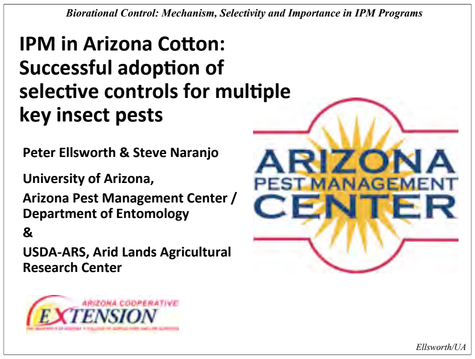
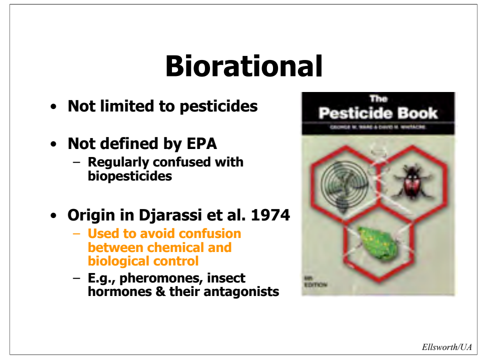



This is a story that we have told before: in different venues, and to different audiences. However, it is a significant success story, and I wanted to take the opportunity to focus this rendition around the basic theme of this symposium, which is biorational control in IPM programs. My co-author, Steve Naranjo, and I have been working for more than 15 years in this system and on the elements I will describe.

Invited symposium talk, 20 min.







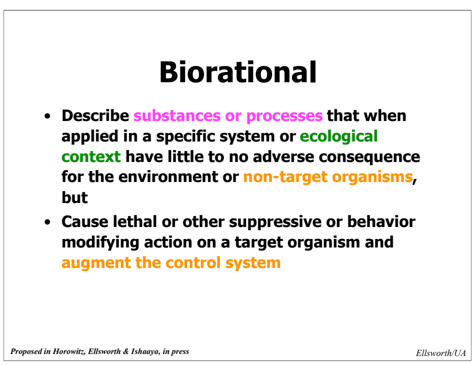

But before we talk about "biorational" control, the subject of this symposium, it is important to consider the origin and perception of this term currently. Biorational, while often used with "pesticides", should not be confined to that usage. Any practice or process could be biorational.

EPA does not define the term, but it is most often confused with biopesticides or pesticides of natural origin; this was Ware's approach in an otherwise authoritative volume on pesticides.

The first usage of the term in the literature was by Djerassi in Science. He gave examples, but did not define the term. His main goal, interestingly was to avoid confusion between chemical and biological control, the very place that biorational pesticides fit best.





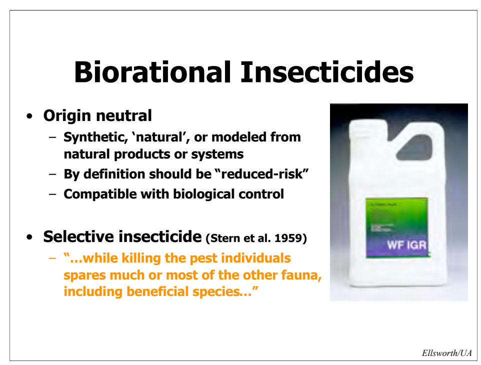



In a recently completed book edited by our session co-organizers, Isaac Ishaaya and Rami Horowitz, we had the opportunity to review the term and suggest some guidelines for its usage.

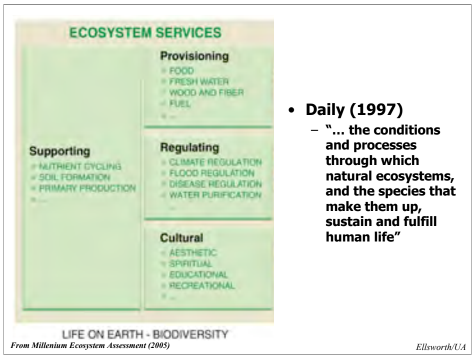
Here, we present a 2-part definition. In short, the substance or process should be relatively safe to non-target organisms and augment the control system.








Interestingly, this concept is consistent with Stern's definition of selective insecticide from 50 years ago. It was this idea that there were these other classes of organisms besides pests that managers should be aware of: beneficial species and "other fauna". This is a precursor to conceptual developments that have been in vogue for the last 10-15 years, specifically "ecosystem services"...

