# Implementation of Biological Control of Major Insect Pests and Weeds in Northern Plains

*Complied By*

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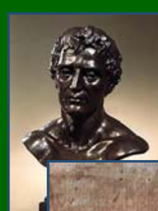
**Western SARE-Professional Development Program**
**Montana State University-Western Triangle Agricultural Research Center**

# Table of Contents

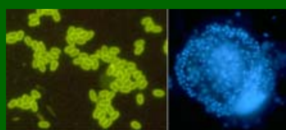

## *Microbes attacking insects is not a new idea*

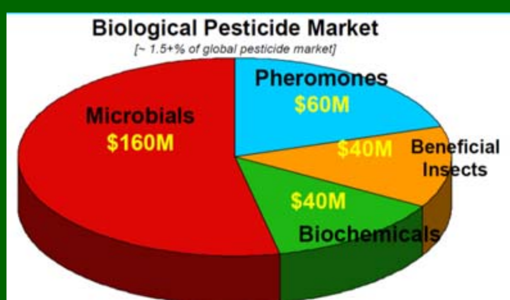
- **Earliest reports of insect disease:**
- **700 BC: China**
- **322 BC- Aristotle**
  - "Historia Animalium"
- **29-32 BC- Virgil**
  - "Georgica"



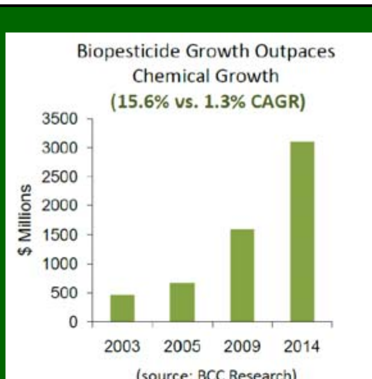
Earliest Illustration of Fungi Killing Insects c.1600

Louis Pasteur may have been *an early insect pathologist* (though he didn't know it) — Pebrine disease in silkworms



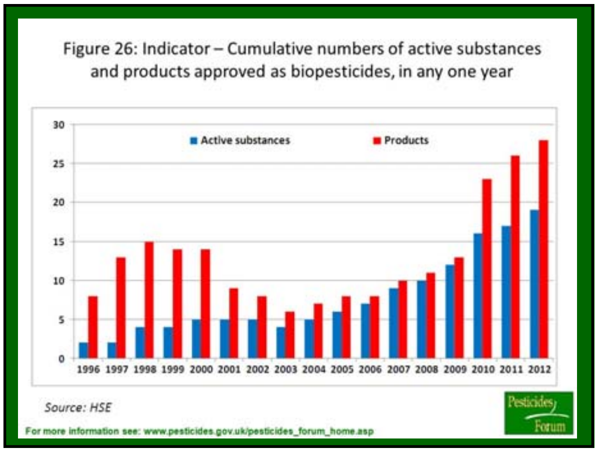


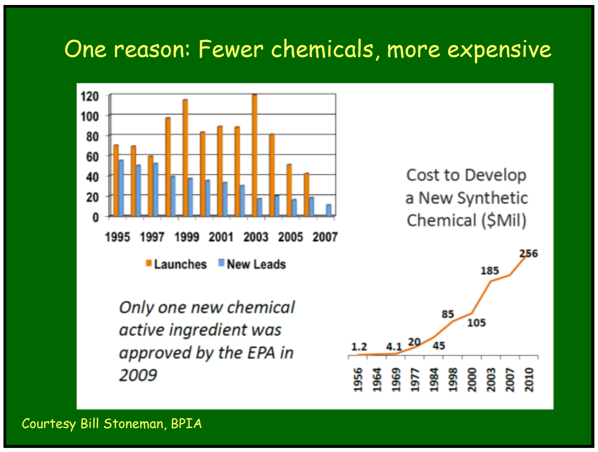

data, Courtesy BPIA




Courtesy Bill Stoneman, Biopesticide Industry Alliance

2014-2020 in U.S. 14.4% CACG




## Current US Microbial Insecticides

- Granulosis Virus
- NucleoPolyhedrosis Virus
- Bacillus popilliae
- Bacillus thuringiensis kurstaki
- B thur. aizawai
- B thur. israelensis
- Bacillus sphaericus
- Chromobacterium subtsugae
- Paenibacillus lentimorbis
- Pasteuria penetrans
- Paranosema locustae
- Lagenidium giganteum
- Beauveria bassiana
- Metarhizium anisopliae
- Isaria fumosorosea

## U.S. Companies 'into' microbials

Agraquest
Agrivir
Anatis Bioprotection
Arvesta
Becker Microbials
Biotepp
Certis
JABB
LAM Intl

Marrone BioInnovations
M&R Durango
Novozymes Biologicals
Planet Natural
Reuter
Troy Biosciences
US Forest Service
Valent Biosciences

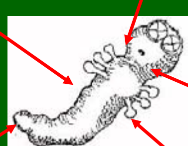
Bayer BASF
Syngenta Monsanto

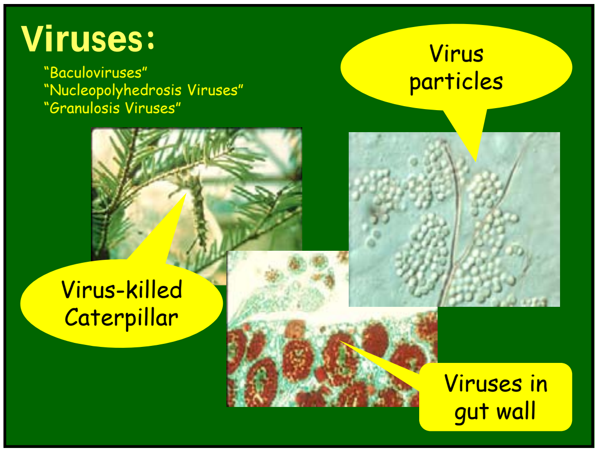
AgBiochem
Arysta Lifescience NA
AZ Cotton Research & Protection Council
Bayer Crop Science
Bioworks
Circle One Global Inc.
Growth Products Ltd
Jet Harvest Systems
Montana Microbial Products
Myco-Forests Corp
Mycologic Inc.
Natural Industries Inc.
Nufarm
NW Agricultural Products
Premier Horticulture Inc
Prophyta
Sylvan Bioproducts
Verdera Oy
OmniLytics

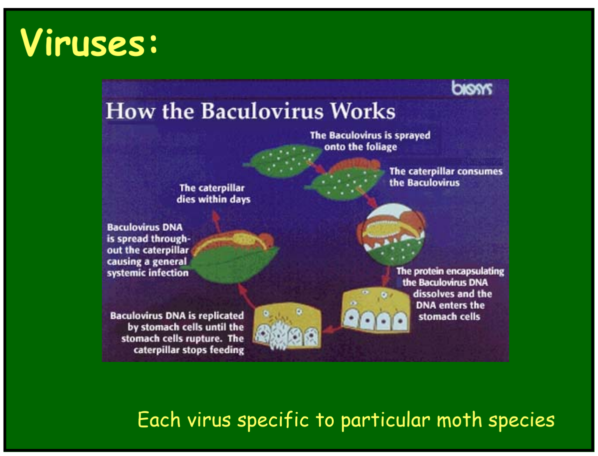
## but first, a primer…

[Insect Pathology 101]

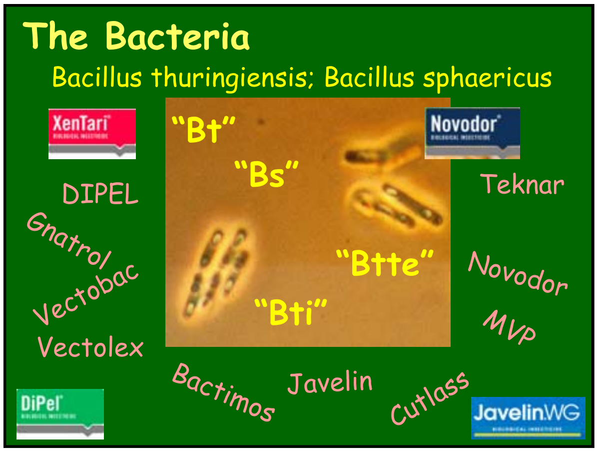
## *Insects have their fill of diseases ...*

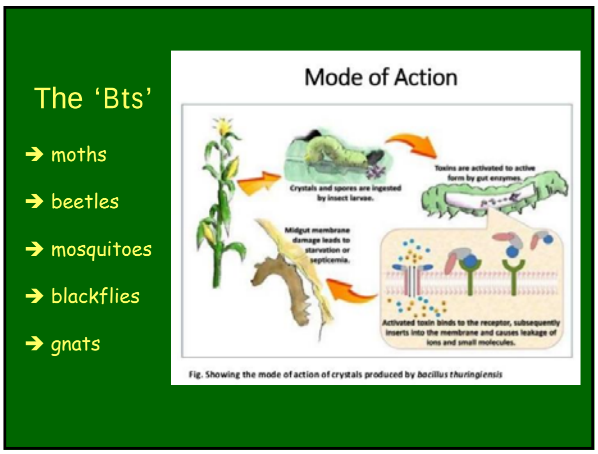


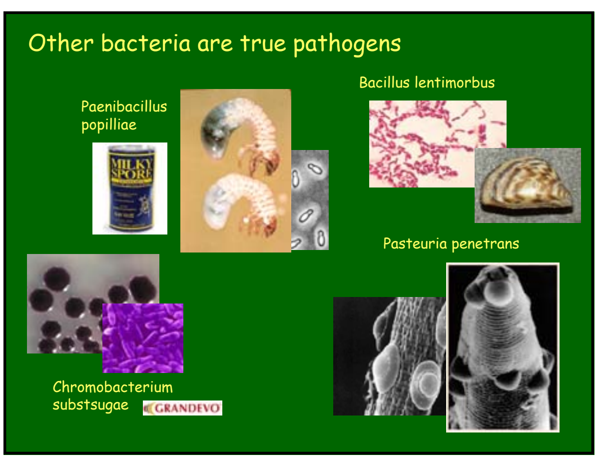

Viruses:
"Baculoviruses"
"Nucleopolyhedrosis Viruses"
"Granulosis Viruses"
Virus particles
Virus-killed Caterpillar
Viruses in gut wall


Viruses:
How the Baculovirus Works
The Baculovirus is sprayed onto the foliage
The caterpillar consumes the Baculovirus
The protein encapsulating the Baculovirus DNA dissolves and the DNA enters the stomach cells
Baculovirus DNA is replicated by stomach cells until the stomach cells rupture. The caterpillar stops feeding
Baculovirus DNA is spread throughout the caterpillar causing a general systemic infection
The caterpillar dies within days
Each virus specific to particular moth species

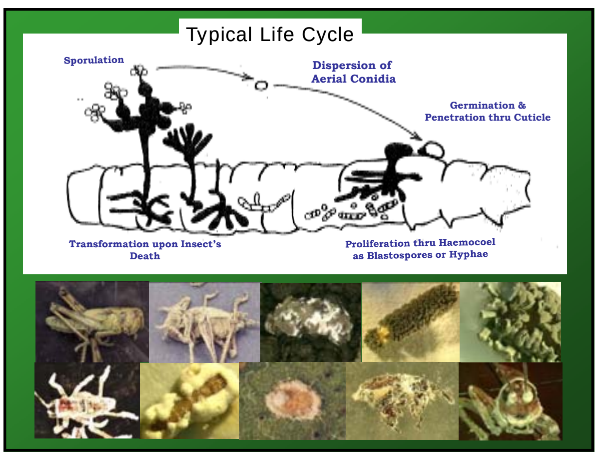

Some virus products
Gemstar
CYD-X
Madex® 3
SPOD-X LC
USDA does not endorse any commercial products. These are provided as examples only.

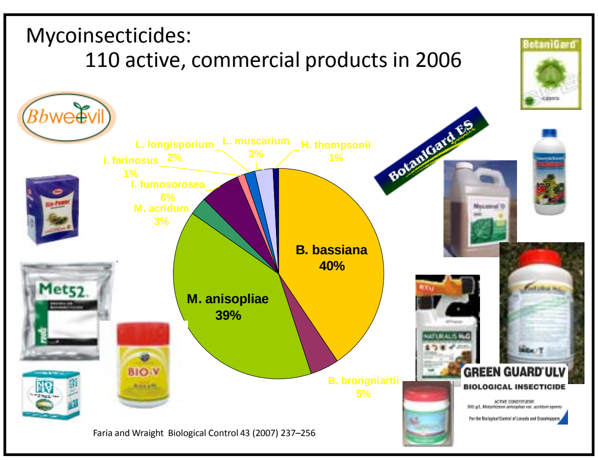

The Bacteria
Bacillus thuringiensis; Bacillus sphaericus
XenTari
"Bt"
"Bs"
Novodor
Teknar
DIPEL
Gnatrol
Vectobac
"Btte"
Novodor
"Bti"
MVP
Vectolex
Bactimos
Javelin
Cutlass
DiPel
JavelinWG


The 'Bts'
➔ moths
➔ beetles
➔ mosquitoes
➔ blackflies
➔ gnats
Mode of Action
Crystals and spores are ingested by insect larvae.
Toxins are activated to active form by gut enzymes.
Midgut membrane damage leads to starvation or septicemia.
Activated toxin binds to the receptor, subsequently inserts into the membrane and causes leakage of ions and small molecules.
Fig. Showing the mode of action of crystals produced by bacillus thuringiensis


Other bacteria are true pathogens
Paenibacillus popilliae
MILKY SPORE
Bacillus lentimorbus
Pasteuria penetrans
Chromobacterium substsugae
GRANDEVO

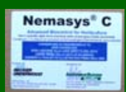

The Fungi
Stinkbug killed by Beauveria
Metarhizium in grasshoppers
Beauveria bassiana in whitefly nymph

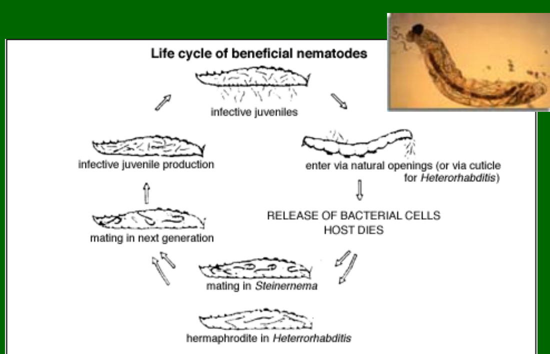

Typical Life Cycle
Sporulation
Dispersion of Aerial Conidia
Germination & Penetration thru Cuticle
Transformation upon Insect's Death
Proliferation thru Haemocoel as Blastospores or Hyphae


Mycoinsecticides:
110 active, commercial products in 2006
Bbweevil
BotaniGard ES
Met52
BIO-V
GREEN GUARD ULV
BIOLOGICAL INSECTICIDE
L. longisporium 2%
L. muscarium 3%
H. thompsonii 1%
I. farinosus 1%
I. fumosorosea 6%
M. acridum 3%
B. bassiana 40%
M. anisopliae 39%
B. brongniartii 5%
Faria and Wraight Biological Control 43 (2007) 237–256

## The Nematodes






## Some Common Nematode Products:

- Nemasys, Nemasys H (Microbio)
- Scanmask, Ecomask, Heteromask (Biologic Co.)
- Grubstake Hb, Grubstake-Hm, GnatNot (Integrated BioControl Systems, Inc.)
- Entonem, Larvanem, Scia-Rid (Koppert B.V.)

## Nematodes actively seek out their targets

Types of Nematode Behavior:

- Cruisers  *Heterorhabditis* *Steinernema riobravis*
- Stalkers  *Steinernema carpocapsae*

## Nematodes are Biologicals

Need refrigerated storage and have definite shelf life

Are affected by soil conditions (moisture, heat, porosity)

Can be affected by greenhouse chemicals.

*So how are we using these microbials*?

As **inundative** (albeit biological) **catastrophic density independent** mortality factors

*i.e. like chemicals …*

*Those danged microbes don't work well enough!*

→ Too weak (need too much, so too expensive)
→ Don't last long enough
→ (sometimes) Too complicated to think about

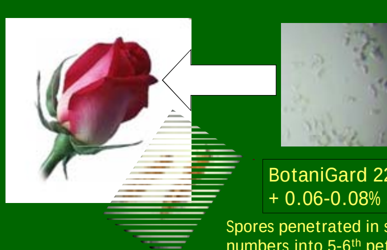
*How to make them work better, cheaper?*

The 'traditional' approaches

- Deliver them more efficiently
- Make them more persistent, work longer
- Make them more virulent

*How to make microbes better, cheaper?*

Make application more efficient thru formulations



BotaniGard 22WP
+ 0.06-0.08% Silwet L77®

Spores penetrated in substantial numbers into 5-6th petals of unopened flower

Control much better than 22WP alone

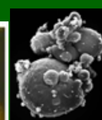
*How to make microbes better, cheaper?*

**Creative, ‘traditional’ approaches**

Make application more efficient thru *novel* formulations

Carnuba wax carrier e.g. Entostat®; or Candelilla wax powder



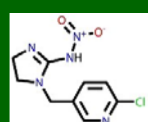


Exosect Ltd.

*How to make microbes better, cheaper?*

**Creative, ‘traditional’ approaches**

Combine chemical stressors with fungi
→ to stress insects’ immunity
→ alter behavior


*How to make them work better, cheaper?*

**Make (get) a ‘better’ microbe**

*How?*

*Traditional*

- Screening for the ‘best’ isolates
  – Let Nature provide
- Classical mutation selection – tradeoffs

*Novel*

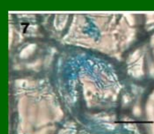
- Transgenic approaches: virulence factors, enhanced detox mechanisms
  – BUT, regulatory, societal challenges

## *Let's think outside the box*

- **Bring the insect to the microbe**
  - Fatty acids attractive to grasshoppers
- **Use the insect to vector the microbe to its kin**
  - Japanese beetle
  - Pine bark beetle
  - Adult click beetle
- **Use another insect to transfer the microbe to where it's needed**
  - bees vector *Beauveria* to flowers
- **Take advantage of target insect's behavior to increase transfer efficiency:**
  - spraying bark over which Gypsy Moth larvae must crawl;
  - Spray mosquito resting habitat (resting boxes in urban area)
  - Put the spores where (cherry fruit fly) larvae fall to pupate

## Outside the box

*The insect pathogenic fungi, Beauveria, Metarhizium, Isaria* as plant endophytes



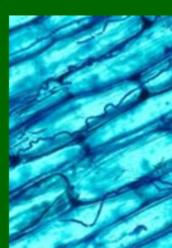

Gomez-Vidal et al., 2006
Micron 37 (2006) 624-632

*Beauveria* are endophytic in
**maize, cocoa, date palm**, **coffee**, **grapes**, **tomato**, **banana**, **sorghum**, **medicinal poppy**, **jute**, **broad bean**, **cassava**, **cotton**, **strawberries**, **wheat …**

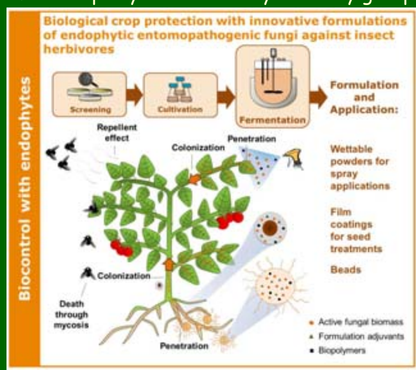
*Metarhizium* are endophytic in
**rape, beans, switchgrass, yew, rice**;
more famously associated with root systems.

*Beauveria*, *Metarhizium*, *Isaria* as endophytes

Can be artificially introduced in at least some plants
- Foliar application
- Seed treatment
- Root dip



Visualization of the concept by one university-industry group

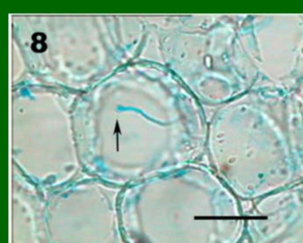



Courtesy Anant Patel, Bielefeld University

*How do these endophytic fungi act on an insect pest?*

➔ Direct infection of insects

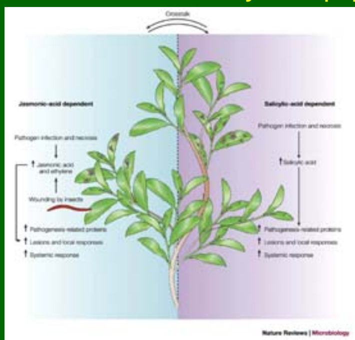
➔ Indirect effect – secreted metabolites

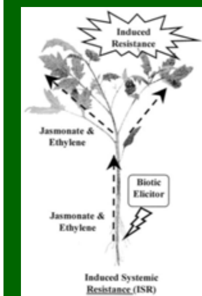



from Quesada-Moraga et al. 2006

**But wait! There's more!**

## Induction of Systemic Resistance, to herbivores, by endophytes

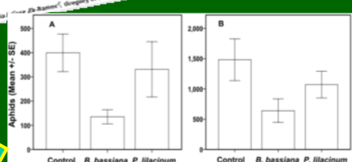



## Induction of Systemic Resistance, to herbivores

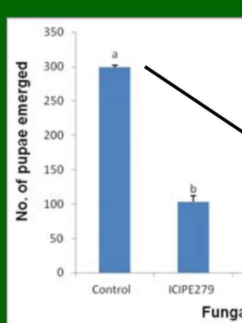

PLOS

The Entomopathogenic Fungal Endophytes *Purpureocillium lilacinum* (Formerly *Paecilomyces lilacinus*) and *Beauveria bassiana* Negatively Affect Cotton Aphid Reproduction under Both Greenhouse and Field Conditions




Aphid colonization affected by Beauveria, Purpureoacillium colonization — IN THE FIELD

## Induction of Systemic Resistance, to herbivores — leaf miners and beans




Endophytic colonization by, or ***more likely, exposure to*** Beauveria and Trichoderma affected survival of two leaf miners in beans

Akutse et al. 2013 Fungal Ecology 6, 293 – 301

## And more…


World J Microbiol Biotechnol (2012) 28:1483–1494
DOI 10.1007/s11274-011-0950-9

ORIGINAL PAPER

**Pure culture of *Metarhizium anisopliae* LHL07 reprograms soybean to higher growth and mitigates salt stress**

Abdul Latif Khan · Muhammad Hamayun · Sumera Afzal Khan · Sang-Mo Kang · Zabta Khan Shinwari · Muhammad Kamran · Shafiq ur Rehman · Jong-Guk Kim · In-Jung Lee

*Metarhizium anisopliae* LHL07-inoculated soybean plants displayed significantly
- higher shoot length,
- shoot fresh and dry biomass,
- chlorophyll contents,
- transpiration rate,
- photosynthetic rate and leaf area,

under salt-induced salt stress as compared to non-inoculated control plants.

Metarhizium LHL07 elevated proline and reduced superoxide dismutase and malondialdehyde, reduced abscisic acid and elevated jasmonic acid levels

Phytohormone Effects?

