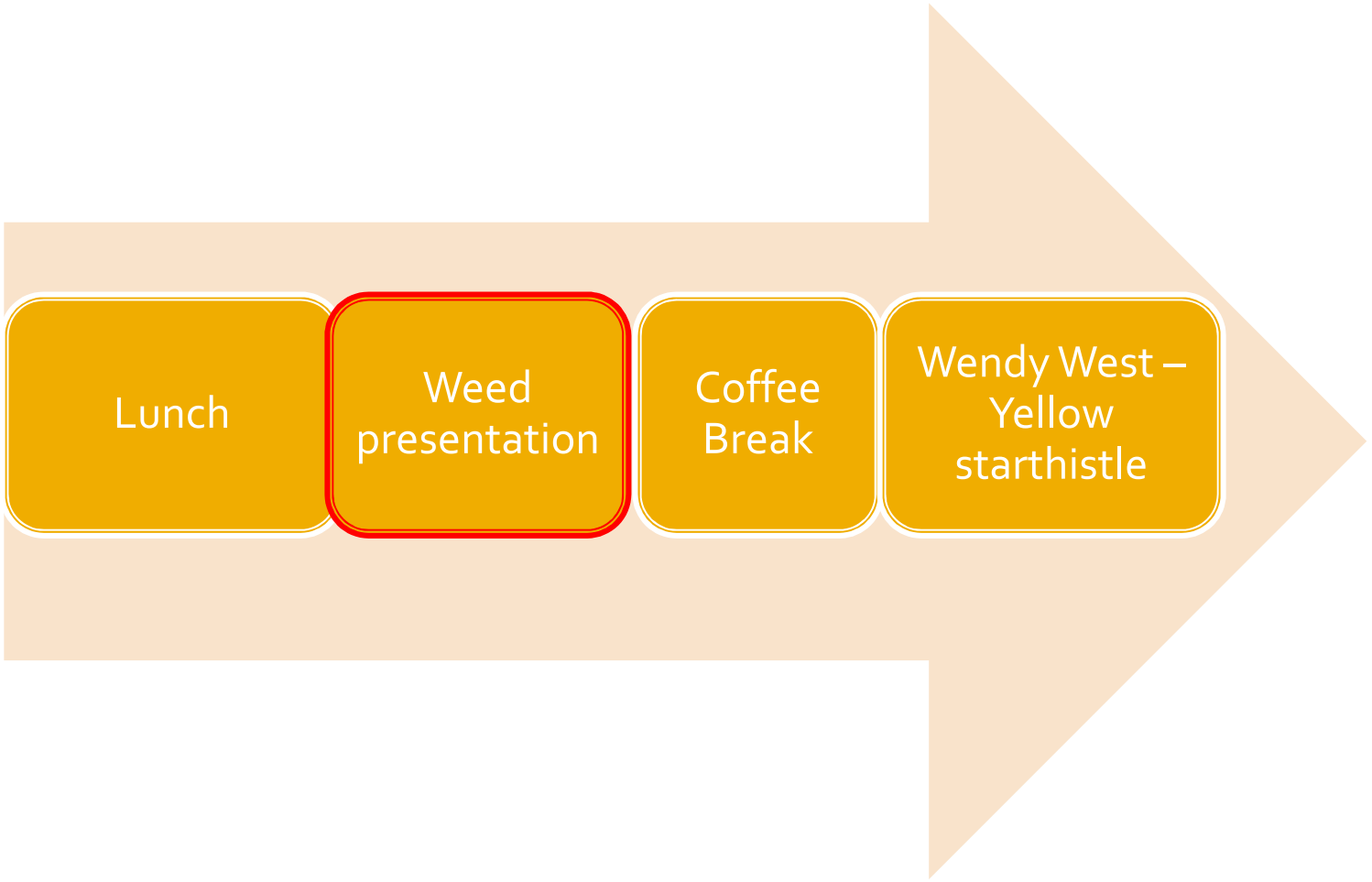
Brad Hanson
UC Davis Weed Science

Glyphosate Resistant Weeds: Impacts, Alternatives, and Current Research

Invasive Weed Workshop
7-20-11
Catheys Valley, CA

You are…. here


Lunch
Weed presentation
Coffee Break
Wendy West – Yellow starthistle

Integrated Weed Management

- Using all available strategies to manage weed populations in a manner that is economically and environmentally sound.
  - cultural
  - mechanical
  - chemical

Goals of IWM

- Both short- and long-term goals
  - Prevent or reduce weed spread
  - Delay and/or suppress weed growth
  - Prevent or suppress weed seed production
  - Reduction of weed seed bank in soil

Developing an IWM

- Understand the problem
  - Identity and biology
- Understand the ecosystem
  - Crop biology
  - Management cost/benefit, tolerance to weeds
- Evaluate management options
  - Cultural
  - Mechanical
  - Chemical
- Refine IWM as needed (keep records)

Understand the problem

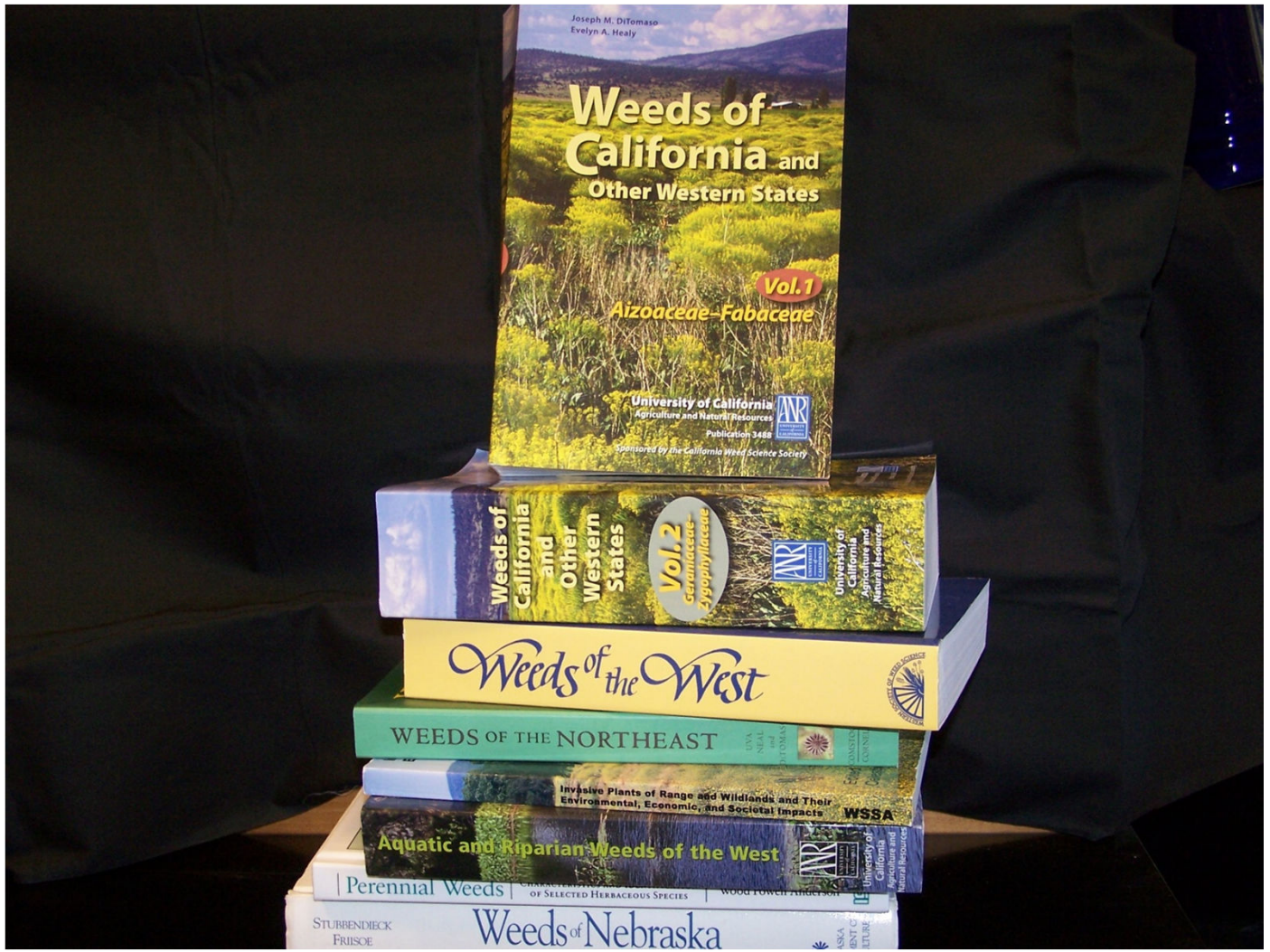
- The first step in understanding any problem is to correctly identify it

