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.

China submitted talk, 15 minutes; 150

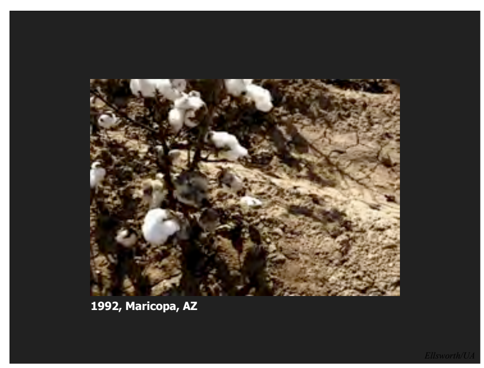
5th International Bemisia Workshop
Guangzhou, China
10 November 2009

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.

5th International Bemisia Workshop
Guangzhou, China
10 November 2009

This was the scene we were facing when the invasive B-biotype came to Arizona. The numerical pressure was overwhelming and impacting not only agricultural areas, but also Arizona's largest city, Phoenix, as seen here on the campus of a local college.

5th International Bemisia Workshop
Guangzhou, China
10 November 2009



Our largest challenge was to protect the major summer crop, cotton, from unacceptable losses of quality due to honeydew and sooty mold contamination.

Integrated Control (IC)

"Applied pest control which combines and integrates biological and chemical control. Chemical control is used as necessary and in a manner which is least disruptive to biological control."

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

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

Steps to Integrated Control

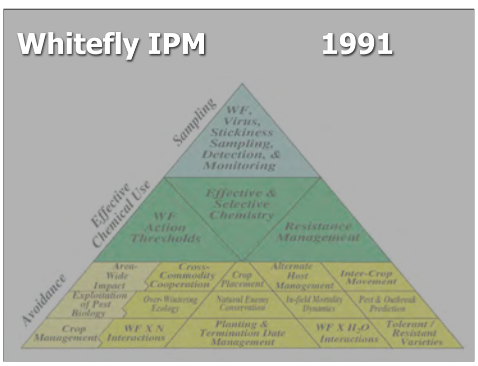
"Integrated control is most successful when sound economic thresholds have been established, rapid sampling methods have been devised, and selective insecticides are available."

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.

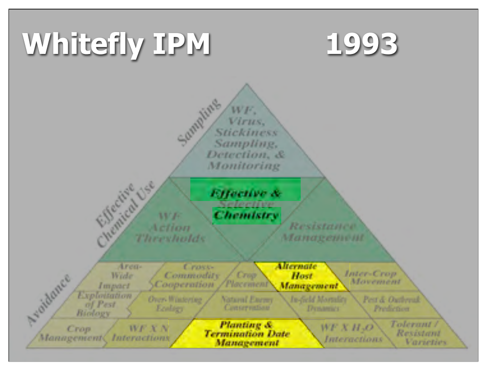
Initially, we had none of these things in place. Our challenge was to envision a new system and develop the scientific and practical assets necessary to overcome this problem.



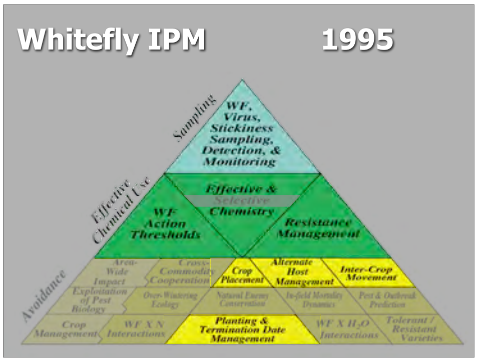
We were starting from nothing in 1991.

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.

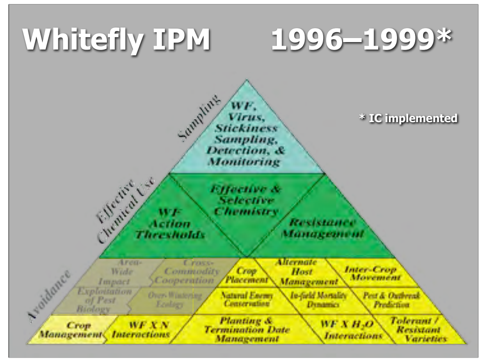
An entire scientific industry mobilized to address the problem, and Steve and I began our collaboration with each other as well as with many other academic and industry stakeholders.



