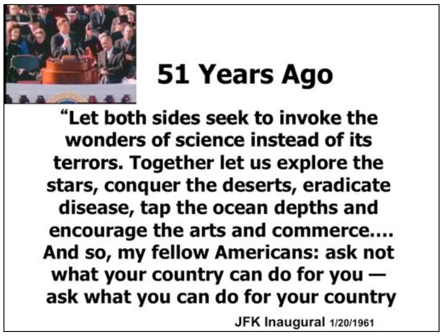
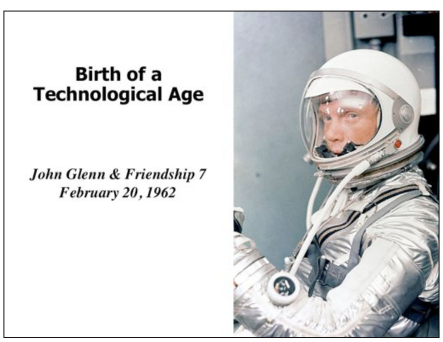


Thank you for the opportunity to address the International IPM Symposium in the closing plenary. I'm following some very inspiring words and messages from our previous speakers. I thought I might and I'm not sure that I have words to match those you've already heard. So I am borrowing an important message from history…

JFK provided this memorable quote (last sentence) during his inaugural just over 51 years ago. However, few have heard or read the words that preceded this now famous quote, and it has to do with the hope and promise of science and innovation in our society. These were hopeful, optimistic positive times, even despite the specter of the Cold War and the Soviet Union.

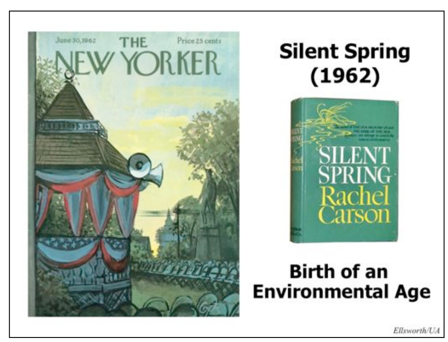
50 years after JFK's message, Obama gave his State of the Union and many observed that he was trying to channel some of that optimism of JFK and those times. These are just some of the quotes from this speech given in 2011.

"Out-innovate" and "out-educate" are key terms here and speak to what we endeavor to do in IPM, our knowledge intensive approach to the management of pest problems.



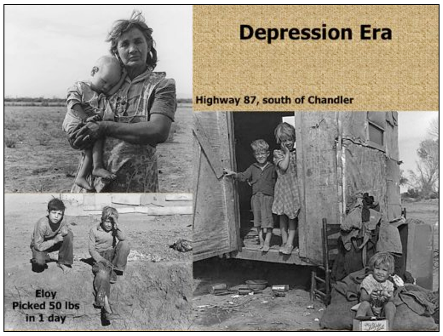
50 years ago last month, we celebrated the anniversary of John Glenn's orbit of the Earth in Friendship 7, as the first U.S. astronaut to do so. This was an important moment in American history and one that signaled the dawning of a new technological age, and the beginning of the fulfillment of JFK's promise to the American people.

The time in history when this was happening was also a dangerous time, with friction mounting between the US and the Soviet Union and with Cuba, and the ultimate threat of technology in the atomic bomb.



That same year in the fall, Rachel Carson's book Silent Spring was published. It may have gone less noticed if not for the pre-publication serialization of excerpts from that book in the New Yorker magazine which was read by thousands of Americans.

Many elements of Carson's book have since been challenged & debated by different parties. But, her general thesis that unbridled use of technology was inherently risky and potentially dangerous is an important one. This was the birth of an Environmental Age.



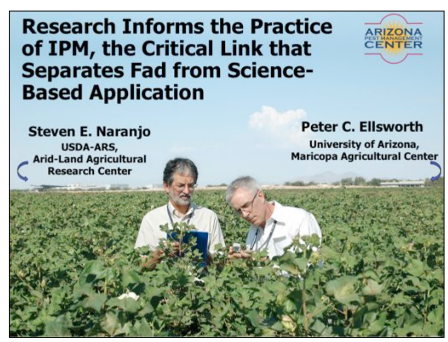
However, we've reached a time in history and in our culture (and some would say in hubris) where many are embracing a "get back to basics" attitude about food and agriculture especially, in an effort to be "green" and "sustainable". And, the fact that society is grappling with issues of food production and the processes involved is a wonderful new engagement of the public in an important dialog. However, I don't think anyone is suggesting discarding all technology and returning to a time where quality of life, standards of living, were very different and very, very difficult. These photos are from the area of AZ where I live and cotton is grown today. Living conditions were very difficult and young boys spent their days picking cotton.

And AZ was facing an immigrant problem then, too. However, it was not from south of the border. It was from across an ocean. These are immigrant laborers from places like Spain, Portugal and Eastern Europe. Growers in AZ were encouraging this immigration of these hard workers to our area to assist the industry in the production and harvest of cotton.

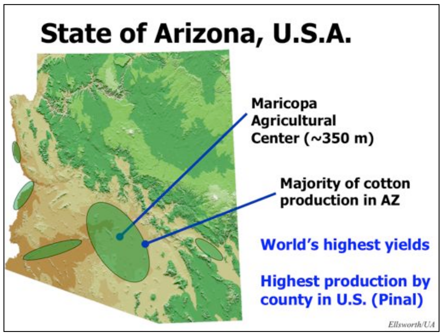
Does anyone want to return to a time before technology enabled the high standard of living we currently enjoy?

In more recent times, the 1970s, Arizona was at the center of a controversy. Largely due to brave entomologists that preceded me in AZ, our state was the first in the U.S. to ban DDT. These IPM scientists saw risks associated with DDT residues that were ending up in milk, via alfalfa forage, which was a crop that did not have a label for DDT. This did not make them popular with growers of the time! And, the risk to raptor populations in particular was central to the issues that culminated in the first Earth Day celebration & in the formation of the EPA. This was also the location for the first federally supported IPM Demonstration by my immediate predecessor, Dr. Leon Moore, in cotton in central AZ. This along with the demo in NC on tobacco that same year was the birth of our federal Extension IPM program. The Growers Pest Management, Inc. was a non-profit scouting service that was spawned from this initial 1971 demonstration in AZ & has endured ever since.

Photo by Tim Knight © http://homepage.mac.com/wildlifeweb/).



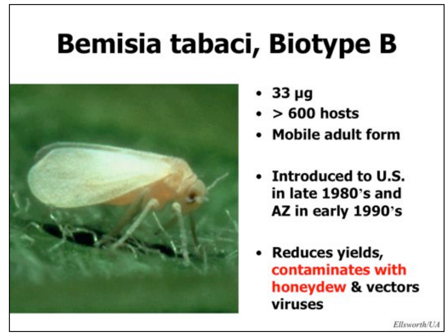
So with that bit of history & hopefully inspiration, I want to address my central theme examining the role of research in the development and practice of IPM. There are many people that have impacted my world view on this and related topics. However, I would like to acknowledge my closest research collaborator, Dr. Steve Naranjo, who is co-located in Maricopa but at the USDA-ARS, ALARC facility pictured on the left adjacent to the UA-MAC facility shown on the right. We have worked together for ca. 20 years in a cotton system challenged by major pest problems.



