitted to it.

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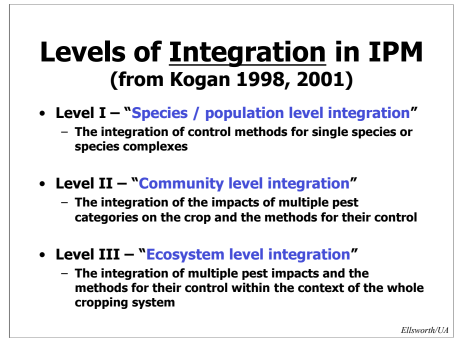

IPM exists at different levels of integration. We wish to raise the level of integration to a point ultimately where the entire ecosystem is considered. Level I integration acts at the species or population scale; Level II at the community scale; and Level III integration operates at the ecosystem scale, the level we wish to advance science and understanding.

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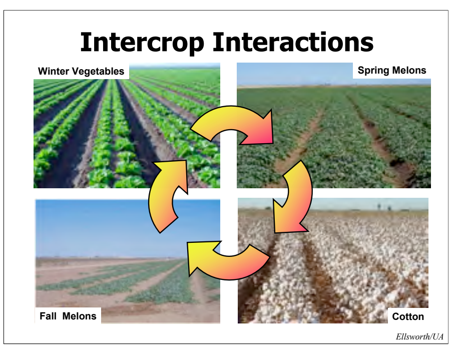

In AZ, our desert ecosystem is transformed by water into a very complex agroecosystem. AZ's year round growing season provides for a sequence of crop plants, winter vegetables like broccoli, lettuce, other cole crops, spring melons (esp. cantaloupes), summer cotton, and fall melons. These crop islands provide for perfect habitat for whiteflies, and our focus was on the intercrop interactions that were possible with this pest and that demanded a high level of integration in our IPM programs. I could describe for you the landmark cross-commodity interactions we had, but instead will just share piece of evidence that re-enforces are interdependence and also relates to the idea that Stern suggested "insecticides" are not permanent features of our system. But perhaps there effects have greater consequence that once believed.

Photo credit: JCP

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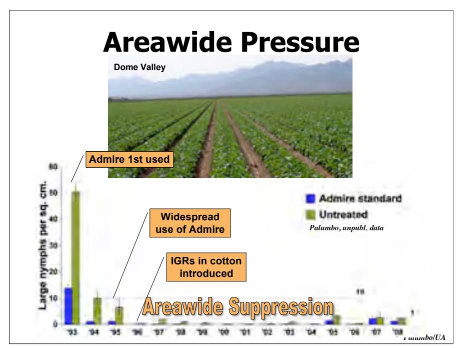

A historic example of cross-commodity (or ecosystem level) interactions: John Palumbo established untreated blocks of lettuce within commercially-treated fields with soil-applied imidacloprid. In this chart, we see whitefly levels starting in 1993 when Admire was 1st used. Pressure was extreme as seen in the UTC green bar, but Admire did an excellent job at reducing these numbers. In 1994-1995, we see a period of widespread use of Admire and numbers were reduced in the UTC by nearly an order of magnitude. In 1996 through today, we enter a period where the IGRs were first registered and used in AZ cotton and used on a wide-scale. The result is another magnitude lowering in the overall whitefly density, and what we think of as area-wide suppression of whitefly populations.

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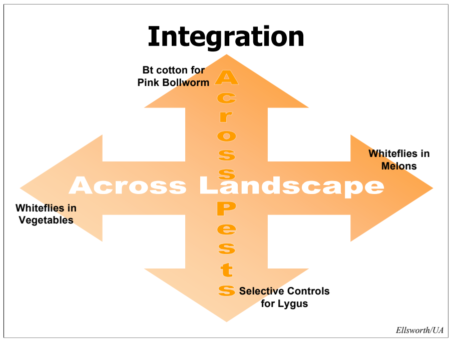
Photo credit: JCP



Integration can be thought of in at least two dimensions. Again, considering Bemisia in cotton as the central focus of our attention, we can see that vertically, within a crop, we must integrate our management programs with advances in controlling other cotton pests, particularly selective ones. At the same time, whiteflies in cotton are directly linked to whiteflies across the entire landscape, in space and in time, from vegetables to melons.