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 agro-ecoystem and were faced with telling growers to shorten their season at all costs to avoid major damage from whiteflies.

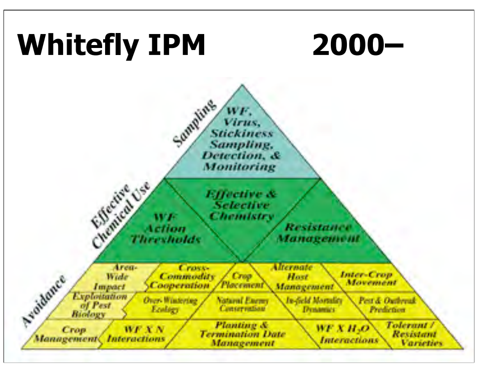


By 1995, we had major progress in the upper layers of the IPM pyramid, in sampling and chemical use. We were also gaining more insight into the areawide impact of whitefly movement and crop placement.

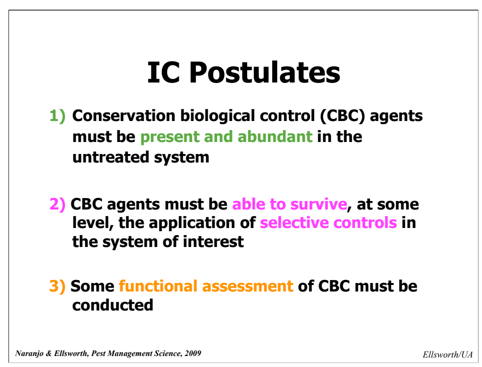


In 1996, we introduced some key selective chemistry that changed everything for us. It enabled a broader base of avoidance tactics, and we were well on our way to stabilizing a previously and seriously destabilized system.

This was the beginning of functional Integrated Control in the Arizona cotton-whitefly 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. 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 wish to focus my presentation today on those elements that allowed Integrated Control in our system.



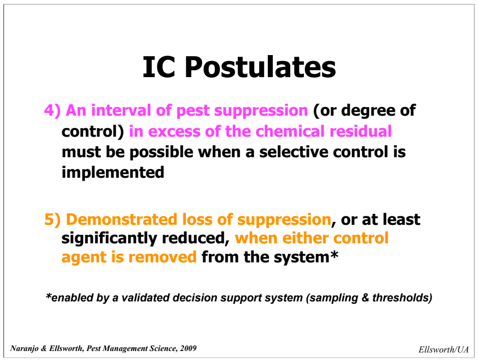
In a recent paper that Steve and I published this past month, we identified five postulates for qualifying an approach as "Integrated Control", as Stern and colleagues originally proposed:

CBC agents must be present & abundant,

Capable of surviving selective controls,

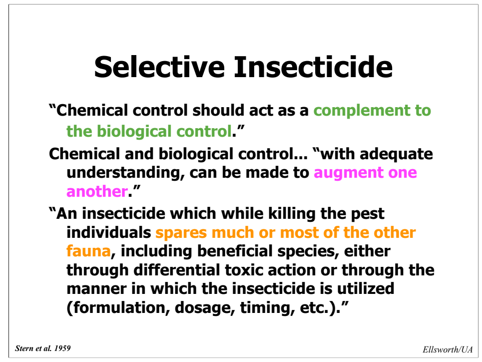
Function to lower pest densities,

…



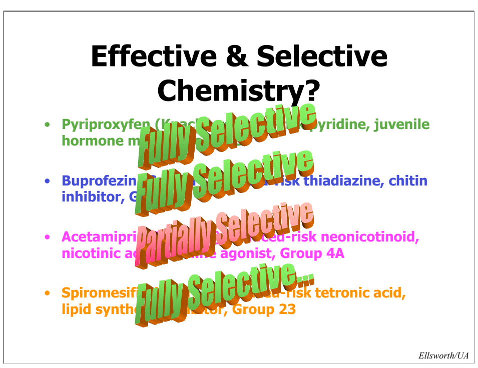
The control system must provide for an interval of suppression in excess of just the chemical residual, and should break down if chemical or biological control agents are removed from the system.