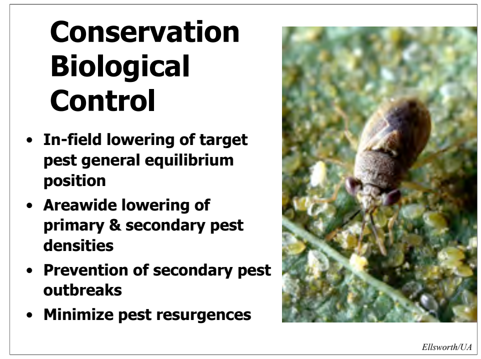



**Ecosystem services are quite simply defined as those things contained in our ecosystems that sustain our life.**

**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, regulating services are a 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.**

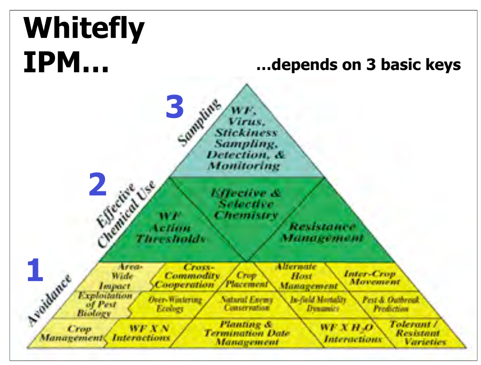




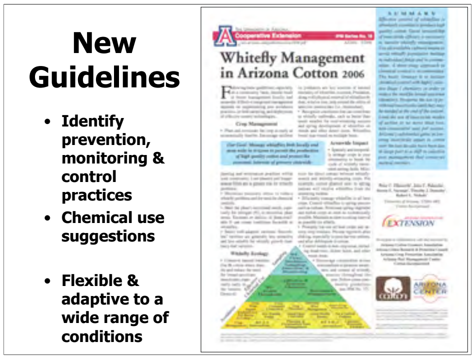

**The Millennium Ecosystem Assessment, which was completed on a global scale in 2005, concluded that pesticide use was diminishing these regulating services and in fact replacing pest control by natural enemies. It is precisely here where we need biorational pesticides more than ever. A well-designed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








**In this pyramid metaphor, we can see the detailed elements that were put into place starting in 1996 with the final and most crucial element added, effective AND selective chemistry. 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 element relevant to the biorationality of the strategy.**

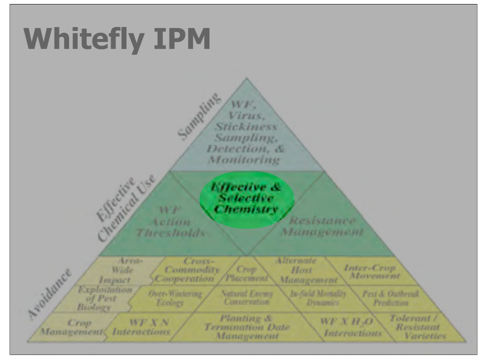



**These cotton guidelines were first introduced in 1996 and have been refined ever-since, including a revision and this re-issuance in 2006.**

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



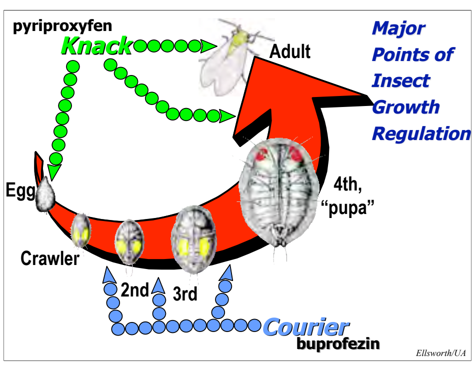





**Central to our IPM plan is effective & selective chemisty. Installing and validating this building block of our plan was critical to our strategy.**





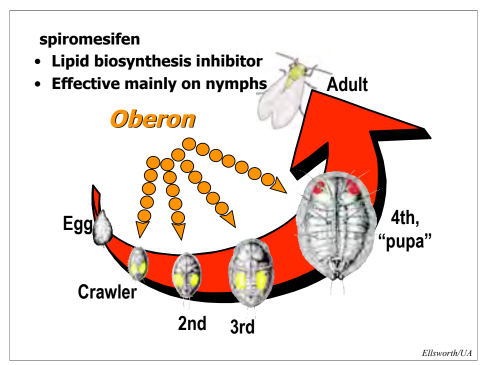



**Pyriproxyfen is a juvenoid, a juvenile hormone mimic, that does not kill adults outright -- neither IGR does this -- however, Knack sterilizes adult females and developing eggs prior to blastokinesis. Knack may also prevent metamorphosis. Buprofezin is entirely different chemistry structurally and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

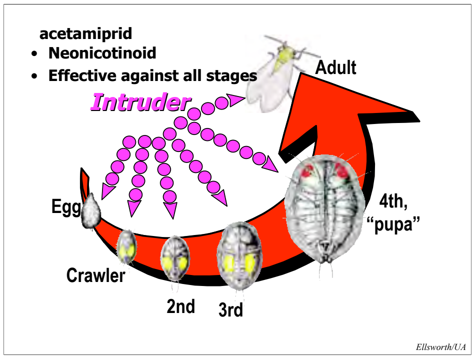
**Both of these IGRs are selective in our system, ultimately killing only our target pest, the whitefly.**








**Spiromesifen is a lipid biosynthesis inhibitor, also with very little direct adult activity, and major affects on younger nymphs.**

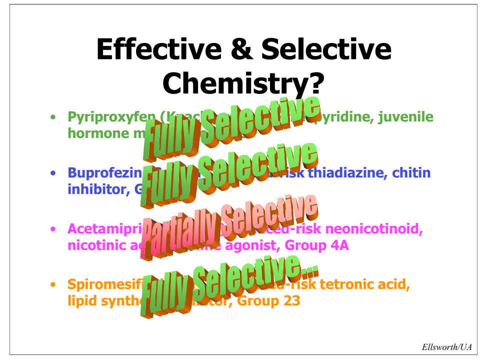



Acetamiprid is arguably biorational, largely through the differential sensitivity of the nicotinic acetylcholine receptor between arthropod and mammalian systems.