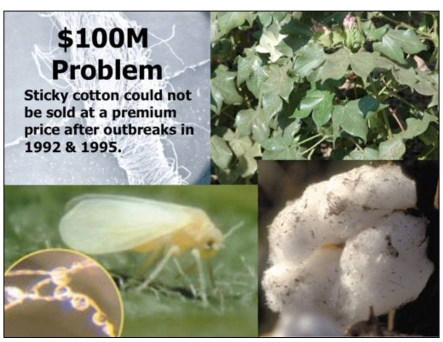
The stage for this epic story is the great state of Arizona, where cotton is grown in fertile alluvial soils of several low desert valleys. My location is in the center of nearly one quarter million acres of cotton in the central part of the state.

Some may not realize that AZ grows cotton, let alone some of the highest quality in the world and leading the world in yields per acre. And, Maricopa is in Pinal County, the county with the highest production levels of cotton in the U.S..

This is not because we plant wall-to-wall cotton. In fact, much of this county's landmass is in native desert. It's our extraordinarily high production & our judicious use of technology that leads to this record County-wide production.



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.



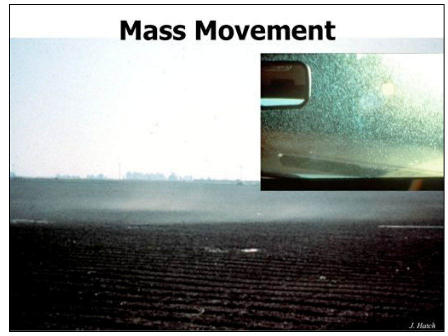
The problem starts with the insect, but the driver of this system is what is shown in this micrograph of a cotton thread. While yield losses have always been a potential problem, the real problem is the deposition of honeydew on exposed cotton lint that then is processed, if it can be processed at all, 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)].

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

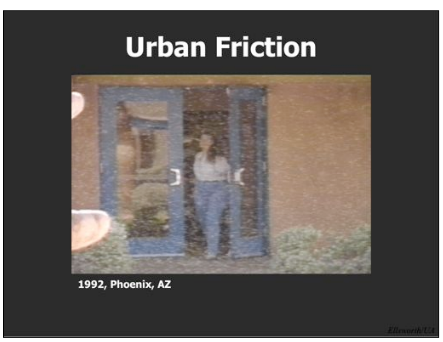
To be clear, this was less a yield problem and much more a quality problem that pushed buyers away from even considering buying AZ grown cotton no matter how clean it was.

This invasive pest attacked many different crops. Here, adults cover the surface of a cotton leaf, and the immobile immatures (eggs and nymphs) encrust the leaf underside. When this first happens in a region and is unfamiliar to growers, what do you do?!

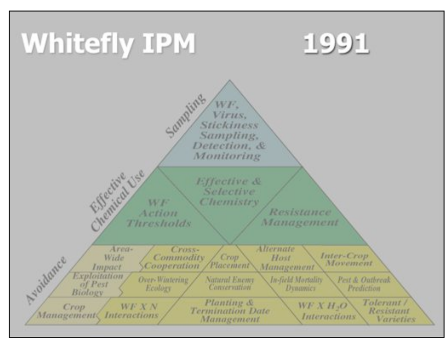
Matters were made worse by the a priori resistance that these whiteflies already had to pyrethroids or organophosphates.



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 that driving through the valley at that time would actually cloud up your windshield. This was a nearly impossible pest management situation.



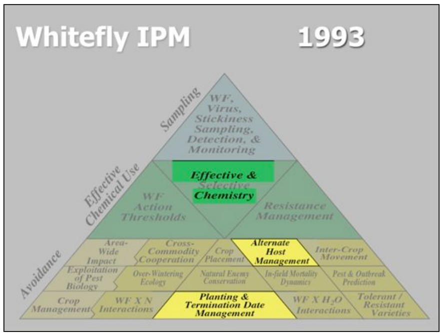
This was the scene we were facing when the invasive B-biotype came to Arizona. The numerical pressure was overwhelming and impacting not only agricultural areas, but also Arizona's largest city, Phoenix, as seen here on the campus of a local college. Pedestrians and bikers of the time would wear surgical masks to protect themselves from swallowing whiteflies.



Through the fog of whiteflies that were present in our landscape, it was very difficult to imagine a system stabilized by a well-organized, research-based IPM strategy. We were starting from nothing in 1991.

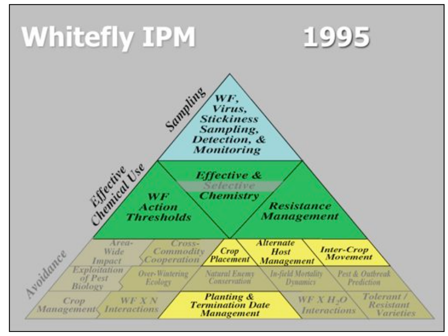
The form that our IPM plan takes today was not even conceivable with the severe pressures we were facing and the vast gaps in our knowledge base that were present at the time.

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

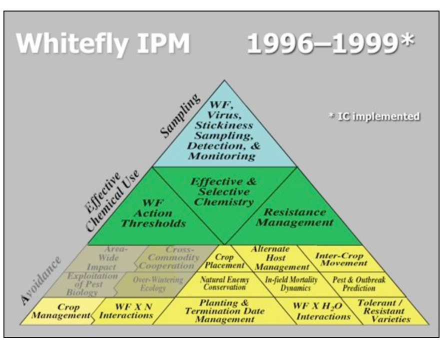


Over time, however, and much research, we slowly began to uncover the building blocks to an IPM system.

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

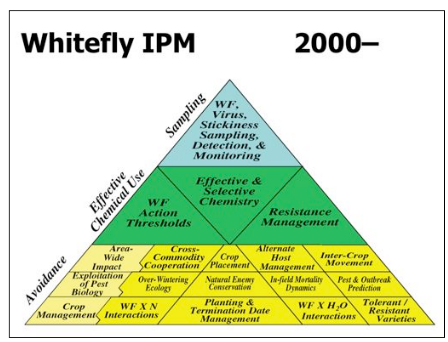


By 1995, we had major progress in the upper layers of the IPM pyramid, in sampling and chemical use. We were also gaining more insight into the areawide impact of whitefly movement and crop placement.

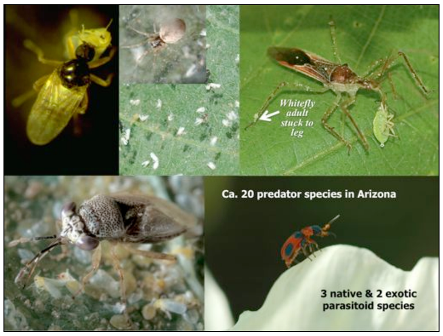


In 1996, we introduced some key selective chemistry that changed everything for us. It enabled a broader base of avoidance tactics, and we were well on our way to stabilizing a previously and seriously destabilized system.