## Induction of Systemic Resistance *without* endophytism does occur

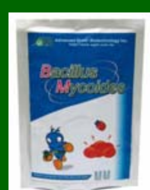

Physiological and Molecular Plant Pathology

Volume 61, Issue 5, November 2002, Pages 289–298

Regular Article

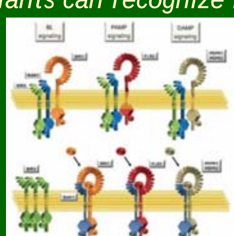
**Characterisation of systemic resistance in sugar beet elicited by a non-pathogenic, phyllosphere-colonizing *Bacillus mycoides*, biological control agent**

R.L Bargabus, N.K Zidack, J.E Sherwood, B.J Jacobsen




## Induction of Systemic Resistance

*Plants can recognize molecular patterns*



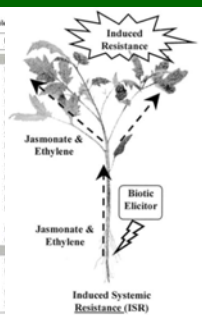
PAMPs
MAMPs
DAMPs
HAMPs

Microbes on plant's cuticle are a molecular pattern …

## There are all sorts of molecular patterns 'perceived' by plants

Table 1 | Microbe-associated molecular patterns (MAMPs) and Damage-associated mol

| Name | Corresponding plant receptor (PRR) |
|---|---|
| **MAMPs** | |
| Flagellin (Flg; flg22) | FLS2 (Arabidopsis) |
| Elongation factor TU (EF-Tu; elf18/26) | EFR (Arabidopsis; Brassicaceae) |
| Peptidoglycan (PGN) | Lym1 and Lym3 (Arabidopsis) |
| Lipopolysaccharide (LPS) | Not identified |
| Bacterial cold shock proteins (RNP1 motif) | Not identified |
| Bacterial superoxide dismutase (Sod) | Not identified |
| Activator of XA21 (Ax21) | XA21 and XA21D (rice) |
| Beta-Glycan (GE) | GEBP (putative receptor soybean) |
| Chitin | CeBip and CERK1 (rice), AtCERK1 (Arabidopsis) |
| Avirulence on Ve1 tomato (Ave1) | Ve1 (putative tomato receptor) |
| Xylanase (EIX) | EIX (tomato) |
| Pep-13 (An oligopeptide of 13 amino acids from *P. mega-sperma*) | Not identified |
| Cellulose-binding elicitor lectin (CBEL) from *Phytophthora* | Not identified |
| **DAMPs** | |
| Systemin | Not identified |
| Pep1 (23 aa part of a cytosolic protein from *Arabidopsis*) | PEPR1 (Arabidopsis) |
| Oligogalacturonides (OGs) | WAK1 (Arabidopsis) |
| Cutin | Not identified |




Newman et al 2013 Frontiers in Plant Science Vol. 4 Art. 139

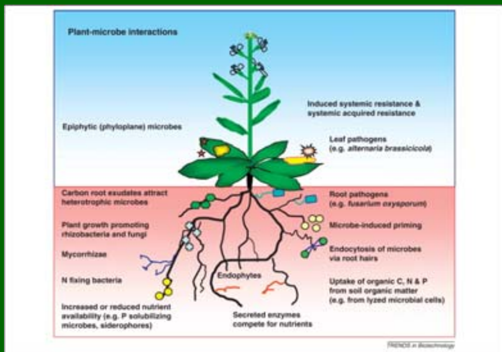
## BUT WAIT! THERE'S EVEN MORE!

Manipulating the existing crop plant microbiome for better plant health


## Plants have their microbiome too!

- → 10,000,000 microbes / $cm^2$ leaf surface;
- → 10,000,000,000 microbes, 30,000 species / gram root associated soil
- → 100s microbe species living in xylem, phloem

## A plant can be a crowded 'hotel.'



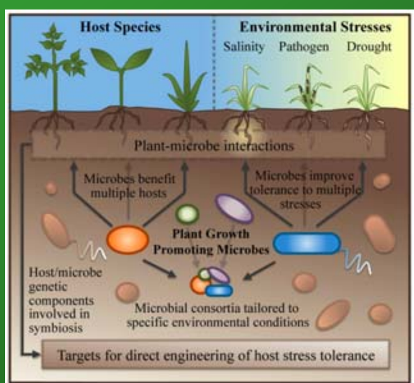
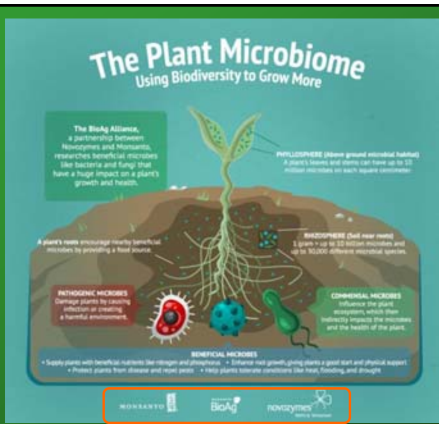




**Table 1.** *Commercial products of plant growth-promoting rhizobacteria in plant health and disease management*

| Bioagent | Trade Name/Formulation |
|---|---|
| *Agrobacterium radiobacter* strain K1026 | Nogall, |
| *A. radiobacter* strain K84 | Galltrol, Diegall |
| *Azospirillum brasilense/Azotobacter chroococcum* | Gmax Nitromax |
| *A. brasilense* | Azo-Green |
| *B. subtilis* MB1600 | BaciGold, HiStick N/T, Subtilex |
| *B. subtilis* strain FZB24 | Rhizo-Plus, Serenade, Rhapsody, Taegro, Tae-Technical |
| *Bacillus chlororaphis* 63-28 | AtEze |
| *Bacillus cereus* BPO1 | Pix plus |
| *Bacillus pumilus* GB 34 | Concentrate; YieldShield |
| *B. pumilus* QST2808 | Sonata ASO, Ballard |
| *B. subtilis* GB03 | Companion, System 3, Kodiak, Kodiak HB, Epic |
| *Bacillus amyloliquefaciens* GB99 | Quantum 4000 |
| *Bacillus licheniformis* SB3086 | EcoGuard, Green Releaf |
| *Burkholderia cepacia* | Blue Circle, Deny, Intercept |
| *P. fluorescens* A506 | BlightBan A506, Conquer, Victus |
| *Pseudomonas syringae* ESC-100 | Bio-Save 10, 11, 100, 110,1000, and 10 LP |
| *Pseudomonas chlororaphis* | Cedomon |
| *Pseudomonas cepacia* | Intercept |
| *Streptomyces griseovirdis* K61 | Mycostop |
| *B. subtilis + B. amyloliquefaciens* | Bio Yield |
| *Pseudomonas* spp. + *Azospirillum* spp. | BioJet |

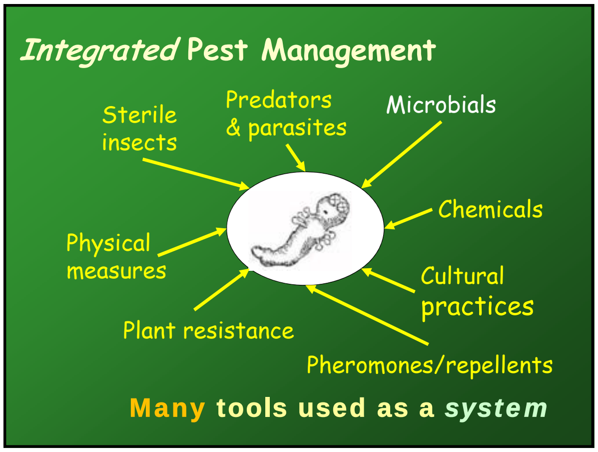



But before we get too excited at these sci-fi prospects,

Let's not forget

**There is no such thing as a magic bullet**

(if you think there is, I have a bridge over the Yellowstone River to sell you).

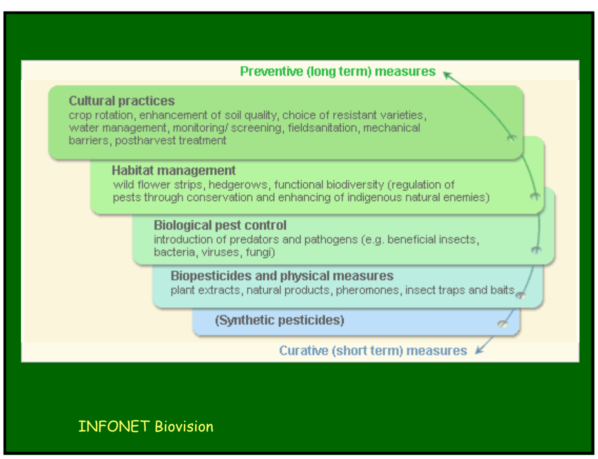



## Integrated Pest Management

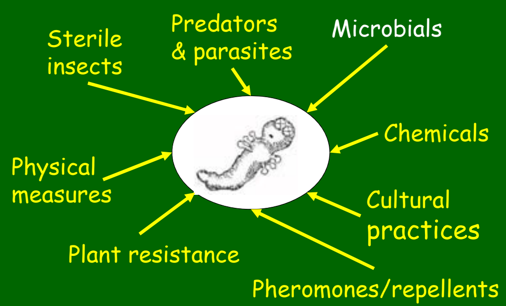
(U.S. National IPM Network).

"Integrated Pest Management (IPM) is a

- sustainable approach
- to managing pests
- by combining biological, cultural, physical and chemical tools in a way that
- minimizes economic, health, and environmental risks".



## *Integrated* Pest Management

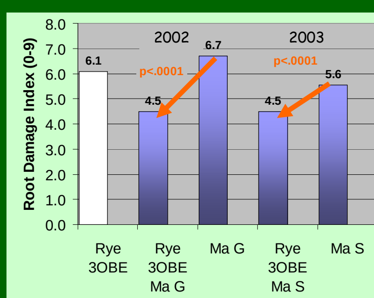



**Many tools used as a *system***

## E.g., Integration with cover crops (sugar beets)

*Plots had significantly lower root damage with Metarhizium when integrated with rye cover crop.*

OBE: Oat-Bushel-Equivalents




## Another example:

Strawberry IPM system – UC Dept of Agriculture & Natural Resources Coop Extension

| | 1st application (Rate/acre) | 2nd application (Rate/acre) | 3rd application (Rate/acre) |
|---|---|---|---|
| 1 | Untreated | Untreated | Untreated |
| 2 | Assail 70 WP (3 oz) **4A*** | Assail 70 WP (3 oz) **4A** | Assail 70 WP (3 oz) **4A** |
| 3 | Vacuum | Vacuum | Vacuum |
| 4 | Rimon 0.83 EC (12 fl oz) **15** + Brigade (16 oz) **3A** | Met52 EC(16 fl oz) + Debug Turbo (104 fl oz) | Met52 EC (16 fl oz) + AzaGuard (16 fl oz) |
| 5 | Sequoia (4.5 oz) **4C** | Sequoia (4.5 oz) **4C** | Vacuum |
| 6 | Pfr-97 (2 lb) + Neemix (9 fl oz) | Pfr-97 (2 lb) + Neemix (9 fl oz) | Vacuum |
| 7 | Vacuum | Sivanto (14 fl oz) **4D** + Debug Turbo (104 fl oz) | Rimon 0.83 EC (12 fl oz) **15** + Brigade (16 oz) **3A** |
| 8 | Sivanto (14 fl oz) **4D** | Sivanto (14 fl oz) **4D** | Vacuum |
| 9 | Sequoia (4.5 oz) **4C** | Sivanto (14 fl oz) **4D** | Beleaf 50 SG (2.8 oz) **9C** |
| 10 | *B. bassiana*+neem (1qrt) | *B. bassiana*+pyrethrum **3A**+neem (1qrt) | *B. bassiana*+pyrethrum **3A** (1qrt) |
| 11 | *B. bassiana*+pyrethrum **3A** (1qrt) | *B. bassiana*+neem (1qrt) | Beleaf 50 SG (2.8 oz) **9C** |
| 12 | *B. bassiana*+pyrethrum **3A** (1qrt) | Vacuum | Rimon 0.83 EC (12 fl oz) **15** + Brigade (16 oz) **3A** |

## IPM with microbial in chrysanthemums

Week 1: introduce *Dacnusa* for leafminers

Week 2: early in week, *Beauveria* for thrips
late in week, apply fungicides

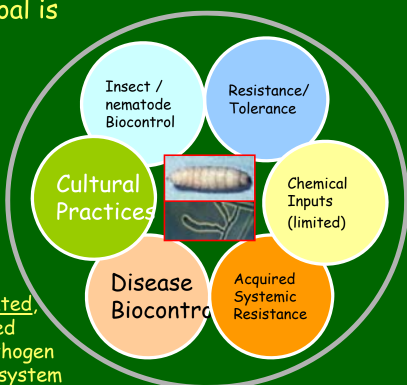
Week 4: Apply predaceous mites
Apply *Beauveria*

Week 6-8: Spray *Beauveria* weekly
Apply Bt for lepidoptera, as needed
Apply cinnamaldehyde (cinnamon oil) only to mite "hotspots"

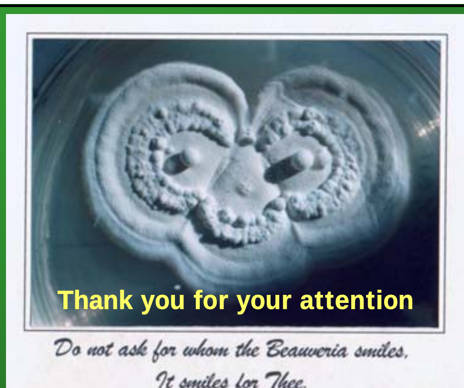
Week 8: Introduce *Diglyphus* for leafminers

And this program was designed by a **farmer**

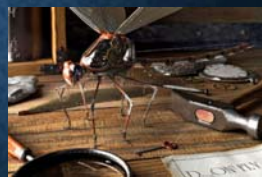
## Ultimate goal is




An integrated, bio-based pest and pathogen management system



## IMPROVING THE EFFICIENCY OF BIOLOGICAL CONTROL
### (OR HOW TO BUILD A BETTER BC AGENT)

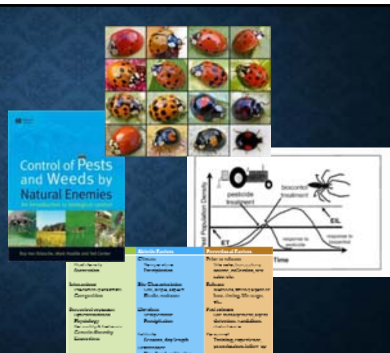



Jeff Littlefield

Department of LRES
Montana State University

## KEY POINTS

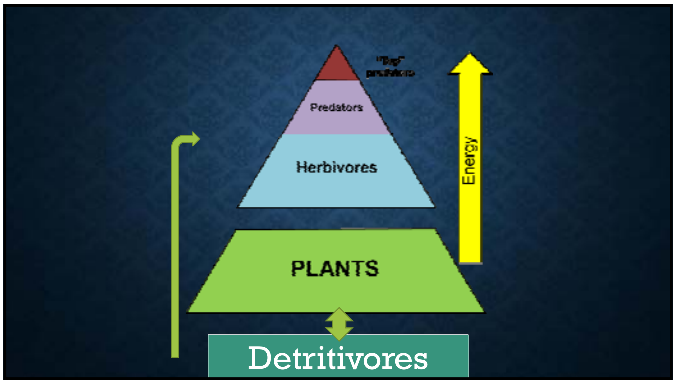
- What is biological control?
- The Players involved
- Types of biocontrol
- Our goals
- Failure matrix




## WHAT IS BIOLOGICAL CONTROL?

Natural control vs Biological control

- **Natural control** – the regulation of a pest populations by naturally occurring enemies



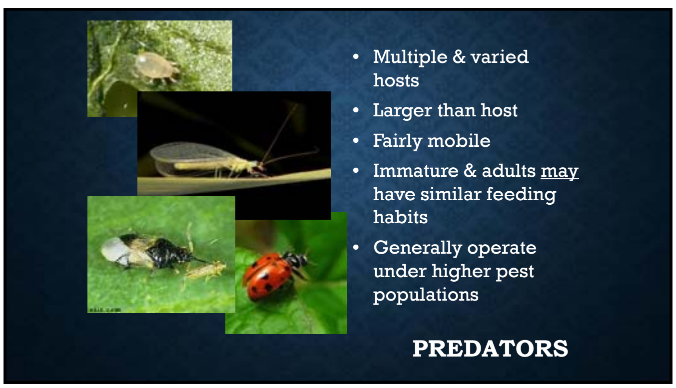

**WHAT IS BIOLOGICAL CONTROL?**

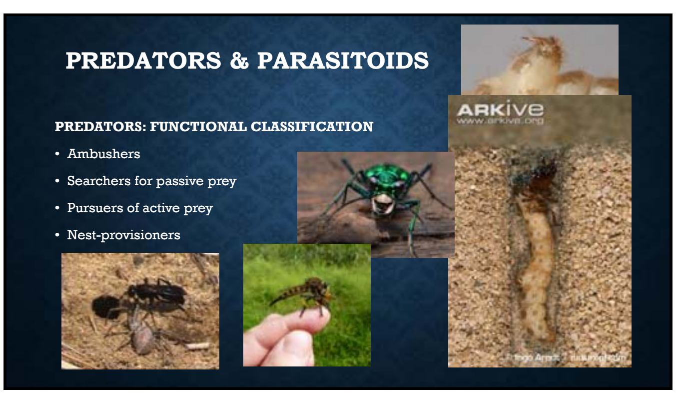
Natural control vs Biological control

- Biological control – the manipulation of natural enemies to achieve desired levels of control

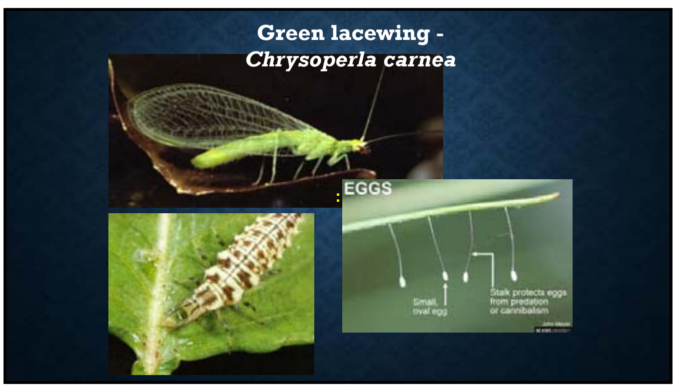
**THE PLAYERS**


Predators
Parasitoids
Nematodes
Pathogens
Weed herbivores
GUILDS OF BIOCONTROL AGENTS


Multiple & varied hosts
Larger than host
Fairly mobile
Immature & adults may have similar feeding habits
Generally operate under higher pest populations
PREDATORS

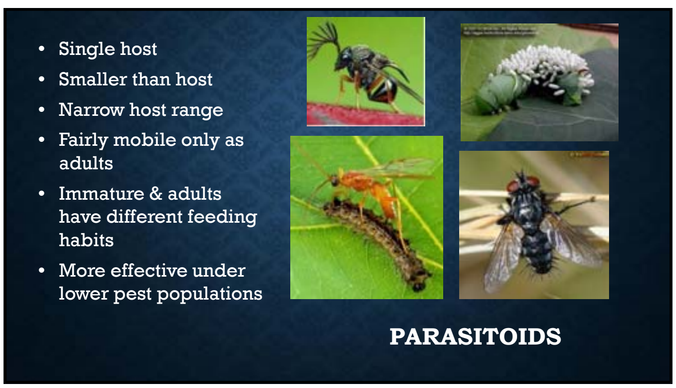

PREDATORS & PARASITOIDS
PREDATORS: FUNCTIONAL CLASSIFICATION
Ambushers
Searchers for passive prey
Pursuers of active prey
Nest-provisioners
ARKive
www.arkive.org

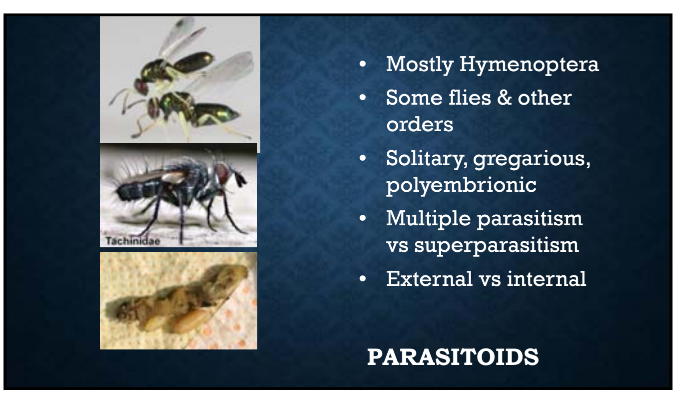

COCCINELIDS
harlequin
ladybird
Harmonia
axyridis


Green lacewing -
Chrysoperla carnea
EGGS
Small,
oval egg
Stalk protects eggs
from predation
or cannibalism

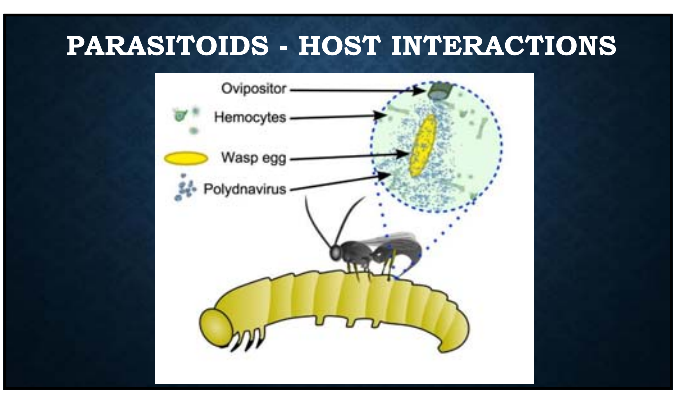

True Bugs


Ground Beetles


• Single host
• Smaller than host
• Narrow host range
• Fairly mobile only as adults
• Immature & adults have different feeding habits
• More effective under lower pest populations
PARASITOIDS

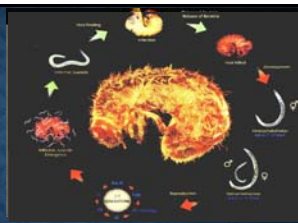

Tachinidae
• Mostly Hymenoptera
• Some flies & other orders
• Solitary, gregarious, polyembrionic
• Multiple parasitism vs superparasitism
• External vs internal
PARASITOIDS

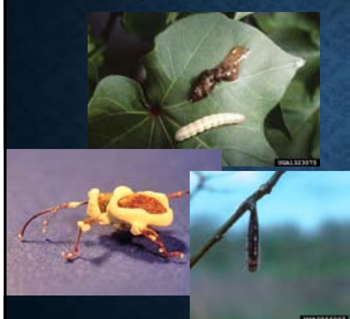

PARASITOIDS CAN ALTER HOST BEHAVIOR
NATIONAL GEOGRAPHIC
REAL
ZOMBIES
The Strange Science of the Living Dead


PARASITOIDS - HOST INTERACTIONS
Ovipositor
Hemocytes
Wasp egg
Polydnavirus

- Small, clear, worm-like
- Three familes: Steinernematidae, Heterorhabditidae & Rhabditidae
- Wide host range
- Cruiser vs ambush spp
- Mutualistic bacteria
- Kill host 24-48 hr
- Sensitive to low moisture
- Optimal temperature

## NEMATODES





- Applied as "biopesticide"
- Include bacteria, fungi, & viruses
- Broad host range
- Limited shelf life
- Sensitive to environmental conditions & UV

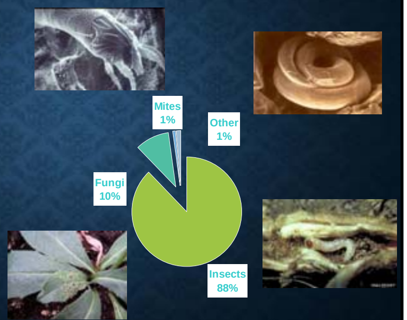
## PATHOGENS

## ENTOPATHOGENS

- Nosema locustae
- Milky spore
- Beauveria bassiana
  - Thrips
  - Whiteflies
  - Aphids
- Bacillus thuringiensis (BT)
  - Lepidoptera larvae
  - Fungus gnats or black flies
  - Beetles

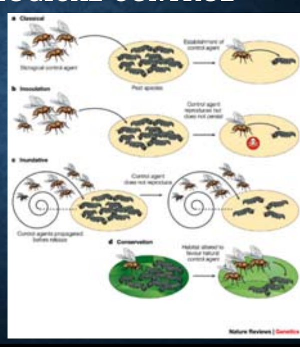
## WEED HERBIVORES

- Mostly insects – weevils, moths, tephritid flies, etc.
- Host specific or narrow host range
- Largely internal feeders or gall makers
- Immatures & adults may or may not have different feeding habits
- Used primarily in classical BC for exotic weeds




## TYPES OF BIOLOGICAL CONTROL

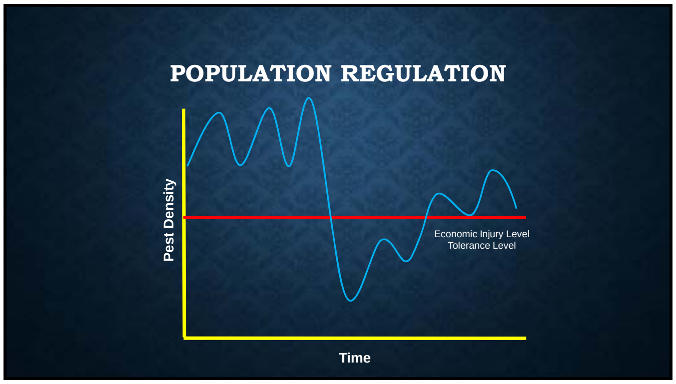
- **Classical/ Inoculation** – initially small numbers of natural enemies are released in target pest areas for long-term control.
- **Augmentative/ Inundative** – large numbers of natural enemies are released to control a target pest for a short amount of time.
- **Conservation** – changing environmental conditions to aid in natural enemy survival.