Producers have made this the number one whitefly insecticide largely because of its excellent adult activity and acropetal systemic action.





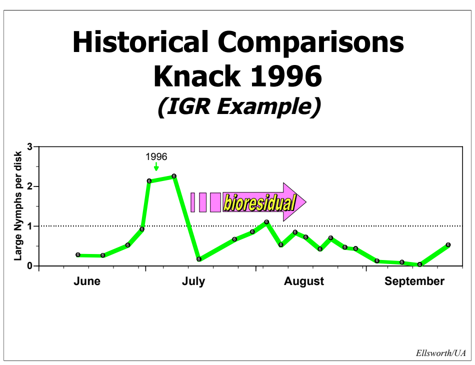



So where do we stand with our 4 best, most effective chemistries when it comes to selectivity. Knack, at least in our system (AZ cotton), is fully selective. Courier (or Applaud), too, is fully selective. Intruder (or Assail, a neonicotinoid) is in fact not selective. It is highly effective, but actually 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 is an open question but our results so far suggest rate-sensitive selectivity with whitefly effective rates acting fully selectively and higher miticidal rates acting somewhat less selectively.



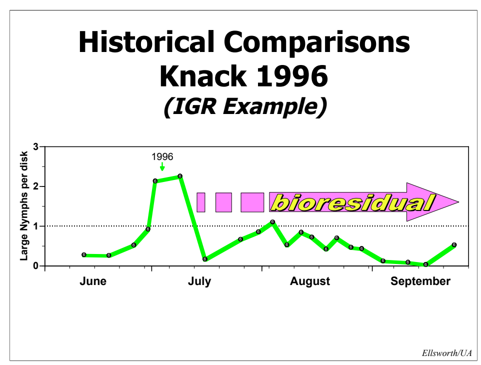




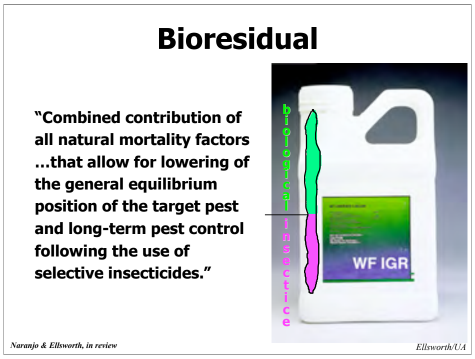

Our IGRs are the classic example of selectivity in action. We've been running commercial scale demos for years. In this one example with Knack in 1996, we can see that we reached threshold (1 large nymph per disk or 40% infested disks), sprayed, densities continued up for a time, and then the population crashed. 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. We term this extended suppressive interval present in a selective system, "bioresidual".

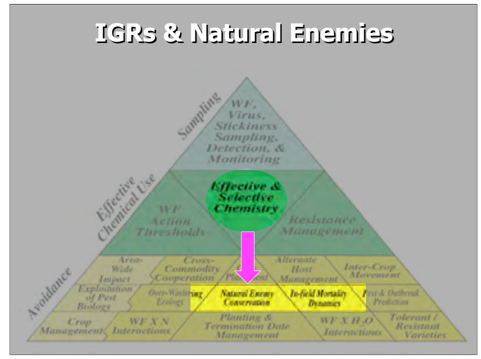



**Specifically, we define bioresidual as follows:…**

**In teaching this concept to growers, I sought out yet another 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 is 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.**



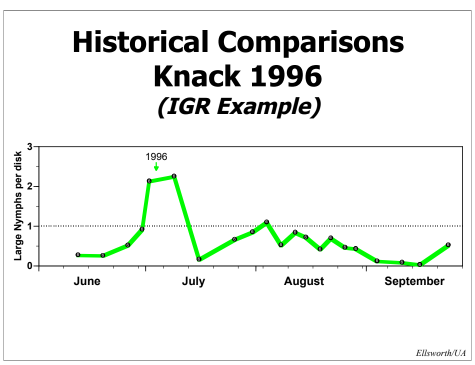





**Central to remedial tactics is an effective chemical arsenal. In AZ, we have shown that when selective options are available and effective, huge gains in both target and collateral control can be achieved due to much better natural enemy conservation and other natural mortalities. This ecosystem service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



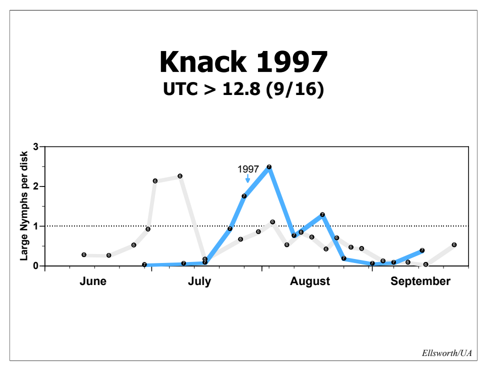





**Drawing out this example further…**



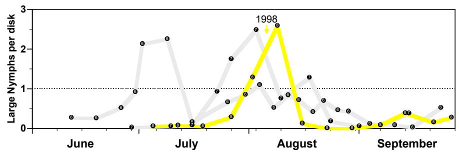





**Note that starting in 1997, we had replicated UTCs available. Note as I step through each year how the maximal population densities in the UTCs change each year; however, the pattern of control through this IGR remains consistent.**