Dandelion

Spiny and annual sowthistle

Weed ID books and pamphlets

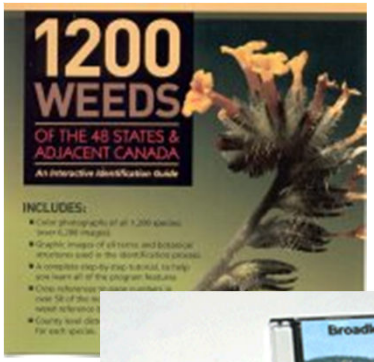
A number of weed books are available

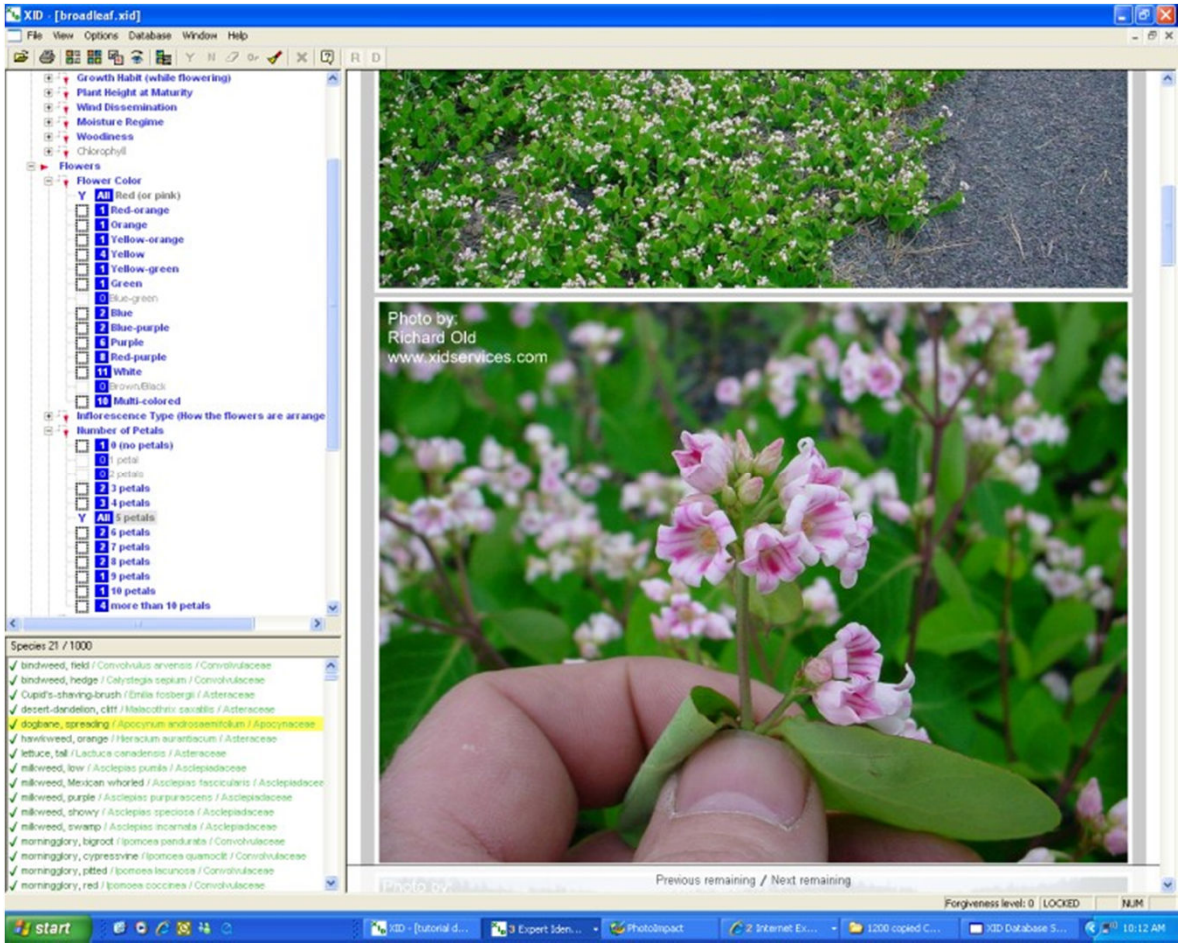


Weed ID - software

Several available.

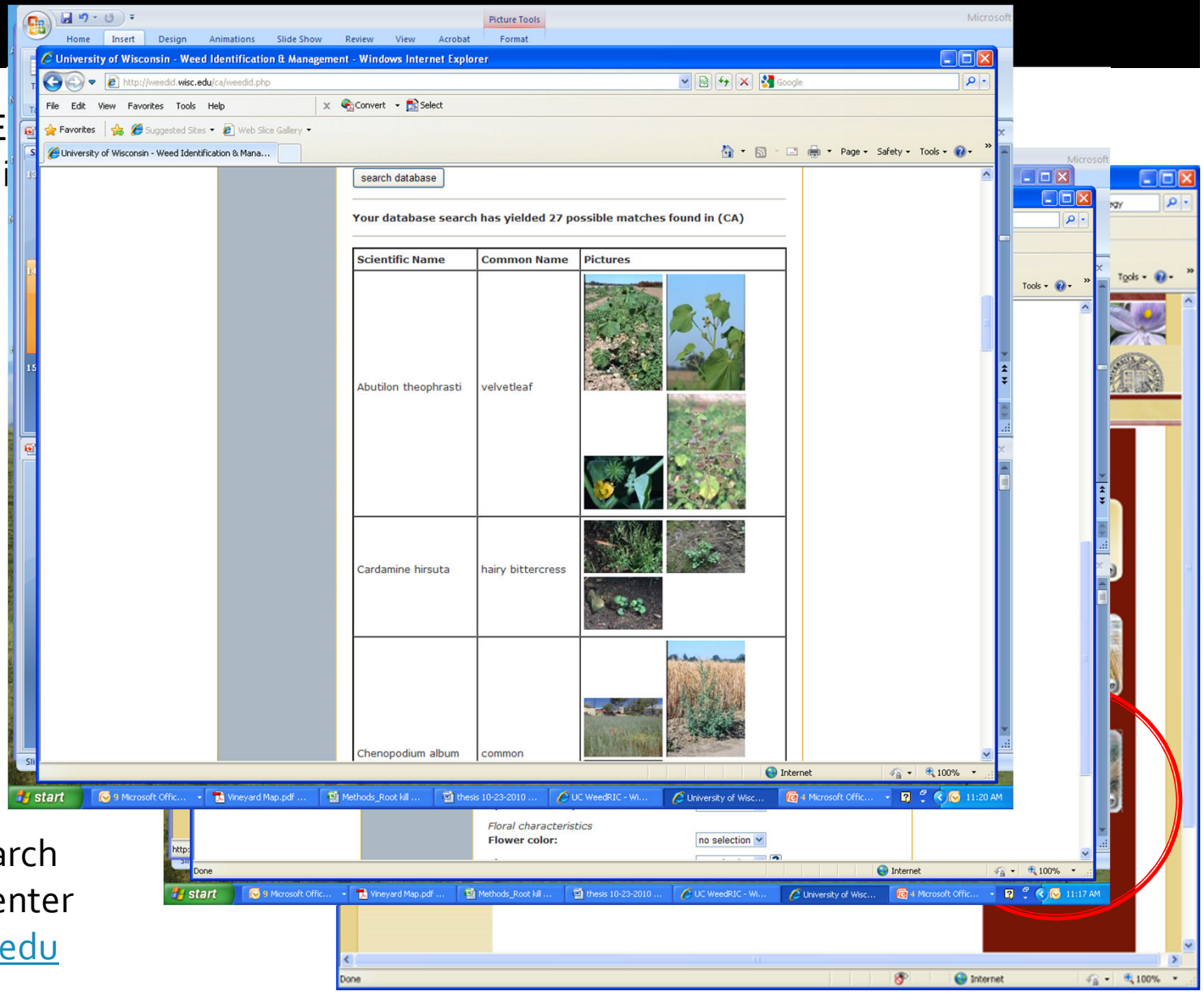
I use a set by XID Services
-UC Davis
-WSSA
-WSWS
- others





Online weed ID resources

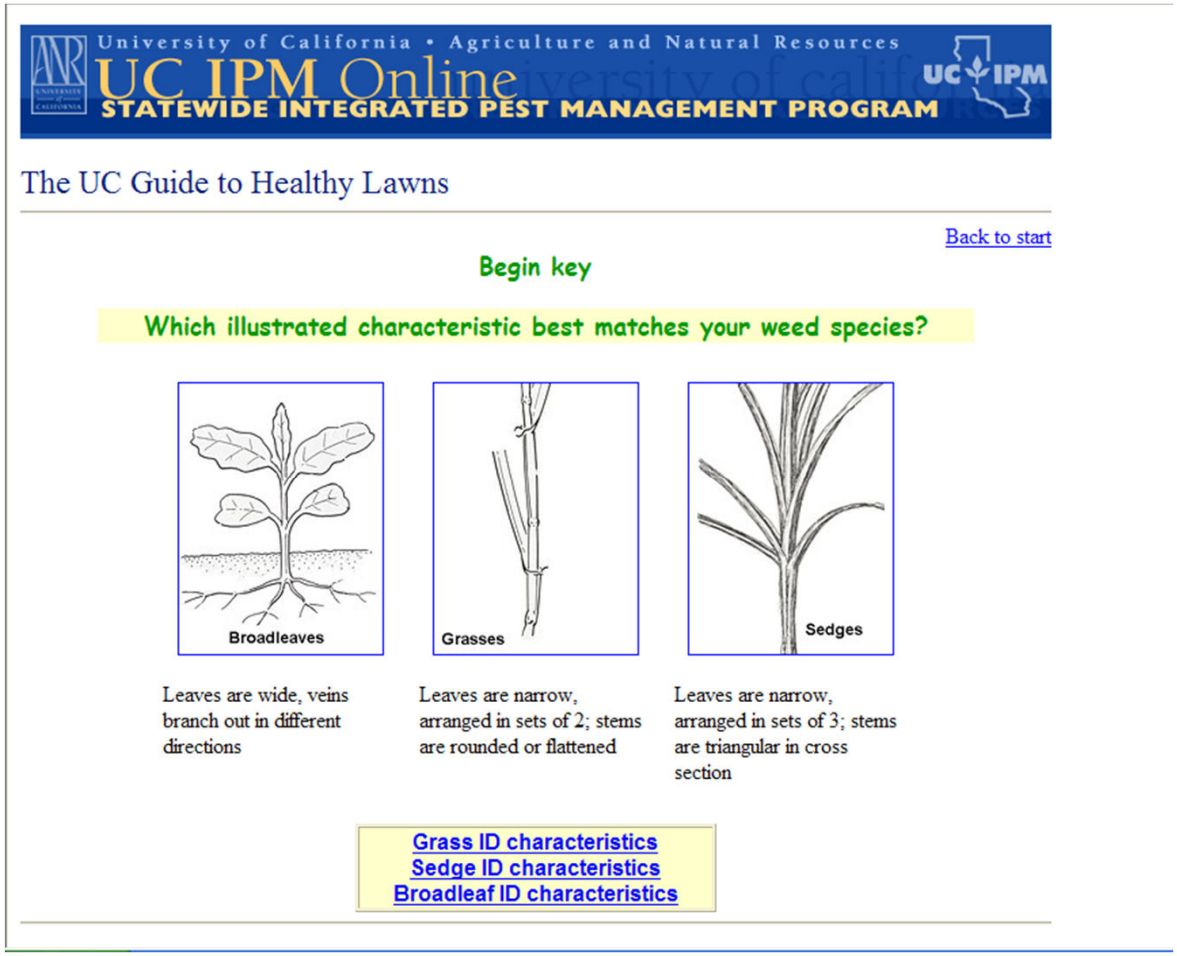
A few online (FRE
resources are avai



UC Davis Weed Research
and Information Center
www.wric.ucdavis.edu

Online weed ID resources

UC Integrated Pest Management Program
http://ipm.ucdavis.edu/PMG/menu.weeds.html



Complex populations

- Rarely just one weed species present
  - Annual vs perennial vs biennial
  - Grass vs sedges vs broadleaf
- Time of emergence
  - Fall vs spring emergence vs year-round
- Reproductive strategy
  - Seed vs vegetative

Weedy characteristics

- Plants that are unusually persistent or pernicious often have:
  - Abundant seed production
    - Also produce seed under adverse conditions
  - Rapid growth and population establishment
  - Seed dormancy
    - Long-term survival of buried seeds
  - Self- and cross-pollinated
  - Adaptations for spread
  - Vegetative reproductive structures
  - Capacity to occupy disturbed sites

Definition of a "difficult" weed

- "Weeds" are the ones your neighbor has
- "Difficult weeds" are the ones you have!
- In reality, difficult weeds are species that withstand, tolerate, or are resistant to the control measures used in a particular system and have an economic impact
  - Varies according to the crop, crop stage, control options, economic situation, etc
  - Example:
    - In SJV, raisin grapes have more "problem" weeds than wine grapes or almonds. Why? Economics.