Further, all this must be enabled by an efficient and validated decision support system.



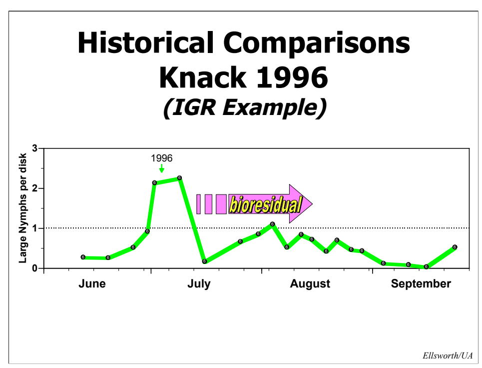
At the heart of Stern's paper, they make several important, simple, and straight-forward statements about chemical control. Namely, chemical control should complement biological control; and the two tactics should be made to augment one another. Within the ICC there is this pervasive idea that an insecticide 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!

When our work began, we had only pyrethroids and organophosphates, but since 1996…

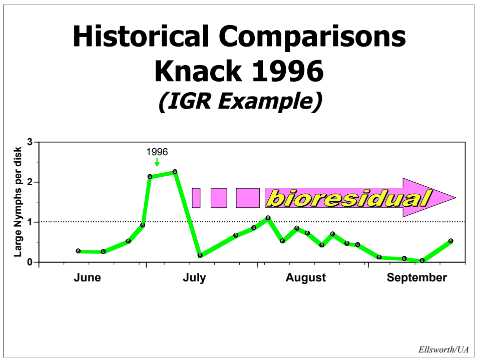


…through today, we have 4 very effective chemistries. In terms of selectivity, Knack, at least in our system (AZ cotton), is fully selective. Courier (or Applaud), too, is fully selective. Intruder (or Assail, a neonicotinoid), however, is in fact not selective. It is highly effective, but actually will 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.

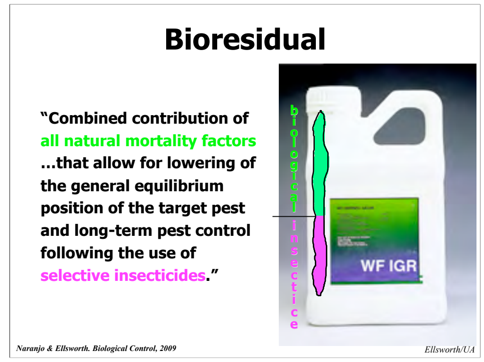
Oberon provides rate-sensitive selectivity, another concept mentioned by Stern et al., where lower, whitefly rates are fully selective, but higher miticidal rates are somewhat less selective.



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 (pyriproxyfen) 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…



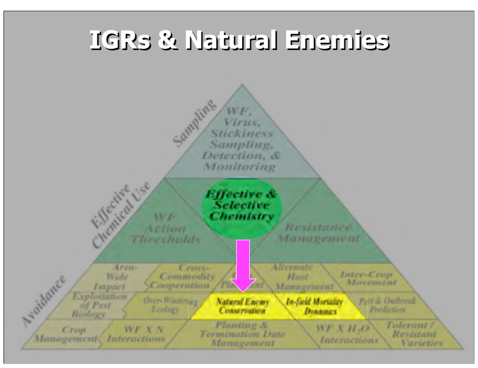
… through the action of predators especially, and other natural sources of mortality, the whitefly population is maintained below threshold well beyond the known period of chemical residual. We term this extended suppressive interval present in a selective system, "bioresidual". We coined this term to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



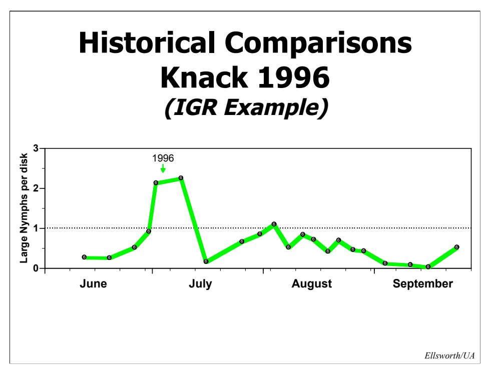
Specifically, we define bioresidual as follows:…

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.