This was the beginning of functional "Integrated Control" in the Arizona cotton-whitefly system.

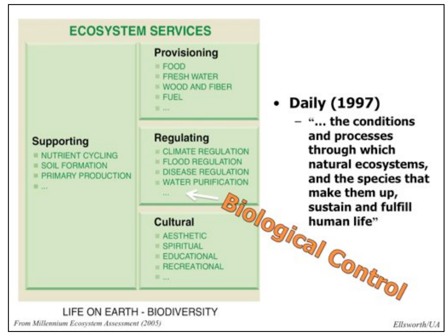


By 2000, we had installed some critical cross-commodity agreements among cotton, vegetable and melon producers and our IPM plan came into full focus. This pyramid metaphor serves as our heuristic representation of whitefly IPM in Arizona cotton. This continues to be our operational IPM plan. At its simplest, 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.

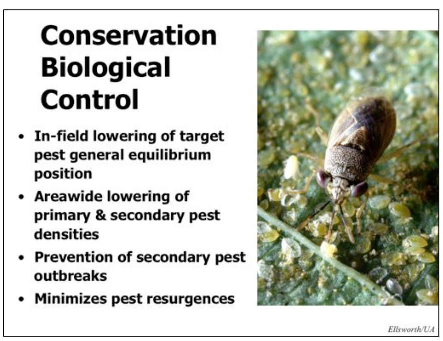


Those that have heard me speak on this subject have heard various parts of this story before including the development of various control tactics and/or the advanced sampling, threshold or resistance management approaches we practice. However, today, I would like to focus on the natural control component of our system as a way to highlight the important and intricate research that was conducted and now supports our understanding and practice of IPM in Arizona cotton. We have a suite of predators, all generalists, that are part of this story. We also have a number of native and exotic parasitoid species that are specific to B. tabaci.

Encarsia sophia and Eretmocerus nr. emiratus (exotics), which replaced Eret. eremicus; other natives: Enc. meritoria and Enc. luteola.



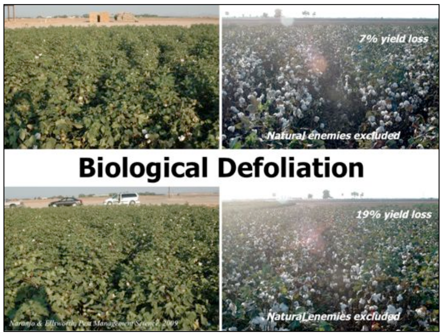
About 15 years ago, the idea of "ecosystem services" came about through the work of Gretchen Daily at Stanford. This has marked a renaissance in the sciences that seek to understand and measure the value of our ecosystem in many ways. Ecosystem services are quite simply defined as those things contained 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. However, we will focus on a key regulating ecosystem service of Biological Control today.



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. These are the basic elements of understanding the natural controls in any IPM system.

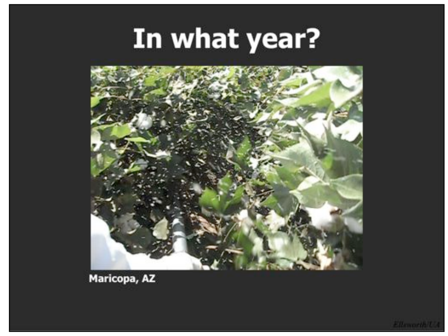
Convincing an industry that used to spray 10-15 times per season with broad-spectrum chemistry that natural enemies can be part of the fabric of their control system is a challenging. Pictures do tell a story, however.

Peter Asiimwe, one of our former graduate students, was trying to understand the relative contribution of NEs and irrigation to the control dynamics of *Bemisia*. 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.



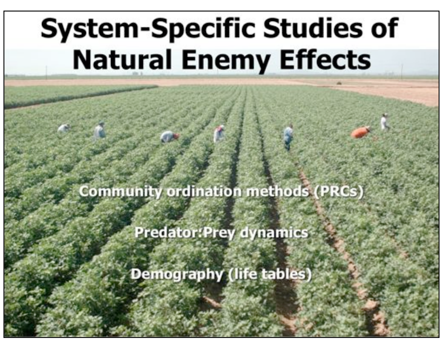
Regardless of irrigation regime, there were major losses to whiteflies where NEs were excluded. These paired pictures were shot on the same day (two weeks after the ones shown on the previous slide) and show cotton that was biologically defoliated by this sucking pest. The cotton on the left was never 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.



Many of the photos and movies I have shown growers over the years come from that outbreak period of the early to mid-1990s. Our system has since stabilized and done so over a long enough period that practitioners either forget how severe the problems were or start to believe that those problems were a problem of the time and not any particular management practice.

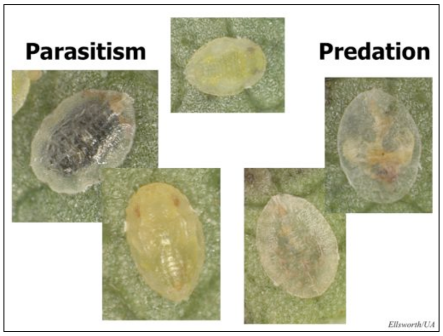
So I generally show this video which shows clouds of whiteflies disrupted in the cotton canopy and pose the question of when what this video shot? The answer is not the early 90’s, it is 2010. These are large scale experiments and plots where we have intentionally made a set of bad decisions, illustrating that 1992- or 1995-like conditions can be replicated at any time.



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.

This is not easy work, but is made easier by the fact that this animal has two immobile life stages, the eggs and the sessile nymphs. By marking the specific locations of eggs and nymphs in the field, we are able to track and document the timing and type of death experienced by each whitefly, as well as those that do manage to survive.



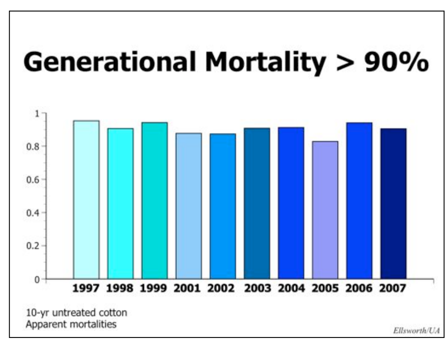
Examples of what can be found and identified in the field. Parasitism on the left; Predation on the right (evacuated cadavers) and a living whitefly nymph in the middle.

Eretmocerus nr emiratus, Encaria sophia and early parasitism

Encarsia sophia and Eretmocerus nr. emiratus (exotics), which replaced Eret. eremicus; other natives: Enc. meritoria and Enc. luteola.

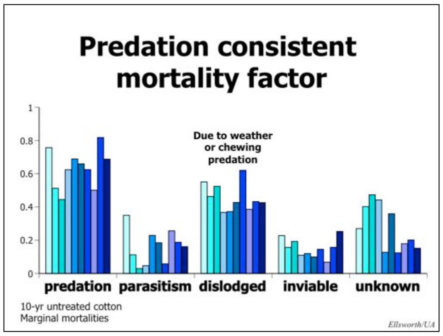
There are also natural features of our climate that contribute to mortality. Haboobs are massive dry dust storms that sweep across our landscape and literally scour plant surfaces and can effectively remove anchored eggs and nymphs from leaves.