Difficult weeds in perennial crops

- Vineyard and orchard managers have a moderate number of chemical choices for weed control
- A few chemicals are VERY important
  - Driven by economics and "sustainability"
- This has lead to the situation where many of the difficult weeds are herbicide-resistant biotypes or populations have shifted to tolerant species

Resistance definitions

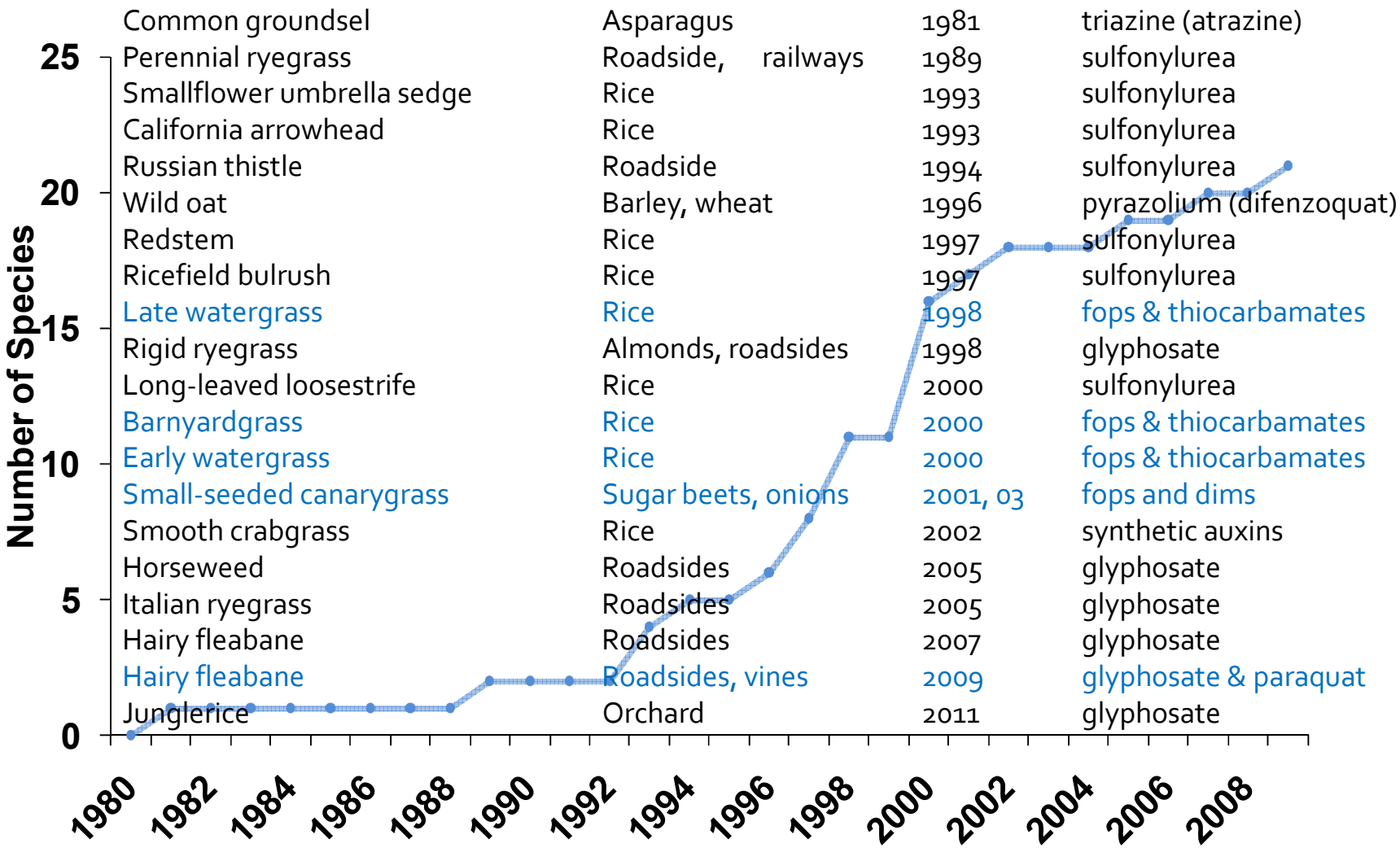
- Herbicide tolerance: the inherent ability of a species to survive and reproduce after herbicide treatment; implies no selection or genetic manipulation to make the plant tolerant
  - "We've never gotten dependable control of this weed with this herbicide…"
- Herbicide resistance: the inherited ability of a plant to survive and reproduce following exposure to a dose of herbicide normally lethal to the wild type
  - "We used to be able to control this weed with this treatment but it doesn't work as well anymore…"

Current state of HRW

- World wide
  - 114 dicots and 80 monocots
  - 19 herbicide families
- USA
  - 76 dicots and 52 monocots
  - 15 herbicide families
- California
  - 7 dicots and 14 monocots
  - 7 herbicide families

www.weedscience.org

HRW in California



Common groundsel	Asparagus	1981	triazine (atrazine)
Perennial ryegrass	Roadside, railways	1989	sulfonylurea
Smallflower umbrella sedge	Rice	1993	sulfonylurea
California arrowhead	Rice	1993	sulfonylurea
Russian thistle	Roadside	1994	sulfonylurea
Wild oat	Barley, wheat	1996	pyrazolium (difenzoquat)
Redstem	Rice	1997	sulfonylurea
Ricefield bulrush	Rice	1997	sulfonylurea
Late watergrass	Rice	1998	fops & thiocarbamates
Rigid ryegrass	Almonds, roadsides	1998	glyphosate
Long-leaved loosestrife	Rice	2000	sulfonylurea
Barnyardgrass	Rice	2000	fops & thiocarbamates
Early watergrass	Rice	2000	fops & thiocarbamates
Small-seeded canarygrass	Sugar beets, onions	2001, 03	fops and dims
Smooth crabgrass	Rice	2002	synthetic auxins
Horseweed	Roadsides	2005	glyphosate
Italian ryegrass	Roadsides	2005	glyphosate
Hairy fleabane	Roadsides	2007	glyphosate
Hairy fleabane	Roadsides, vines	2009	glyphosate & paraquat
Junglerice	Orchard	2011	glyphosate

www.weedscience.org

Factors affecting selection of herbicide-resistant weeds

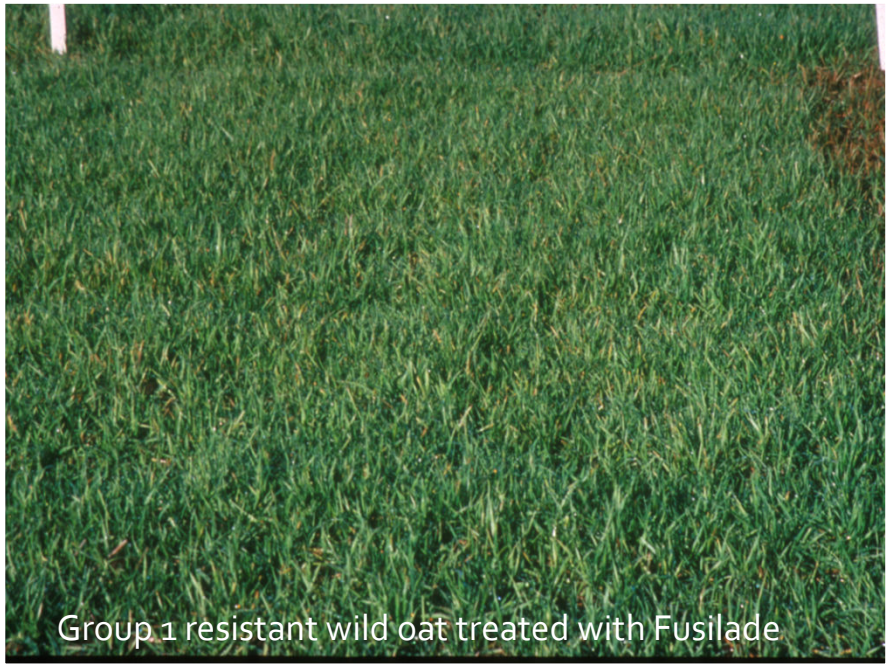
- Agronomic production practices
- Weed biology
- Herbicide properties

Agronomic factors

- Crop rotation
- Tillage
- Crop competitiveness
- Herbicide rotation (different modes of action)
  - Changes selection pressure

HRW in field crops

	~# resistant biotypes
Cereals	60
Corn	52
Rice	28
Soybean	24
Canola	11
Cotton	5
Sugarbeet	4



Group 1 resistant wild oat treated with Fusilade

HRW in other crops

	~# resistant biotypes
Vegetables	16
Orchard	37
Pasture	23
Forestry	8
Other perennial	8
Non-crop	35

Weed characteristics

- Annual growth habit
- High seed production
- Little seed dormancy
- Seed longevity in soil
- Original frequency of R trait in population
- Multiple generations per year
- Gene flow (pollen and seed)
- Fitness of R v. S biotype
- Highly susceptible to the herbicide

SU-resistant Russian thistle dispersal
- Stallings et al. 1995

Propensity of a species to develop resistance

- Some species are more prone to develop herbicide resistance
  - 28 spp. with resistance to 2 MOA
  - 10 to 3 MOA
  - 3 to 4 MOA
  - 1 to 5 MOA
  - 3 to 6 MOA
  - 1 to 8 MOA
    - one rigid ryegrass biotype has resistance to 8 MOA!