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So I'd like to talk about how we are trying to advance our understanding of Lygus movement and management across the entire agroecosystem of the West and integrate that with existing IPM programs. We are so large that we've never had everyone in one spot at one time, but this is about half of the overall team (including collaborators). Yves Carriere, Al Fournier (UA, adjunct), Steve Naranjo (USDA, adjunct), and Peter Ellsworth from entomology are shown. As part of our project, we organized an international Lygus symposium.

The project team. Missing PIs: Larry Godfrey (UC-Davis); David Kerns (Texas A&M); Jay Rosenheim (UC-Davis); Scott Bundy (NMSU).

Picture is from the 2nd International Lygus Symposium held at Asilomar Conference Center, Pacific Grove, CA, 15-19 April 2007, and sponsored in part by the APMC and the USDA-RAMP grant.

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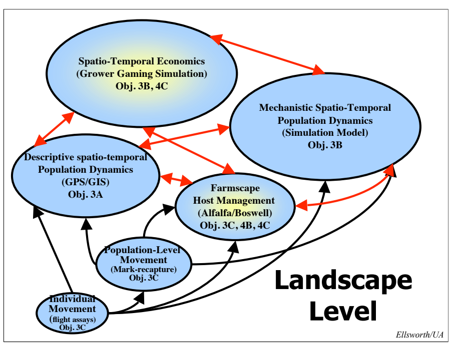

This large RAMP has studies operating or having impact on a Landscape or Farmscape level, starting with studies of individual behavior on up through progressively larger spatial scales.

A conceptual flow-diagram of landscape-level RAMP components. Arrows depict flow of information. Within the Landscape-Level domain the size of the ovals indicate the spatial context of that element from very localized (e.g., individual movement) to regional and multi-state (e.g. spatio-temporal economics).

I wish to focus on the descriptive spatio-temporal studies we are embarked upon currently.

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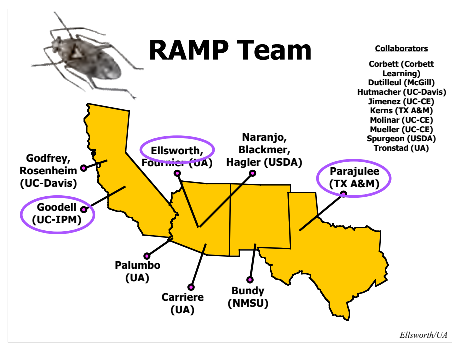
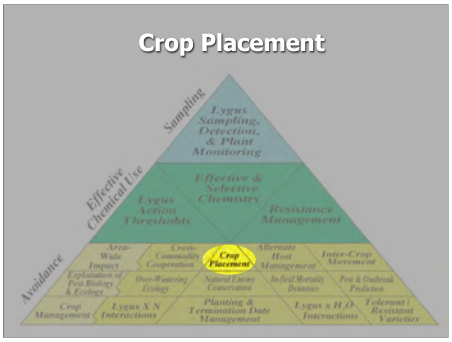


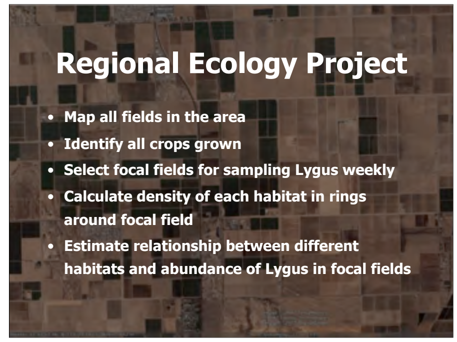
Two years ago we received a grant from the USDA-Risk Avoidance and Mitigation Program (RAMP) for the purpose of developing information that will help growers more efficiently manage Lygus over the entire western landscape. This is a large collaboration that we at the University of Arizona are leading.