In 2011, a particularly large and well-organized haboob made the international news as it hit the city of Phoenix.



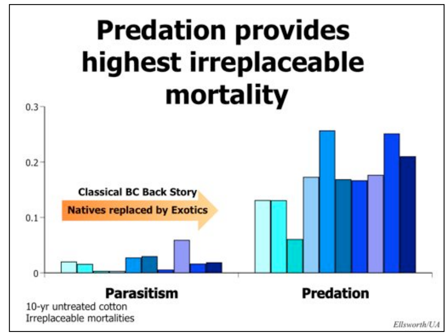
From our life table studies, we can examine the apparent mortality rates for whitefly generations over time. There are two striking aspects to these data. First, mortality is naturally very high in unsprayed cotton, usually in excess of 90%. Second, there is little variation over time. These effects are quite stable.

These are apparent mortalities for 1 generation of whiteflies on untreated cotton for each year.



We can also partition this mortality into its source components and examine marginal mortality rates. Quickly we can see the importance of predation in each year. We also can note here that "dislodged" or the disappearance of whiteflies from leaves can be sourced to either weather (e.g., the haboobs we reviewed) or to chewing predation like coccinellids or Collops beetles.

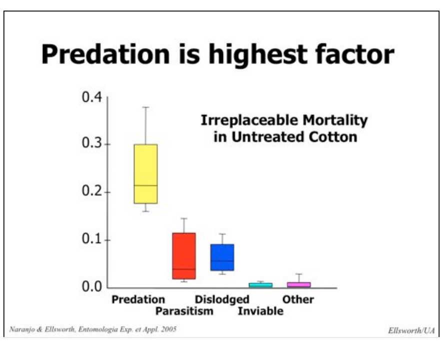
These are marginal mortalities by source factor in untreated cotton.



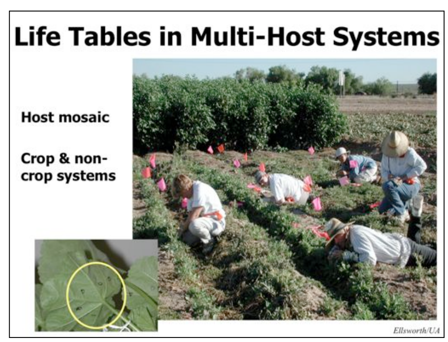
We can also mathematically calculate irreplaceable mortalities, or that mortality which otherwise would not occur if not for that factor. In this analysis, predation is always the most important mortality factor. In fact, parasitism produces very little irreplaceable mortality and is a relatively minor component of our system.

In fact, there is a whole back story that involves the exploration, discovery, and introduction of parasitoids in the 1990s in a classical approach to biological control. However, our data would suggest that all we have managed to do is replace the native suite of parasitoids with an exotic complement of parasitoids without any great overall effect on Bemisia mortality in cotton.

These are irreplaceable mortalities for parasitism & predation in untreated cotton.



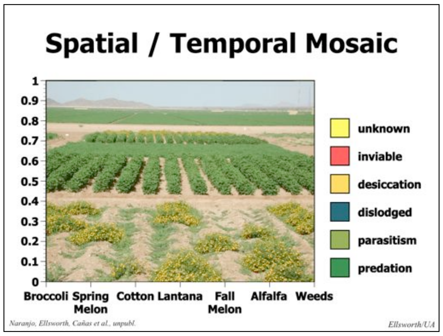
For whiteflies in cotton, predation is by far the most important mortality factor. These are results from 14 generations measured over multiple years. The remaining factors are not nearly as important. Incidentally, despite major changes, if not, wholesale species replacements over the last decade, parasitoids exert very little irreplaceable mortality. Here, too, a portion of 'missing' is due to chewing predation (& part to haboobs).



We have also established host mosaics and examined whitefly mortality dynamics in multiple crop and non-crop systems.
Here the crew is marking the locations of a new cohort under study in a spring weed system.

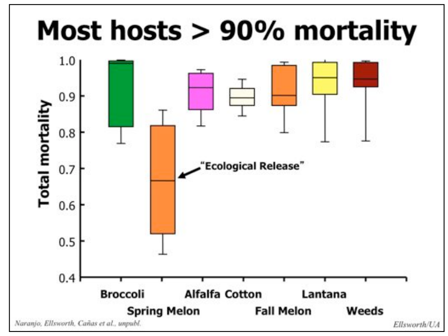
Individuals are marked on the undersides of leaves and then revisited regularly to determine the fate of each insect.

Crew establishing a ***B. tabaci*** cohort in ***Sonchus asper***.

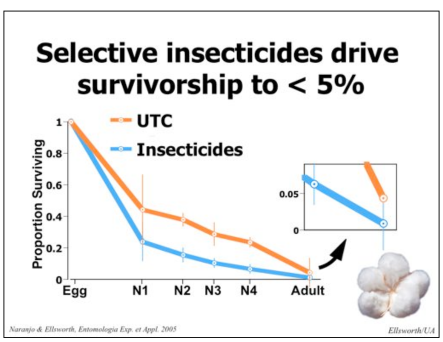


This spatial / temporal mosaic of hosts included in approximate seasonal order: winter broccoli, spring melons, summer cotton, perennial lantana (a common ornamental plant), fall melons, perennial alfalfa, and both summer and winter weeds.

We examined mortality dynamics in all these systems over a 3-yr study with a former post-doc, Dr. Luis Cañas.



Looking at total Bemisia mortality over a wide range of untreated crop and non-crop hosts in Arizona, we see once again very high and very similar rates of natural mortality except in spring cantaloupes, which are subject to much less natural mortality and as a result serve as an "ecological release" of Bemisia in our system.



Looking at 14 summer generations of whiteflies in untreated cotton, 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 the 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.

This use of selective insecticides to leverage a strategic piece of irreplaceable mortality is what is at the heart of the Integrated Control Concept as proposed by Stern and his colleagues more than 50 years ago…

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

Ellsworth/UA

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.

Selective Insecticide

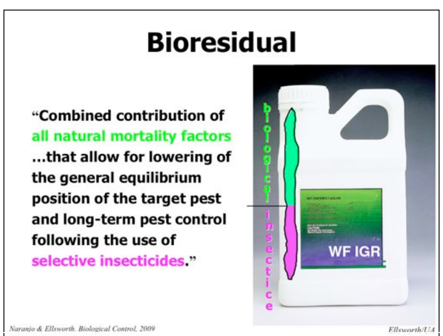
"Chemical control should act as a complement to the biological control."