# Knack 1998

**UTC > 3.0 (8/10)**

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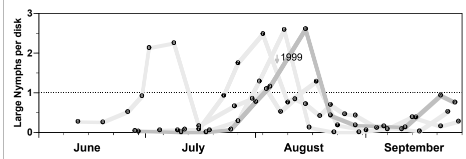
# Knack 1999

**UTC > 3.3 (8/16)**

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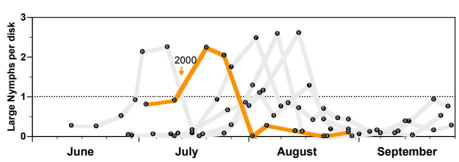
# Knack 2000

**UTC > 10.6 (8/3)**

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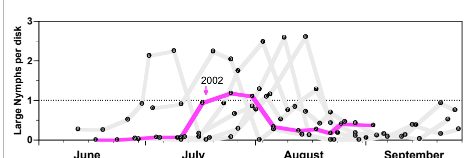
# Knack 2002

**UTC > 6.4 (9/18)**

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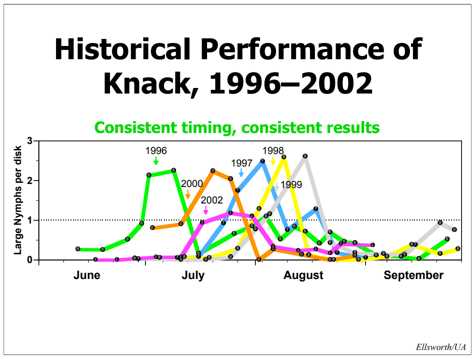
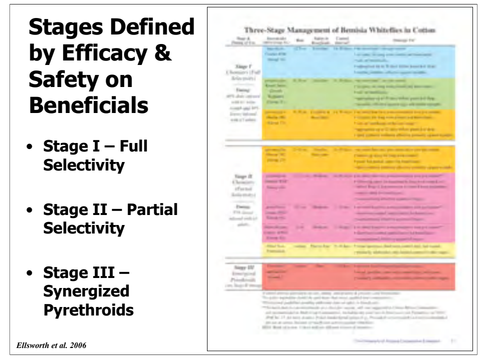



On average over the last 13 years, growers have sprayed whiteflies in cotton just 1 time per season.



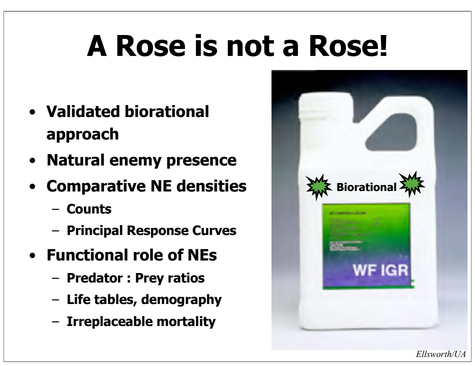





As part of our IPM program, a 3-stage chemical use plan identifies chemistry based on efficacy and selectivity attributes, with the ultimate goal of exploiting selectivity as much as is possible. It does not mandate a sequence but teaches growers that more selective approaches will create more effective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







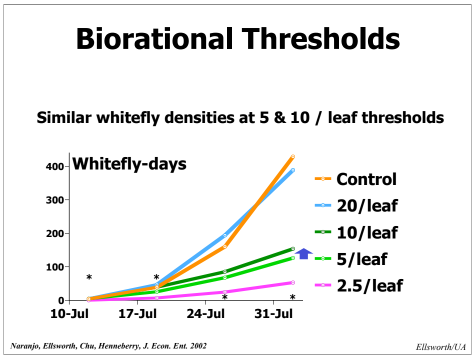

Designing and labeling a product as "biorational" is not sufficient to establishing its biorationality. Because it is subject to a specific ecological context, some effort must be made to validate the candidate approach or product in the system of interest. Thus, a product may be fully "biorational" within one environment and catastrophically disruptive in another.