Worst HRW worldwide - based on # infested sites

- Rigid ryegrass
- Wild oat
- Redroot pigweed
- Common lambsquarters
- Green foxtail
- Barnyardgrass
- Goosegrass
- Kochia
- Horseweed
- Smooth pigweed

- Think:
  - Annual growth habit
  - High seed production
  - Little seed dormancy
  - Seed longevity in soil
  - Gene flow
  - Highly susceptible to herbicide

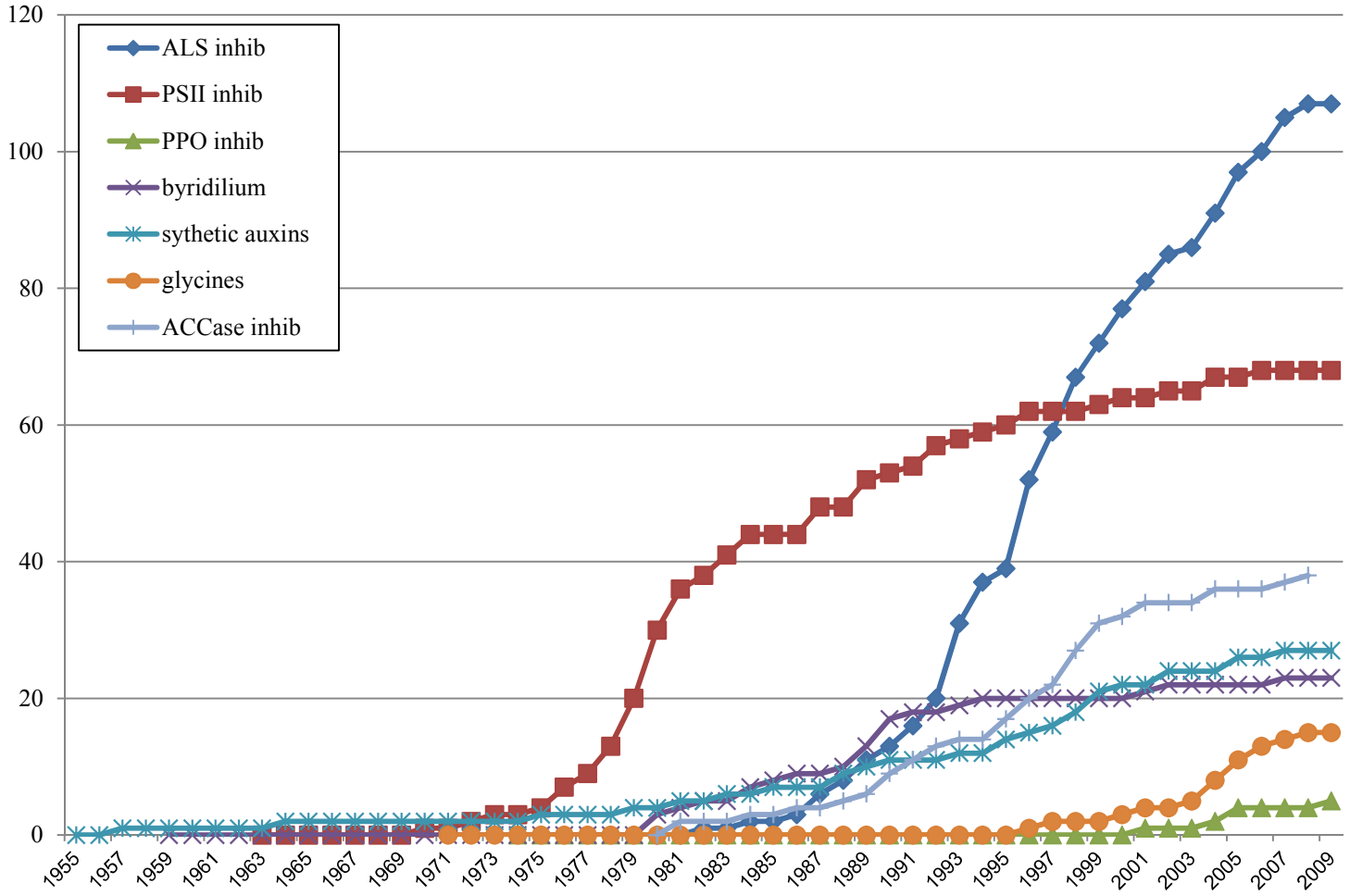
Herbicide characteristics

- Single site of action
- High efficacy
  – selection pressure
- High use rate (relative to amount needed)
- Long soil residual activity
- High frequency of use (yearly or multiple applications per year)

Think:

- Sulfonylurea in wheat/rice
- Triazines in field and hort crops
- ACCase inhibitors in cereals
- Paraquat and glyphosate in orchards

World-wide resistance by MOA



What's next?

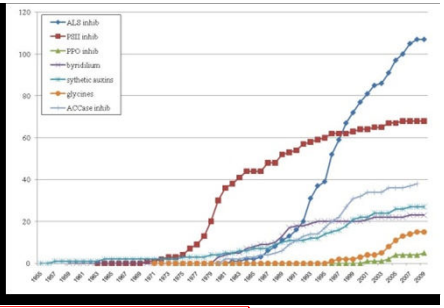
- What are we "selecting" with our weed management strategies?
  - Common weeds – prone to resistance
  - Important herbicides use and reliance trends
  - Agronomic actions
    - Perennial crops, specialty crops, reduced tillage

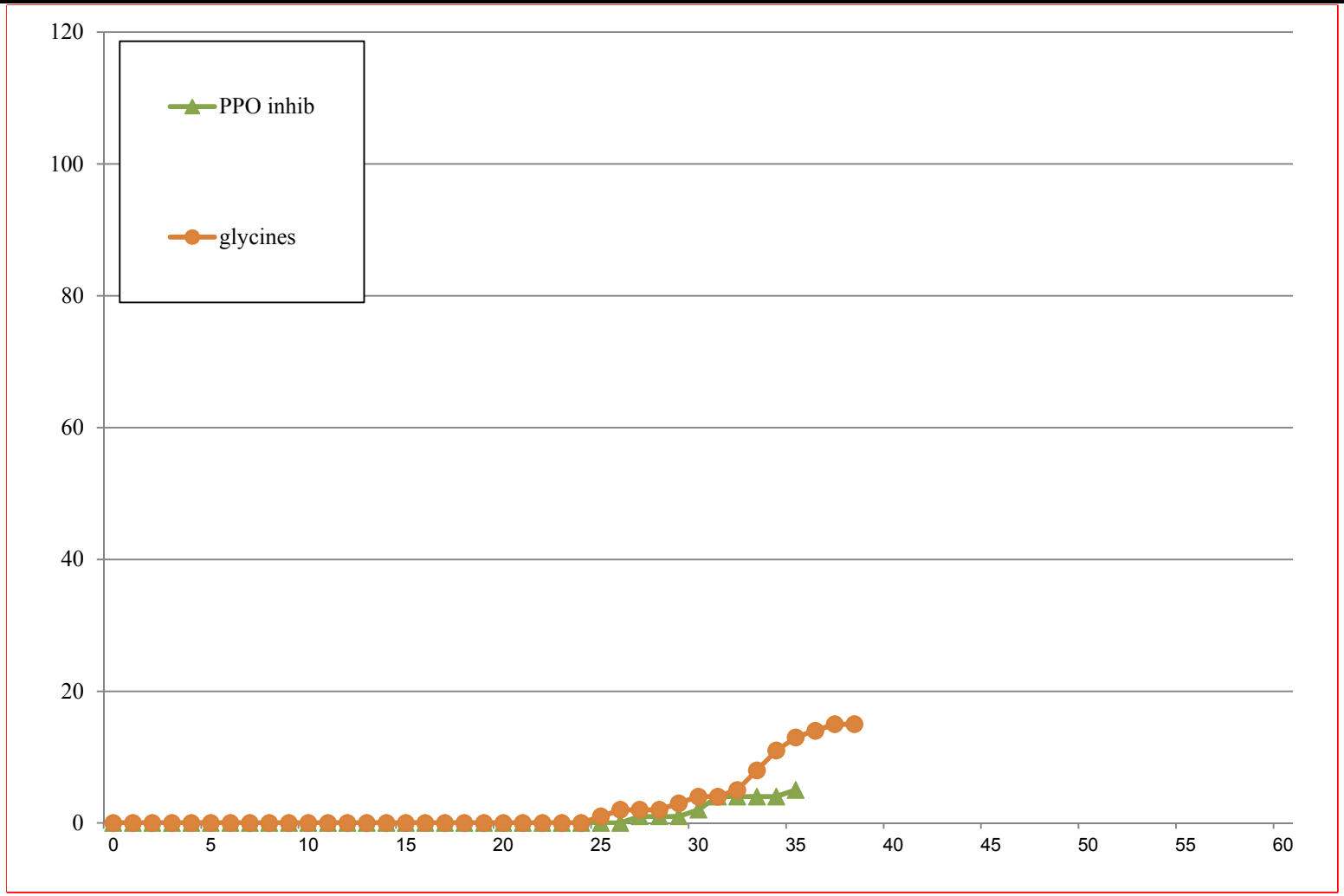
Worst HRW worldwide (# sites)

	Present in CA	Resistance outside CA	Resistance reported in CA
Rigid ryegrass	☑	8 modes of action	☑ glyphosate
Wild oat	☑	6 MOA	☑ difenzoquat
Redroot pigweed	☑	3 MOA	
Common lambsquarters	☑	4 MOA	
Green foxtail	☑	4 MOA	
Barnyardgrass	☑	7 MOA	☑ ACCase, thiocarbamates
Goosegrass	☑	4 MOA	
Kochia	☑	3 MOA	
Horseweed	☑	5 MOA	☑ glyphosate, paraquat
Smooth pigweed	☑	2 MOA	