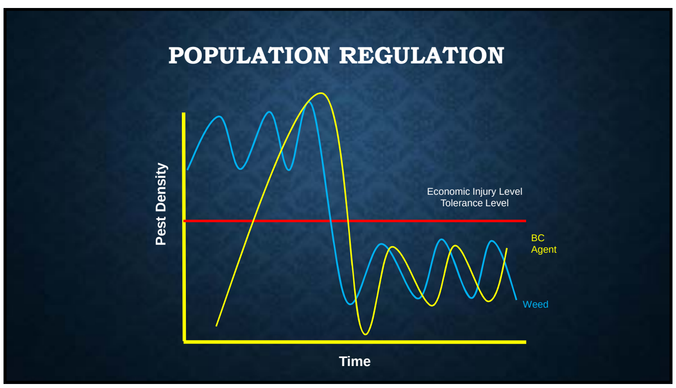


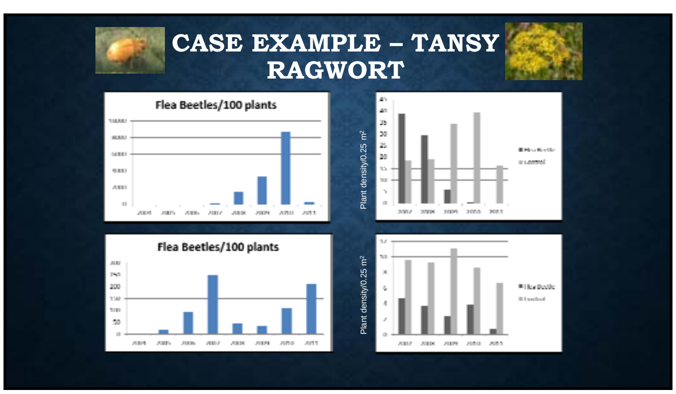
## GOALS?

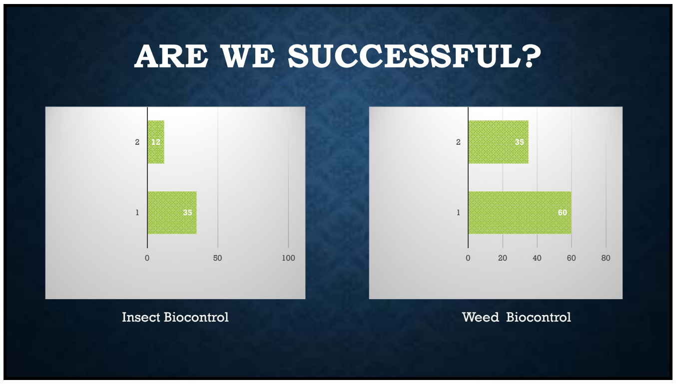
Dependent upon:

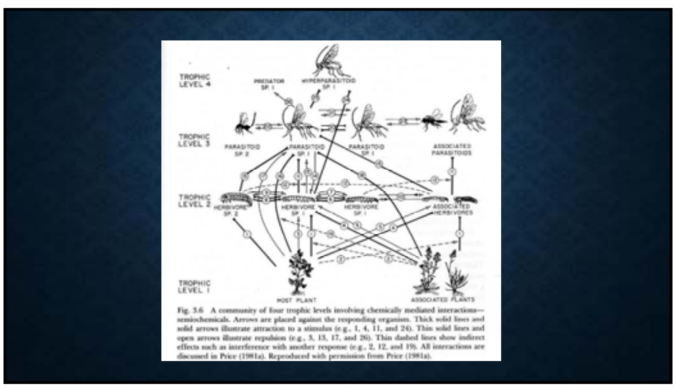
- Type of pest
- Level of control required
- Speed of control
- Scale of control

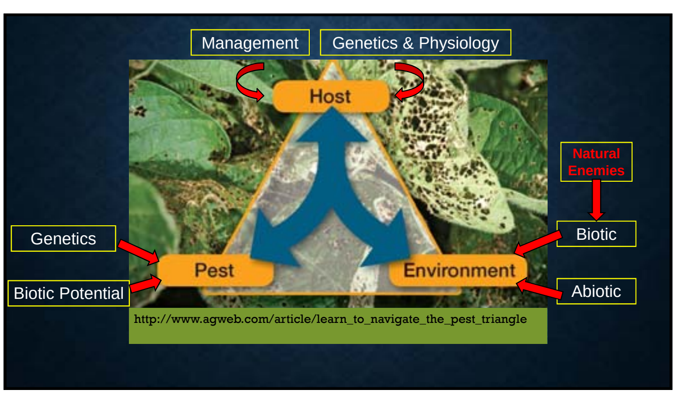

POPULATION REGULATION
Pest Density
Economic Injury Level
Tolerance Level
Time


POPULATION REGULATION
Pest Density
Economic Injury Level
Tolerance Level
BC
Agent
Weed
Time


CASE EXAMPLE – TANSY RAGWORT
Flea Beetles/100 plants
Plant density/0.25 m²
Flea Beetles/100 plants
Plant density/0.25 m²


ARE WE SUCCESSFUL?
2
1
12
35
0
50
100
Insect Biocontrol
2
1
35
60
0
20
40
60
80
Weed Biocontrol


TROPHIC LEVEL 4
PREDATOR SP. 1
HYPERPARASITOID SP. 1
TROPHIC LEVEL 3
PARASITOID SP. 2
PARASITOID SP. 1
PARASITOID SP. 1
ASSOCIATED PARASITOIDS
TROPHIC LEVEL 2
HERBIVORE SP. 2
HERBIVORE SP. 1
HERBIVORE SP. 1
ASSOCIATED HERBIVORES
TROPHIC LEVEL 1
HOST PLANT
ASSOCIATED PLANTS
Fig. 3.6 A community of four trophic levels involving chemically mediated interactions—semiochemicals. Arrows are placed against the responding organism. Thick solid lines and solid arrows illustrate attraction to a stimulus (e.g., 1, 4, 11, and 24). Thin solid lines and open arrows illustrate repulsion (e.g., 3, 13, 17, and 26). Thin dashed lines show indirect effects such as interference with another response (e.g., 2, 12, and 19). All interactions are discussed in Price (1981a). Reproduced with permission from Price (1981a).


Management
Genetics & Physiology
Host
Natural Enemies
Biotic
Genetics
Pest
Environment
Biotic Potential
Abiotic
http://www.agweb.com/article/learn_to_navigate_the_pest_triangle

## FAILURE MATRIX (WEED BC)

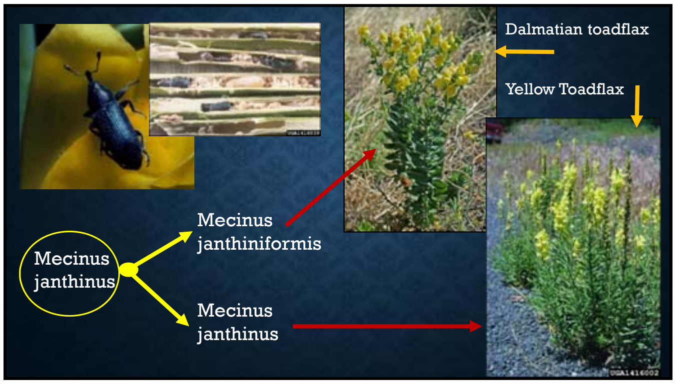
| Biotic Factors | Abiotic Factors | Procedural Factors |
|---|---|---|
| Plant Community<br>Host density<br>Succession | Climate<br>Temperature<br>Precipitation | Prior to release<br>Site selection, colony source, collection, sex ratio, etc. |
| Interactions<br>Predation/parasitism<br>Competition | Site Characteristics<br>Soil, slope, aspect<br>Shade, moisture | Release<br>Methods, wrong agent or host, timing, life stage, etc. |
| Biocontrol organism<br>Synchronization<br>Physiology<br>Fecundity & behavior<br>Genetic diversity<br>Emigration | Elevation<br>Temperature<br>Precipitation | Post release<br>Site management, agent detection, vandalism, disturbance |
| | Latitude<br>Seasons, day length<br>Disturbance<br>Fire, flood, cultivation | Personnel<br>Training, experience, prioritization, follow-up |

Modified from Coombs OR Dept. Ag.

## TOP 10 REASONS FOR BIOCONTROL FAILURE


## TOP 10 REASONS FOR BIOCONTROL FAILURE

# 10 - My pest is not the **PEST**


Dalmatian toadflax
Yellow Toadflax
Mecinus janthinus
Mecinus janthiniformis
Mecinus janthinus


TOP 10 REASONS FOR BIOCONTROL FAILURE
# 9 - Mating failure (or are my beer goggles fogged up?)


USING SEMIOCHEMICALS TO MANIPULATE THE SPATIAL DISTRIBUTION OF *DIORHABDA CARINULATA*
ALEX M. GAFFKE[1], DAVID K. WEAVER[1], SHARLENE E. SING[2]
1. Department of Land Resources and Environmental Sciences, Montana State University, Bozeman, Montana, United States 2. Department of Land Resources and Environmental Sciences, Montana State University, Bozeman, Montana, United States, 3. USDA-USFS Rocky Mountain Research Station, Bozeman, Montana,
36
USDA Forest Service
MONTANA
Rocky Mountain Research Station

## WHY MANIPULATE AN AGENT

- Increase establishment
- Easier to monitoring
- Control agent's distribution
  - Increase herbivory on target plant
  - Manage spread to avoid critical habitat

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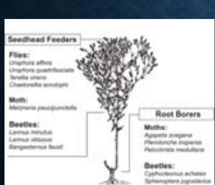
## SEMIOCHEMICALS

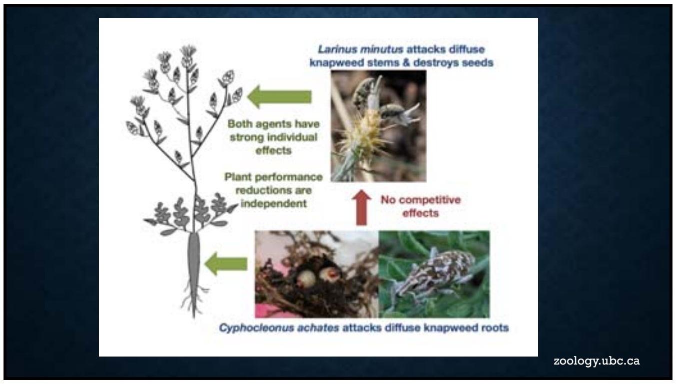
- Male produced aggregation pheromone
  - (2*E*, 4*Z*)-2,4-heptadien-1-ol (Cossé et al. 2005)
- Aggregation causing green leaf volatiles (Cossé et al. 2006)
  - (*E*)-2-hexenal
  - (*Z*)-3-hexenal
  - (*Z*)-3-hexen-1-ol
  - (*Z*)-3-hexenyl acetate

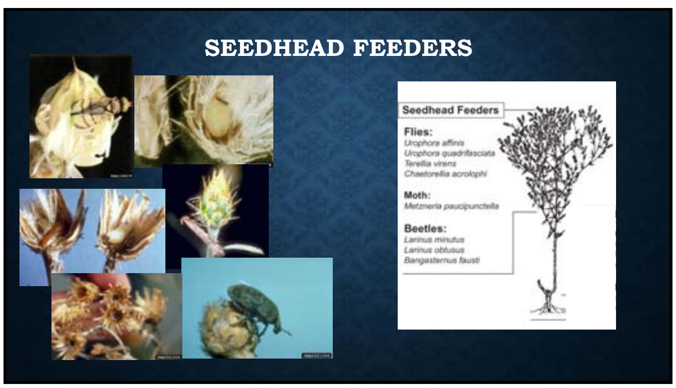
38

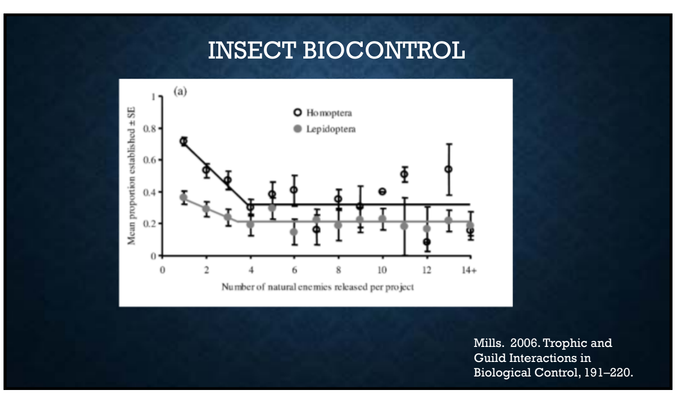
## TOP 10 REASONS FOR BIOCONTROL FAILURE

# 8 - You call this a niche?



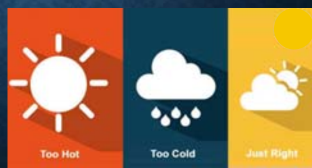


Larinus minutus attacks diffuse knapweed stems & destroys seeds
Both agents have strong individual effects
Plant performance reductions are independent
No competitive effects
Cyphocleonus achates attacks diffuse knapweed roots
zoology.ubc.ca


SEEDHEAD FEEDERS
Seedhead Feeders
Flies:
Urophora affinis
Urophora quadrifasciata
Terellia virens
Chaetorellia acrolophi
Moth:
Metzneria paucipunctella
Beetles:
Larinus minutus
Larinus obtusus
Bangasternus fausti

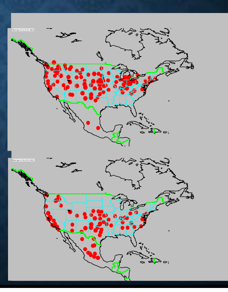

INSECT BIOCONTROL
(a)
Homoptera
Lepidoptera
Mean proportion established ± SE
Number of natural enemies released per project
Mills. 2006. Trophic and Guild Interactions in Biological Control, 191–220.

## TOP 10 REASONS FOR BIOCONTROL FAILURE

# 7 – Too HOT - Too COLD – Too Dry - Too WET (The Goldilocks Syndrome)

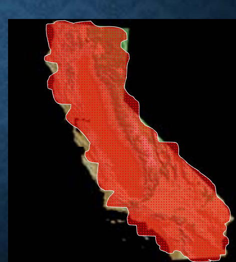



## PUNCTUREVINE BIOCONTROL



## THE COTTON CUSHION SCALE

California introduced 1880
State-wide 1886



## NATURAL ENEMIES FOUND


Rodolia cardinalis

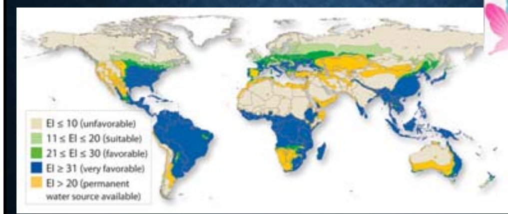

Cryptochaetum iceryae

## NATURAL ENEMY RELEASED

1890: Cotton Cushion scale eliminated

## OTHER IMPORTED NATURAL ENEMY OF THE COTTON CUSHION SCALE

## CLIMEX - SOFTWARE TO PREDICT THE EFFECTS OF CLIMATE ON SPECIES

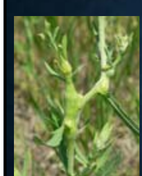



CLIMEX

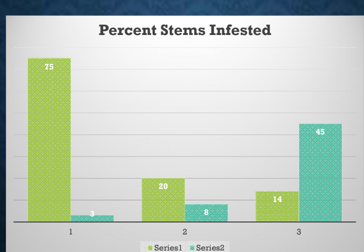
## TOP 10 REASONS FOR BIOCONTROL FAILURE

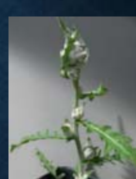
# 6 – Hey! Some *#@$#!!! sprayed (set fire to, cultivated, flooded, etc.) <u>my</u> plots

## RUSSIAN KNAPWEED & GRAZING



Aulacidea
Aa

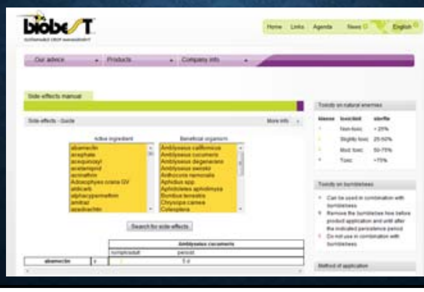


Japiella
Ja

## PESTICIDES SIDE EFFECTS DATA BASE

http://www.biobest.ca/ http://side-effects.koppert.nl/



## TOP 10 REASONS FOR BIOCONTROL FAILURE

# 5 - Wrong place – wrong time

(I should have checked my Outlook calendar)

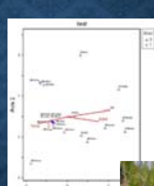

## SITE SELECTION & RELEASE

Site selection

- Suitable habitat
- Sites not prone to fires, flooding, or other natural disturbances
- Adequate plants
- Small vs. large infestations

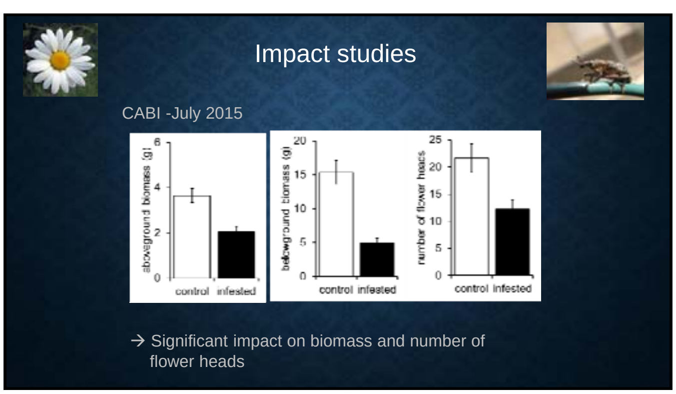
Release methods

- Timing
- Numbers released

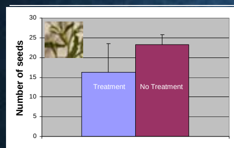



TOP 10 REASONS FOR BIOCONTROL FAILURE
# 4 - When the consumers are consumed
80 60 40 20 0
June Oct.
% Galls Eaten
40 30 20 10 0
June Sept.
% Parasitism
100 50 0
June Oct.
% Parasitism

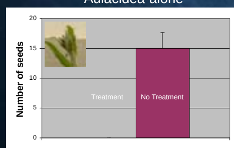

TOP 10 REASONS FOR BIOCONTROL FAILURE
# 3 - "The Little moth …. beetle ….fly… that couldn't (or Too little or Too late)
WELL KIDS,


Impact studies
CABI -July 2015
aboveground biomass (g)
control infested
belowground biomass (g)
control infested
number of flower heads
control infested
→ Significant impact on biomass and number of flower heads

## Interactions among biocontrol agents




Aulacidea alone




Jaapiella alone

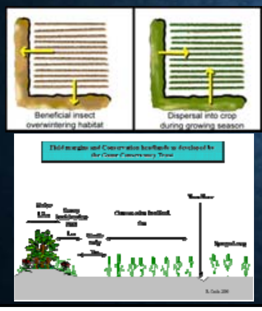
## TOP 10 REASONS FOR BIOCONTROL FAILURE

# 2 – The penguin effect – What we have here is a lack of diversity!

## TOP 10 REASONS FOR BIOCONTROL FAILURE

# 2 – The penguin affect

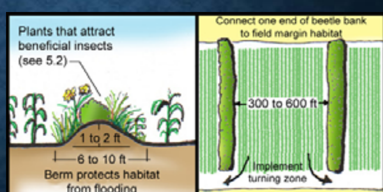
## INCREASING DIVERSITY & STRUCTURE



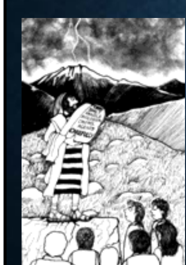

Key Design Considerations

- Provide plant diversity and structure in the buffer.
- Protect buffer from disturbances (e.g., pesticides, tillage).
- Predation of insect pests generally increases with the percentage of buffer habitat in the area.
- Locate buffers throughout the fields and landscape to encourage dispersal of beneficial insects.
- Buffers may provide habitat for some pest insects but this can be reduced by selecting appropriate plants.
- Beetle banks are long, planted berms that provide habitat for beneficial insects .