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





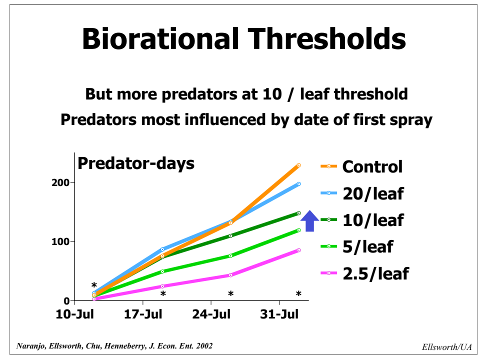

General observation can establish the presence and function of natural enemies. In this example, we can see two of the whitefly's flattened nymphs on the underside of a cotton leaf. Upon closer inspection, however, we can determine that in fact these nymphs are dead and have been evacuated by some kind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




**Processes and not products per se can be biorational. 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. Note 5/leaf is our current threshold for adults. However,...**



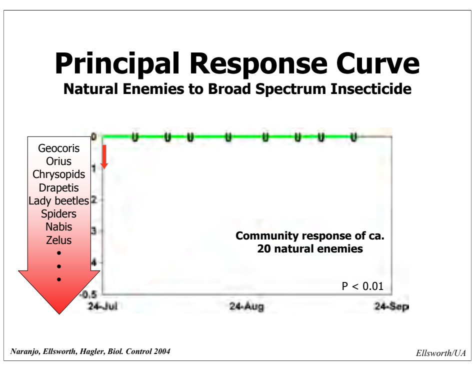





**Substantially more predators can be found in the 10/leaf threshold. In fact, in these studies, predators were most influenced by the date of first spray. So a more biorational threshold would be one that serves to delay the usage of a broad-spectrum insecticide.**



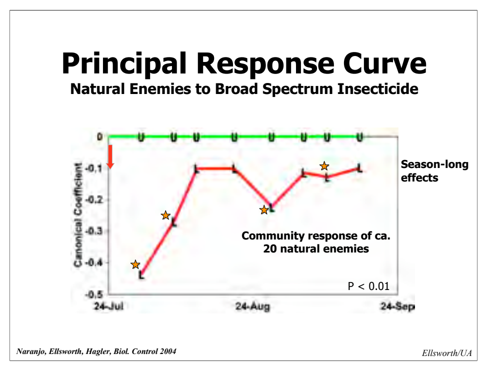




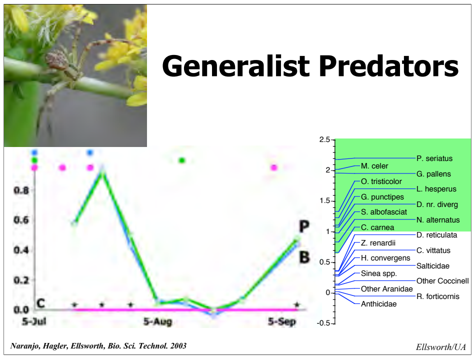

**Another way to validate a biorational approach is to measure and analyze whole community responses. We used a multivariate, time-dependent, analytic approach that is represented graphically in Principal Response Curves. In this example we can see the green 'U' line representing the UTC as a baseline 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...**







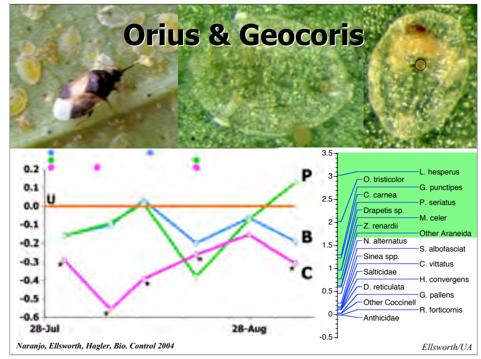

**...What we see is a dramatic and immediate lowering of the density of these natural enemies in comparison to the UTC. What is more sobering is the duration and significance of this effect, all the way out to 7 weeks post-treatment. These season-long effects have grave consequences in the control of 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.**



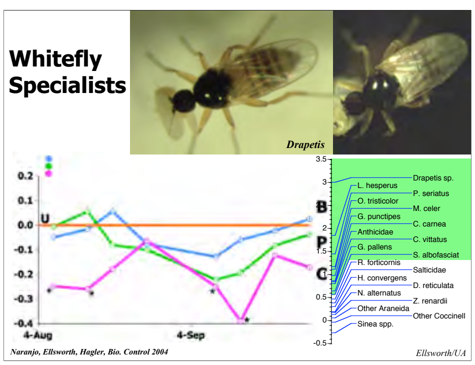





**In subsequent years, we ran very large scale replicated studies that included an untreated check, the orange baseline. Once again, however, the (C)onventional chemistry suppressed NEs for period that extended almost the entire season. The IGRs, on the other hand, rarely departed significantly from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





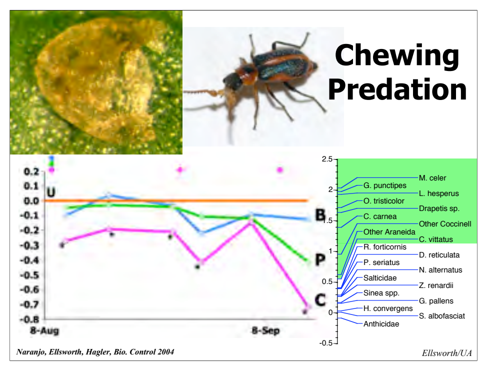



**In another example, an unusual predaceous Empidid fly, Drapetis, drove the overall PRC. This adult fly, while technically not restricted to whitefly prey, does seem to specialize on feeding on adult whiteflies. A related species is present in Israeli cotton where whiteflies are also a key pest.**