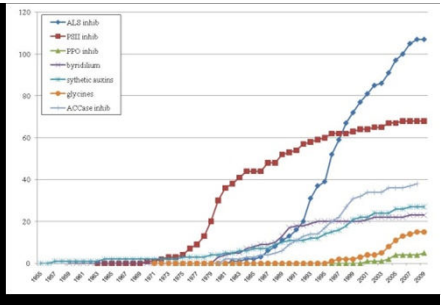
10 worst weeds from www.weedscience.org

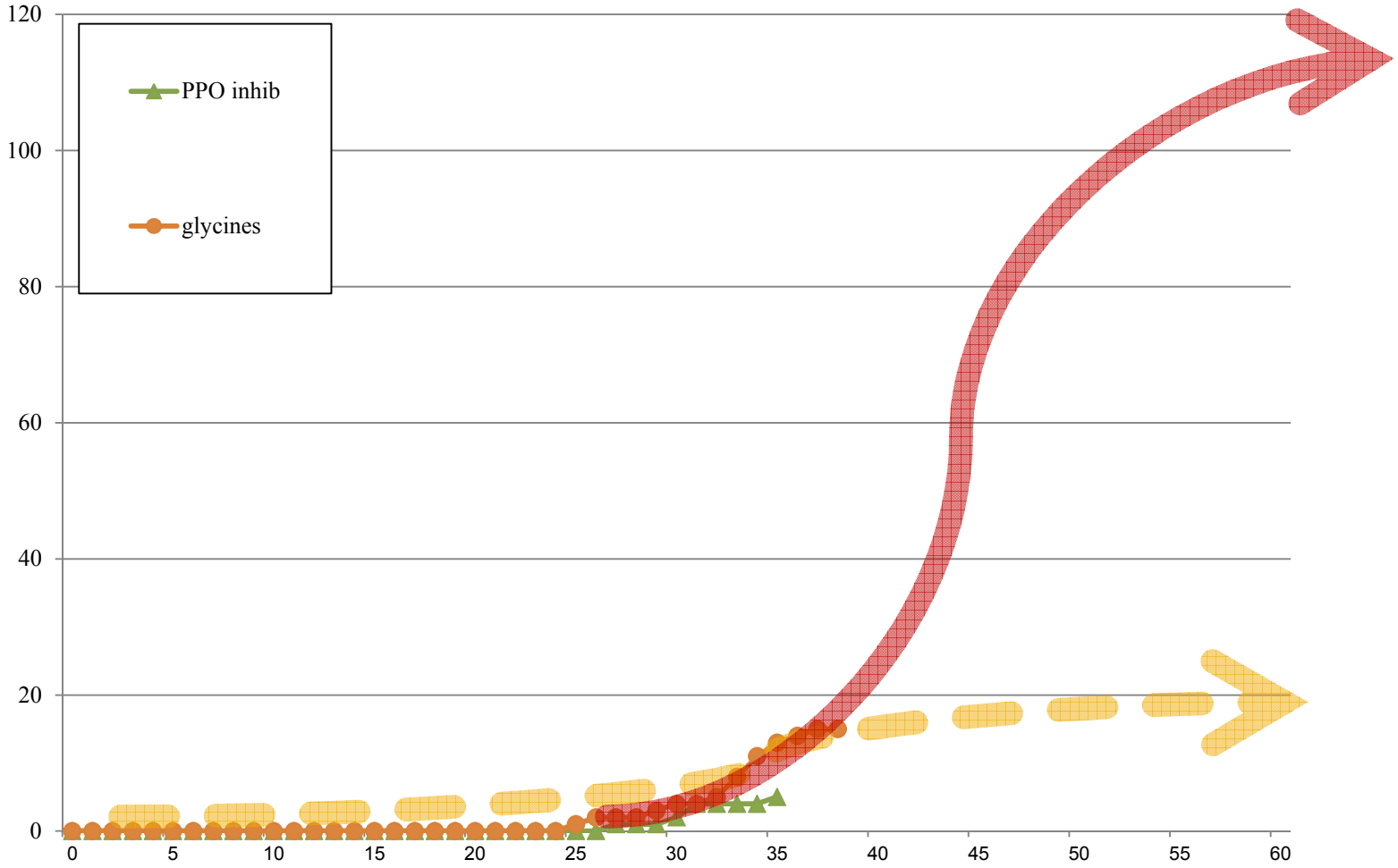
Resistance trends





The future?




120
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60

Reported glyphosate resistance

	Resistance USA	Resistance CA
Amaranthus palmeri, A. rudis)	☑ ☑	
Ambrosia artemisifolia, A. trifada	☑ ☑	
Conyza bonariensis, C. canadensis	☑ ☑	☑ ☑
Digitaria insularis		
Echinochloa colona	☑	☑
Eleusine indica		
Euphorbia heterophylla		
Lolium multiflorum, L. rigidum	☑ ☑	☑ ☑
Parthinium hysterophorus		
Plantago lanceolata		
Sorghum halapense	☑	
Urochloa panicoides		

Rigid and Italian ryegrass

- Often co-exist (swarm)
- Annual grass
- Obligate outcrossers
- Throughout CA but more common weed in northern Central Valley
- 2 to 15-fold resistance
- Usually target site mutation

Italian ryegrass

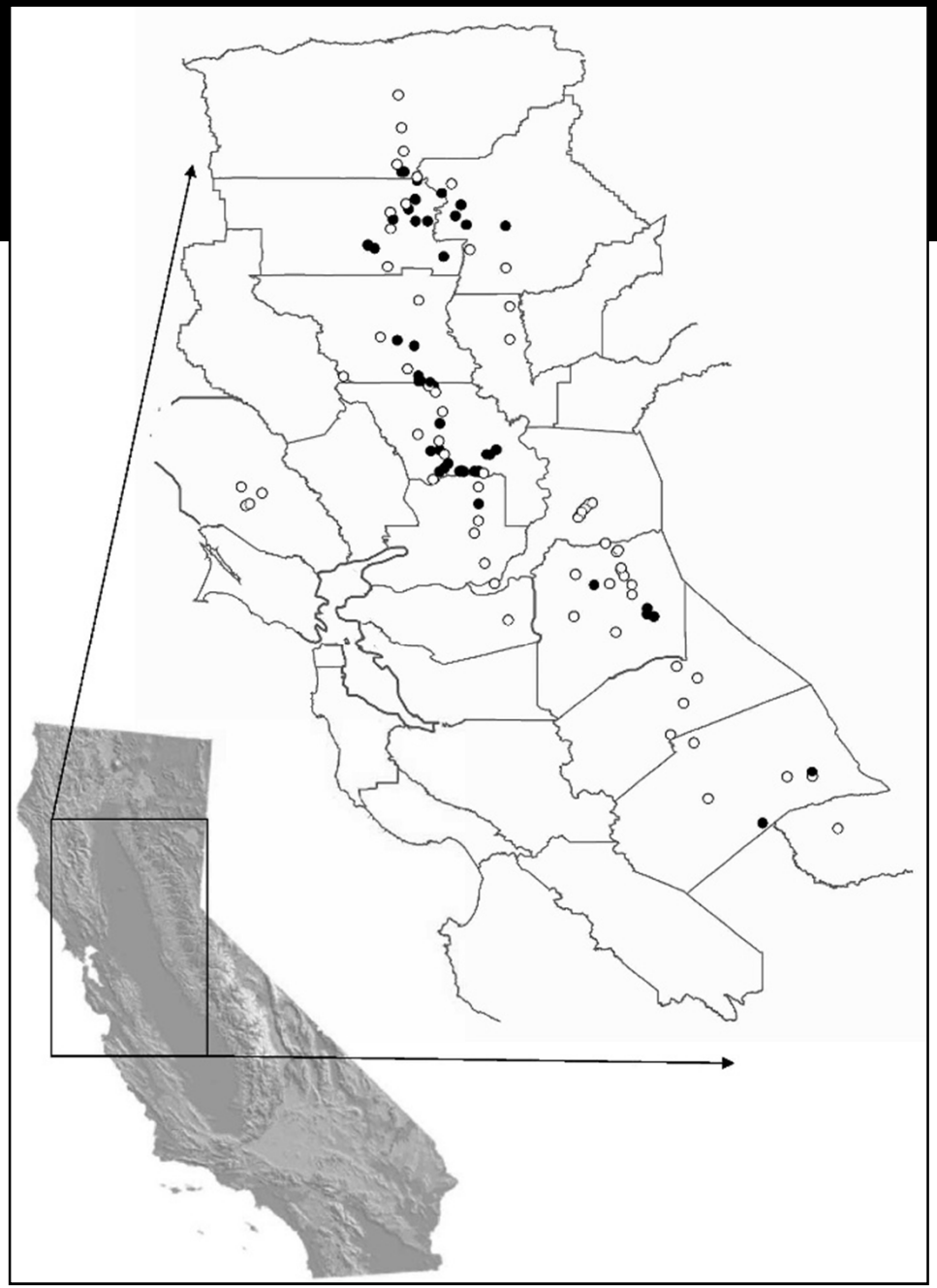


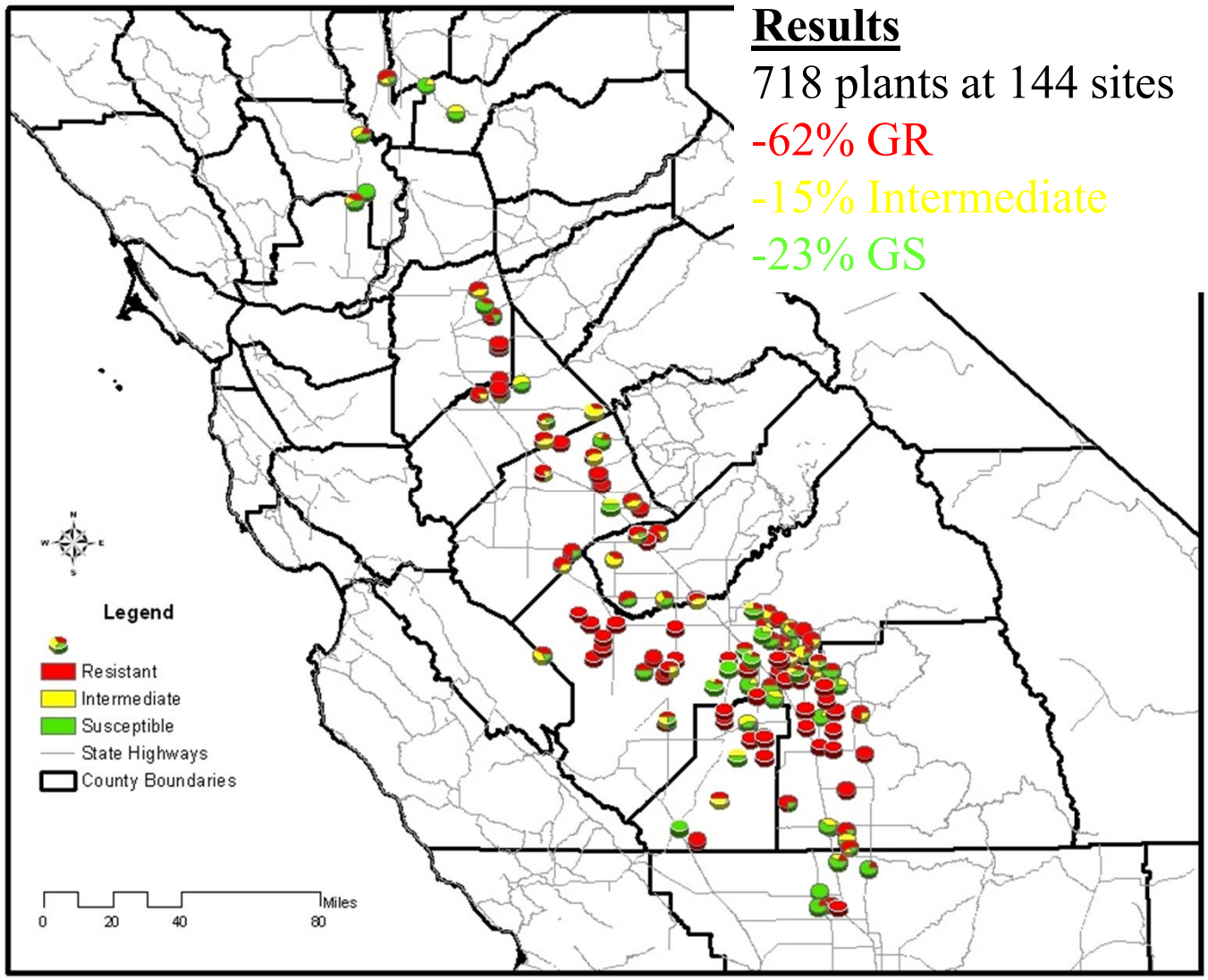
Figure 1. Map of California showing the geographical distribution of Italian ryegrass populations sampled for this study. Closed circles indicate populations with more than 20% seedlings surviving treatment with glyphosate t 866 g ae / ha; open circles indicate populations with 5% (two populations) or no surviving seedlings. Forty seedlings from each population were tested for glyphosate response.