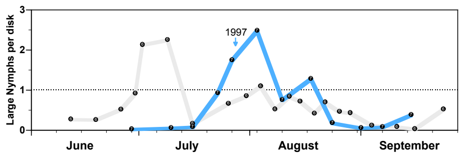


Central to remedial tactics is an effective chemical arsenal. In AZ, we have shown that when selective options are available and effective, huge gains in both target and collateral control can be achieved due to much better natural enemy conservation and other natural mortalities. This ecosystem service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



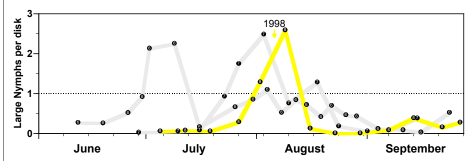
Returning to our replicated commercial assessments, we can show how durable and predictable the patterns of control are.

Knack 1997



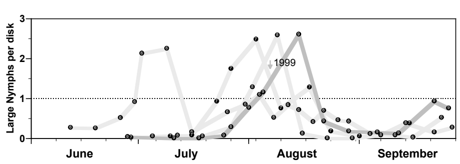
Ellsworth/UA

Knack 1998



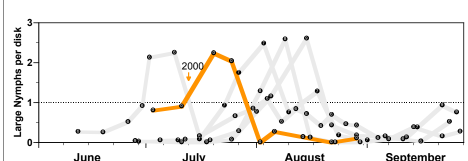
Ellsworth/UA

Knack 1999

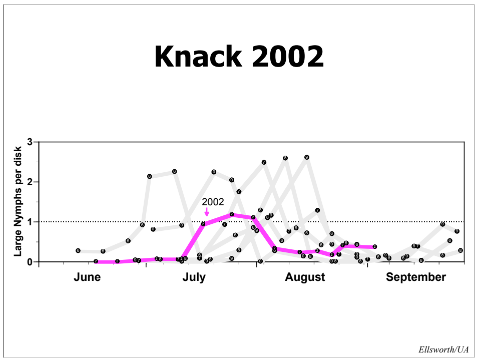


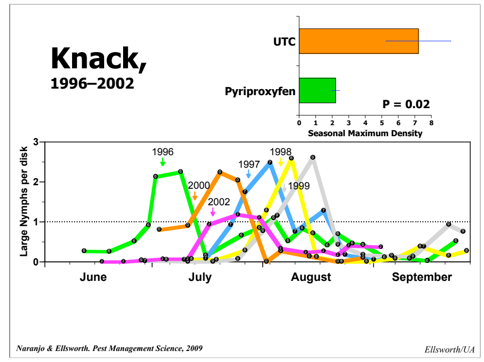
Ellsworth/UA

Knack 2000



Ellsworth/UA

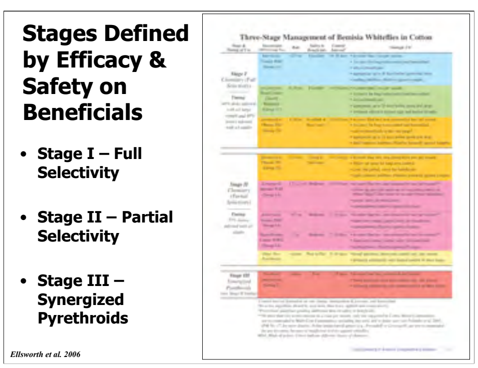




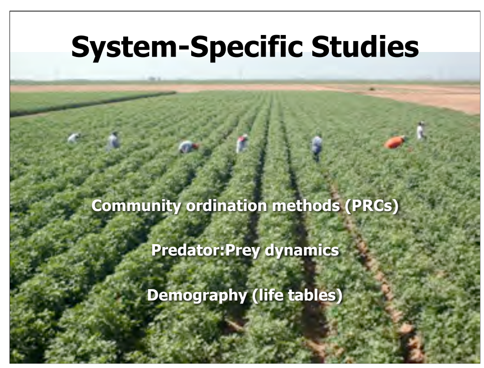
When growers experienced difficulties with this approach, it was almost always due to problems with timing. So I used these demonstrations to show growers that consistent timing of these slower-acting IGRs gives very consistent results.