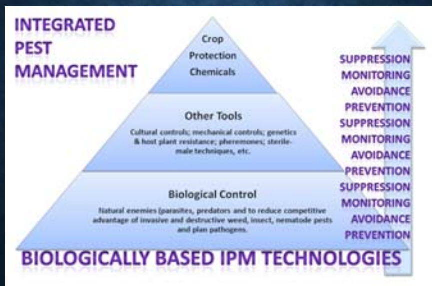
## Beetle Banks




## TOP 10 REASONS FOR BIOCONTROL FAILURE



# 1 – Stupid peoples (we have met the enemy and they are us)




## ADDITIONAL REFERENCES


Cow philosophy

The Xerces Society: Farming with Native Beneficial Insects.
http://www.xerces.org/conservationbiocontrol/

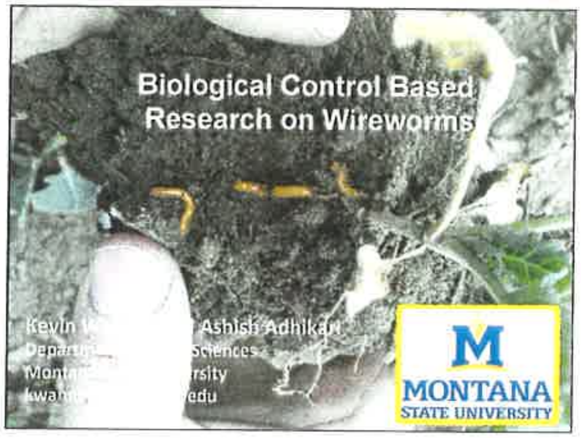
Conservation Biological Control – Pedro Barbosa, Academic Press

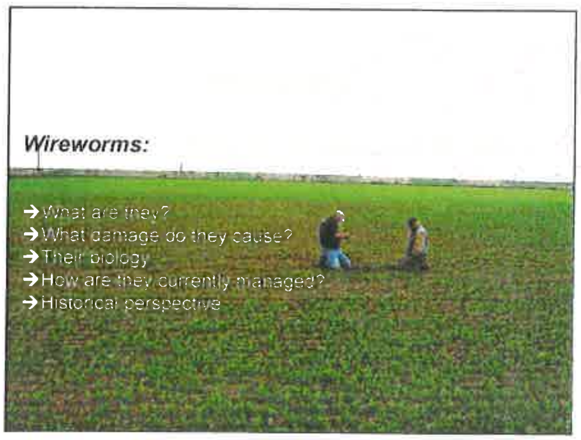
Michigan State U.: http://nativeplants.msu.edu/

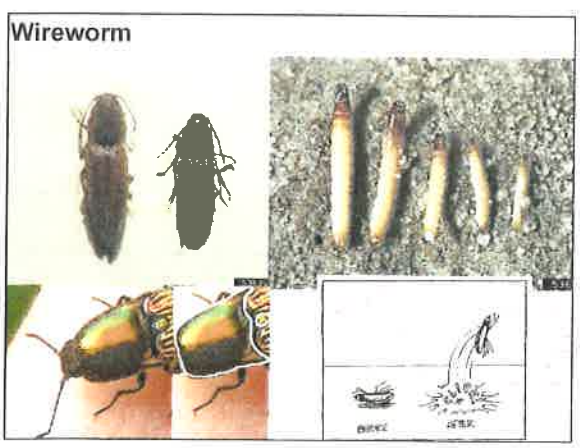
British Columbia Ministry of Forests, Lands & Natural Resource Operations (Publications & manuals):
http://www.for.gov.bc.ca/hra/Plants/publications.htm#manuals

EDDMapS Biological Control of Invasive Plants (USFS Manuals):
http://www.eddmaps.org/biocontrol

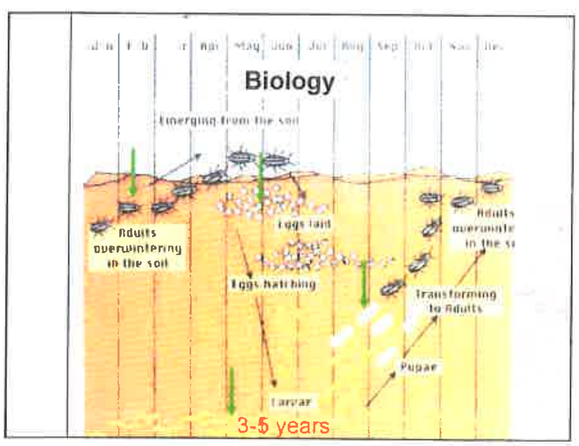
Jeff Littlefield Department of LRES, MSU, PO 173120, Bozeman, MT 59717 (406) 994-4722 e-mail: JeffreyL@Montana.edu

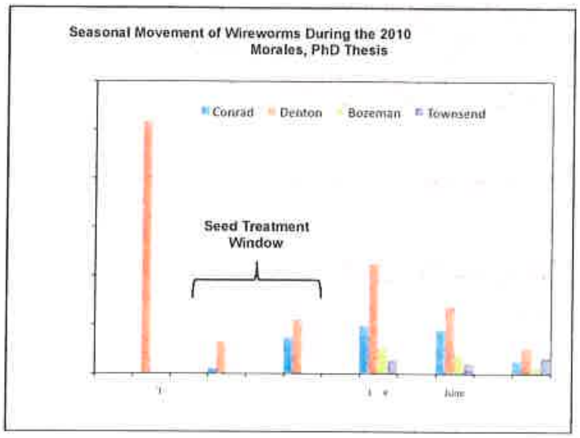

Biological Control Based
Research on Wireworms
Ashish Adhikari
MONTANA
STATE UNIVERSITY

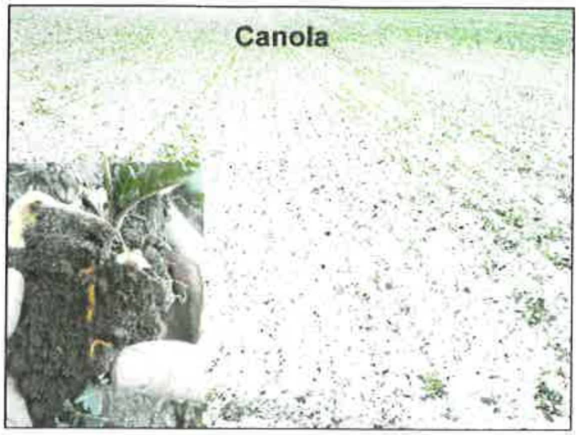

Wireworms:
→What are they?
→What damage do they cause?
→Their biology
→How are they currently managed?
→Historical perspective


Wireworm


Damage Rating
2 B
0
1


Biology
Emerging from the soil
Adults overwintering in the soil
Eggs laid
Eggs hatching
Transforming to Adults
Pupae
Larvae
3-5 years


Seasonal Movement of Wireworms During the 2010
Morales, PhD Thesis
Conrad
Denton
Bozeman
Townsend
Seed Treatment
Window

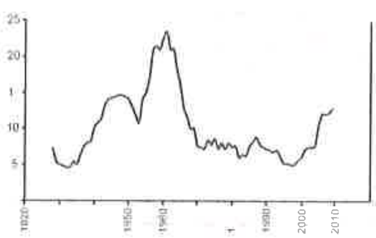

Canola


Pulse crops: lentil field in rotation with wheat

## History

seed

"We
to



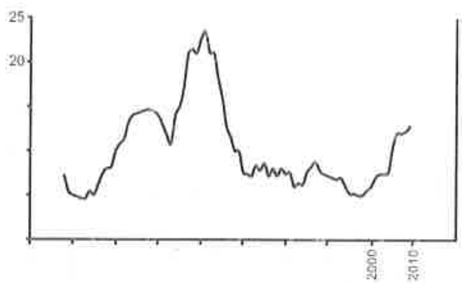

## What Happened ?

TABLE [illegible] Chemical [illegible] and Their Effects

| | | | | | |
|---|---|---|---|---|---|
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | Dichlorodiphenyltrichloroethane (DDT [illegible]) Hexachlorocyclohexanes (Lindane) Chlorinated cyclodiene (Chlordane, Aldrin, Dieldrin, Endosulfan, Heptachlor) Other (Kepone, Mirex) | [illegible] | [illegible] | [illegible] |
| | [illegible] | Most toxic: Phosdrin, Parathion, Dichlorovos, TEPP. Moderately to[illegible]: DDVP, Dimethoate, Baytex, Diazinon. Less to[illegible]: Ronnel, Cardona, Abate, Malathion | Insecticide | [illegible] | [illegible] |

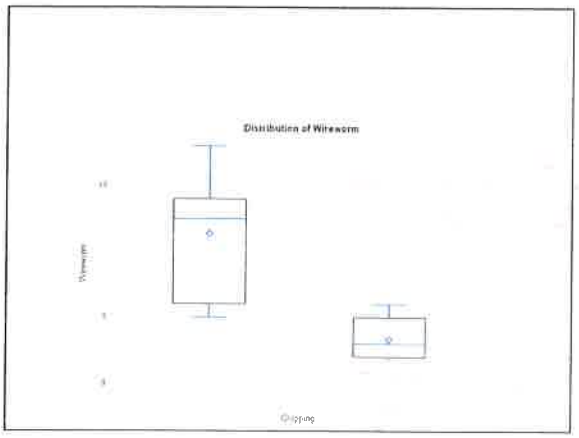
and


SILENT SPRING
Rachel Carson
Rachel Carson, 1962


25
20
2000
2010

ponse?


PREVENTION
SCIENCE
Extension


Distribution of Wireworm

## Other Cultural Options

John Henry Comstock (1849–1931)
Professor of Entomology, Cornell University

METHODS OF EXPERIMENTATIONS.

been kept growing. In cages 1 and 2 where no more vegetation

alive so long in cages containing clover and timothy.

Therefore our experiments do not indicate that a crop of mustard will render the soil so free from wireworms that the succeeding crop will escape their ravages.

RAPE.

usually recommended for starving out the wireworms are buckwheat, mustard and rape.

keep it free from all vegetation in the hope that he may thus starve out the wireworms.

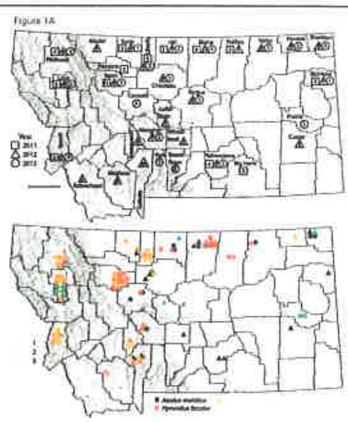
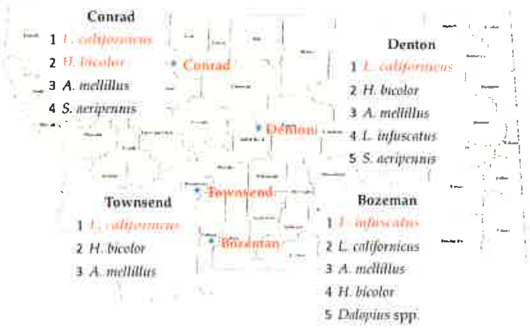


Figure 1A

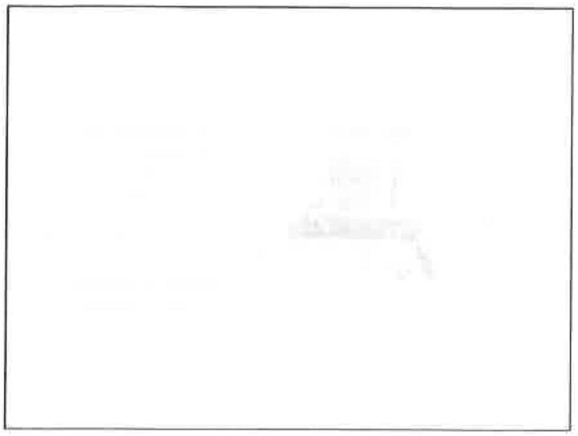
## Intensive Sampling




Parasitoides and Predators

*Limonius californicus**

*Synaptus filiformis*



# Ecology and Biological Control of Alfalfa Weevil

Tatyana A. Rand

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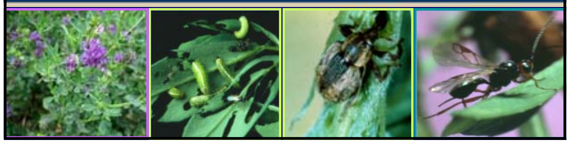
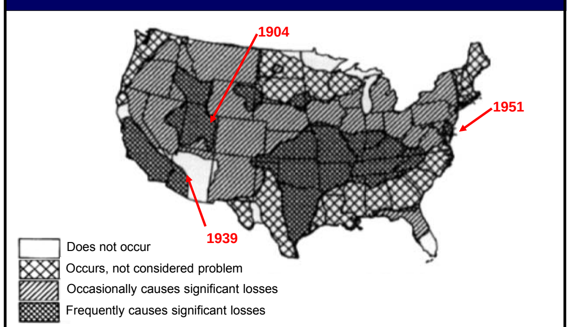
USDA-ARS NORTHERN PLAINS AGRICULTURAL RESEARCH LABORATORY
Sidney, Montana



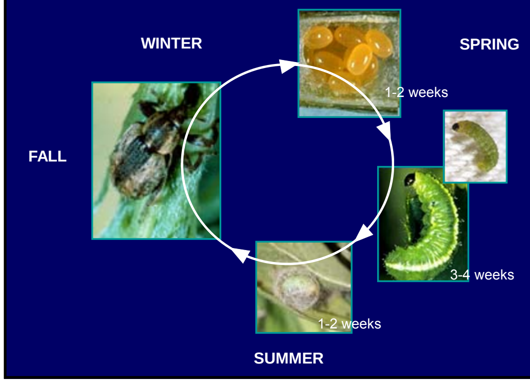
## Outline

- Alfalfa weevil biology/ecology
- Biocontrol research at USDA-ARS-NPARL
  - Identifying key biocontrol parasitoids
  - Assessing the role of generalist predators
  - Identifying field and landscape scale drivers of biological control success

## Alfalfa Weevil Distribution and Impact



## Alfalfa Weevil Life Cycle




## Damage

Larval feeding results in:

- Reduced yield (1st cutting)
- Delayed regrowth (2nd cutting)
- Reduced plant vigor
- Decreased stand density

## Determining Infestation Levels

Larval sampling:

- Sweep sampling: 38 cm diam net, 10-sweeps, 5 locations, count larvae; ET = 20 larvae/sweep
- Cut 6 stems, shake in 5-gallon bucket, count dislodged larvae, repeat at 5 locations ET= 2 larvae/stem

Plant inspections:

- Examine 10-20 stems at 5 locations / field
- Assess % damaged plants

## Cultural and Chemical Control (NDSU-Extension)

### Cultural Control

- If close to cutting, best strategy is to cut early
- After cutting, monitor carefully for damage to crowns / delayed regrowth

### Insecticides

- 1st Cutting: If weevils infest crop at early stage (<15 inches), 7-10 days from harvest, **treat** if 2 larvae / stem and/or 35 to 40% plants show tip feeding
- 2nd cutting: Treat if 50% of the crowns damaged, re-growth delayed 3-6 days

## Biological Control

- The action of parasites, predators or pathogens in maintaining pest numbers at lower average levels than would occur in their absence
  - DeBach, 1964
- Restore ecological balance
- Can provide self-sustaining and environmentally friendly control of pest populations

## National alfalfa weevil biocontrol program

- National biological control program carried out by USDA, 1957-1988; 9 parasitoid wasps established in US
- Parasitoid wasps and disease highly effective at controlling weevils in the eastern US
- Many parasitoid species re-distributed throughout the US in the 1980’s (including in MT, ND)

## Records of releases in Montana (Bryan et al 1993)

***Microctonus aethiopoides***

Specimens released in Montana

| | | | |
|---|---|---|---|
| Carbon | 1983 | Indiana, Michigan | 272 |
| Carbon | 1984 | Michigan | 1,490 |
| Carbon | 1985 | Michigan | 2,500 |
| Carbon | 1986 | Michigan | 1,500 |
| Flathead | 1984 | Michigan | 995 |
| Flathead | 1985 | Michigan | 2,500 |
| Lake | 1986 | Michigan | 500 |
| Lake | 1988 | Michigan | 386 |
| Ravalli | 1971 | Pennsylvania | 218 |
| Roosevelt | 1986 | Michigan | 478 |
| Sanders | 1987 | Michigan | 2,230 |
| Valley | 1986 | Michigan | 500 |
| | | Montana total: | 13,569 |

***Tetrastichus incertus***

Specimens released in Montana

| | | | |
|---|---|---|---|
| Carbon | 1983 | Sweden | 5,490 |
| | | Montana total: | 5,490 |

## General Research Questions

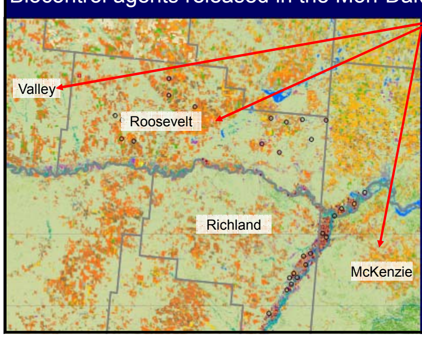
I. Which biological control species are present/dominant in alfalfa fields in the region and what is their potential impact?

II. Do generalist predators play a role in biological control of alfalfa weevils?

III. What field or landscape characteristics might promote beneficial natural enemies and maximize biological control?

## I. Identifying Dominant Natural Enemies of Alfalfa weevil

Biocontrol agents released in the Mon-Dak region




4 Parasitoid Wasps

*Bathyplectes anurus*

*Oomyzus incertus*

*Microctonus aethiopoides*

*Microctonus colesi*

## Study Goals

- Characterize the parasitoid complex of alfalfa weevil in the region
- Determine whether habitat characteristics (dryland vs. flood irrigated) affect parasitoid effectiveness
- Assess the role of host density in driving levels of parasitism

## Study Design


- Large scale surveys (>30 sites) over 2 years
- Irrigated and dryland systems
- Reared larval and adult weevils to ID parasitoids and calculate parasitism levels

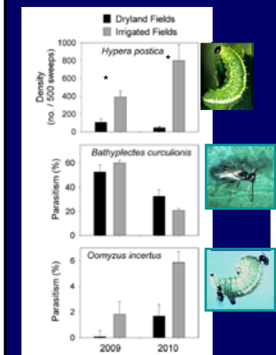
## Survey Results

*Oomyzus incertus*

*Bathyplectes curculionis*

- Weevils present in every field every year surveyed
- Parasitoid present in >90% of fields surveyed
- 2 larval parasitoids recovered
- No Adult parasitoids recovered

## Dryland vs irrigated systems



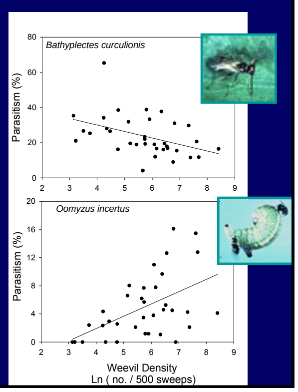

| Response | Predictor | F | P |
|---|---|---|---|
| 2009 proportion parasitism | | | |
| *Bathyplectes curculionis* | Host density (ln) | $F_{1,22} = 4.22$ | 0.0527 |
| | Habitat type | $F_{1,21} = 0.19$ | 0.6656 |
| 2010 proportion parasitism | | | |
| *Bathyplectes curculionis* | Host density (ln) | $F_{1,33} = 6.14$ | 0.0187 |
| | Habitat type | $F_{1,32} = 1.27$ | 0.2685 |
| *Oomyzus incertus* | Host density (ln) | $F_{1,31} = 7.13$ | 0.0118 |
| | Habitat type | $F_{1,32} = 0.53$ | 0.4704 |

- Rand (2012) Env Ent

## Parasitoids responses to weevil density

- Parasitoids killed lots of weevil larvae (often > than half the larvae in a field)
  - Different species are differentially effective at high and low weevil densities
  - In 2012, outbreak year for weevils, parasitism by Oi reached 25% at one site

- Rand (2012) Env Ent

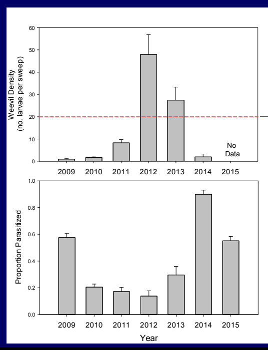



## Pathogens (disease)

- *Zoophthora phytonomi* (rare but present in MT)

- *Metarhizium spp.*
- *Beauveria spp.*

## Variability in alfalfa weevil numbers and parasitism through time



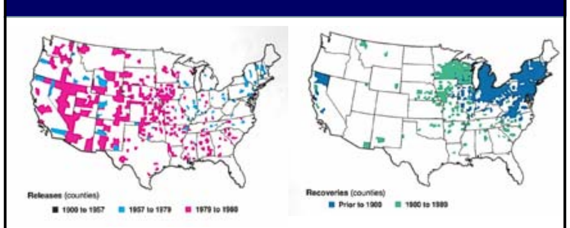

Economic threshold

## I. Conclusions

- Larval parasitoids of alfalfa weevil are common in the region, and parasitism pressure can be high in some sites and years
- Parasitoids seem to lag behind weevils, not keeping up in outbreak years
- Parasitoids of adult weevils are lacking, but might significantly complement the exiting parasitoid complex

## Future Directions

- 4 State (MT, WY, ND, SD) survey for adult parasitoids
- Identify potential source populations in MN



## II. Assessing the Potential Importance of Generalist Predators


## Many predators described, lack of field based measures of impact (Barney & Armbrust 1981)

**Table 1.—Insect predators of the alfalfa weevil, with information on the role of each predator**

| Species | Prey stage[a] | Impor-tance[b] | Obser-vation[c] | Reference( |
|---|---|---|---|---|
| Hemiptera | | | | |
| Nabidae | | | | |
| *Nabis alternatus* Parshley | Larva | Minor | Both | 19, 22, 15 |
| *N. americoferus* Carayon | Larva | Minor | Both | 9, 22 |
| *N. ferus* (L.) | Larva | Minor | Lab | 15 |
| Lygaeidae | | | | |
| *Geocoris pallens pallens* (Stal) | Larva | Minor | Lab | 9 |
| Reduviidae | | | | |
| *Sinea diadema* (F.) | Larva | Minor | Field | 12 |
| Pentatomidae | | | | |
| *Podisus maculiventris* (Say) | Larva | Major | Field | 22 |
| *P. placidus* Uhler | Larva | Minor | Field | 22 |
| *Stiretrus anchorago* (F.) | Larva | Uncertain | Both | 18 |
| Coleoptera | | | | |
| Cicindelidae | | | | |
| *Cicindela pusilla imperfecta* LeConte | Larva | Uncertain | Both | 21 |
| Carabidae | | | | |
| *Pasimachus elongatus* LeConte | Adult | Minor | Both | 3 |
| Melyridae | | | | |
| *Collops bipunctatus* (Say) | Larva | Major | Both | 21, 9, 15 |
| *C. discretes* Fall | Larva | Minor | Field | 16 |
| *C. quadrimaculatus* (F.) | Larva | Uncertain | Field | 20 |
| *C. vittatus* (Say) | Larva | Minor | Lab | 15 |
| Coccinellidae | | | | |
| *Coleomegilla maculata* (DeGeer) | Larva | Minor | Both | 23, 22 |
| *Hippodamia convergens* Guerin-Meneville | Egg, larva | Major | Both | 21, 2, 16, 23, 9, 22, 1 |
| *H. glacialis* (F.) | Larva | Minor | Field | 22 |
| *H. parenthesis* (Say) | Larva | Minor | Lab | 23 |

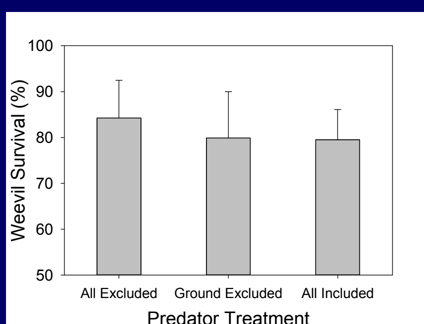
## Study Goals

- Examine the potential impact of different enemy groups (ground vs. foliage foraging) on larval weevil survival and plant damage
- Predictions:
  - Predators will reduce weevil numbers and damage
  - Foliage foragers will have the greatest impact

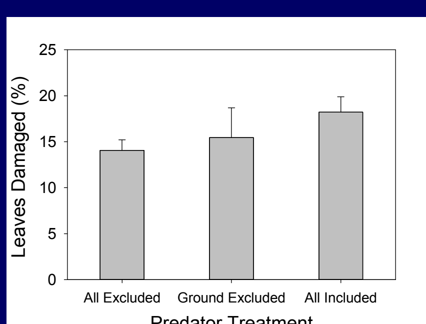
## Study Design


- 50 1st instar weevil larvae added to caged alfalfa plants
- 3 cage treatments imposed for ~3 weeks
- Responses: weevil survival, plant damage