From Jasieniuk et al. 2008.
Weed Sci 56:496-502

Horseweed

- AKA mare's tail
- Annual weed
- Prolific seed producer
- Wind-blown seed
- Early colonizer
- Doesn't tolerate disturbance
- 6-fold resistance (whole plant)
- 4-8 fold resistance (in vivo)
- Mechanism not known. Suspected translocation mutation

Horseweed survey



Results

718 plants at 144 sites

-62% GR

-15% Intermediate

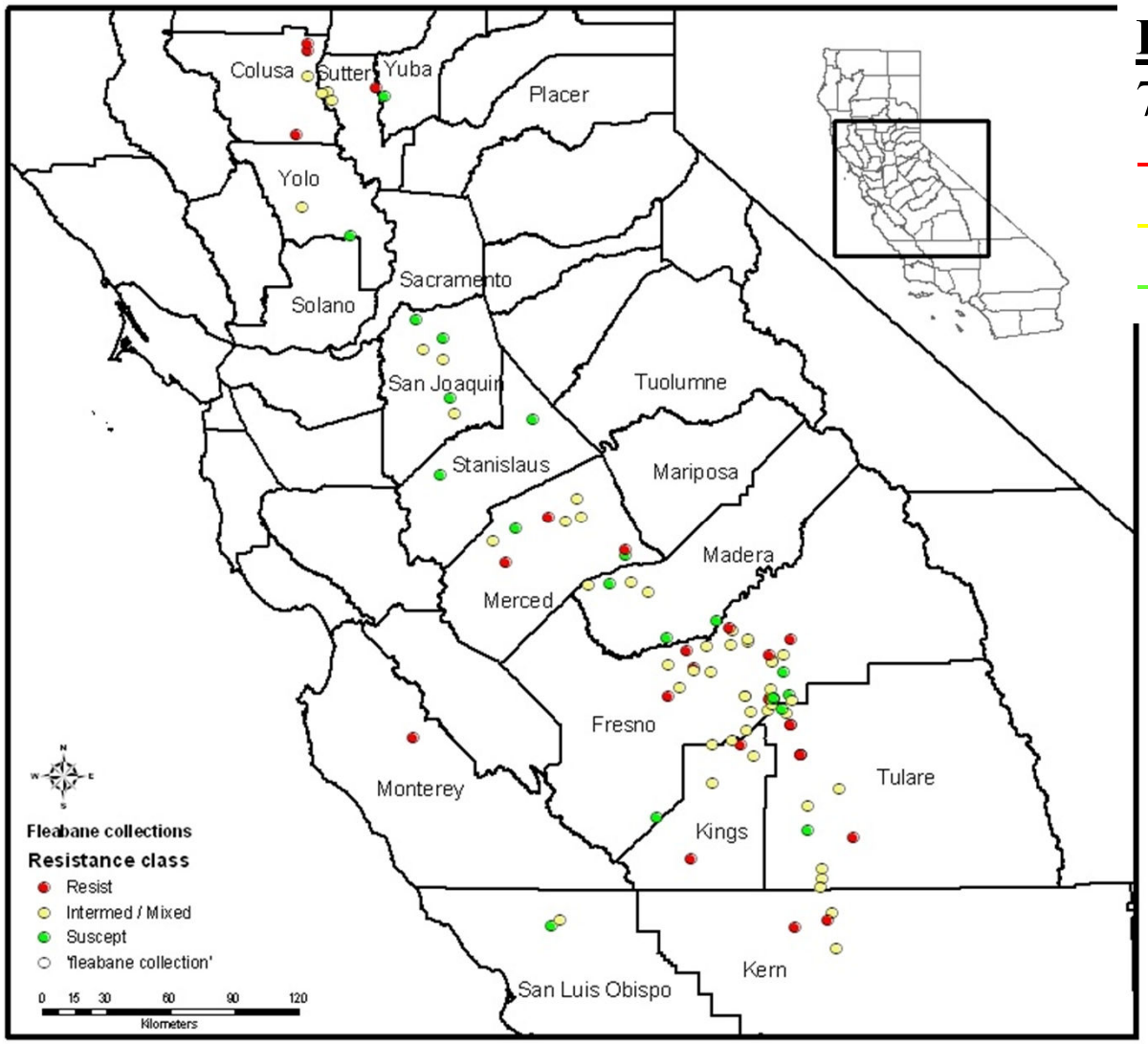
-23% GS

Hanson et al. 2009
Weed Sci 57:48-53

Hairy fleabane

- AKA flaxleaf fleabane
- Annual weed
- Wind-blown seed
- Early colonizer
- Doesn't tolerate disturbance
- 3 to 10-fold resistance (whole plant screening)
- ~ 4-fold resistance in vivo
- Mechanism not known

Hairy fleabane survey - 2009



Prelim Results

75 populations

-27% GR

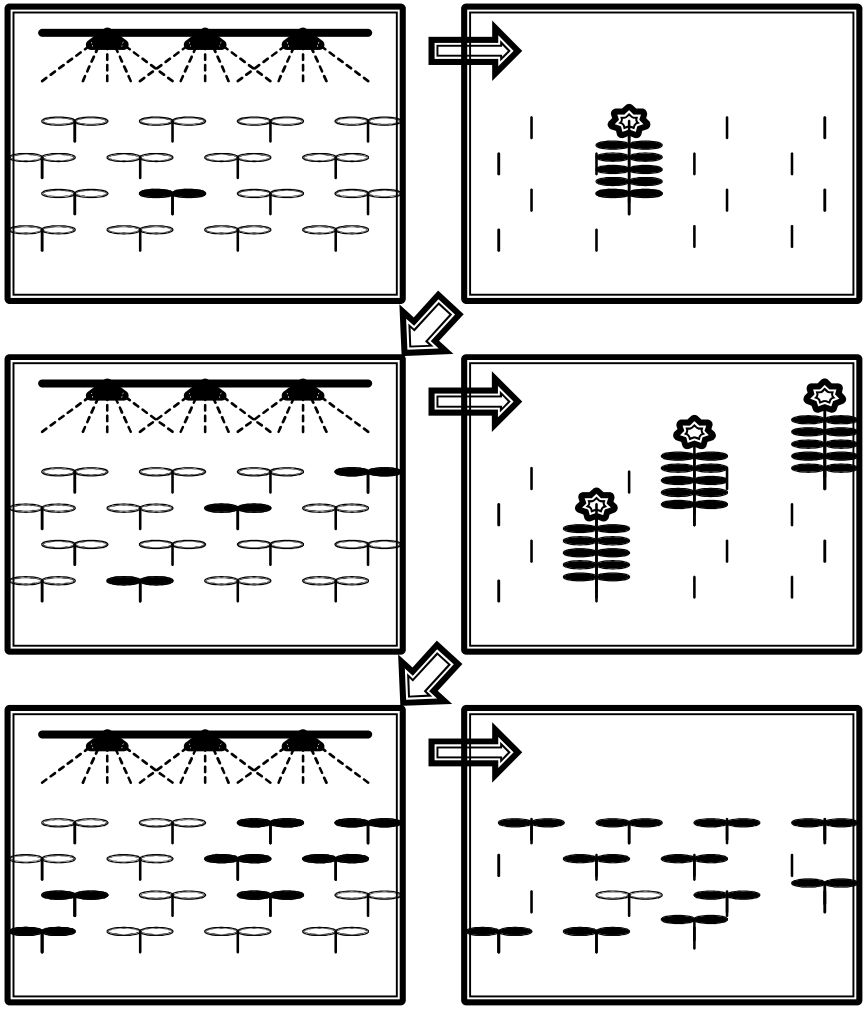
-52% Mixed

-21% GS

Zozaya et al. 2010
CWSS poster session

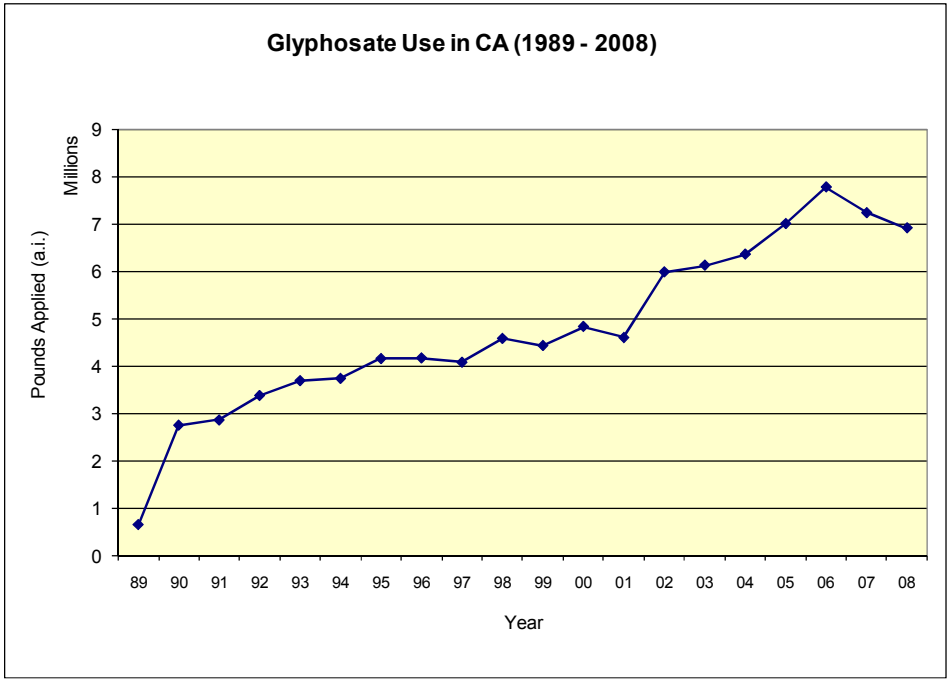
Junglerice

Selection pressure



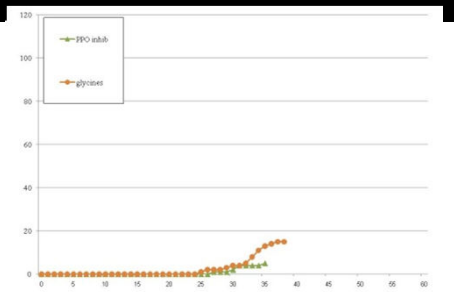
Selection for resistance

- Repeated use can select for resistant biotypes
  - Any herbicide or other weed management tool



~41% of all herbicides in CA (lbs ai) are glyphosate!