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.

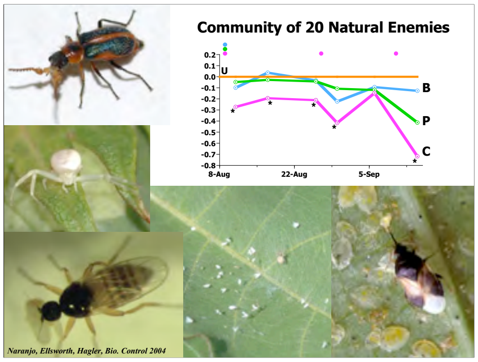


As part of our IPM program, a 3-stage chemical use plan identifies chemistry based on efficacy and selectivity attributes, with the ultimate goal of exploiting selectivity as much as is possible. It does not mandate a sequence but teaches growers that more selective approaches will create more effective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



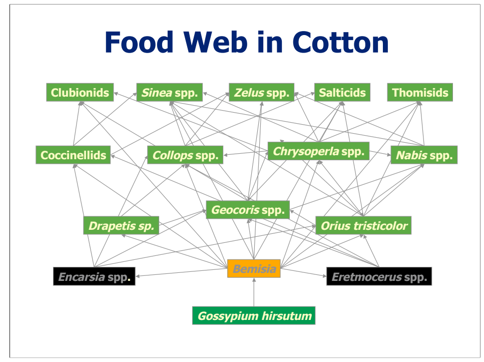
Over many years, we have conducted ecosystem-specific studies and used various approaches to identify the presence and function of natural enemies and the impact of all mortality factors.

These include community ordination methods that permit the analyses of whole NE communities and construction of Principal Response Curves (PRCs); exhaustive surveys of canopy arthropods and whitefly densities to develop predator:prey ratios; and demography. From these data, we constructed life tables that tell us what mortalities are operational and which ones are most influential in population regulation.



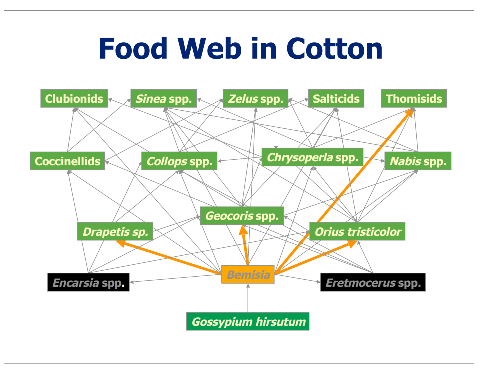
Without dwelling on the data for each year, let me say that the PRCs show convincingly that sparing usage of IGRs (often just one spray) provided equivalent control as multiple sprays of broad spectrum insecticides, but also conserved a whole suite of natural enemies important in the control of whiteflies and other pests. Conventional chemistry, the purple line, significantly lowered densities of all predators.

Because we are working in a very dynamic system, in some years 1 set of species may drive the PRC, while in other years another set of species drives the relationship.

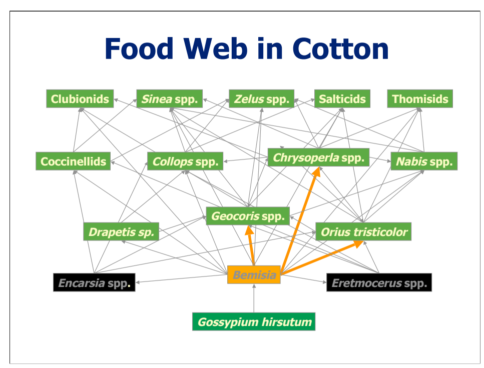


The idea that different species dominate the PRC in different years or locations in AZ cotton is a remarkable testament to the complexity of the food web. Certain conditions may favor certain pathways in certain years and other pathways in other years. Yet the same, generally, level of natural mortality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