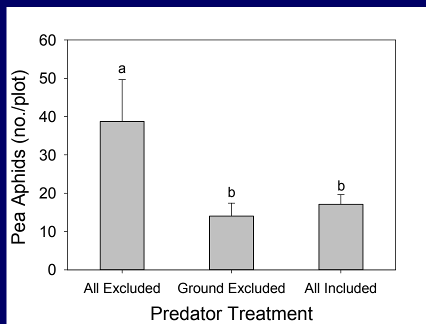
## Predator Impacts on Weevil Survival




## Predator Impacts on Plant Damage



## Predator Impacts on Pea Aphids



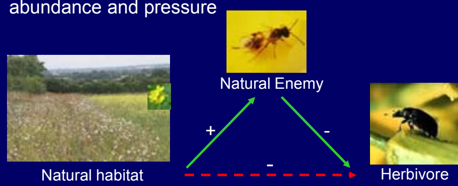

## II. Conclusions

- Predators had minimal effects on alfalfa weevil larval survivorship and thus levels of plant damage
- In contrast, predators appear to have major effects on pea aphid densities
- Effects on alfalfa weevil may be higher at other sites or years
  - Quantify predator densities across sites
  - Repeat experiment in more years

## III. Effects of field and landscape variables on alfalfa weevil numbers and biological control

## Semi-natural habitats promote conservation biocontrol

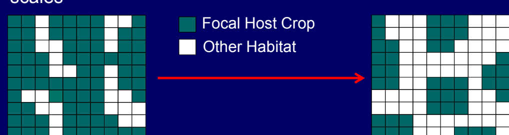
- Smaller crop fields, and higher edge-area ratios, increase enemy colonization from adjacent natural habitats promoting biocontrol
- Increasing natural habitat cover at landscape scales (500-3000 m) is associated with increased enemy diversity, abundance and pressure




– Landis et al (2000) Ann Rev Ent; Chaplin-Kramer et al (2011) Ecol Lett; Zumoffen et al (2012) Agr Ecosys Env; Veres et al (2013) Agr Ecosys Env

## "Fragmentation" of host plant (e.g. focal crop) area can negatively impact specialized insect pests

- Reduced habitat area results in increased emigration and extinction, reduced colonization → reduced population densities
- Herbivore pressure declines in smaller, or more isolated, patches and with reductions in habitat cover at landscape scales




– Veres et al (2013) Agr Ecosys Env; Martinson and Fagan (2014) Ecol Lett; Rand et al. (2014) Agr Ecosys Env

## Landscape studies on pest control lack longer-term view:

- Lack of multi-year studies prevents our understanding of landscape effects on insect population dynamics and system stability

  – Chaplin-Kramer et al (2011) Ecol Lett; Veres et al (2013) Agr Ecosy Env

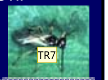
- Landscape complexity is predicted to increase temporal stability in insect numbers and biological control

  – Tscharntke et al. (2012) Biol Rev; Zhao et al (2015) Basic and Appl Ecol

## Study Goals

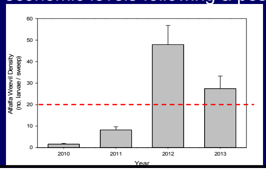
- Examine the effects of field and landscape characteristics on mean levels of, and temporal variability in, alfalfa weevil densities and parasitism over 4 years

*Hypera postica*

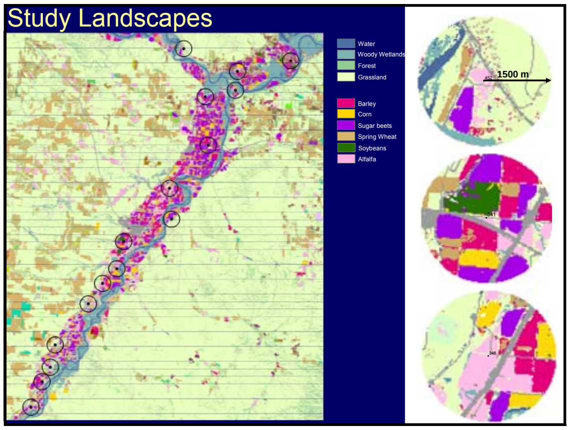



*Bathyplectes curculionis*

- Measures of System Stability:
  - Coefficient of Variation (CV) = Standard Deviation / Mean
  - "System Resilience" = Probability of populations returning to sub-economic levels following a pest outbreak




## Study Landscapes




## Methods

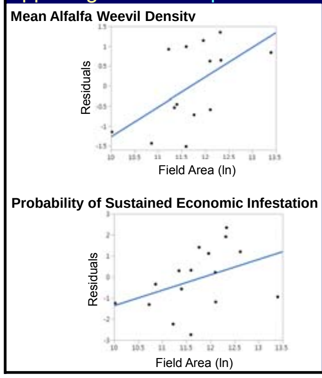
- Quantified larval densities and parasitism
- Used generalized linear modeling (model selection-AIC)
  - Predictors
    - Field variables: area, perimeter-area ratio
    - Landscape variables: % Natural and % Alfalfa Cover (500m, 1500m)
  - Responses Mean and Temporal Variability (CV) in alfalfa weevil densities and parasitism; probability of sustained economic infestations

**Slide 34**

**TR7** s the time required for an ecosystem to return to an equilibrium or steady-state following a perturbation (which is also defined as stability by some authors).
Tatyana Rand, 11/10/2015

## Pests respond to local and landscape alfalfa cover in opposing directions: positive at local scales

TR8 TR9



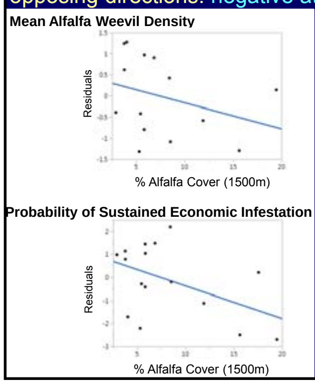

Generalized Linear Model Results

| Source | LR-Chi² | P |
|---|---|---|
| **Field Area (ln)** | **6.34** | **0.010** |
| Alfalfa Cover (1500m) | 8.48 | 0.003 |

Generalized Linear Model Results

| Source | LR-Chi² | P |
|---|---|---|
| **Field Area (ln)** | **6.77** | **0.009** |
| Alfalfa Cover (1500m) | 4.65 | 0.031 |

## Pests respond to local and landscape alfalfa cover in opposing directions: negative at landscape scales




Generalized Linear Model Results

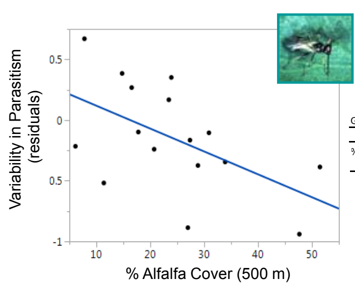
| Source | LR-Chi² | P |
|---|---|---|
| Field Area (ln) | 6.34 | 0.010 |
| **Alfalfa Cover (1500m)** | **8.48** | **0.003** |

Generalized Linear Model Results

| Source | LR-Chi² | P |
|---|---|---|
| Field Area (ln) | 6.77 | 0.009 |
| **Alfalfa Cover (1500m)** | **4.65** | **0.031** |

## More alfalfa cover in the landscape results in more stable biological control

TR10




Generalized Linear Model Results

| Source | LR-Chi² | P |
|---|---|---|
| % Alfalfa Cover (500m) | 5.08 | 0.024 |

**Slide 37**

**TR9** Hypotheses to explain negative density area relationships
1. Lower predation rates
2. Lower emmigration rates
3.
Tatyana Rand, 11/9/2015

**TR8** For each response variable, the y-axis represents residuals from a model removing effects of other significant predictors
Tatyana Rand, 11/13/2015

**Slide 39**

**TR10** Tatyana Rand 11/6/2015
y-axis represents residual parasitism rate after removing effects of other block and singificant predictors
Tatyana Rand, 11/9/2015

## III. Results

- Increasing natural habitat cover was not significantly related to either mean levels of, or variability in, pest densities or parasitism across years
- Instead, crop pest and natural enemy dynamics were strongly linked with local and landscape patterns in the focal crop
- Increasing field size was associated with higher alfalfa weevil densities
- Increasing host crop area at landscape scales was associated with reduced weevil densities, reduced outbreak duration, and increased stability in parasitism





## Final Summary

- Alfalfa weevil larval parasitoids are widely established, and likely play a role in reducing weevil numbers on average (parasitism levels exceeded the 30% critical threshold in 4 of 7 years surveyed to date)
- However, parasitism is negatively related to host density across sites and years (i.e. parasitoids can't keep up in areas or years of very high weevil density). Re-introducing additional parasitoids (e.g. those that attack adults) could be a solution
- Generalist predators do not appear to be important agents of mortality for alfalfa weevil larvae
- Planting designs that reduce individual field sizes and spread fields more evenly across the landscape could both reduce weevil numbers directly, and promote the stability of biological control

## Acknowledgements

Funding: USDA-ARS

Field and Lab Assistance: Deb Waters, Amelia Jurkowska, Megan Greenwood, Alyssa Kessell, Jana Seright, Rhonda Lawhead, Joyce Wick, Anna Petroff, Lance Turner, Morgan Manger, Sarah Mason, Ellen Titus

Numerous alfalfa growers in the Yellowstone valley for permission to sample their fields over many years

**Biological Control of Orange Wheat Blossom Midge (Diptera: Cecidomyiidae)**

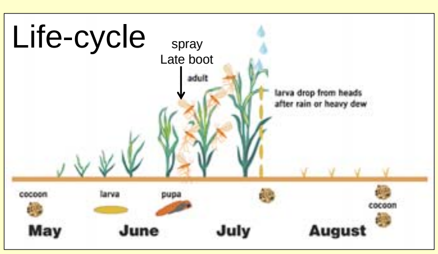
**Gadi V.P. Reddy, Brian Thompson, Dan Picard and Govinda Shrestha**
Montana State University
Western Triangle Ag Research Center
9546 Old Shelby Rd., P. O. Box 656
Conrad, MT 59425, USA

MONTANA STATE UNIVERSITY
Mountains & Minds

Orange Wheat Blossom Midge, *Sitodiplosis mosellana* (Diptera: Cecidomyiidae)

- First Reported in Flathead County during 2006 and has continued to be a significant pest.
- MSU Extension Pondera County Agriculture and 4-H Agent have installed pheromone baited traps in wheat fields for the past 5 years to determine if midge was present in Pondera county.
- Positive ID made in 2011.
- During 2012, detected in irrigated spring wheat fields near Valier MT and in an irrigated field west of Conrad.

*Threshold = 1 midge/4 - 5 wheat heads
**Pesticide only recommended before crop reaches anthesis. After = No effect




* In Central Montana this life-cycle is shifted two weeks into late June early July.

**Importation of *Macroglenes penetrans* (Hymenoptera: Pteromalidae) from Alberta, Canada for release into the environment of Montana**

- In 2008 Northwestern Agricultural Research Center, MSU obtained *Macroglenes penetrans* from NDSU and released them at Kalispell.

Midge carries 4-105 eggs (mean 80) per female while *M. penetrans* carries an average of 205 eggs per female.

No sign of establishment until 2014.

2mm

4

## OWBM Parasitoid Project

- In 2014, Team of Entomologists from WTARC, headed up a team to collect *M. penetrans* from the Lethbridge area. The collection was released at Conrad and Kalispell.

Biocontrol…

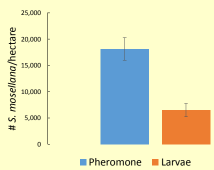
About 700 *M. penetrans* was collected from Alberta and released in Pondera and Flathead County in Montana on July 10, 2014.

*M. penetrans*: 40 - 80% control

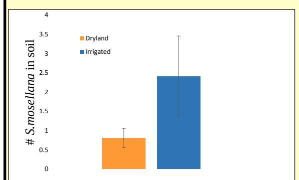
Another 20-40% control: Two parasitoids

Collection site | Sweep net survey | Release site

Cropping System effects:

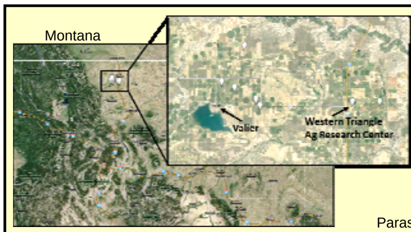



Midge are sampled with pheromone traps

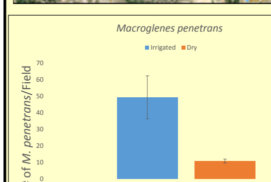



Midge larvae are sampled by threshing wheat heads.

Montana




*M. Penetrans* were sampled between Valier and Western Triangle Agricultural Research Center




Parasitoids are sampled using a sweep net. As shown to the left

2mm

# What is being done:

Monitoring = (pestweb.montana.edu)
Resistant wheat = (Egan)
Biological control = (*Macroglenes penetrans &…*)

*Platygaster tuberosula* and *Platygater tuberusula* is a new parasitoid we are introducing to help *M. penetrans* control midge in Montana.

**Importation of two parasitoids of a wheat midge, *Euxestonotus error* and *Platygater tuberusula* (Hymenoptera: Platygastridae) from Saskatchewan, Canada for release into the environment of Montana**

*Platygaster tuberosula* *Euxestonotus error*

2mm 2mm

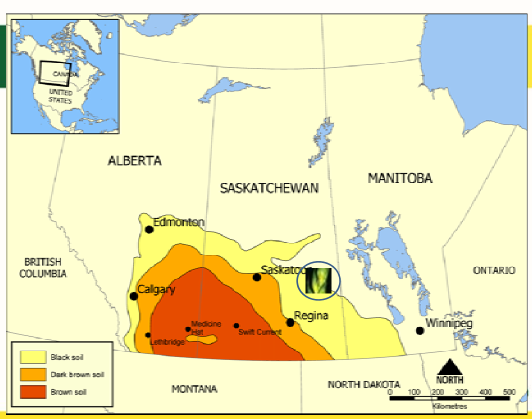
# Wheat Midge Parasitism in Saskatchewan

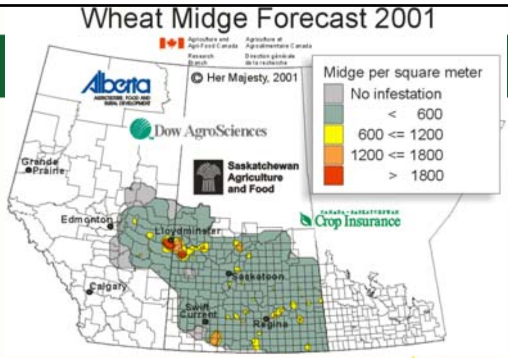
S.A.R.E Workshop
Great Falls, Montana
March 2, 2016

Scott Hartley P.Ag.
Saskatchewan Ministry of Agriculture
Dr. Owen Olfert
Agriculture and Agri-Food Canada

saskatchewan.ca

Government of Saskatchewan






saskatchewan.ca

Government of Saskatchewan

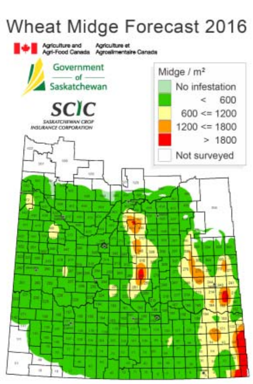
## Wheat Midge

- Wheat midge surveys were introduced in the late 1980s and expanded with the increasing distribution of the wheat midge.
- A survey is conducted annually, in the fall, to determine the density and distribution of wheat midge cocoons over-wintering in the soil in Saskatchewan.
- All cocoons are extracted and dissected to determine parasitism levels - parasitized larvae are deducted from total number of cocoons to estimate viable midge larvae.
- Only the viable midge are depicted on the forecast maps.

saskatchewan.ca

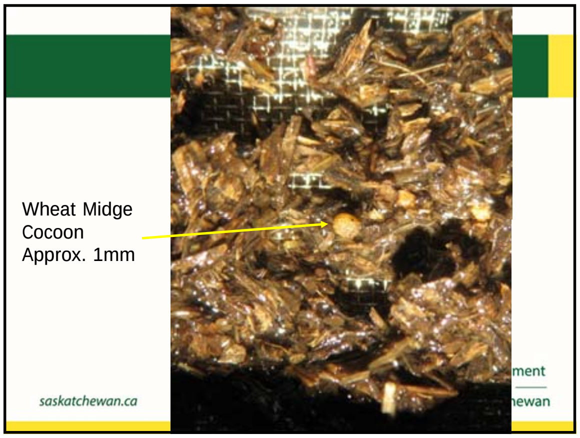
Government of Saskatchewan

Soil samples were collected in the fall of 2015, from 421 sites in Saskatchewan to produce the 2016 Forecast map.

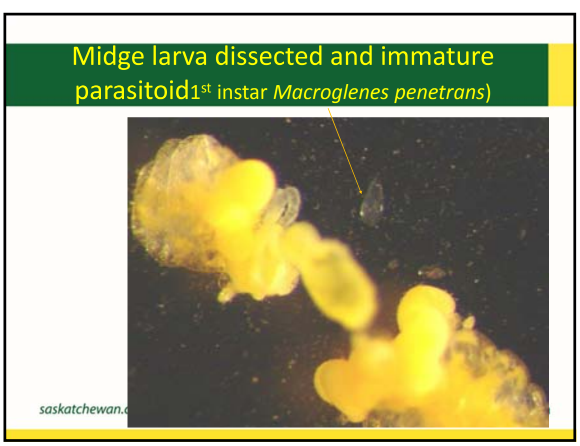



saskatchewan.ca

Government of Saskatchewan


Wheat Midge
Cocoon
Approx. 1mm
saskatchewan.ca


Wheat midge cocoon / larva free from cocoon case
saskatchewan.ca


Midge larva dissected and immature parasitoid1st instar *Macroglenes penetrans*)
saskatchewan.

## Wheat Midge - Parasitism

- Adult wasp (native)
  - *Macroglenes penetrans* (female)
- Surveys : average parasitism
  - 1998 - 42%
  - 1999 - 36%
- Higher levels in established areas, lower in new areas

saskatchewan.ca

Government of Saskatchewan

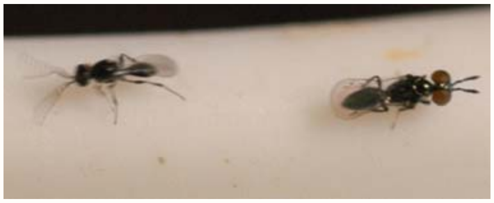
## Wheat Midge - Parasitism

- *Macroglenes penetrans* (adult male)
  - a small 1 to 2 mm long parasitic wasp

saskatchewan.ca

Government of Saskatchewan

## Parasites of Wheat Midge



Introduced species *Platygaster tuberosula* (left) native *M. penetrans* (right) - actual size approx. 2 mm in length

saskatchewan.ca

Government of Saskatchewan

## Wheat Midge Management

- Chemical Control
  - Insecticide application during advanced stages of flowering is discouraged for the following reasons:
  - By late flowering, wheat heads are no longer susceptible to damage (damage is less than 1%)
  - Treatments applied during advanced flowering are not effective because larvae have already hatched and caused damage
  - **Sprays are also discouraged during advanced flowering because it would have a negative impact on midge parasites**

*saskatchewan.ca*

Government of Saskatchewan

## *Wheat Midge Parasitoid – Success Story*

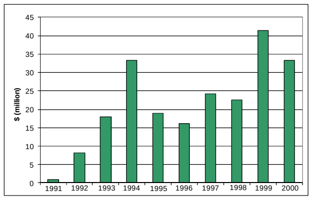
- ✓ *Macroglenes penetrans* discovered in SK in 1984
- ✓ *Platygaster tuberosula* and *Euxestonotus error* were introduced from Europe in 1990s
- ✓ Monitoring tool was developed to estimate populations of both pest and parasitoid and to track their expansions

## *Benefits ($) – Wheat Midge Biocontrol*

Objective: To estimate the value of parasitoids we assessed the area of wheat production over 10 years that did not require an insecticide application

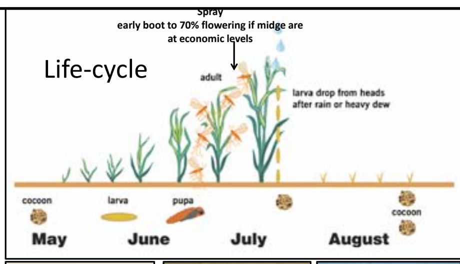
- ✓ Quantify areas where viable wheat midge cocoons in the soil were controlled by the parasitoid to below economic threshold levels (<600/$m^2$)
- ✓ The study did not include environmental benefits nor increases in crop yield

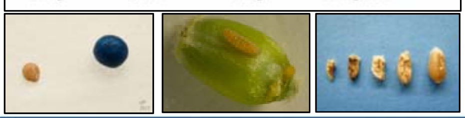
## *Farm Savings Due to Parasitoid*

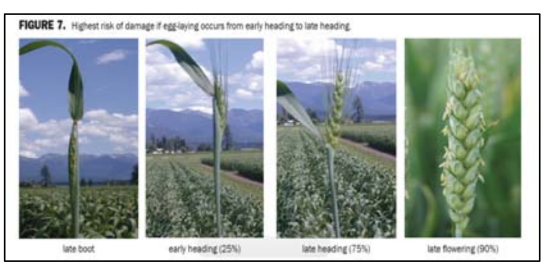



- ✓ 1991-2000, there were ~15.5 million ha of wheat that did not require a pesticide application because of parasitism
- ✓ At a cost of $16.00/ha, the total saving in pesticide costs alone were over $200 million in the 1990's

## 2015-16 Orange Wheat Blossom Midge Monitoring Update



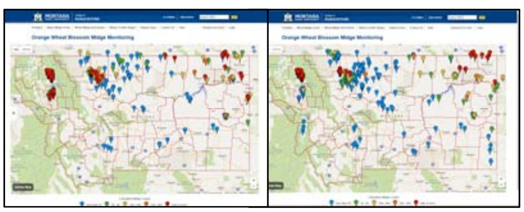

Monitor late boot through flowering

# OWBM Monitoring Supplies

2016 Trap Kits will be around $10 for growers and consultants



**Montana Pestweb-Montana's Pest Management Network**




| 2014 | 2015 |
|---|---|
| **27 counties** | **31 counties** |
| **265 traps reporting** | **275 traps reporting** |
| **297 owbm per trap (avg.)** | **238 owbm per trap (avg.)** |



## Pestweb Summary for 2015

| Participating County | Number of Traps | Total Trap Count | Average Count Per Trap | Participating County | Number of traps | Total Trap Count | Average Count Per Trap |
|---|---|---|---|---|---|---|---|
| Flathead | 55 | 34403 | 626 | Toole | 3 | 5 | 2 |
| Pondera | 44 | 14373 | 327 | Judith Basin | 5 | 1 | 0 |
| Sheridan | 4 | 5541 | 1385 | Bighorn | 1 | 0 | 0 |
| Valley | 13 | 4605 | 354 | Blaine | 6 | 0 | 0 |
| Richland | 6 | 1843 | 307 | Broadwater | 2 | 0 | 0 |
| Liberty | 25 | 892 | 36 | Carter | 5 | 0 | 0 |
| Roosevelt | 4 | 799 | 200 | Cascade | 2 | 0 | 0 |
| McCone | 3 | 706 | 235 | Chouteau | 14 | 0 | 0 |
| Daniels | 5 | 700 | 140 | Custer | 2 | 0 | 0 |
| Phillips | 3 | 471 | 157 | Fergus | 5 | 0 | 0 |
| Glacier | 15 | 351 | 23 | Gallatin | 4 | 0 | 0 |
| Lake | 14 | 299 | 21 | Hill | 10 | 0 | 0 |
| Williams Co. ND | 2 | 248 | 124 | Ravalli | 4 | 0 | 0 |
| Prairie | 4 | 208 | 52 | Treasure | 1 | 0 | 0 |
| Teton | 7 | 41 | 6 | Yellowstone | 3 | 0 | 0 |
| Garfield | 4 | 29 | 7 | TOTAL | 275 | 65515 | na |

## 2016 Statewide OWBM Monitoring Program

- Presentations-speakers available on OWBM for various grower meetings, conventions, and field days.
- Pheromone traps/supplies are available at no cost to 8 Research Centers and 27 or more MSU Extension Agents.
- Additional supplies for Pheromone traps may be ordered through 3 Extension offices for growers and consultants.
- Detailed trap use, placement recommendations, and reporting record sheet will be handed out with each trap order.
- Cooperators were urged to report trap location and counts on Pestweb-0 is a number.