Changes in glyphosate use



- Adoption of RR crops (early 90's)
  - Corn, soybean, cotton, canola, alfalfa
  - Sugarbeet, wheat, bentgrass
- Increasing dependence on glyphosate in CA
  - RoundUp off patent in 2000 – price decrease
  - GWPA
  - Growers switching to POST weed management
    - Almond 2009: 740,000 bearing acres but 1.3 million acres treated with glyphosate!

CA almond herbicide use

	Top 10 active ingredients	2009 treated acreage
1	glyphosate	1,300,394
2	oxyfluorfen (Goal, Goaltender)	723,524
3	glufosinate (Rely)	271,135
4	paraquat (Gramoxone Inteon)	250,156
5	pendimethalin (Prowl)	167,689
6	2,4-D	152,455
7	oryzalin (Surflan, etc)	99,220
8	simazine (Princep, etc)	92,220
9	flumioxazin (Chateau)	90,718
10	carfentrazone (Shark)	68,360
11	rimsulfuron (Matrix)	52,577

* Mostly strip treatments!

740,000 A bearing almond (2010)

CA walnut herbicide use

	Top 10 active ingredients	2009 treated acreage
1	glyphosate	212,270
2	oxyfluorfen (Goal, Goaltender)	113,113
3	glufosinate (Rely)	46,773
4	paraquat (Gramoxone Inteon)	30,495
5	pendimethalin (Prowl)	24,329
6	2,4-D	23,351
7	simazine (Princep, etc)	23,243
8	carfentrazone (Shark)	17,708
9	diuron (Karmex, etc)	16,887
10	oryzalin (Surflan, etc)	16,862

223,000 A bearing walnut

CA grape herbicide use

	Top 10 active ingredients	2009 treated acreage
1	glyphosate	203,808
2	glufosinate (Rely)	147,387
3	oxyfluorfen (Goal, Goaltender)	59,289
4	paraquat (Gramoxone Inteon)	49,012
5	pendimethalin (Prowl)	48,286
6	flumioxazin (Chateau)	44,232
7	2,4-D	24,736
8	oryzalin (Surflan, etc)	22,766
9	rimsulfuron (Matrix, Mana, etc)	21,267
10	trifluralin (Treflan, etc)	10,763

482,000 A wine grapes
83,000 A table grapes
221,000 A raisin grapes

Consider the cost

- Many residual herbicides cost more than burndown herbicides
  - But do they?
- Consider the full cost of repeated burndown applications?
  - active + adjuvants + machine costs + time
  - More mowing or tillage?
  - Timely weed control (wet winter/spring)
- Consider weed costs over several years

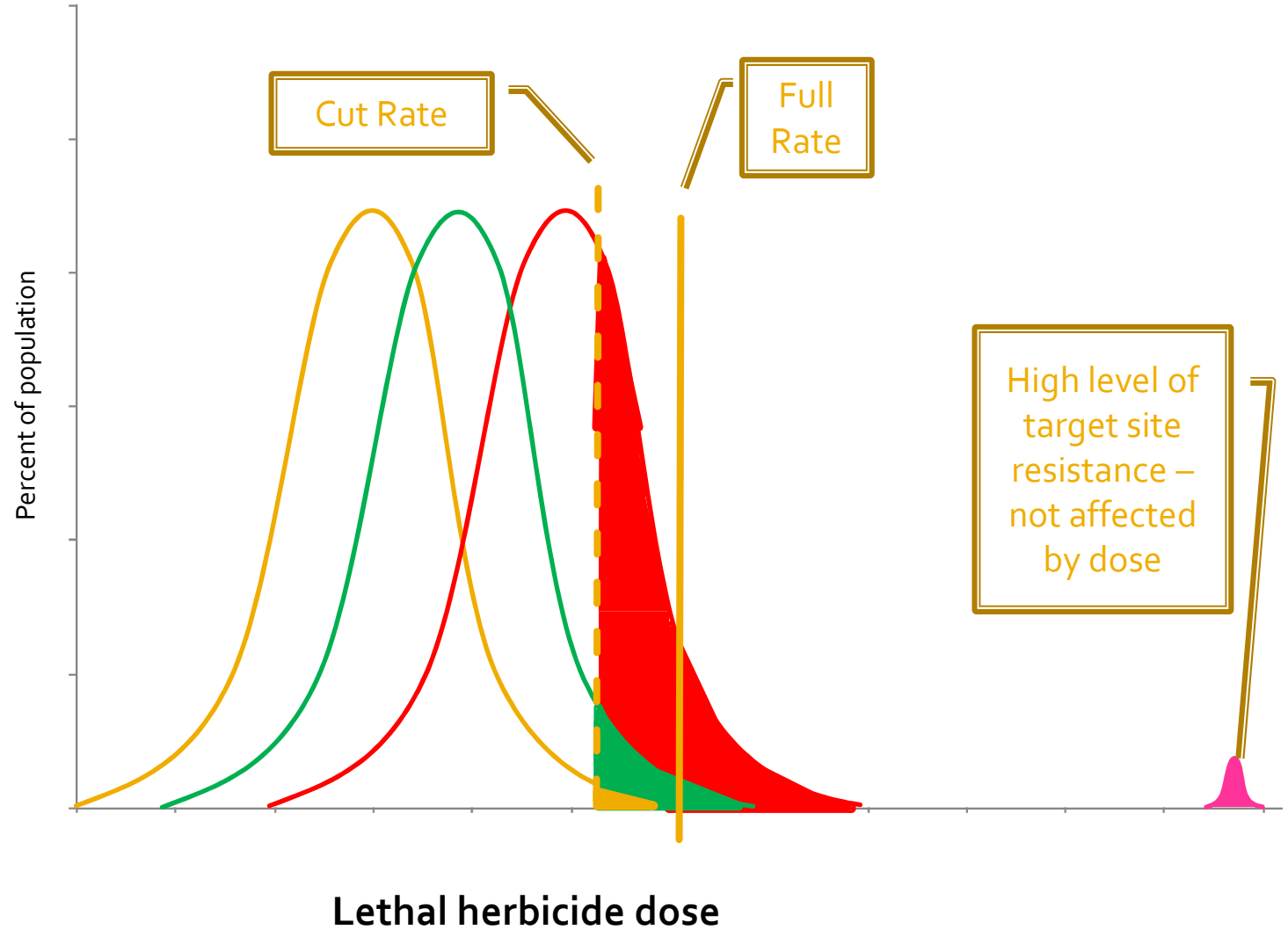
Weeds of GR concern in CA

- Cooperative research project recently initiated
  - UCD, UCCE, CSUF
- Focus on screening, quantifying, and mapping, and identifying mechanisms of resistance in:
  - Junglerice (Echinochloa colona)
  - Barnyardgrass (Echinochloa crus-galli)
  - Common lambquarters (Chenopodium album)
  - Johnsongrass (Sorghum halepense)
  - Pigweeds (Amaranthus spp.)
    - 11 pigweed species with resistance, 7 different MOA

Preserving glyphosate

- Need to diversify weed management to preserve glyphosate as a tool
  - Genetics? Probably not soon in tree/vine crops
  - New herbicides? A few new products coming in tree/vine markets
  - Use PRE products in addition to POST
  - Alternate or combine POST materials
  - Use full rates
  - Mechanical (tillage, mowing, mulches?)

Creeping resistance

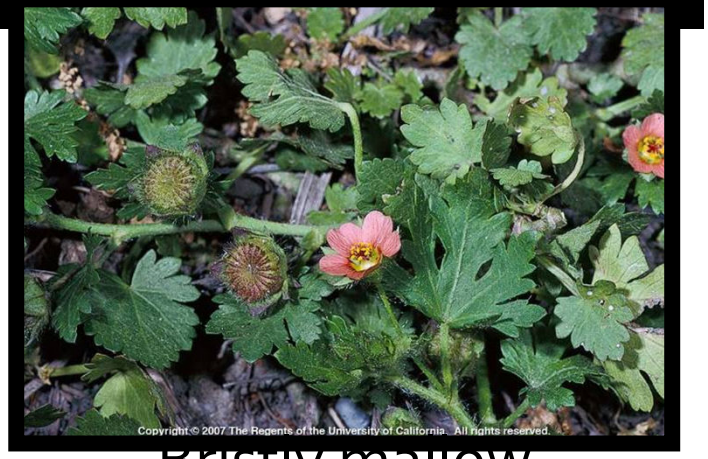


Weed shifts

- Glyphosate is BROAD spectrum but not COMPLETE spectrum
  - Some species not well controlled
    - Pigweeds, lambsquarters, morningglory, etc
- Dependence on glyphosate has resulted in many crops changing to a POST only program
  - Especially in RoundUp Ready crops
  - Also in tree and vine crops

Other "local" problem weeds

- Johnsongrass
- Bristly mallow
- Cutleaf evening primrose
- Witchgrass
- Sharp-point fluevellin
- Tall willowherb
- Others?