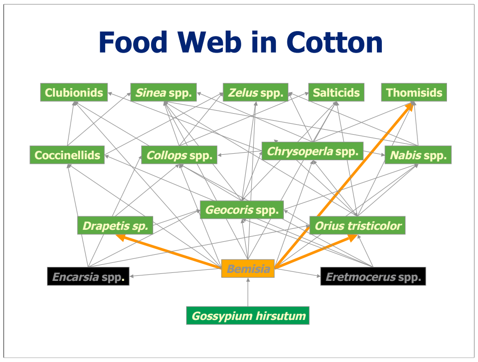
Note parasitoids in general, while present, rarely contributed major sources of irreplaceable mortality in this system, despite rather large shifts in parasitoid diversity favoring exotic species.



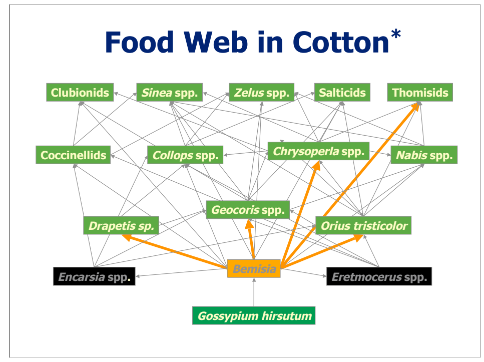
Four predators dominated the PRC in this year.



Three species in this year.

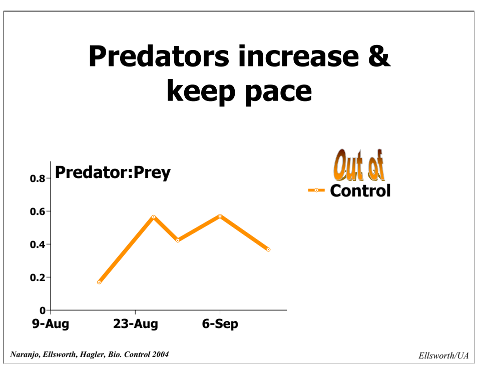


And a different set of 3 species in this year.



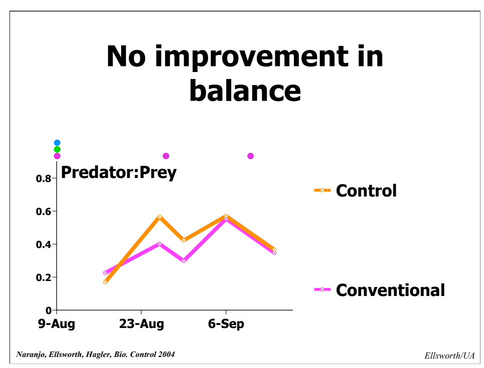
And 5 species dominated the PRC this year.

These analyses documented the presence and abundance of a large web of natural enemies; however, a different approach is needed to develop a functional understanding of NE contribution to IC.



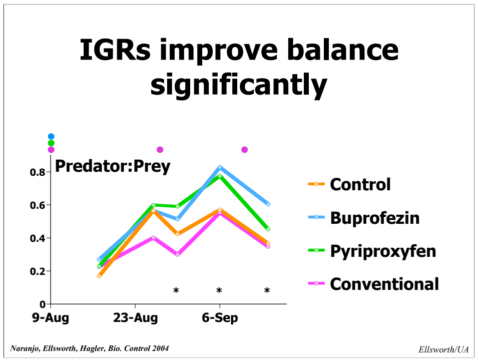
One way to do this is to examine Predator:Prey ratios. In this example, all predators captured in 50 sweeps compared to all whiteflies per leaf in cotton. Here we see that predator numbers increase and stay level relative to prey numbers, which are increasing through this time period.