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. *80 million lbs of DDT used in 1959 Ellsworth/UA

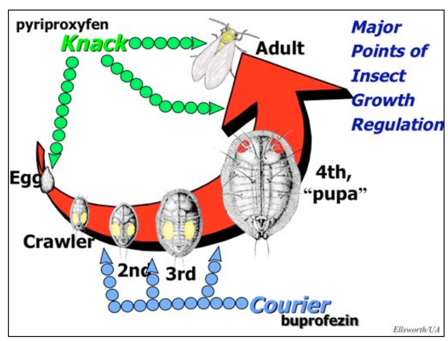
At the heart of Stern's paper, they make several important, simple, and straight-forward statements about chemical control. Namely, chemical control should complement biological control; and the two tactics should be made to augment one another. Within the ICC there is this pervasive idea that an insecticide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



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.

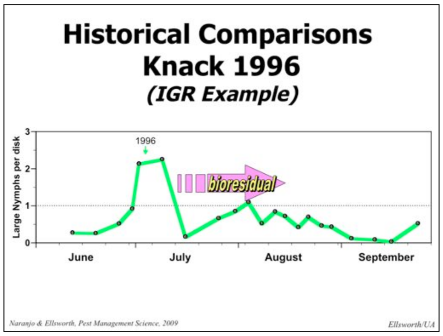
This has been a powerful metaphor for explaining why one might refrain from mixing IGRs with less selective materials. I.e., it is tantamount to dumping out half of the contents of the IGR jug.

We have coined this term "bioresidual" to better communicate and to contrast with chemical residual.

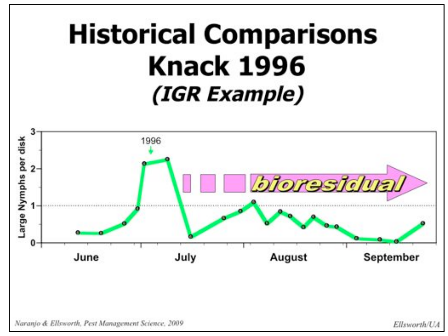


Pyriproxyfen is a juvenoid, a juvenile hormone mimic, that does not kill adults outright -- neither IGR does this -- however, Knack sterilizes adult females and developing eggs prior to blastokinesis. Knack may also prevent metamorphosis. Buprofezin is entirely different chemistry structurally and functionally.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

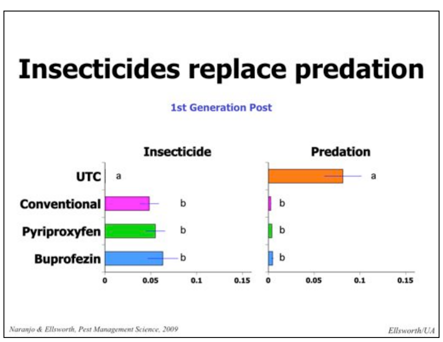
Both of these IGRs are selective in our system, ultimately killing only our target pest, the whitefly.



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 the most, 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.

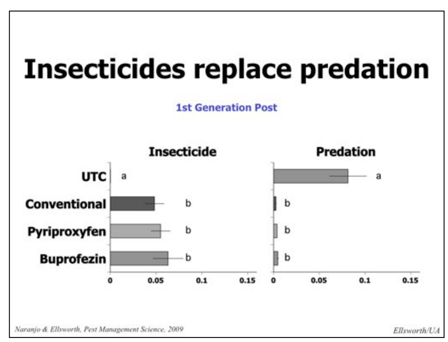


This "bioresidual" is of varying duration, as would make sense for something so dependent on the dynamics of the ecological system. Many times and in many locations this bioresidual last several weeks at least. However, most of the time, and assuming no other disruptions, this bioresidual can last season-long in the suppression of whitefly populations below threshold.

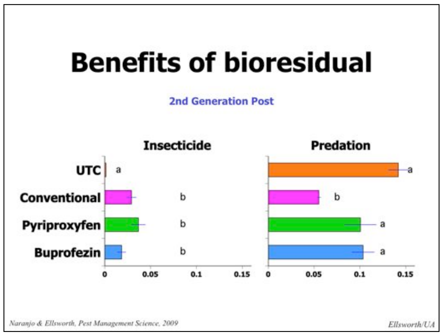


We examined patterns of irreplaceable mortality in selective vs. conventional systems. The two major sources of mortality are insecticide & predation. No insecticide-related mortality was present in the UTC. But insecticide mortality is at similar levels for each compound during the first generation exposed to the sprays, regardless of type of insecticide. Predation was significantly higher in the UTC, as expected. Even though predation is present in the IGR regimes, it is replaceable by the insecticidal action of the IGRs. Predation hardly occurs in the conventional system.

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

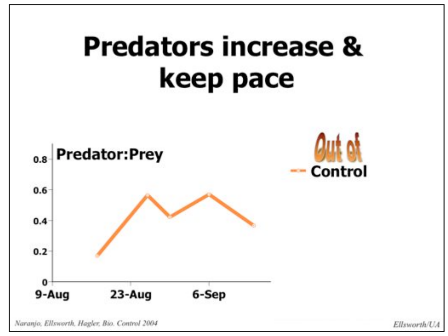


Things change as we advance our time step forward by one generation.

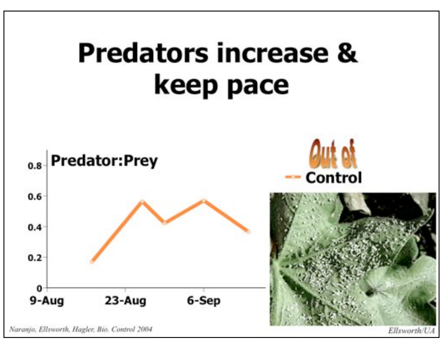


The 2nd generation after initiating sprays, we see that rates of insecticidal mortality are still present where insecticides are used, but lower than before. Residues are diminished. Irreplaceable mortality due to predation, however, grows substantially in the IGR regimes, but much less so in the conventional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

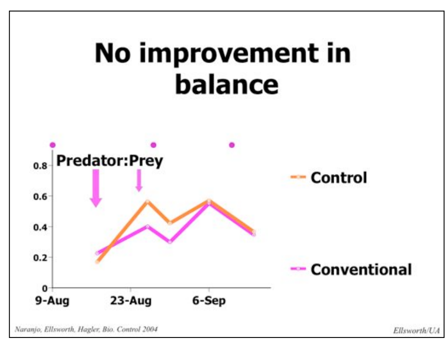
Thus, the bioresidual effect is starting to exert influence over the population, because predators in particular were selectively conserved in the IGR system.



Another way to examine the biological control in this system is through 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.

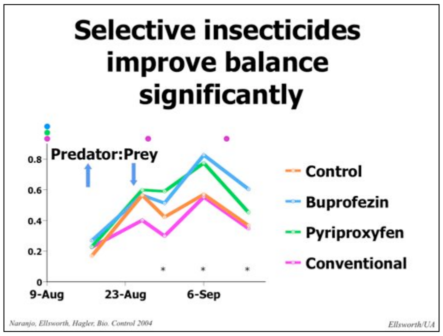


I prefer to think about our control as our out-of-control with respect to whitefly populations, i.e., something resulting in outbreak levels similar to in our movies of whiteflies.