Bristly mallow

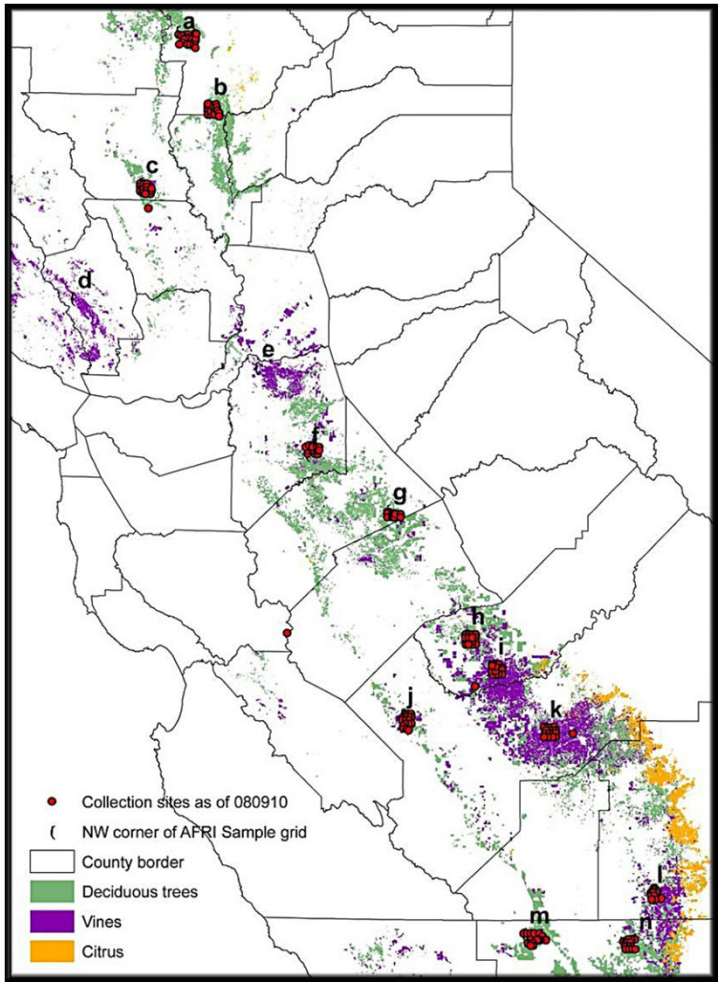
willowherb

Current research program

- Methyl bromide alternatives
  - Alt. fumigants and non-fumigant solutions
- Orchard/vineyard weed management
  - Herbicide testing
  - Application technology
- Herbicide resistance
  - Management
  - Weed surveys, grower/PCA surveys
- Herbicide issues
  - Fate, drift, non-target effects

Current: resistance screening

- Collected weed seed from several perennial crop production areas and treat in the greenhouse



Resistance management

Drift management

- Prevent off-target movement of herbicides
  - Within and outside of the orchard
- Make sure your equipment is set up correctly
  - Nozzle choice
    - Size, design, drift reduction?
  - Operating pressure
  - Ground speed
  - Boom height
- Environment
  - Breeze, wind gusts, temperature, humidity

Some mistakes are minor…

…but some can be costly!

…some are REALLY costly!

Nozzle choice affects droplet size

- Directly affects:
  - Application uniformity
  - Spray coverage
  - Drift potential
- Which impacts:
  - Weed control efficacy
  - Economics
  - Environmental quality

Photo: Bruce Barker

Nozzle thoughts

- Spray nozzles are a small but critical part of a spray system
  - Highly engineered components for high performance
- Over-, under-, and variable-applications cost time, money, and efficacy
- Better quality nozzles may cost more initially but should last much longer
  - Nozzle replacement is cheap compared to the investment in chemicals and application equipment!

2011 tree and vine crops herbicide registration chart

Herbicide Registration on Horticultural Tree and Vine Crops–Oct. 2010

	Herbicide-Common Name (example trade name)	Almond	Pecan	Pistachio	Walnut	Apple	Pear	Apricot	Cherry	Nectarine	Peach	Plum / Prune	Avocado	Citrus	Date	Fig	Grape	Kiwi	Olive	Pomegranate
		tree nut				pome		stonefruit												
Preemergence*	bromacil (*Hyvar*)	N	N	N	N	N	N	N	N	N	N	N	N	R	N	N	N	N	N	N
	dichlobenil (*Casoron*)	N	N	N	N	R	R	N	R	N	N	N	N	N	N	N	R	N	N	N
	diuron (*Karmex,Diurex*)	N	R	N	R	R	R	N	N	N	R	N	N	R	N	N	R	N	R	N
	EPTC (*Eptam*)	R	N	N	R	N	N	N	N	N	N	N	N	R	N	N	N	N	N	N
	flumioxazin (*Chateau*)	R	NB	R	NB	R	R	R	R	R	R	R	NB	NB	N	NB	R	N	NB	NB
	isoxaben (*Gallery*)	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	N	NB	NB	NB	NB	NB
	napropamide (*Devrinol*)	R	R	N	N	N	N	N	N	N	N	N	N	N	N	N	R	R	N	N
	norflurazon (*Solicam*)	R	R	N	R	R	R	R	R	R	R	R	R	R	N	N	R	N	N	N
	oryzalin (*Surflan, Farm Saver*)	R	R	R	R	R	R	R	R	R	R	R	R	R	N	R	R	R	R	R
	oxyfluorfen (*Goal, GoalTender*)	R	R	R	R	R	R	R	R	R	R	R	R	NB	R	R	R	R	R	R
	pendimethalin (*Prowl H,O*)	R	R	R	R	R	R	R	R	R	R	R	N	R	N	N	R	N	R	R
	penoxsulam (*Pindar GT*)	R	R	R	R	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
	pronamide (*Kerb*)	N	N	N	N	R	R	R	R	R	R	R	N	N	N	N	R	N	N	N
	rimsulfuron (*Matrix, Mana*)	R	R	R	R	R	R	R	R	R	R	R	N	R	N	N	R	N	N	N
	simazine (*Princep,Caliber 90*)	R	R	N	R	R	R	N	R**	R	R	N	R	R	N	N	R	N	R	N
	thiazopyr (*Visor*)	NB	N	NB	NB	N	N	NB	NB	NB	NB	NB	N	R**	N	N	NB	N	N	N
	trifluralin (*Treflan*)	R	R	N	R	N	N	R	N	R	R	R	N	R	N	N	R	N	N	N
Postemergence	carfentrazone (*Shark, Rage*)	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
	clethodim (*Prism*)	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	N	R	N	N	NB	N	NB	N
	clove oil (*Matratec*)	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
	2,4-D (*Clean-crop, Orchard Master*)	R	R	R	R	R	R	R	R	R	R	R	N	N	N	N	R	N	N	N
	diquat (*Diquat*)	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB
	d-limonene (*GreenMatch*)	R	R	R	R	R	R	R	R	R	R	R	N	R	N	R	R	R	N	N
	fluazifop-p-butyl (*Fusilade*)	NB	R	NB	NB	NB	NB	R	R	R	R	R	NB	NB	NB	NB	NB	N	NB	NB
	glyphosate (*Roundup, Touchdown*)	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
	glufosinate (*Rely 280*)	R	R	N	R	R	N	N	N	N	N	N	N	N	N	N	R	N	N	N
	halosulfuron (*Sandea*)	N	R	R	R	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
	paraquat (*Gramoxone Inteon*)	R	R	R	R	R	R	R	R	R	R	R	R	R	N	R	R	R	R	N
	pelargonic acid (*Scythe*)	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	N
	pyraflufen (*Venue*)	R	R	R	R	R	R	R	R	R	R	R	N	N	R	R	R	R	R	R
	saflufenacil (*Treevix, Kixor*)	R	N	R	R	R	N	N	N	N	N	N	N	R	N	N	N	N	N	N
	sethoxydim (*Poast*)	R	R	R	R	R	R	R	R	R	R	NB	NB	R	NB	NB	R	N	NB	NB

Note: This is a general guide to perennial crop herbicide registrations in California. Labels change frequently and often contain special restrictions; therefore you should always consult a current label before applying any herbicide.

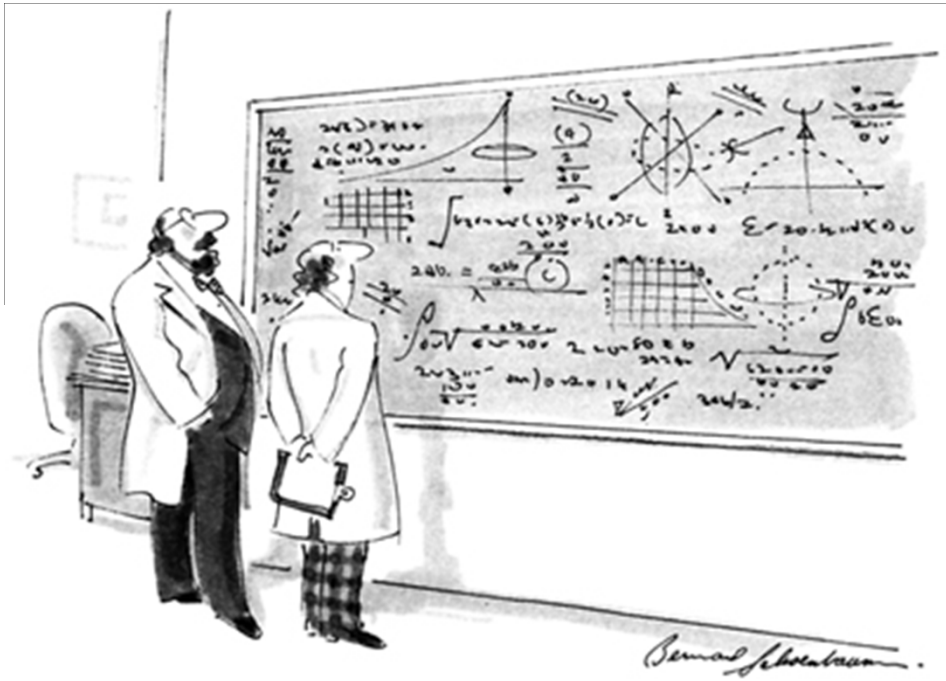
N = Not registered, NB = nonbearing, R = Registered

* Several herbicides listed under preemergence also have some postemergence activity.

** Simazine is registered on only sour cherry in CA. Thiazopyr is registered on orange and grapefruit only.

Weed susceptibility information can be found at the **Weed Research and Information Center** (http://wric.ucdavis.edu)

UC Davis Weed Research and Information Center
http://wric.ucdavis.edu/



"Wow – that IS pretty simple!"

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UC Davis Weed Research and Information Center
http://wric.ucdavis.edu/
http://ucanr.org/blogs/UCDWeedScience/

UC Davis Statewide Integrated Pest Management Program
http://www.ipm.ucdavis.edu/


Thanks