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



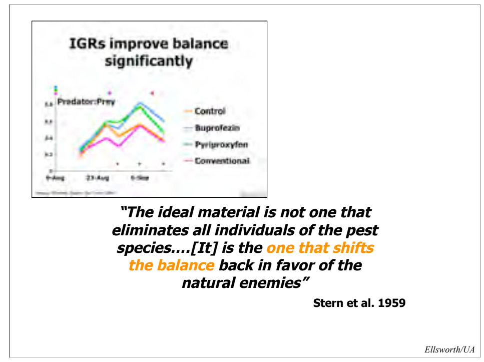
Conventional sprays served to lower prey densities, but predator densities as well. Thus, there is no improvement in the balance.

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.

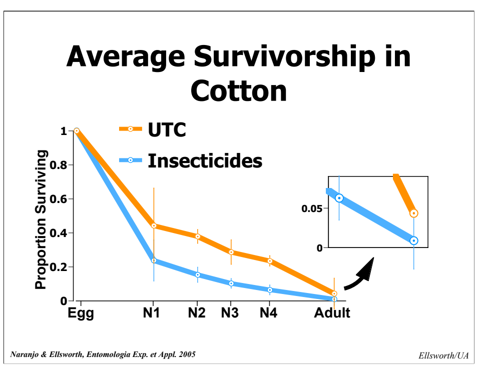
So the question is how are we changing the survivorship of whiteflies when we apply IGRs…



This balance was central to Stern's ideas about selective insecticides and how they enable IC.

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.

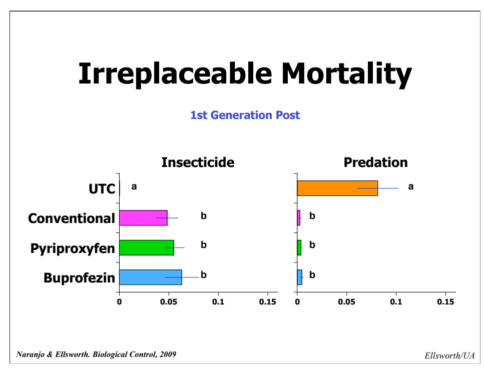
So what does whitefly survivorship look like with and without selective insecticides…



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.

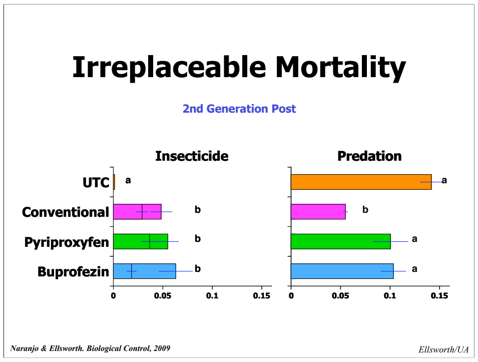
When we compare this to systems managed with these selective insecticides, we see what appears to be only a subtly different outcome.

There <u>is</u> a difference in survivorship: the yellow line represents an out-of-control growing population, while the blue 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.



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.

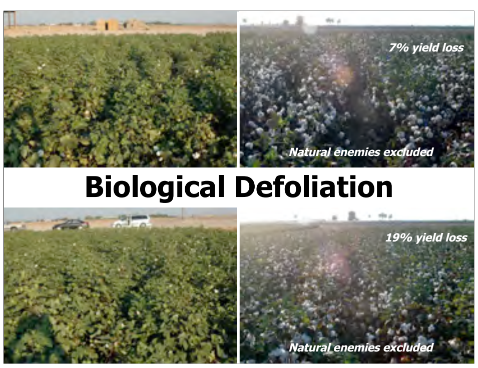
If we advance our time step to the next generation, ca. 3-6 weeks later…



We see a general lowering of the insecticide effects; however, the story of IC plays out in the irreplaceable mortality due to predation where the IGR levels are very similar to the UTC demonstrating not only conservation of the predator fauna but also an enabling of their function one generation later. Conventional chemistry, while effective if repeatedly used, reduces predator levels and reduces their functional utility in the system.