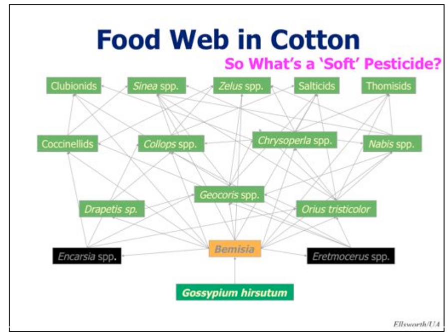


Conventional sprays served to lower prey densities, but predator densities as well. Thus, there is no improvement in the balance.

Whiteflies are in fact well-controlled by conventional chemistry but required 3 sprays to do so in this example and at a cost of reducing predators even more than whiteflies.

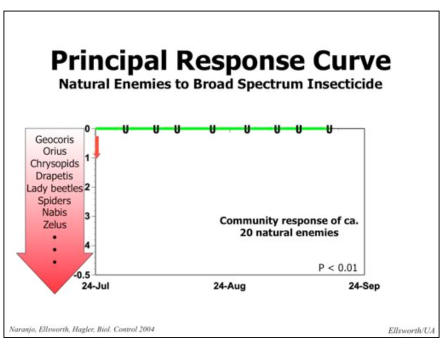


IGRs on the other hand not only reduce prey numbers, they conserve existing predator numbers and create a more favorable balance of predators to prey resulting in a more efficient control system that creates collateral benefits in regulation of other pests in the system. Only 1 IGR spray was needed.



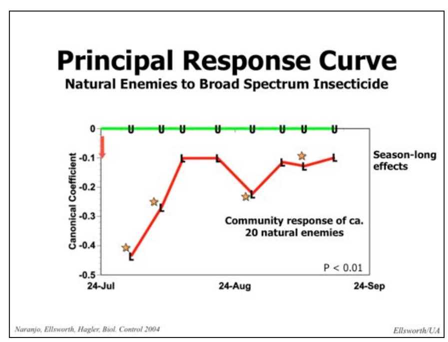
So what makes this story even more interesting is the interrelationships among generalist predators that make up the Bemisia-Cotton food web. With so many players, it becomes difficult to ascribe the biocontrol potential to any single species or group of species. Note these are mostly generalist predators who spend time feeding on each other as well as on pest insects besides Bemisia.

And, we've seen the benefits of a selective insecticide. So "What's a 'Soft' Pesticide?" I honestly don't know and don't like much the term "soft pesticide". Soft water can be defined and measured. Soft pesticide is like calling something "green" these days. And these days, what technology is advanced that doesn't lay claim to being "green" or pesticide that doesn't lay claim to being "soft"?

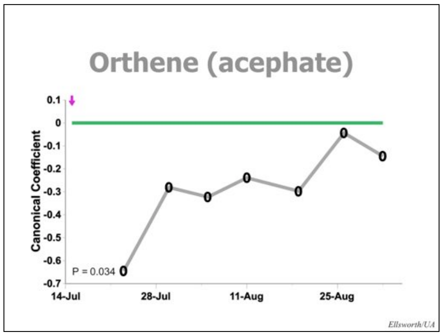


One way to validate a selective approach is to measure and analyze whole community responses. Thanks to a Dutch group that developed the methodology, we can use a multivariate, time-dependent, analytic approach that is represented graphically in Principal Response Curves. In this example we can see the 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…

U = UTC = Untreated check (testigo sin tratar)

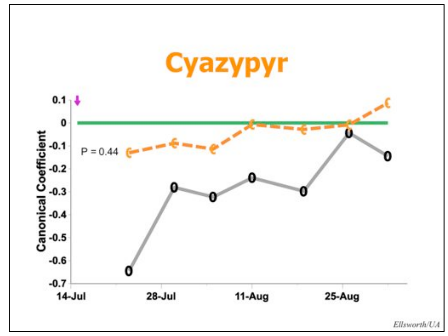


…What we see is a dramatic and immediate lowering of the density of these natural enemies in comparison to the UTC. What is more sobering is the duration and significance of this effect, all the way out to 7 weeks post-treatment. These season-long effects have grave consequences in the control of many 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. And, the decision to use a broad spectrum insecticide in cotton any time during the season, let alone as an early season spray, should be taken very seriously with these consequences well in mind.

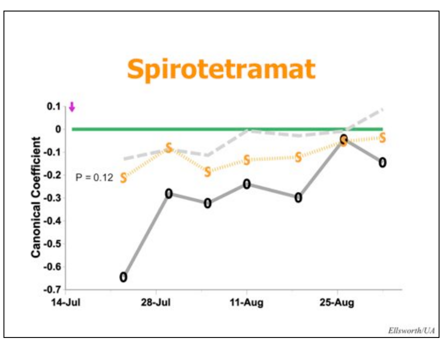


So our program continues to examine the selective attributes of each major insecticide developed for our system. In this example we see the familiar pattern of negative impacts on the natural enemy community after a single spray of acephate relative to the green-line UTC.

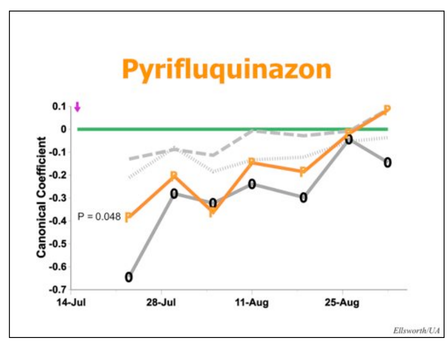
Orthene when used just once is highly destructive to the NE community present in our cotton system.



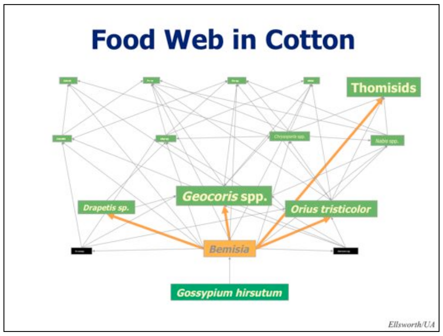
Cyazypyr, under development by DuPont, is not significantly different from the untreated check, suggesting excellent safety for our NE community.



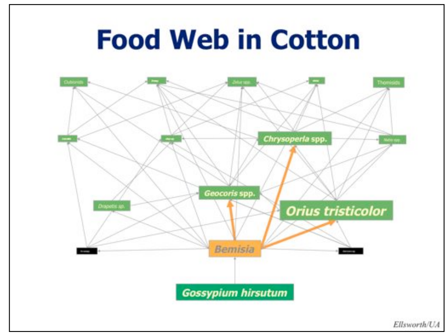
Spirotetramat or Movento under development by Bayer also appears to be quite safe to our NE community.



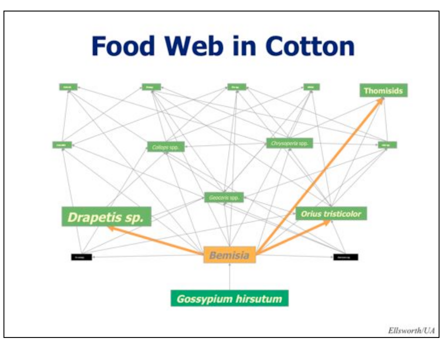
Pyrifluquinazon, while very effective against *Bemisia* whiteflies, appears to be more damaging to the NE community, though not nearly as much as acephate (Orthene). These negative impacts appear to be driven largely in the first 3 weeks post-application.