7

## 2015 OWBM Observations

- Midge starting flying on June 16th in Pondera County
- Peak emergence in Pondera County was at 1,149 degree days (base 40) on June 29th. Flathead was on June 23 at 1,196 degree days
- Traps with medium to high counts do not always correlate to economic midge levels being detected while scouting
- Currently, midge are being found primarily in northwestern, northcentral and northeastern counties.
- Counties, with midge detected, in one or more years, went from six in 2013 to twenty two in 2015 in part due to the expanded monitoring effort.
- White Delta Traps needed to painted green and put out by June 10th

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## Sm1 Gene-Midge Resistant Spring Wheat

- Dr. Luther Talbert, MSU Spring Wheat Breeder, is heading up the effort in Montana
- New spring wheat variety-Egan is available for growers to seed this spring. (District 1 only)
- Several lines with Sm1 plus solid stems are in yield trials-will take a couple of years
- Very important industry and growers maintain 90-10 refuge mix to maintain effectiveness of SM1 gene.

9

Agriculture and Agri-Food Canada / Agriculture et Agroalimentaire Canada

## Biological control of field crop insect pests in the Canadian Prairies.

Héctor Cárcamo

Lethbridge Research and Development Centre

Canada

## Collaborators

- Arash Kheirodin
  - Current Ph. D. student with Alejandro Costamagna (U of MB)
- Catalina Fernandez (MSc student)
  - With Rob Laird (University of Lethbridge)
- Swaroop Kher, Meghan Vankosky
  - U of Alberta, With Lloyd Dosdall
- Vince Hervet
  - Master student (2010, France) with L. Dosdall, U. of Alberta
- John Gavloski, Manitoba Ag (Carman)

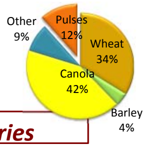
2

## Outline

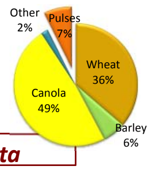
- Background
  - Cropping systems in the Canadian Prairies
  - Major insect pests
- 3 case studies
  - *Cereal leaf beetle*
  - *Lygus bugs*
  - *Sitona weevils (pea leaf weevil)*
- Future needs

3

## Economics - *Crop Receipts 2014*




***Prairies***




***Alberta***

Prairies - Total crop receipts ($'000,000)

| | Wheat | Barley | Canola | Other | Pulses | Total |
|---|---|---|---|---|---|---|
| ***Manitoba*** | 906 | 69 | 1,066 | 688 | 71 | 2,800 |
| ***Saskatchewan*** | 3,076 | 311 | 3,693 | 717 | 1,561 | 9,358 |
| ***Alberta*** | 1,900 | 308 | 2,541 | 98 | 384 | 5,231 |
| ***Total*** | 5,883 | 688 | 7,300 | 1,503 | 2,016 | 17,390 |

Data source: Statistics Canada

**Slide courtesy of Barbieri, Torgundrud and Smith**

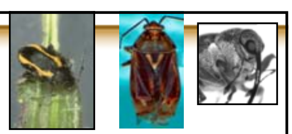
## Most Popular Western Canada Crop Rotations

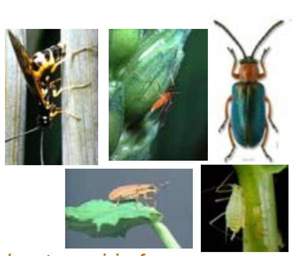
| # | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| 1 | Canola | Wheat | Canola | Wheat | |
| 2 | Canola | Wheat | Wheat or Barley or Peas | Canola | |
| 3 | Canola | Canola | Canola | Canola | |
| | | | | | |
| ? | Wheat | Winter wheat | Forage (3 yr) | Wheat | Canola |

Courtesy of Neil Harker

## Costs – historical "guesstimates"

- Canola:
  - Flea beetles $ 100 M
  - Lygus bugs $20 M
  - Seedpod weevils $ 5 M
- Wheat:
  - wheat midge $ 60 -120 M
  - sawfly $10 - $50 M
  - Grasshoppers, cutworms, wireworms, large?
  - New threats – cereal leaf beetle





Other field crops: e.g. pulses – aphids (MB), Sitona (AB, SK), lygus in faba beans

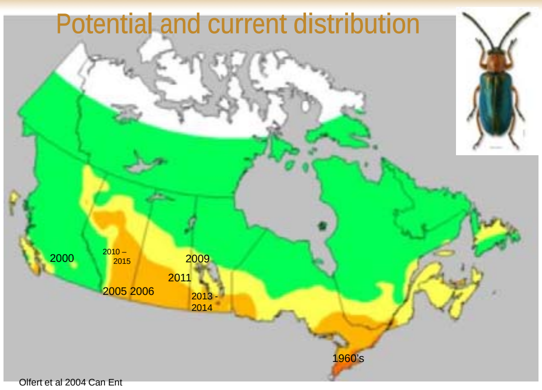
Insects cost > $200 M / yr to prairie farmers...

## Cereal leaf beetle

- Family: Chrysomelidae
  - Includes flea beetles, colorado potato beetle
- Genus: *Oulema*
- Species: *Oulema melanopus*
  - Only species of genus in Canada?
- From Eurasia
- Serious pest of most cultivated cereals in temperate world
- Quarantinable pest in Canadian Prairies up to 2009
  - Trade barrier, e.g. California

7

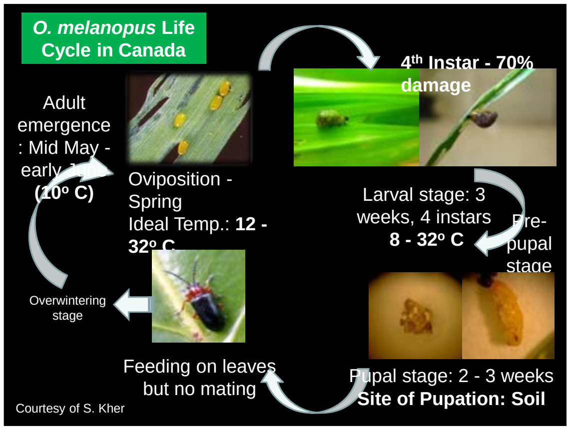
## Potential and current distribution




Olfert et al 2004 Can Ent

## Update on distribution of Cereal Leaf Beetle as of 2014


9

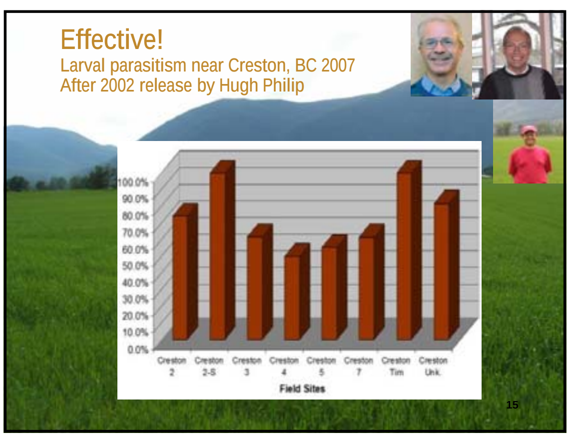

O. melanopus Life Cycle in Canada
Adult emergence : Mid May - early
(10º C)
Oviposition - Spring
Ideal Temp.: 12 - 32º C
4th Instar - 70% damage
Larval stage: 3 weeks, 4 instars
8 - 32º C
Pre-pupal stage
Overwintering stage
Feeding on leaves but no mating
Pupal stage: 2 - 3 weeks
Site of Pupation: Soil
Courtesy of S. Kher


CLB Adult Damage
Courtesy of Gary Brown

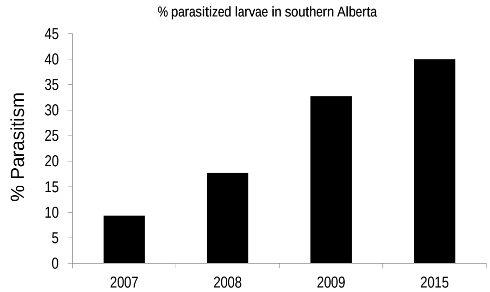

Cereal Leaf Beetle Larva
Courtesy of Gary Brown


Cereal Leaf Beetle
larval parasitoid
Tetrastichus julis

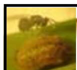
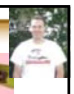

Gregarious parasitoid
ca. 5 T. julis/CLB
S. Kher
T. Larson
14


Effective!
Larval parasitism near Creston, BC 2007
After 2002 release by Hugh Philip
100.0%
90.0%
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
Creston 2
Creston 2-S
Creston 3
Creston 4
Creston 5
Creston 7
Creston Tim
Creston Unk.
Field Sites
15

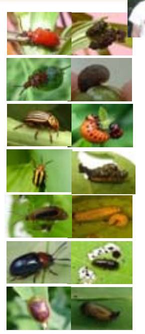
## *T. julis* adventive in Southern Alberta a welcome invasive!




## Host specific!

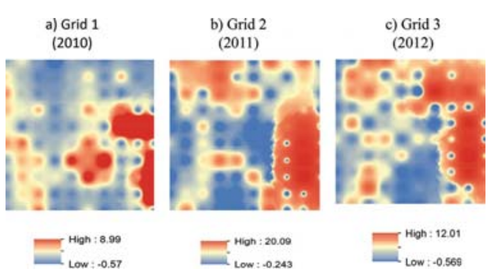




- Lily leaf beetle
- Twelve-spotted asparagus beetle
- Colorado potato beetle
- Three-lined potato beetle
- *Galerucella calmariensis*
- *Gastrophysa polygoni*
- *Cassida azurea*



Hervet, V., Carcamo, H., **Dosdall, L.**, Kher, S. 2016. Biological Control, In Press

## Strong spatial association of *T. julis* with CLB larvae



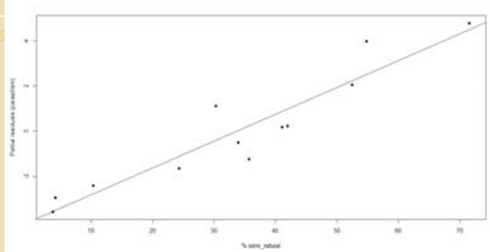

Kher et al. 2014 Environ. Entomol.

## Landscape analysis

Arash and Alejandro – U of MB

- Select landscapes ranging from simple to complex.
- GPS to record geographical information
- Digital map by ARC MAP 10. proportion of different habitat and diversity of these habitats.
- Around 60 sites mapped (2014-15): CLB and *T. julis* data

## Positive effects of semi natural habitats on parasitism rate (preliminary analysis)



Semi_ natural consist of: native pasture, cultivated pasture, road ditches, riparian and trees.

## Relocation of *T. julis* throughout Prairies

- Enhance biological control of Cereal Leaf Beetle in the Prairies
  - Identify areas with beetle pest that lack parasitoid or have low levels of parasitism
  - Relocate *T. julis* to those areas

## Method

- Laboratory rearing
  - Expose CLB larvae to parasitoid and rear adult wasps



## Method

- Field collection
  - Collections around southern AB
  - Focus on areas with high levels of parasitism
  - Rear adult wasps
  - Also second generation overwintering larvae in beetle cocoons



Best way to get *T. julis* is to collect larvae
In the field and rear in green house in large cage

| source | CLB larvae | *T. julis* |
|---|---|---|
| Buckets in field | 400 | 65 |
| lab exposed larvae dishes | 630 | 12 |
| lab exposed larvae cages | 500 | 300 |
| field coll. Larvae dishes | 450 | 926 |
| field coll. Larvae - Cages in GH | | 8, 770 |
| Sweeps for T. julis adults | . | 1, 000 |
| total | 1980 | 11073 |

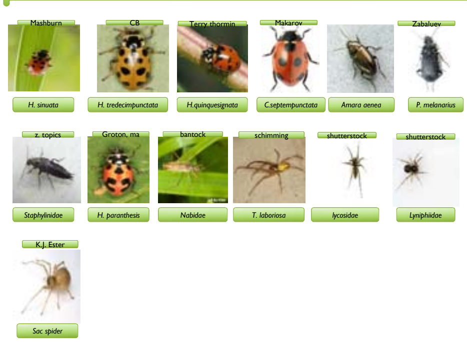
## Shipping them to their new home…

25

## Relocations of *T. julis* in 2015


## Kheirodin predation studies, in progress

Predators consume eggs and/or larvae of cereal leaf beetle



## Future related work

- Dynamic Economic Threshold - including natural enemies to discourage spraying insecticides in fields with low damage
- Continue working with plant breeder to diversify IPM tool box

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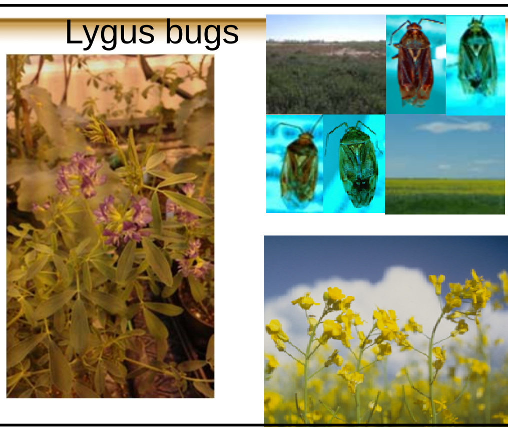
## Lygus bugs

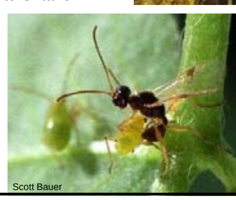


## Lygus management

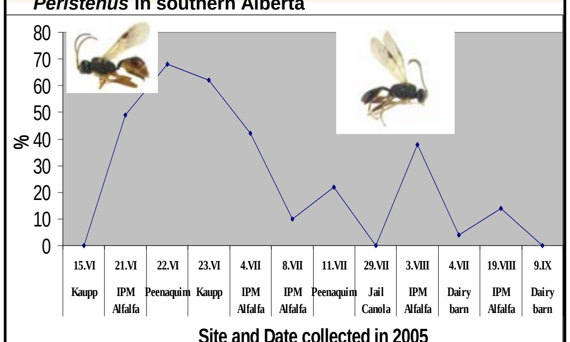
- Insecticides only
- Economic thresholds:
  - 1 per sweep at end of flower to early pod Or 2 per sweep at mid pod
  - Biocontrol possibilities?
  - For a native pest?
    - Neo-classical biocontrol

## Parasitoid effective in NE USA

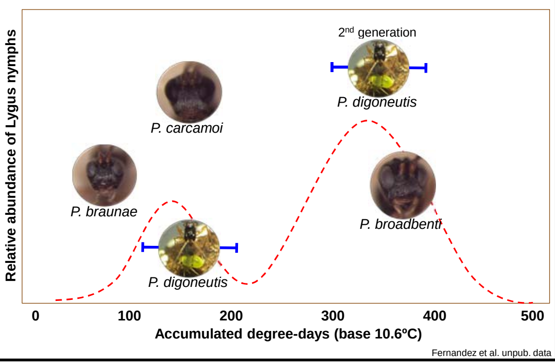
- *Peristenus digoneutis* (European)
- Introduced to NE USA
- Reduced lygus in alfalfa and other crops
- Adventive migration to Ontario and Quebec
- Relocate west?


## Proportion of lygus nymphs parasitised by native *Peristenus* in southern Alberta



Potential competitive interactions, displacement?




# Introduction of an exotic wasp to control native lygus pests – a risky strategy?

- **Competition lab studies in progress and ongoing field studies in Ontario (Mason & Lachance).**
- **Considered low risk in eastern Canada and North East USA.**
- **Benefits thought to outweigh risks in California (more aggressive *Peristenus stygicus* introduced there)**

# Pea Leaf Weevil

- Sitona (broad nosed weevils)
  - ~23 spp in Canada, native and introduced
- *Sitona lineatus* (native to Europe, N. Africa)
- Adult 5 mm long
- Light brown stripes extend to wing covers

- Larva milky white body and dark head
- grub-like, curved shape
- legless

## Life Cycle in Alberta

Alfalfa & tree shelters | Pea fields | Pea roots | Pea field harve

Sept-May | May-June-July | June-July-August | August-Sept

## Host plants

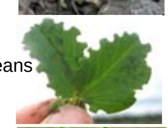
- Feeding hosts
  - Adults feed on many leguminaceae (e.g. alfalfa, beans, clover, lentils, lupins, vetch) but generally don't cause economic damage
- Reproductive hosts
  - Peas
  - Faba beans

## Damage- Adults

- Notching of leaf margins in June-July
- Plants can compensate

Field peas

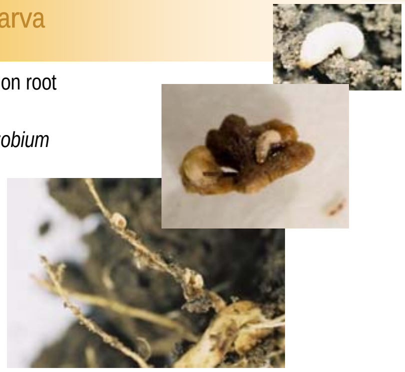
Faba beans



Lupins

## Damage- larva

- Larvae feed on root nodules
- destroy *Rhizobium*

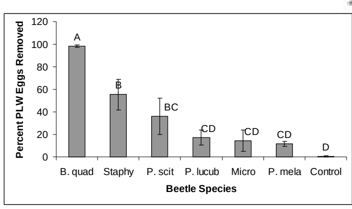


## Biocontrol of *Sitona* species

- A few releases targeting sweet clover weevil or alfalfa weevil adults
  - *Microctonus* and *Perilitus* (Braconidae)
- Parasitoids were reared on pea leaf weevil
- No parasitoids of eggs or adults found by Vankosky (2010)
- Extensive survey lacking
- Endemic predators…

Carcamo & Vankosky 2013

## Egg predators of Pea Leaf Weevil




Ground beetle – egg predator

Vankosky et al. 2010. J. Appl Entomol.

## Conservation practices

- Practice Integrated Crop Management
  - Include perennial legume forages in rotation to build up beneficials
  - Select varieties or crops resistant to pests
  - Choose big seeds to get strong seedlings and uniform stand
- Spray only if absolutely necessary – i.e. follow economic thresholds
  - Means sampling for pest and keeping an eye on beneficial insects
- If beneficials abundant, give them a chance!
  - Choose products that are "softer" on beneficials,
  - e.g., microbial biopesticides if available, seed treatments,
  - Time spraying to avoid beneficials
    - Larval parasitoids active a little later than pests
    - Less active early am or late pm

## Conservation practices

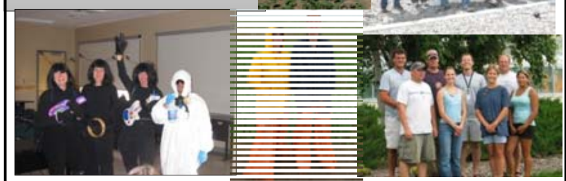
- Use a trap crop to concentrate pest
  - e.g., cabbage seedpod weevil
- Less tillage
  - Low soil disturbance key for cereal leaf beetle parasitoid survivorship
  - Not for all species!
- Taller stubble
  - Benefits sawfly parasitoid
- Some flowers in or near field may enhance beneficials by providing nectar fuel – plant diversity through intercropping
  - Variety blends or solid/hollow wheat may enhance sawfly parasitoids

## Future

- Biocontrol research lags far behind other strategies such as chemical and host plant resistance
- Research needs
  - Inventory of beneficial arthropods (basic biodiversity studies)
  - Basic ecological information on seasonal activity, relationship of natural enemies with pest (impact studies) and plants
  - Habitat features that enhance their populations and efficacy
  - Integration into current or modified agronomic practice
  - Exotic natural enemies, other biocontrols such as microbial pesticides

## Acknowledgements


- A-base/matching funds of AAFC
- Pest Management Centre, Insecticide Risk Reduction Program of AAFC
- Universities of Alberta, Lethbridge, Manitoba
- Alberta Crop Industry Development Fund, Canola Council of Canada, Alberta Canola Producers Copmmission, Alberta Pulse Growers Commission

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## Conservation Biological Control of Wheat Stem Sawfly: Applying Agroecology to Enhance Integrated Pest Management

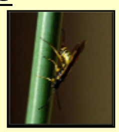
**David K. Weaver**[1], Scott B. Meers[2], Brian L. Beres[3], Micaela Buteler[4], Megan L. Hofland[1], Justin B. Runyon[5], Ryan J. Bixenmann[6], Dayane A. Reis[1], and Perry R. Miller[1]

*(1)Land Resources and Environmental Sciences, Montana State University, Bozeman, MT; (2)Crop Diversification Centre South, Alberta Agriculture and Rural Development, Brooks, AB, Canada; (3)Lethbridge Research Centre, Agriculture & Agri-Food Canada, Lethbridge, AB, Canada; (4)Instituto de Investigaciones en Biodiversidad y Medio Ambiente (INIBIOMA), Consejo Nacional de Investigaciones Cientificas y Tecnicas (CONICET), Bariloche Rio Negro, Argentina,(5)Rocky Mountain Research Station, USDA Forest Service, Bozeman, MT, (6) STEM Education and Communication, Government Relations, AAAS, Washington DC*

## OUTLINE

- **Background**
  - Distribution and Damage
  - Field and Crop Ecology
  - Attempts at Management
- **Endemic Native Parasitoids**
  - Characterize Benefits
  - Conservation Biocontrol in Fields
- **"Trap" Crops**
  - The "Trap" Idea
  - Benefits of Field Periphery
  - Source-Sink
  - The Return of Nectar
- **Summary**

## Wheat Stem Sawflies

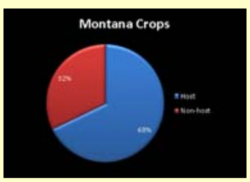


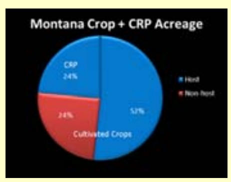
*Cephus cinctus*
**(Norton)**

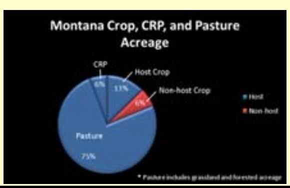
- Early members of Hymenoptera
- Cephidae - specialists on grasses
- Semi-arid regions
- Crop associations (*Cephus, Trachelus)*
- Diversity greatest at origin of wheat cultivation
- Occur in more than 50% of world wheat crops
- Exclusively in the Northern Hemisphere
- Estimated losses - > **$2 billion** annually