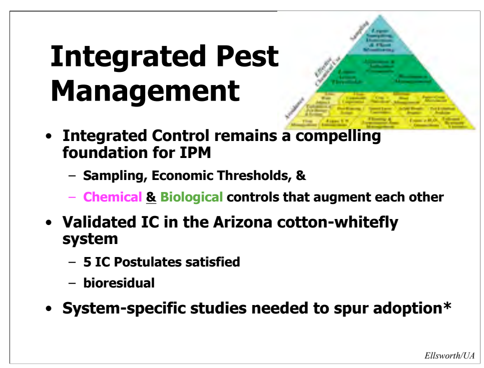
To finally validate the Integrated Control is operational and biological and chemical control are in fact "augmenting" each other, we should be able to disable one or the other control agents and show a collapse in control.

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.



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.

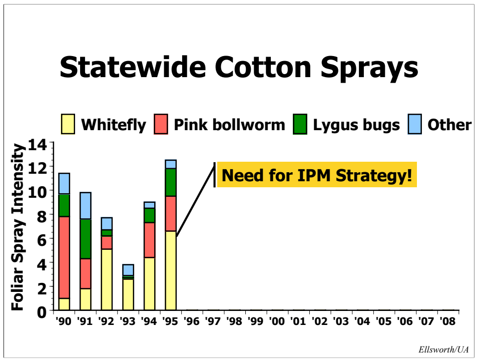
This example stresses the interactions of our control systems for Lygus and whiteflies. That is, no matter how selective our control system is for whiteflies, if growers are spraying for Lygus or other pests with broad-spectrum materials, selective advantages may be lost.



Integrated Control as envisioned by Stern and colleagues remains a compelling foundation for IPM, and is solidly based in an efficient decision-support system, and most importantly in chemical AND biological controls that augment each other.

In Arizona, through many years of study, we have validated this vision in the cotton-whitefly system and shown that it satisfies all five IC postulates. We have introduced the concept of bioresidual to more readily communicate the value of the natural mortalities possible in an IC system.

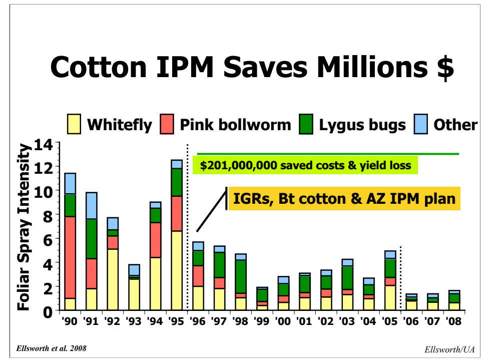
More system-specific studies are needed. Workers in biocontrol and chemical control must actively engage each other to better realize Stern's vision for the future, now 50 years later.



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).

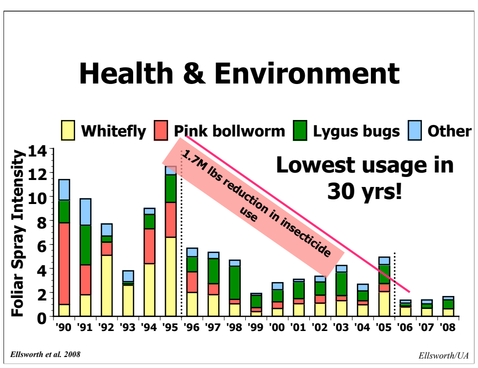


The results have been striking. A watershed of change occurred in 1996 with the introduction of very safe and selective Insect Growth Regulators for whitefly control, and transgenic Bt cotton, along with an IPM plan for whitefly management.

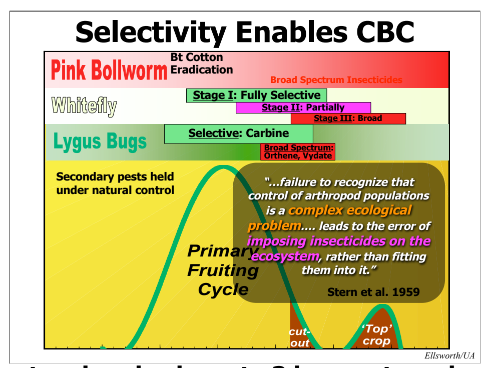
More recently, state agencies began PBW eradication in 2006. For the first time since the mid-1960's, AZ growers statewide did not spray at all for PBW! Bt cotton is grown on 98.25% of the acreage. And whiteflies have faded from memory as a severe and unmanageable pest.

[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.



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. 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.

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