There are many projects in this grant designed to help us understand Lygus management and movement across the landscape. The large study that I wish to describe now is taking place in the central valley of California under Dr. Goodell's leadership, in west Texas under Dr. Parajulee's leadership, and in central Arizona under my leadership.



Right at the heart of our IPM strategy is "Crop Placement". Crop placement is central to its availability to other pests. By strategically considering how we arrange and place our crops both in space and time, we can help to deny our crops as a resource for pest insects.

The problem until now is that we have only very limited information on how to strategically arrange our crops to prevent or minimize damage from insect pests.



So we have developed an approach using new mapping and analytical technologies that will allow us to ultimately advise growers how to minimize damaging Lygus populations through crop placement.

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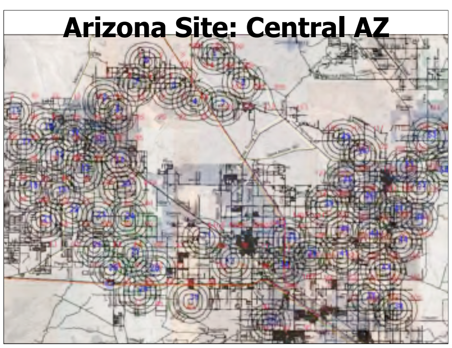
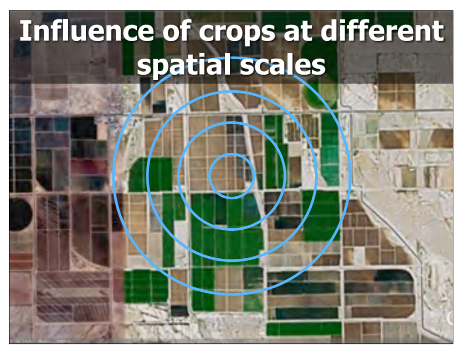


Our area of study is located in the greatest concentration of cotton in the state in central Arizona, Pinal County.

This map shows about 54 randomly selected cotton fields on which we focus our study of Lygus dynamics.



The objective of this project is to map out the agricultural landscape and measure the influence of different crops on Lygus dynamics through the system at various spatial scales.

The goal would be to identify patterns in our ecosystem that can be exploited for pest management.

Analyses can take place at any spatial interval over any scale. In our case we are looking at 0.75 km intervals out to 3 km.

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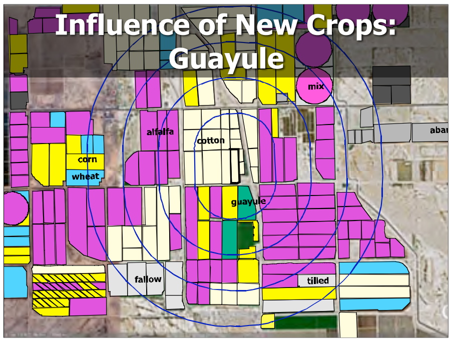

Guayule is a desert-adapted, commercial crop that is new to us and expanding with a projected western acreage of 250,000 A one day spanning W. TX to the SJV of CA. It is grown as a perennial and is a known reproductive host for Lygus. It was grown on about 4,000 A in AZ in 2007 and 2,000 A in 2008.

Is it a source, a sink, or both depending on season?

We just don't know at this point, but this example shows a focal cotton field adjacent to a 40A field of guayule.