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

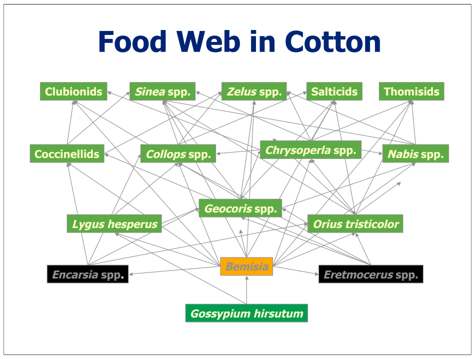







**Evidence of chewing predation is rarely seen because it results in the complete removal of the nymphal or egg stage whitefly. While Hippodamia is often present in cottonfields early in the season, Collops spp. beetles are far more common and more likely to be influential on whitefly dynamics, along 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.**

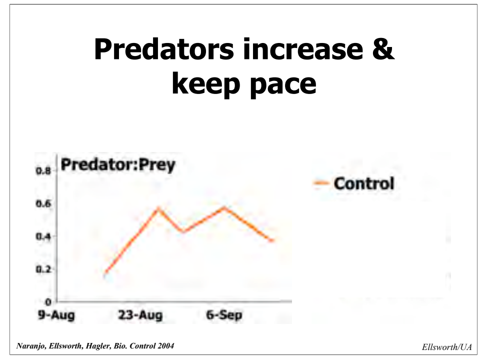



**The idea that different species dominate the PRC in different years or locations in AZ cotton is a remarkable testament to the complexity of the food web. Certain conditions may favor certain pathways in certain years and other pathways in other years. Yet the same, generally, level of natural mortality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

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



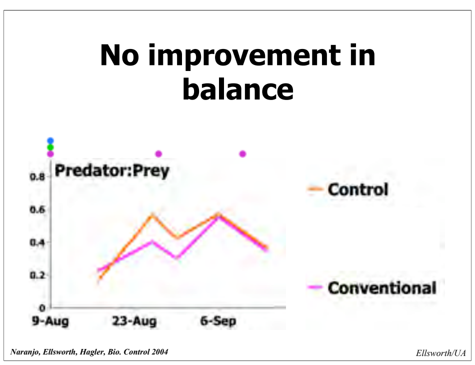





**One way to do this is to examine Predator:Prey ratios. In this example, all predators captured in 50 sweeps compared to all whiteflies per leaf in cotton. Here we see that predator numbers increase and stay level relative to prey numbers, which are increasing through this time period.**



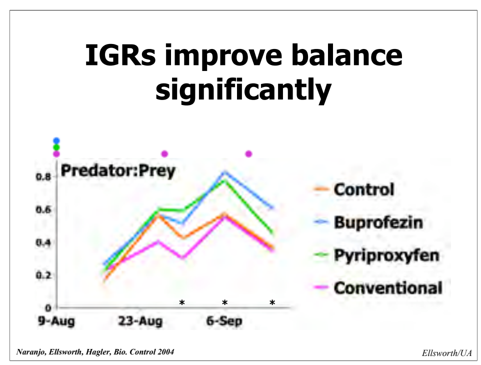





**Conventional sprays made serve to lower prey densities, but predator densities as well. Thus, there is no improvement in the balance.**

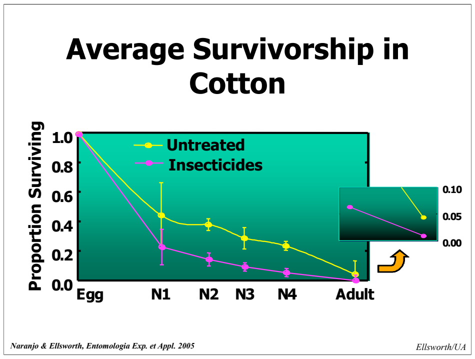







**IGRs on the other hand not only reduce prey numbers, they conserve existing predator numbers and create a more favorable balance of predators to prey resulting in a more efficient control system that creates collateral benefits in regulation of other pests in the system.**

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



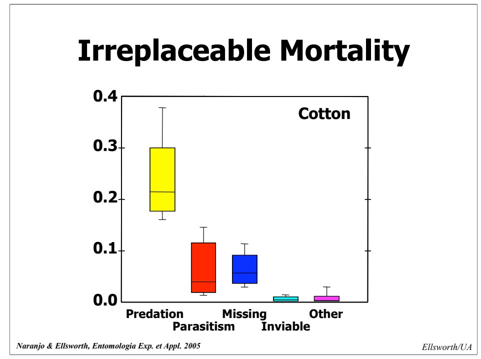

Steve and I examined 14 summer generations of whiteflies in cotton and constructed life tables. In untreated systems, whiteflies survived to adult at what appear to be very low rates. Rates that belie the explosive potential of this pest.

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

There is, however, a difference in survivorship. Bear in mind that 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.