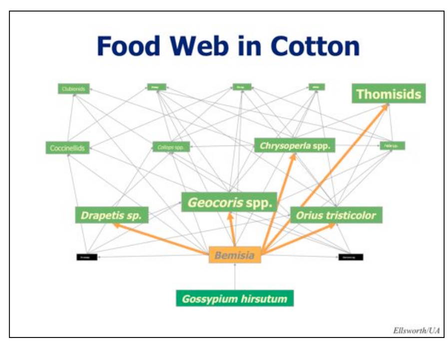
For the total relationships shown, there are a set of species weights. Here I have represented these weights by sizes of their labels in the food web. In this particular year for the cotton-whitefly system, we can see that there are 4 species that dominate the PRC for that year and location.



However, in this year and location, these three species are driving the PRC.

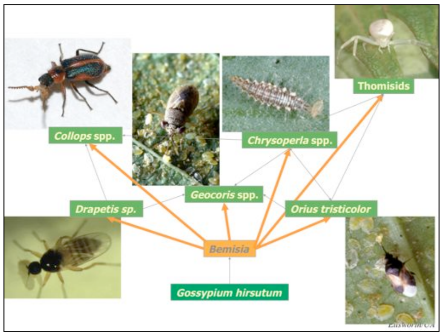


And a different set of 3 species in this year.



And 5 species dominated the PRC this year.

So this is a testament to the resiliency and flexibility of a complex food web that has multiple membership by generalist predators. Each year, each location might be more or less affected by any number of predators. This is also why studying single species or very small species assemblages in lab or caged studies are less informative of the dynamics that really play out in the cotton system.



Over many years of intensive field study, Naranjo and I have found that most often one or more of these six predators dominated the relationship between whiteflies and their predation.

A small empidid fly that feeds exclusively on whitefly adults (not eggs or nymphs).

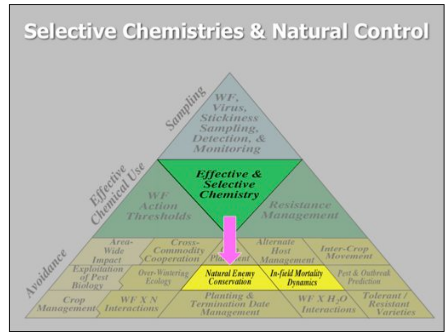
Collops beetle.

Big-eyed bugs.

Lacewings.

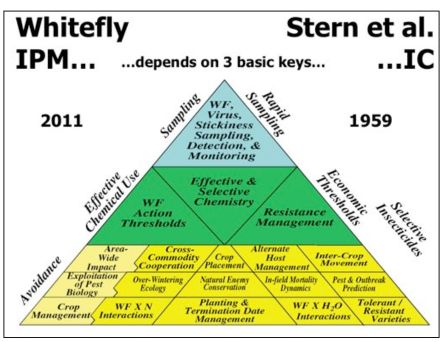
Crab and other spiders.

Minute Pirate bugs.

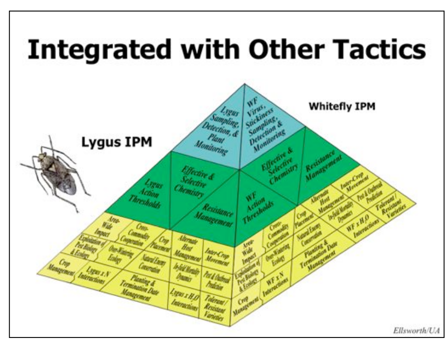


So our management system has evolved into a highly refined system of management where remedial chemical controls should be both effective and selective. In AZ, we have shown that when selective options are available and effective, huge gains in both target and collateral control can be achieved due to 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.

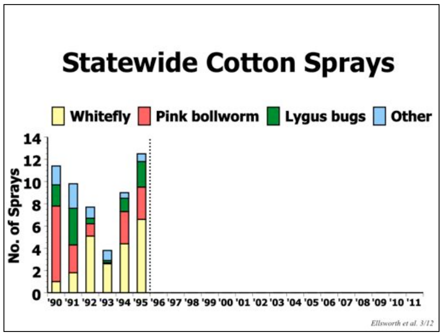
And this combination of tactics, chemical and biological control, was exactly what was suggested by Stern and colleagues over 50 years ago.



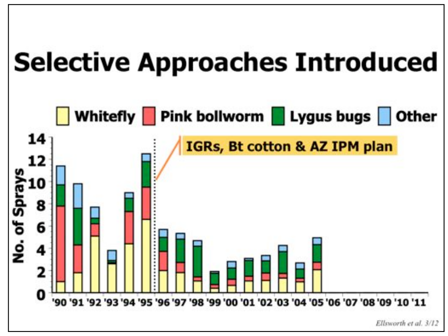
Our overall management system for whiteflies in Arizona cotton today depends on sampling, effective chemical use all laid on a foundation of avoidance. While this involves many ideas and aspects in Integrated Pest Management, there is great similarity to the 3 basic steps that Stern and colleagues suggested were needed to accomplish Integrated Control: Rapid Sampling, Economic Thresholds, and Selective Insecticides.



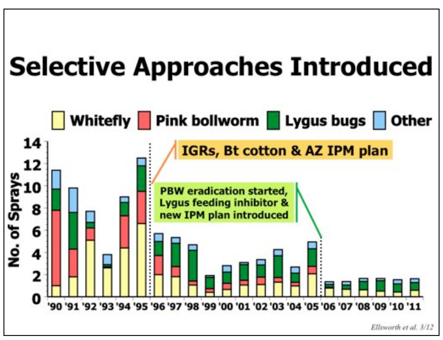
At the same time, we have never lost sight of the fact that management is rarely possible on just a single species or pest group. Our whitefly program is very much integrated with the management of the other major pests of cotton, each a facet on this Rubik's cube like management structure.



Let's review the history of deployment of selective tactics against key pests in our Arizona system. It is a striking history, where we can see the no. of foliar insecticides used to control each of 3 key pests over time, whitefly, pink bollworm and Lygus bugs.

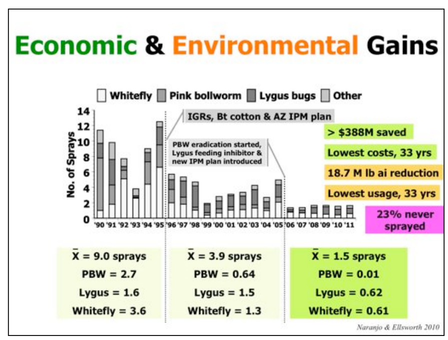


The results have been striking. A watershed of change occurred in 1996 with the introduction of very safe and selective Insect Growth Regulators (IGRs) for whitefly control, and transgenic Bt cotton, along with an IPM plan for whitefly management and comprehensive outreach campaign that consisted of extensive grower and pest manager education.