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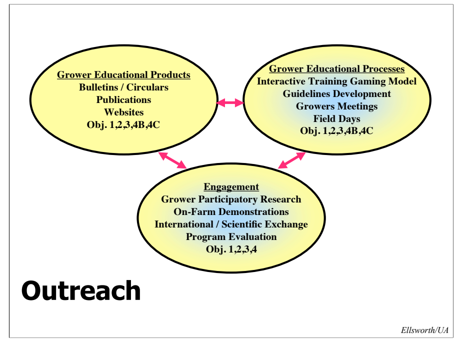
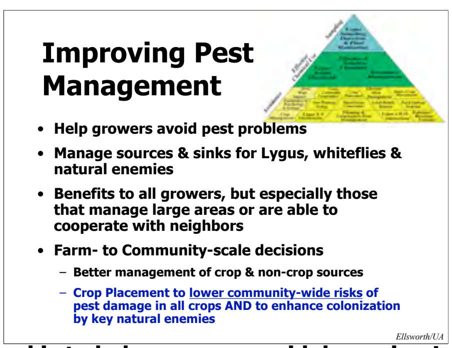
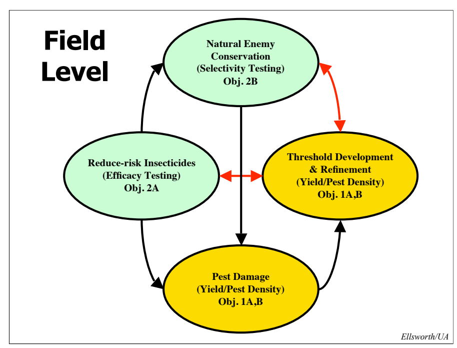


Our RAMP also has innovative outreach activities planned including the development of a game training simulation model that will be used to help growers learn about the benefits of cooperation, specifically in terms of crop placement and risks to the community of Lygus damage.

Outreach activities bridge field- and landscape-level components and provide critical feedback to ensure that research is relevant and provides practical solutions to risk mitigation while also fostering an improved fundamental understanding of pest impact, behavior, biology, and ecology at multiple spatial scales.

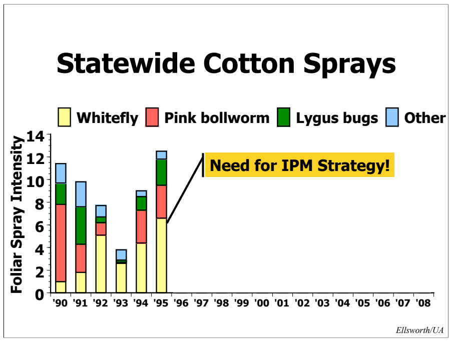


Our goal is to help growers avoid damaging Lygus populations right from the start. We hope to do this by giving them specific advice on how to manage the plantings of their many crops. By knowing what crop placements lead to more "sinks" for Lygus than "sources", a grower can become more profitable while reducing risks to the human health and the environment. This work is being extended to whitefly spatial dynamics through an NRI led by Yves Carriere, and to natural enemies. Our hope is we will develop a useful understanding of how pests and natural enemies colonize and move through an agroecosystem. Any grower can benefit but especially those that control a larger part of the landscape. Ultimately, we wish to lower the general equilibrium position and overall community-wide risk.



Which brings us back to field level processes, where we are working to develop and refine thresholds, and develop selective options for Lygus control, the very things that Stern et al. said are integral to the ICC.

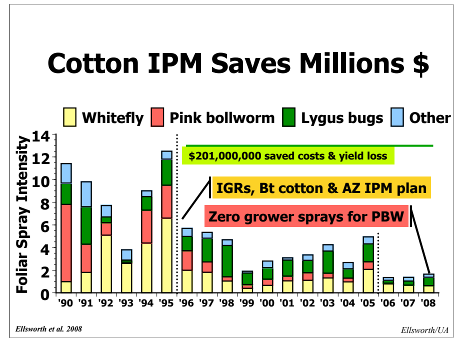
Field-level components feed into the landscape-level by governing localized population dynamics and management practices that ultimately determine population processes and management strategies within larger landscape contexts. Feedback occurs when landscape-level processes result in lowering of Lygus risks such that field-level practices become more functional (e.g., natural enemy conservation & biological control).



The need was great; the situation dire. Cotton growers were spraying 5-15 times to control an array of pests. Whitefly, Pink Bollworm, and Lygus bugs are our 3 key pests of cotton in AZ.

There was a critical need for an IPM strategy, especially after the whitefly outbreak of 1995 precipitated in part by a resistance episode.

Statewide average cotton foliar insecticide spray intensity by year and insect pest (Ellsworth et al., 2008).