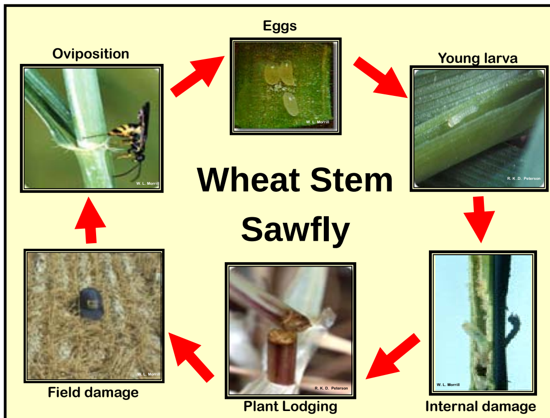
## Shortgrass Prairie& Alpine Meadows

## Metapopulation



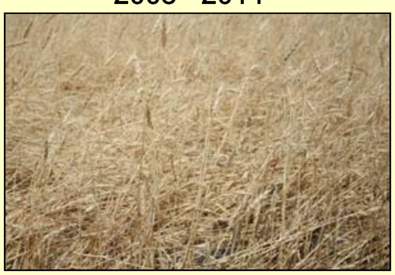



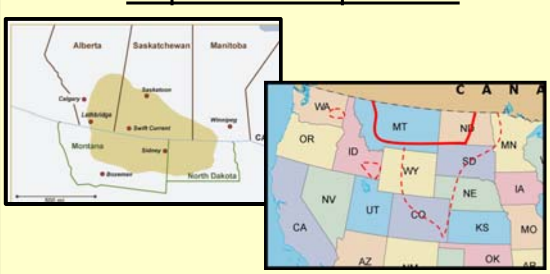
## Data Collection

## Losses in Montana

$ 45 - 80 Million Annually
2008 - 2014



## Population Expansion




≈ $350 million losses annually
Damaging populations since 1910

## Damage

All immature stages are in the stem
All damage occurs within stem

Internal Feeding
10 - 20% Loss

Plant Lodging
10 -15% Loss (or more)

Greater Lodging
Compounds Losses

## Lodging Challenges

- Volunteer wheat
  - uses water
  - herbicide

- Decreased snow retention
- Slower harvest
  - harvest one way
  - more fuel; swathing
- Equipment damage
- *Extra equipment

## Management Attempts

## Swathing to "Save" Crop

- Saves money in heavy infestation
- Continues or worsens infestation
- Money lost in kernel weight
- 10 - 30% with no correction
- *Reduces larval survival only with losses

*Goosey 1999*

## Tilling Residue

**Survival in exposed, bare crowns- 10 - 15%**

**Survival in soil associated crowns- 85 - 90%**

*Goosey 1999*

## Burning Residue

**No appreciable mortality in stubble**

**No change in mortality in stubble with straw added to increase fuel load**

*Criddle 1907, Ainslie 1920*

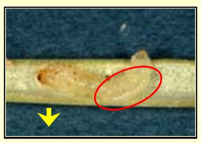
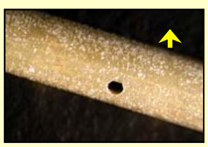
## Natural Enemies

## Braconid Parasitoids


*Bracon cephi* *Bracon lissogaster*

Sympatric, congeneric, bivoltine larval idiobionts
Specialists, uncertain ovigeny, egg maturation

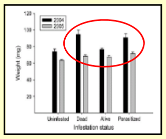
## Braconid Parasitoids


## Braconid Parasitoids

*Bracon lissogaster* **is also gregarious**

## Retain Yield




Buteler et al. 2008

Table 4. Correlation matrix of insect-related variables, grain yield, yield components, and grain protein in spring wheat grown in areas prone to wheat stem sawfly (WSS) attack.

| | Pearson correlation coefficients | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Variable | Stem solidness | Rate of parasitism on WSS | Stems infested by WSS | Grain yield | Stand establishment | Spike density | Spikes per plant | Grain protein |
| Stem diameter | –† | – | – | – | −0.53 | 0.27 | 0.49 | – |
| Stem solidness | 1 | −0.42 | – | −0.22 | – | – | – | – |
| Rate of parasitism | | 1 | 0.77 | 0.23 | −0.53 | – | 0.42 | – |
| Stems infested by WSS | | | 1 | – | −0.42 | −0.26 | – | −0.26 |
| Grain yield | | | | 1 | −0.48 | 0.71 | 0.70 | −0.23 |
| Stand establishment | | | | | 1 | −0.22 | −0.82 | 0.25 |
| Spike density | | | | | | 1 | 0.56 | – |
| Spikes per plant | | | | | | | 1 | – |
| Grain protein | | | | | | | | 1 |

† '–' = $P > 0.05$; all other r values presented at $P < 0.05$.

Beres et al. 2011

MONTANA STATE UNIVERSITY | EXTENSION

**PESTICIDE NEWS**

**Thimet 20-G® for Wheat Stem Sawfly Management**
Dr. Kevin Wanner, MSU Extension Specialist, Crop Entomology
Cecil Tharp, MSU Extension Pesticide Education Specialist

**RESTRICTED USE PESTICIDE**
**Due to acute oral, dermal and inhalation toxicity and avian hazards**
For retail sale to and use only by Certified Applicators or persons under their direct supervision, and only for those uses covered by the Certified Applicator's certification

**THIMET® 20-G**
**Lock 'n Load® Closed Loading System**

**EPA Reg. No. 5481-530**
**EPA SLN No. MT-150001**

**FIFRA 24(c) SPECIAL LOCAL NEED LABELING**

**FOR USE ON WHEAT IN MONTANA TO CONTROL WHEAT STEM SAWFLY LARVAE**

MONTANA STATE UNIVERSITY | EXTENSION

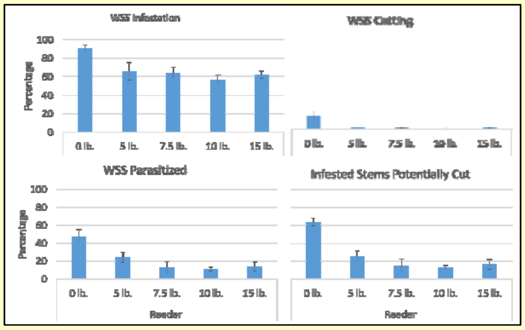
**PESTICIDE NEWS**

**Thimet 20-G® for Wheat Stem Sawfly Management**
Dr. Kevin Wanner, MSU Extension Specialist, Crop Entomology
Cecil Tharp, MSU Extension Pesticide Education Specialist

- **Apply at 5 lb acre - granular, post-emergence**
- **Soil incorporated at 1 inch below surface**
- **85 day pre-harvest interval (critical)**
- **Systemic, post-emergence timing**

- **Yield recovery 5.4 bu (spring) – 6.1 bu (winter)**
- **64 - 100% reduction in stem cutting**
- **This is due to combined parasitoids and product**

## INSECTICIDE



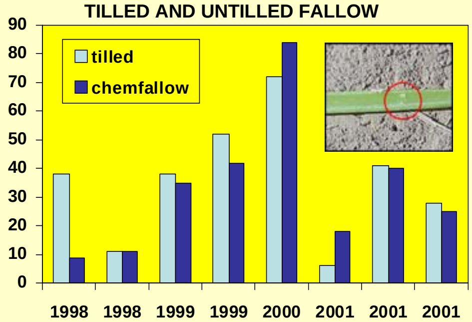

## Parasitoid Conservation

## Zero-till - Herbicide

## Light Tillage

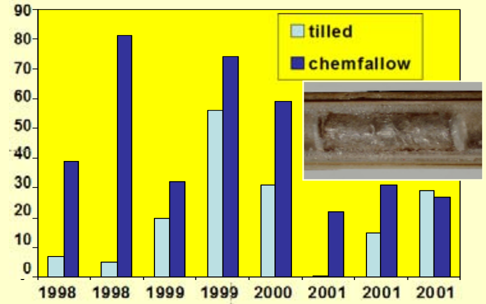
## Heavy Tillage

**SAWFLY INFESTATION IN FIELDS BORDERING TILLED AND UNTILLED FALLOW**



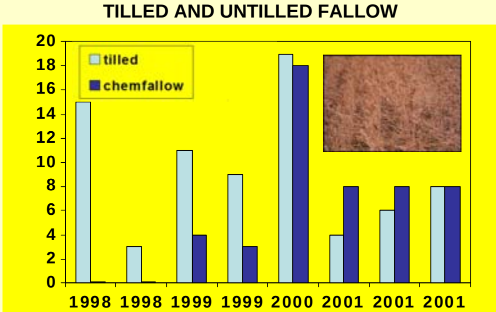

Reference: Runyon et al. 2002. J. Econ. Entomology 95: 1130-1134.

**PERCENT SAWFLY LARVAE KILLED BY PARASITOIDS IN FIELDS BORDERING TILLED AND UNTILLED FALLOW**




Reference: Runyon et al. 2002. J. Econ. Entomology 95: 1130-1134.

**PERCENT SAWFLY CUTTING IN FIELDS BORDERING TILLED AND UNTILLED FALLOW**




Reference: Runyon et al. 2002. J. Econ. Entomology 95: 1130-1134.

## Impact of Tillage

- Heavy tillage has more impact on parasitoids than sawflies
  - Sawfly overwinter in underground stubs – adapted to emerge from soil
  - Parasitoids overwinter in above-ground part of stems – not adapted to emerge from soil

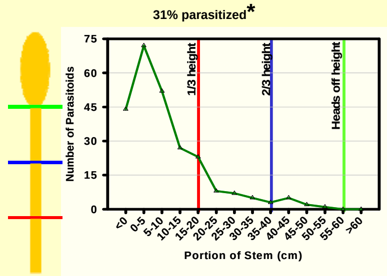
## Impact of Harvest

- Where are the parasitoids in the stem interior?
- What is the impact of cutting heights?

## Parasitoid Distribution

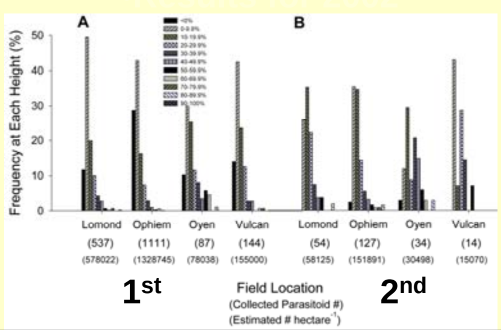
14,556 stems, 63% infested

31% parasitized*

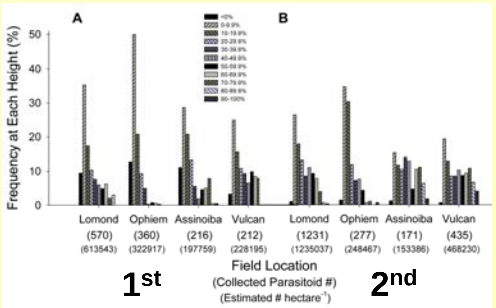



*Data collected from spring wheat fields in Alberta and Montana over 2 years. Image is for one field.

## Parasitoid Distribution - 2002



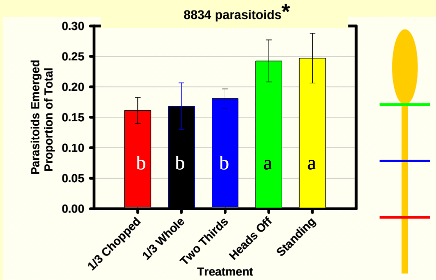
## Parasitoid Distribution - 2003




## Parasitoid Conservation

## Parasitoid Conservation

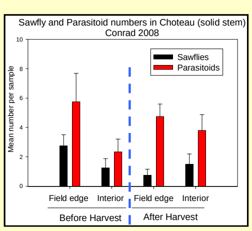
# Parasitoid Conservation

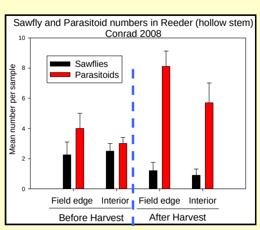



*Data collected from spring wheat experiments in fields and Research Centers in Alberta, Saskatchewan and Montana over 2 years. Total for all fields.

# Parasitoid Conservation

# Postharvest Survival



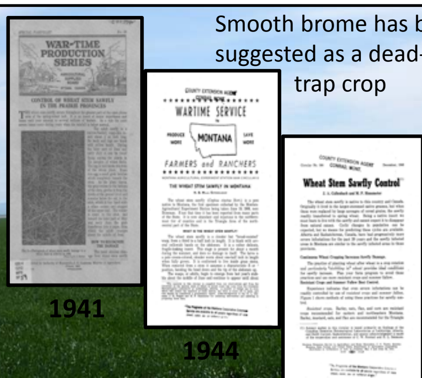

Second generation parasitism increases after harvest

# “Trap” Crops

## Smooth Brome *(Bromus inermis)*

- Non-native, perennial, cool-season, bunch grass
- Stems 30-130 cm tall and 1-5mm at first node
- Common along roadsides and disturbed areas throughout North America

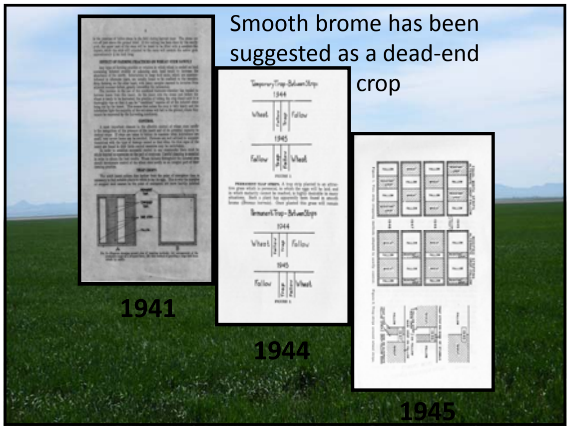
Smooth brome has been suggested as a dead-end trap crop

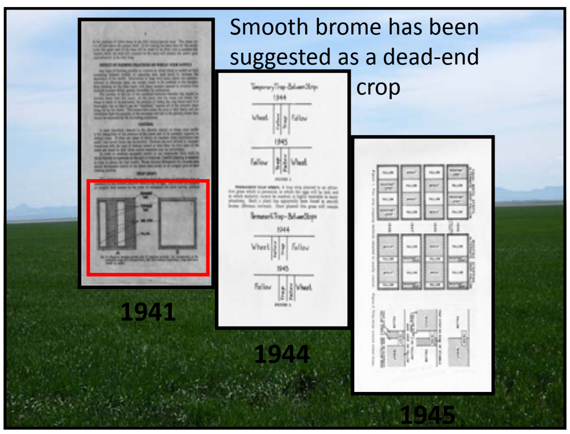



1941

1944

1945


Smooth brome has been suggested as a dead-end crop
1941
1944
1945


Smooth brome has been suggested as a dead-end crop
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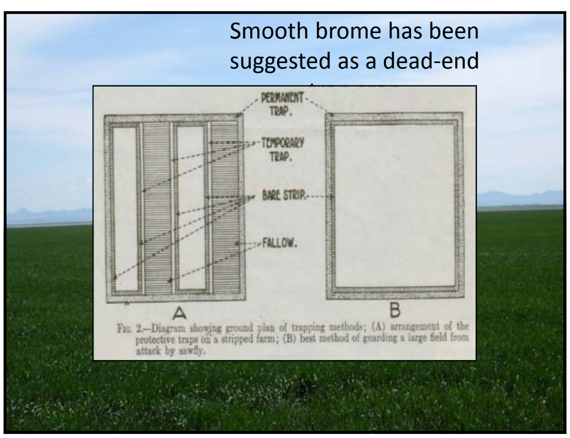
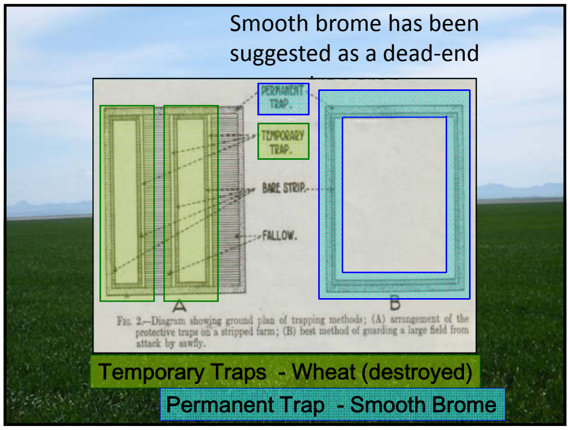
1944
1945


Smooth brome has been suggested as a dead-end
PERMANENT TRAP.
TEMPORARY TRAP.
BARE STRIP.
FALLOW.
A
B
FIG. 2.—Diagram showing ground plan of trapping methods; (A) arrangement of the protective traps on a stripped farm; (B) best method of guarding a large field from attack by sawfly.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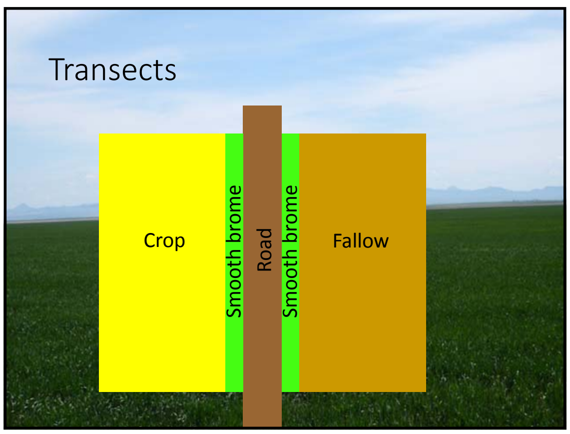
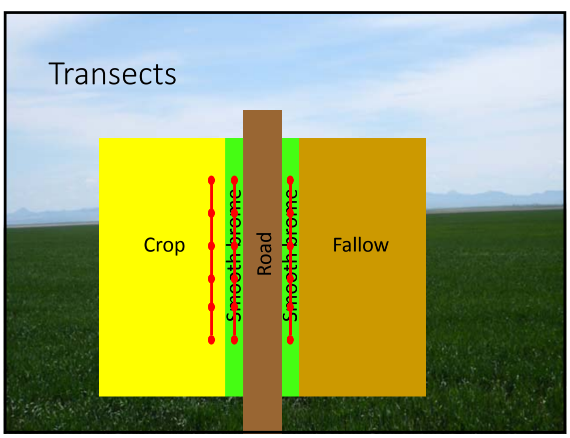
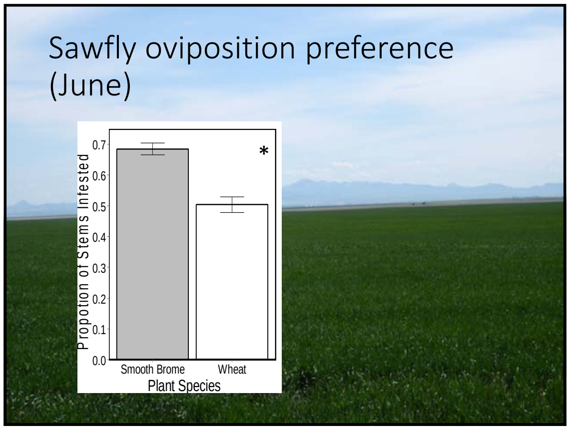
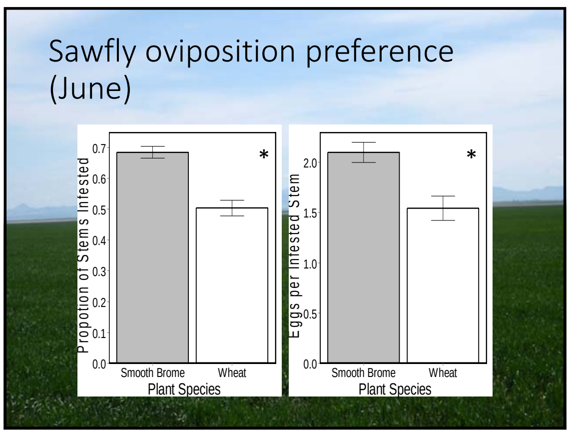
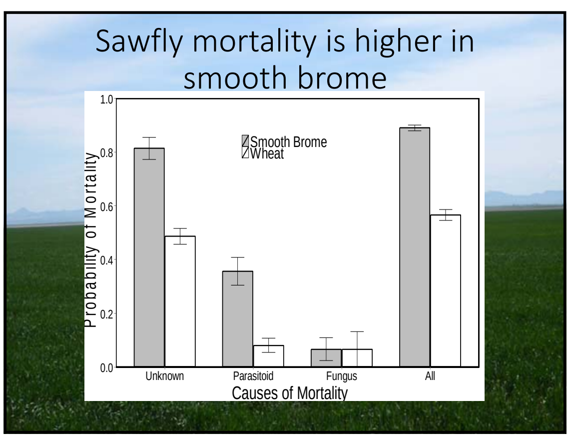
PERMANENT TRAP.
TEMPORARY TRAP.
BARE STRIP.
FALLOW.
A
B
Fig. 2.—Diagram showing ground plan of trapping methods; (A) arrangement of the protective traps on a stripped farm; (B) best method of guarding a large field from attack by sawfly.
Temporary Traps - Wheat (destroyed)
Permanent Trap - Smooth Brome

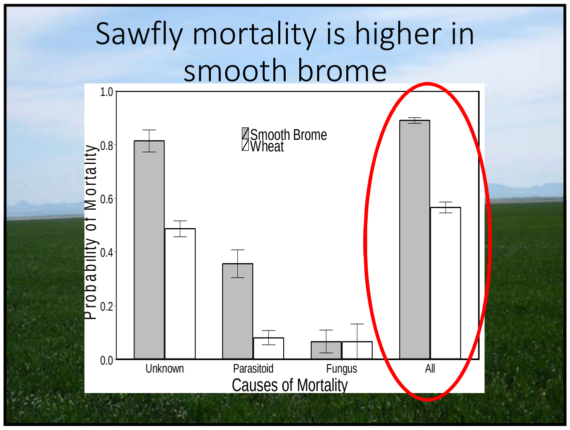

Transects
Crop
Smooth brome
Road
Smooth brome
Fallow

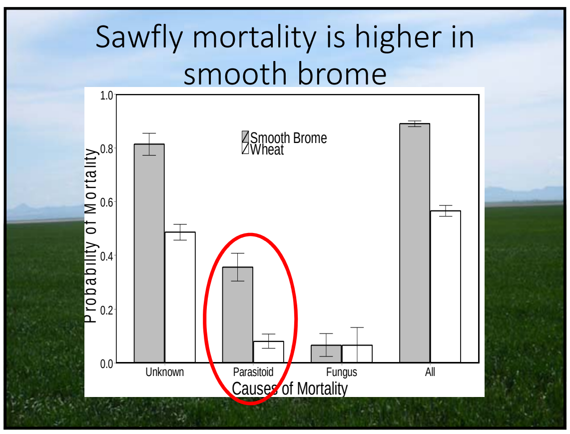

Transects
Crop
Smooth brome
Road
Smooth brome
Fallow

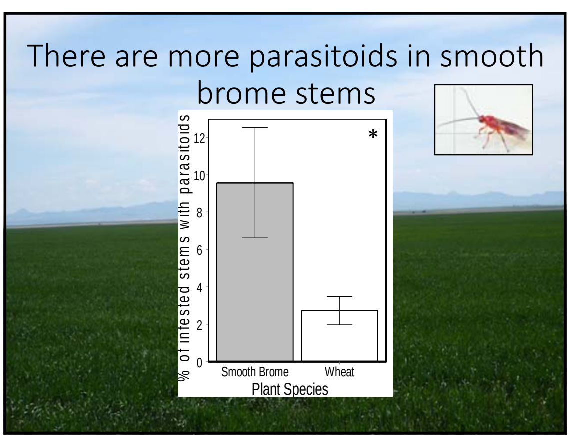

Sawfly oviposition preference (June)
Propotion of Stems Infested
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
*
Smooth Brome
Wheat
Plant Species


Sawfly oviposition preference (June)
Propotion of Stems Infested
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
*
Smooth Brome
Wheat
Plant Species
Eggs per Infested Stem
0.0
0.5
1.0
1.5
2.0
*
Smooth Brome
Wheat
Plant Species

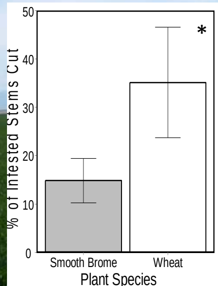

Sawfly mortality is higher in smooth brome
Probability of Mortality
0.0
0.2
0.4
0.6
0.8
1.0
Smooth Brome
Wheat
Unknown
Parasitoid
Fungus
All
Causes of Mortality


Sawfly mortality is higher in smooth brome
1.0
0.8
0.6
0.4
0.2
0.0
Probability of Mortality
Smooth Brome
Wheat
Unknown
Parasitoid
Fungus
All
Causes of Mortality


Sawfly mortality is higher in smooth brome
1.0
0.8
0.6
0.4
0.2
0.0
Probability of Mortality
Smooth Brome
Wheat
Unknown
Parasitoid
Fungus
All
Causes of Mortality


There are more parasitoids in smooth brome stems
% of infested stems with parasitoids
12
10
8
6
4
2
0
*
Smooth Brome
Wheat
Plant Species

Sawfly cutting is lower in smooth brome




Smooth brome is a source of parasitoids and a sink for wheat stem sawflies.