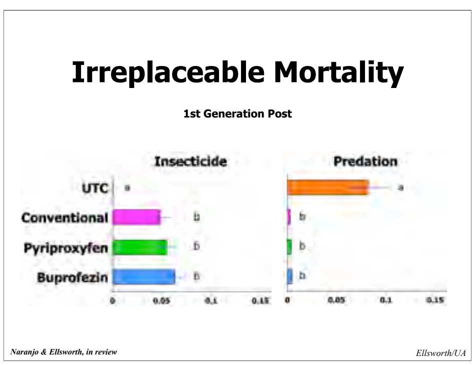



You can only die once! So even though one mortality factor can act to kill a whitefly like pyriproxyfen killing a large nymph, a predator can come along and then feed directly on the newly dead cadaver. Math allows us to estimate which factors are more "irreplaceable" or indispensible in untreated cotton and 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.



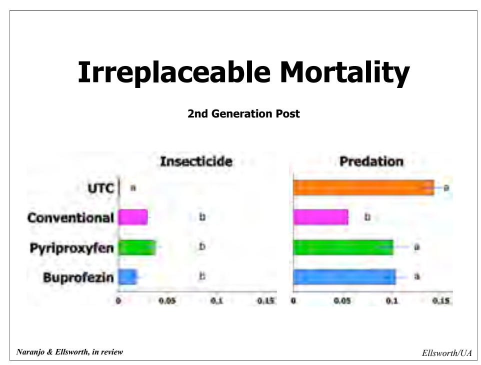





We examined patterns of irreplaceable mortality in selective vs. conventional systems. The two major sources of mortality are "insecticide" and predation. No insecticide-related mortality was measured in the UTC, but similar levels for each compound used in the first generation exposed to the sprays. 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.





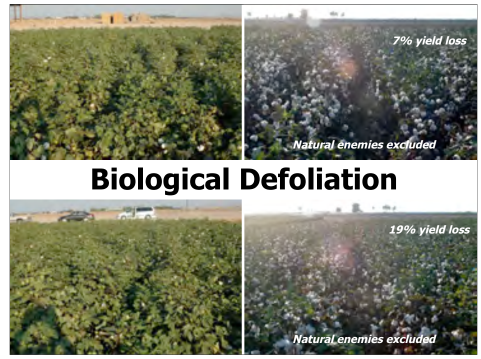



Looking at the next time course, i.e., the 2nd generation after initiating sprays, we see that rates of insecticidal mortality are still present where insecticides are used, but lower than before. Residues are diminished. Irreplaceable mortality due to predation, however, grows substantially in the IGR 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.


**Peter Asiimwe, our 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.**





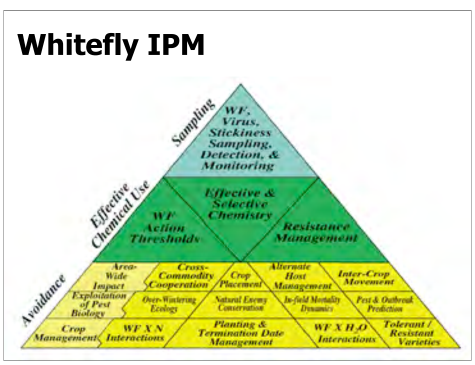



**Regardless of irrigation regime, there were major losses to whiteflies where NEs were excluded. These paired pictures were shot on the same day and show cotton that was biologically defoliated by this sucking pest. The cotton on the left was never sprayed for any pest and also had commercially unacceptable 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.**



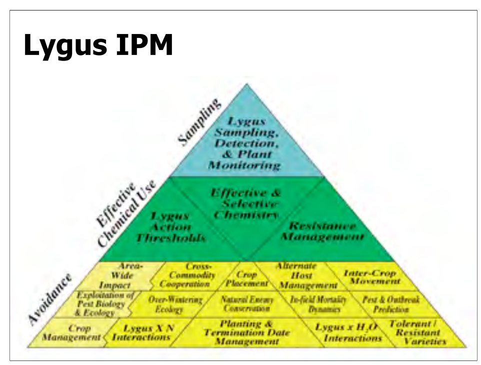




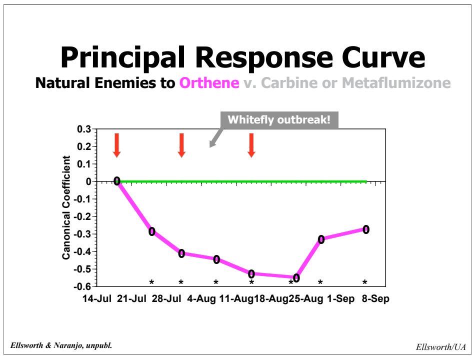

**Thus, our whitefly IPM system needs to be complementary with our other pest management systems…**







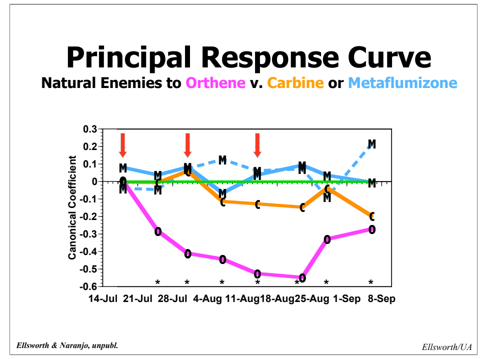

**Not surprisingly, the same key set of elements are necessary for management of Lygus. For decades, we have had “effective” control chemistry for Lygus, but no selective or biorational options until very recently.**