More recently, growers in collaboration with state agencies began PBW eradication in 2006. At the same time, we introduced flonicamid (Carbine) in 2006 as our first fully selective control agent, a feeding inhibitor, for Lygus, and a new IPM plan to support this management system.

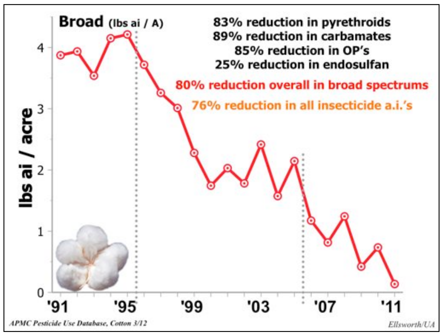
Adapted from Naranjo & Ellsworth 2009.



If we draw out information from these critical periods, we can see rather dramatic declines in overall insecticide use, as well as huge declines in PBW, Lygus and whitefly sprays made by growers.

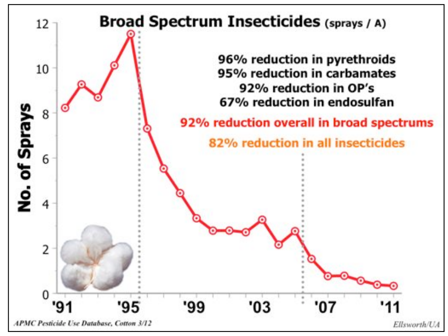
At one time, we averaged 9 sprays. Our 1996 programs cut that by more than half to ca. 4 sprays, and our 2006 programs have cut this by more than half again to just 1.5 sprays. In the process we are in the lowest foliar insecticide control costs in history, we're spraying less than at any time in history, and have saved growers cumulatively over $388M in 2011 constant dollars and prevented nearly 19M lbs of insecticide ai from reaching the environment.

On average today, ca. 23% of our acreage is never sprayed for arthropods, something we never thought would be possible on a single acre 20 years ago.



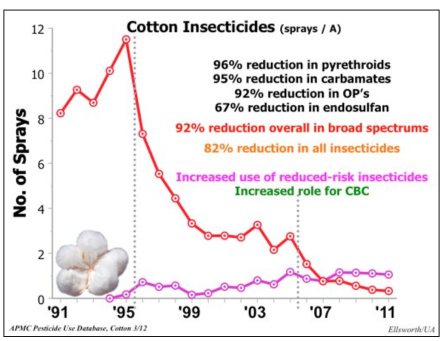
As impressive as these gains are, what has been key has been the shift away from broad spectrum insecticidal inputs. We've seen huge reductions in pyrethroid, carbamate, OP, and endosulfan usage, with an overall reduction in lbs ai / A of 80% in broad spectrum inputs.

1990-1995 v. 2006-2011



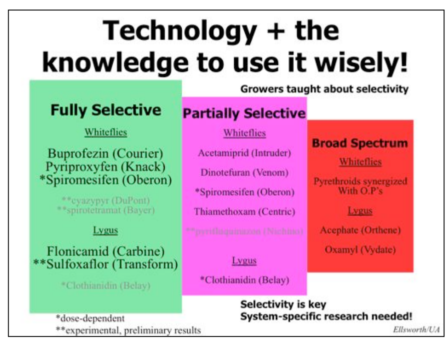
These are the data from the same source indicating the number of sprays made of broad spectrum insecticides. We have reduced all insecticide usage by more than 80% and broad spectrum usage by more than 90%.

1990-1995 v. 2006-2011



These gains were accomplished by the comprehensive IPM programs enacted in 1996 and progressively improved since with major changes to our Lygus control system in 2006. Furthermore, this was enabled by the strategic introduction of selective technologies into our system, and now we see the usage of reduced-risk insecticides out numbering broad spectrum insecticides. Most importantly, this has created opportunity for an ever increasing role for conservation biological control.

1990-1995 v. 2006-2011



So we teach growers not only the efficacy of key insecticides but their selectivity in our system. We place all chemistry into one of three boxes and encourage growers to use fully or partially selective insecticides, if needed and whenever possible.

The key message here is that our goal is to avoid the pitfall of "unbridled use of technology" and instead develop technology side-by-side with the information and knowledge needed for growers to use it wisely. These studies are specific to our system and one cannot infer safety or selectivity for these technologies just anywhere. So these types of studies will become more and more important as other systems attempt to renovate their IPM programs.

NOTE: Data for Transform are based on a single study, small plot study (2009). Belay in "fully selective" <u>and</u> partially selective box is tentative and preliminary, until further studies are analyzed.

American Innovation

"Over the past decade or longer, U.S. innovation stalled in almost every sector except information technology and agriculture, say scholars who study innovation…. the nation's agriculture productivity has raced ahead of the rest of the world."

Washington Post 1/28/2011

So a few days after Obama's State of the Union in 2011, many onlookers noted his emphasis on American innovation. However, scholars in this area are critical of our innovation. There are few sectors where the U.S. leads the world…

Agriculture, however, has been exceptionally important in not only feeding the world but in helping local state economies through these most difficult of times. Arizona is no exception. Without the billions in economic activity that agriculture represents, our state's economy would be much, much worse off.

American Innovation

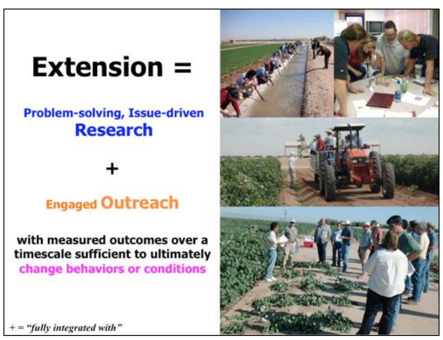
"Innovation scholars point to a 'valley of death' where new technologies go to die. The federal government funds basic research. Private industry commercializes technologies springing from that work. But crossing the chasm between the two can be hugely difficult."

Washington Post 1/28/2011

The article goes on to say…

I would like to focus my final comment on this hugely difficult chasm. It is my contention that this is where Cooperative Extension plays a unique role in our society, because we develop technologies in partnership with industry and most importantly we develop the knowledge to use that technology wisely helping to insure its safe and successful introduction into society. These are the often unseen and unmeasured benefits of Cooperative Extension to society.

And because "Extension" appears in different brands around the U.S., I will conclude with what is my own working definition of Extension at least as it is practiced in Arizona.



Extension is problem-solving, issue-driven RESEARCH that is fully INTEGRATED with ENGAGED OUTREACH with measured outcomes that result in changed behaviors or conditions.

Thus, Cooperative Extension is part research enterprise. Our research is less question-driven and more issue-driven. But it is the full integration with organized programs of engaged outreach that make us unique among University functions and in a society made up of others who "improve people's lives".

Our work spans a timescale that permits a continuity of enduring programs and with the ability to measure outcomes and impacts.

Thank you for your attention and thanks to the organizers for this opportunity for us to share our story of successful IPM in Arizona cotton.

Thanks, too, to the many growers, pest control advisors and others who collaborate to make this such a successful program.

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, *(http://cals.arizona.edu/crops),* including a copy of this presentation.

Photo credit: J. Silvertooth