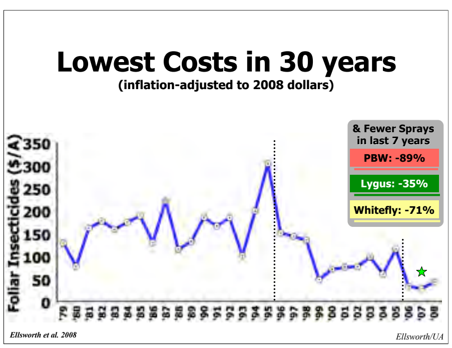


The results have been striking. A watershed of change occurred in 1996 with the introduction of very safe and selective Insect Growth Regulators for whitefly control, and transgenic Bt cotton, along with an IPM plan for whitefly management.

More recently, state agencies began PBW eradication in 2006. For the first time since the mid-1960's, AZ growers statewide did not spray at all for PBW! Bt cotton is grown on 98.25% of the acreage. And whiteflies have faded from memory as a severe and unmanageable pest.

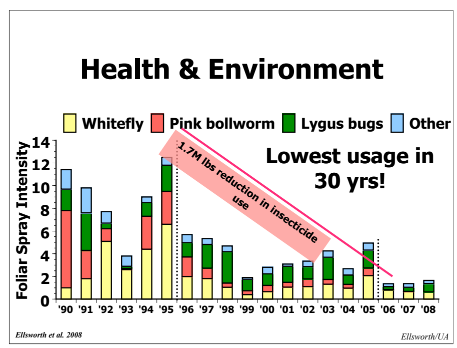
[Carbine for Lygus control first adopted in 2007.]

The credit we take for any part of this is shared with many, many others, but the result has been over $200M saved cumulatively since 1996.

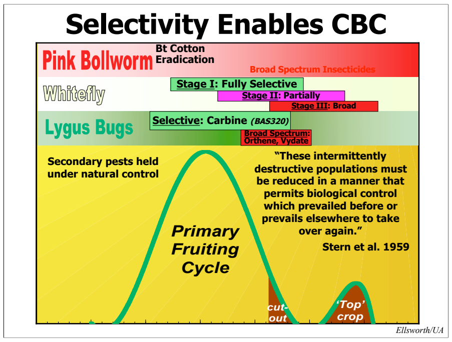


Growers spent less on insecticides in 2007 than at any other time on record (30 years). Comparing the last 7 years to the 6 preceding the 1996 introduction of our new IPM plan, growers have sprayed far less than before. The average grower now sprays once or twice, with compounds that are relatively safe, far safer than anything used in the past, to control all insect / arthropod pests season-long. Cotton is grown from March to October.

Statewide average cotton foliar insecticide spray intensity by year and insect pest (Ellsworth et al., 2008).



The benefits extend to health and safety of workers on farm and the greater environment at large. Comparing our 30-year high in 1995 to our lowest usage in 2006, growers used 1.7 million lbs less insecticide!



Our system breaks down to 3 key pests and a large array of secondary pests that never become significant, IF disruptions of natural controls do not occur. For PBW, Bt cotton is the ultimate biorational, and now with eradication, broad spectrum insecticides for its control are fading completely from our system. For whitefly, we have organized our insecticides into 3-stages based on selectivity, deferring all broad-spectrum inputs until the end of the season, if needed at all. For Lygus, we have one selective insecticide, flonicamid, with another soon to become available. Cotton IPM in AZ has become an exceptionally well-developed and selective system where conservation biological control is firmly established as a key element. "Chemical control augments biological control." Stern et al. saw it; Stern et al. predicted it.

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The program developed and presented here was supported by a massive research and extension effort that was funded through many competitive grants and gifts from sponsors to which we give thanks. Special thanks to co-author, Steve Naranjo.

The Arizona Pest Management Center (APMC) as part of its function maintains a website, the Arizona Crop Information Site (ACIS), which houses all crop production and protection information for our low desert crops, including a PDF version of this and related presentations for those interested in reviewing its content (cals.arizona.edu/crops).

The University of Arizona IPM Program is managed by the APMC, which also maintains an organizational website at cals.arizona.edu/apmc

Photo credit: J. Silvertooth