**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 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.**







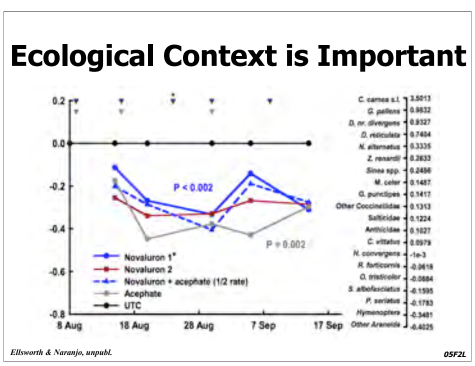

**Carbine or flonicamid (orange line) showed no significant declines in the NE community. Metaflumizone at its maximum rate and for two different formulations (blue lines) also had no impact on the NE community.**

**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 2007.**





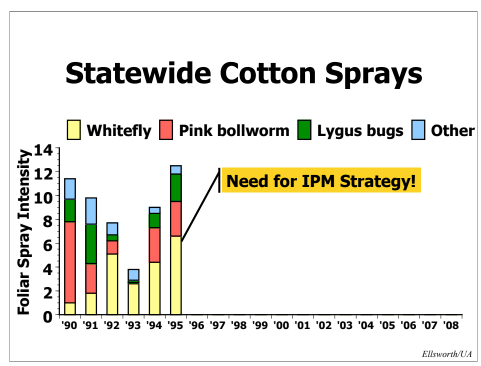



**Ecological context is critical to understanding the biorational potential of any approach. Novaluron, ostensibly an insect growth regulator, is actually quite a broad spectrum chitin inhibitor. In some systems, it may perform biorationally. However, by these measures and in our ecological context (the 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.**



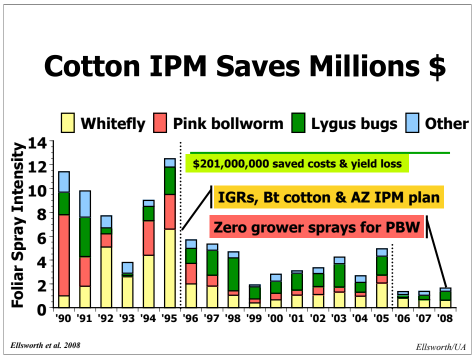





**The situation in the past was dire. Cotton growers were spraying 5-15 times to control an array of pests. Whitefly, Pink Bollworm, and Lygus bugs are our 3 key pests of cotton in AZ.**

**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).**



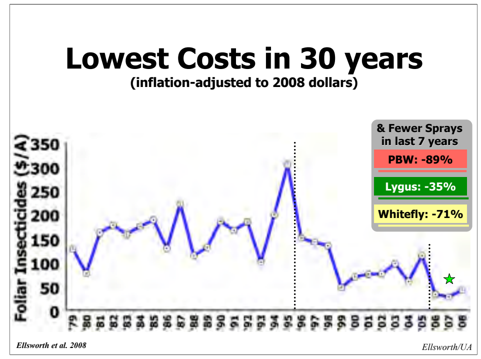

**The results have been striking. A watershed of change occurred in 1996 with the introduction of very safe and selective Insect Growth Regulators for whitefly control, and transgenic Bt cotton, along with an IPM plan for whitefly management.**

**More recently, state agencies began a 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.**

**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.**





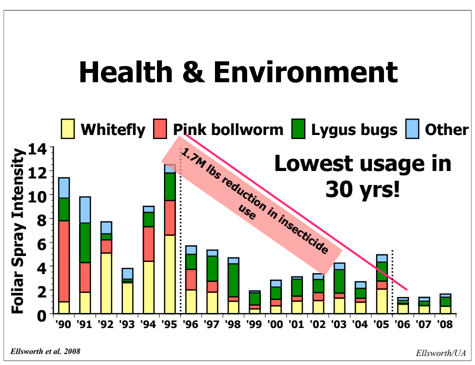



**Growers spent less on insecticides in 2007 than at any other time on record (30 years). Comparing the last 7 years to the 6 preceding the 1996 introduction of our new IPM plan, growers have sprayed far less than before. The average grower now sprays once or twice, with compounds that are relatively 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).**



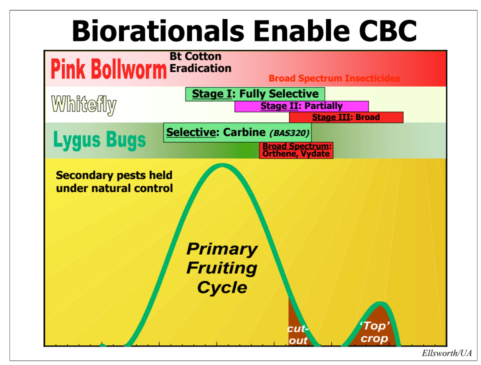





**The benefits extend to health and safety of workers on farm and the greater environment at large. Comparing our 30-year high in 1995 to our lowest usage in 2006, growers used 1.7 million lbs less insecticide!**








**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 currently registered "biorational" in flonicamid with another soon to become available. Cotton IPM in AZ has become an exceptionally well-developed and biorational system where conservation biological control is firmly established as key element.**