A grass periphery can have greater value than expected, even surrounding a wheat field

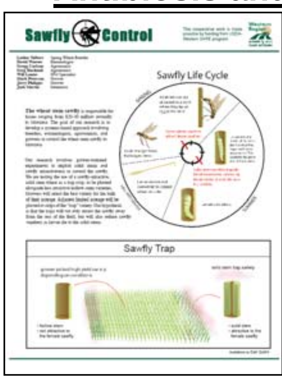
Trap Crops

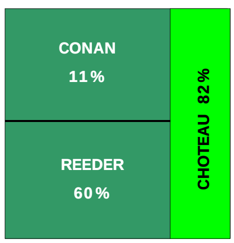
## Terms Used

**Antixenosis** – unattractive
(not recognized or repellent)

**Antibiosis** – causing mortality
(typically chemically-based)

## Antibiosis and Antixenosis



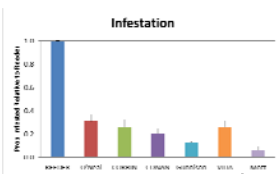



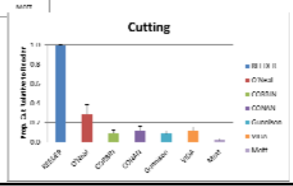

Antixenosis is rare.

## Grower Trap Crops

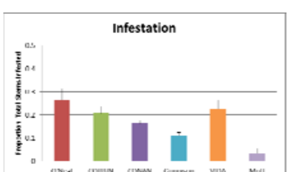
**Hill Plots**

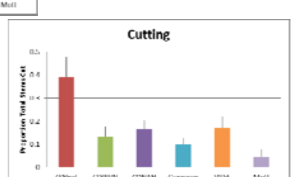
Unattractive Spring Wheat Varieties



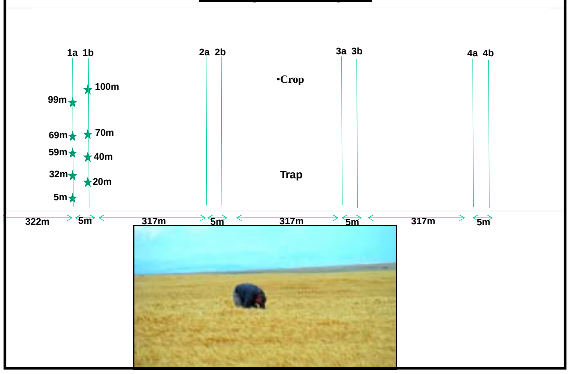




Unattractive Variety Comparison

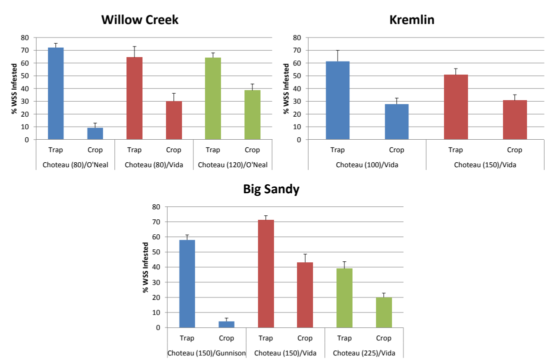


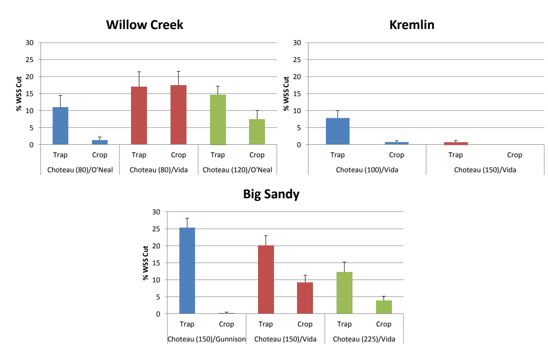
# Trap Crops



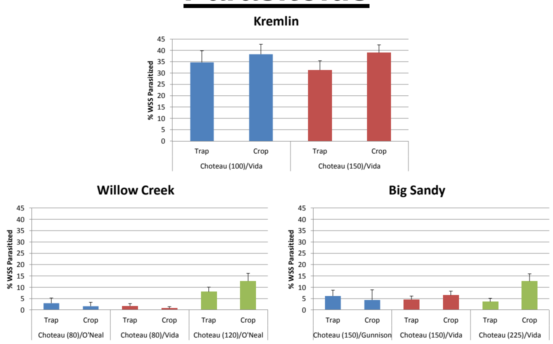

# Infestation



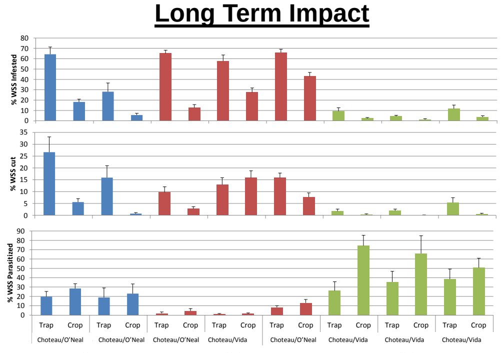

# Cutting



# Parasitoids




# Long Term Impact




Willow Creek, MT

# Cover Crops (nectar)

Female *B. cephi* longevity (days)

| Treatment | Mean ± SE | W | P-value |
|---|---|---|---|
| w/o flowers -Mustard | 5 ± 0.88 | 75 | 0.05668 |
| w/o flowers- Buckwheat | 4.5 ± 0.80 | 72.5 | 0.07659 |
| Mustard | 6.5 ± 3.41 | 65 | 0.2497 |
| **Buckwheat** | **36.7 ± 3.10** | **0** | **0.0001317** |
| Blank | 6.4 ± 2.02 | 63 | 0.3307 |
| Water | 7.1 ± 2.20 | | |

## Summary

1. Native parasitoids and host pest species have moved into cultivated wheat in Montana
2. This represents a change from perennial to annual monoculture vegetation that cannot be restored
3. Strategies that further sustainability and resilience can be applied to conservation biological control of wheat stem sawfly by native species
4. Considerable complexity exists that must be understood by ecological observation and experimentation
5. Demonstrating an immediate benefit in yield from parasitism events is compelling to growers
6. New crop rotations, cover crops and attention to ecosystem services promise continued gains in IPM

## Acknowledgments

Funds supporting this research were provided by competitive and earmarked State, Regional, and Federal sources, in addition to the Montana Ag Experiment Station.

USDA United States Department of Agriculture

MONTANA BOARD OF RESEARCH AND COMMERCIALIZATION TECHNOLOGY

Montana Wheat & Barley Committee

MONTANA STATE UNIVERSITY College of Agriculture

USDA United States Department of Agriculture National Institute of Food and Agriculture

The projects described above involve a number of researchers, graduate students, skilled laboratory staff, and many undergraduate student laborers. Implementation of the research relies heavily on collaboration across research disciplines, plus critical support from Ag Research Centers, County Extension Personnel, and numerous wheat growers statewide.

# Questions?

***Phyllobaenus dubius***

# Incorporating classical biological control into integrated management of invasive weeds

Sharlene E. Sing

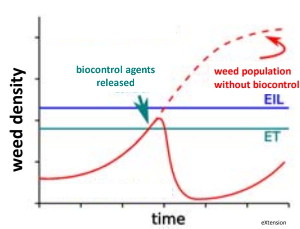
Western SARE Professional Development Program Workshop
Best Western Plus Heritage Inn – Great Falls, MT
March 1-2, 2016

## What makes it classical biological control?

- the target weed is **not** a native species
  - weed's native range is on another **continent** - *not* North America
  - weed was moved **intentionally** or **accidentally** from native range
  - weed became **established** and then **invasive** in North America
- weed's natural enemies are also **not native** to North America

## Goal of weed biocontrol:

- same rationale as for all weed control approaches - to safely suppress weed population below an **economic** or **ecological** threshold



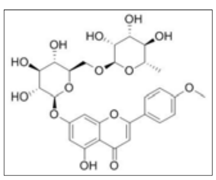
Goal of weed biocontrol:

NOT

- growing lots of bugs on weeds
- causing **cosmetic** damage only to weeds
- impacting only individual weeds

## Why use foreign bugs?

- all plants produce **phytoprotectants** - biologically active and often toxic compounds, to protect themselves from predation or infection



linarin

## Why use foreign bugs?

- all plants produce **phytoprotectants** - biologically active and often toxic compounds, to protect themselves from predation
- insect herbivores evolve adaptations through selection or spontaneous mutation
- this allows them to withstand the negative effects of ingesting or contacting phytoprotectants

## Why use foreign bugs?

- adaptation is very 'costly' so insect herbivores often specialize on only a few related plant species
- adaptation occurs through lengthy host plant - herbivore association in their shared native range

## Why use foreign bugs?

- the target weed's native range is often the best place to find candidate biocontrol agents that:
  - **want to** eat/use the weed
  - **can safely** eat/use the weed
- this chemistry is also the basis of **host specificity:**
  - degree to which a potential biocontrol agent is restricted in the number of plant hosts utilized

## Integrating biocontrol into weed management programs:

**I. determine if weed biocontrol will complement land use activities and management objectives for the affected area**

- use the following questions to help determine if biocontrol will be appropriate:

## Integrating biocontrol into weed management programs:

1. **What are the short- and long-term land use objectives for the affected area, and how have they changed?**
   - did the weed infestation follow a significant change in land use:
     - resource extraction – grazing vs. timber harvest vs. gas/oil wells vs. mining?
     - road or other construction?
2. **How urgent is the weed problem?**
   - long standing, chronic infestations of established, widespread weed species more suited to biocontrol than
     - new invaders (Priority 1A, 1B)
     - species invading previously uncolonized areas (Priority 2A)
     - small-sized or isolated infestations of well established weed species (Priority 2B)
3. **How tolerant will neighbors or the public be if target weed abundance is slow to decline?**

## Integrating biocontrol into weed management programs:

**II. determine the scope of the weed problem**

1. develop a weed distribution map at a scale that allows you to address the problem in a manner consistent with your overall land management objectives and your available weed management resources
2. in large landscapes with significant weed infestations and limited mapping resources, identify priority areas for additional survey and weed management efforts

## Integrating biocontrol into weed management programs:

**III. define overall goals of the IWM program**

- **goals** broadly define the "what" or desired outcome of management
  - goals state general land use decisions or targets over large areas and/or extended periods of time
  - manage for something specific, instead of generically against weeds
- **objectives** define the "how" or specific activities through which desired outcomes can be achieved
  - objectives must be SMART: **s**pecific, **m**easurable, **a**chievable, **r**ealistic, and **t**imely
- by defining what you want to achieve, you will be able to determine if, when, and where you can integrate biological control

## Integrating biocontrol into weed management programs:

**IV. understand the control methods available for accomplishing your IWM goals**

1. review available weed control methods (biological control, physical treatments, cultural practices, and herbicides)
   - determine the conditions (when, where, if, etc.) under which it might be appropriate to use each method or combination of methods
   - be realistic about control method benefits and limitations
2. identify resources that will be available for weed management activities
   - determine if they will be consistently available until you meet your weed management program objectives

## Biocontrol advantages

- selective
- sustainable - agents generally do not have to be reintroduced once established
- public acceptance is generally higher than with other weed control methods
- most economical option for large infestations

## Biocontrol disadvantages

- perceivable changes in target weed density are slow, especially for showy (or particularly annoying) weed species
- population level impacts of biocontrol on the target weed, not to mention effects of biocontrol on the wider plant community, are often difficult to detect through observation, and complicated to measure
- some risk of undesirable effects on nontarget plants
- permanent; cannot be undone
- not successful in all situations
- treatment efficacy is not predictable

## Interaction of biocontrol with other weed control methods:

- **Physical treatments**:
  - hand pulling, mowing, tilling, etc.
  - not recommended for weed species that reproduce from stem or root fragments, or if germination increases following disturbance
  - labor intensive, difficult on rough terrain
  - removes or destroys agents developing in weed stems or roots
  - removes stage-specific food resources of agents
  - biocontrol can be applied to large, main infestations while physical treatments can be used on surrounding small, satellite weed populations
  - mowing can be compatible with agents that develop in the roots of the target weed

## Interaction of biocontrol with other weed control methods:

- **Cultural control**:
  - flooding, burning, grazing, seeding with competitive species, etc.
  - not recommended for weed species adapted to specific cultural control methods
    - fire adapted species: toadflax
    - flood adapted species: saltcedar
  - grazing can remove or destroy agents developing in weed stems, flowers or seeds
    - may not have a negative impact on root dwelling agents
    - compatible with bison grazing (selective grass feeders)
  - strategically timed grazing can increase attractiveness of target weeds to biocontrol agents, and increase competitive ability of desirable plant species

## Interaction of biocontrol with other weed control methods:

- **Chemical control**:
  - most effective on small infestations, including newly established populations and recently established satellite patches arising from nearby older, larger infestations
    - may also be useful on the leading edge of large, advancing infestations
  - often too costly to be of practical use in treating extensive infestations
  - impractical in hard-to-access and environmentally sensitive areas
  - repeated applications may be required over time
  - potential for nontarget damage to associated vegetation

## Interaction of biocontrol with other weed control methods:

- **Chemical control**:
  - all approved classical biological control agents are host specific
    - herbicide treatments reduce the local availability of target weed stems, leaves, and flowers
    - agents relying on food and shelter resources provided by affected weeds may not survive if herbicides are applied when they are unable to move on to hosts in an untreated area
  - chemical and biological control can be successfully integrated when agents are released on large infestations and herbicides are applied to control smaller satellite patches
  - herbicide can be used to reduce dense above ground biomass to make weed patches more hospitable for biocontrol agents

## Developing, implementing, and managing IWM programs:

**I. selecting appropriate release sites**

1. infestations of at least 4 acres (1.6 hectares) are typically the minimum size recommended for biological control releases - larger infestations are even more desirable
2. consider the site's ease of accessibility, terrain, and slope
3. consider land use and rare vs. chronic disturbance factors
4. survey for presence of biological control agents

## Developing, implementing, and managing IWM programs:

**II. select appropriate bicontrol agents to release**

1. agent efficacy
   - what will work well under your field conditions?
     - are your weed patches seasonally flooded?
     - under snow until mid or late July?
     - subject to heavy wildlife or livestock grazing at 'sensitive' points in agent's life cycle?
2. agent availability
   - do you know where you can get high quality agents?
3. match weed distribution and density to preferences of agent(s)
   - are your weed patches too sparse, too dense, or too far apart?

## Developing, implementing, and managing IWM programs:

**III. documenting releases**

- permanently mark release sites
- record GPS coordinates
- generate a map and written directions to release site
- select a photo point with a unique, permanent landmark in the background
  - used to visually document changes in weed infestations and the plant community over time following the release of biocontrol agents
  - avoid capturing images that mostly show only the target weed without reference points that can identify specific release sites!

## Developing, implementing, and managing IWM programs:

**IV. monitoring the success of the program**

- field observations of agent specific damage on the target weed, annual photo points of the release site, or simple monitoring transects to assess year-to year changes in weed and agent populations, and plant community, to determine:

1. where is it working?
2. are unanticipated ecological interactions positively or negatively affecting control?
3. where is establishment or realized control lower than expected, and why?

## Standardized Impact Monitoring Protocol (SIMP)

- systematic monitoring approach to assess changes in the densities of both weed biocontrol agents and the target weed
- can be easily modified to meet personal or agency needs for monitoring most weed biocontrol releases
- Available online at: http://www.agri.state.id.us/AGRI/Categories/PlantsInsects/NoxiousWeeds/Bio_Control.php

*Monitoring biological control agents is an essential component of a successful biological control program. Monitoring data can be used to accurately document the impact of this weed management practice. This monitoring form has been endorsed by the Nez Perce Biocontrol Center, University of Idaho, Forest Health Protection, Bureau of Land Management, and Idaho State Department of Agriculture. The monitoring information from this form will be used to document vegetation cover, target weed density, and biological control agent abundance. When conducted annually, this monitoring data will document changes that occur over time.*

**Standardized Impact Monitoring Protocol (SIMP) Biological Control Monitoring Form**

General Information:

| | | | |
|---|---|---|---|
| Observer(s): | | Date: | Landowner: |
| Permanent site? Y N | Site name: | | Weed: |
| Biological control agent: | | Insect Stage: | |
| Lat/Long: N ° ' | W ° ' | UTM Datum: | UTM E: |
| | | UTM Year: | UTM N: |

Weed Infestation:

| | | | |
|---|---|---|---|
| Size in acres: | Picture taken? | Yes No | If Y, picture direction: |

Vegetation cover (all in %, rows add to 100%):

| Frame | Target weed% | Other weed% | Forb/shrub% | Perennial Grass% | Bare ground% | Litter% | Moss% | Total% |
|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | |
| 2 | | | | | | | | |
| 3 | | | | | | | | |
| 4 | | | | | | | | |
| 5 | | | | | | | | |
| 6 | | | | | | | | |
| 7 | | | | | | | | |
| 8 | | | | | | | | |
| 9 | | | | | | | | |
| 10 | | | | | | | | |

Target weed size/density:

| Frame | Number of Stems | Height of tallest stem (cm) |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | |
| 5 | | |
| 6 | | |
| 7 | | |
| 8 | | |
| 9 | | |
| 10 | | |

Biological control agent:

10 sweeps repeated 6 times (for AP, GA, LA, CYAC & OBER) **OR** a 3 minute timed count repeated 6 times (for MEJA, ACMA galls & URCA galls)

| Count site | Insect (or gall) count |
|---|---|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | |

Notes:

**A step-by-step guide for completing the SIMP biological control monitoring form:**

General Information:

- Observer(s) – Who are you?
- Date – Today's date.
- Landowner – Who is the landowner/land manager?
- Permanent? – Is this a permanent monitoring site?
- Site name – Which site are you monitoring? This could have a specific name if it is a permanent site.
- Weed – Which target weed are you are monitoring?
- Biological control agent – Which biological control agent you are monitoring?
- Insect Stage – What is the developmental stage of the agent are you monitoring (egg, larva, nymph, pupa adult)?
- Lat/Long OR UTM – What are the GPS coordinates of the site you are monitoring? If UTM (preferred), what datum and year is your coordinate system?

Annual grass – note stems which are typically solitary or in a few stemmed tufts.

Vegetation Cover (all in %, rows add up to 100%) – All percentages are to be estimated to the nearest 5%. If there is a trace of any of the vegetation you monitoring in the frame, round up to 5%.

- Frame – Which frame number are you working on (1= 2m, 2= 4m, ...,10 = 20m)?
- Target weed % – What is % cover of the target weed to the nearest 5%?
- Other weeds % – What is the % cover of any other weeds in the frame to the nearest 5%? Count undesirable annual grasses as weeds.
- Forb/Shrub % – What is the % cover of native forbs/shrubs in the frame to the nearest 5%?
- Grass % – What is the % cover of perennial grass to the nearest 5%?
- Bare Ground/Litter % – What is the % cover of bare ground/litter to the nearest 5%?

Perennial grass – note the multiple stem base with multiple year's growth.

Target Weed Size/Density

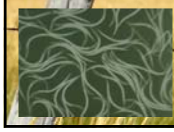
- Frame – Which frame number are you working on (1=2m, 2=4m,...,10=20m)?
- Number of stems – How many stems of the target weed are in the frame?
- Height of tallest stems (cm) – How tall is the tallest stem of the target weed in the frame (in cm)?

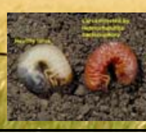
Biological Control Agent

- Count location – Identify 6 sites at least 5 paces away from the vegetation transect but within the same weed infestation.
- # of insects per 10 sweeps – How many insects are in your net after 10 sweeps of the surrounding vegetation? Take one step between each sweep. Repeat 5 more times (for a total of 6 sweep sites, 60 sweeps) moving at least 2 steps away from the last sweep location **(for AP, CYAC, GA, LA, & OBER).**
- # of biological control insects or galls per 3 min. count – How many biological control agents or galls do you see in a 3 minute period? Carefully approach the plants and be sure to count insects one time only. Please repeat 5 times (for a total of 6) moving at least 4 paces away from the first count location **(for, MEJA, ACMA galls & URCA galls).**

## Biological Control of Insect Pests Using Entomopathogenic Nematodes

Scott Portman
Postdoctoral Researcher
WTARC

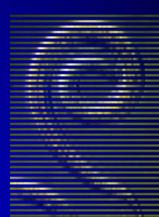




MONTANA STATE UNIVERSITY
College of Agriculture & Montana Agricultural Experiment Station

## Outline

- Part I -Biology and life cycle of entomopathogenic nematodes (EPNs).
- Part II -Application of EPNs for insect pest management.
- Part III -Work at WTARC using EPNs against sawflies and wireworms.

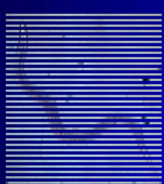


## Part I
Biology and Life Cycle

## Nematode trophic ecology


## insect pathogenic vs. plant pathogenic

**Plant pathogenic nematodes have stylet**



Entomopathogenic

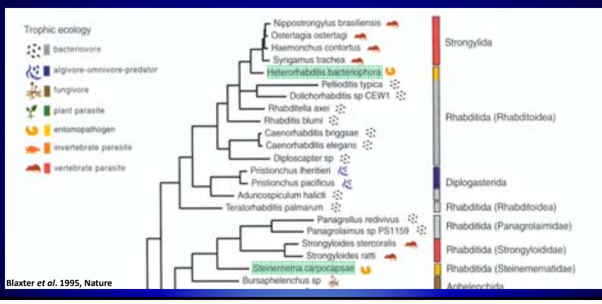
Phytopathogenic

Close-up of stylet

## What are EPNs?

- EPNs are round worms -Phylum Nematoda
- EPNs are microscopic.
- Inhabit a variety of soil environments.
- Exclusively prey on insects.

## Evolution of entomopathy




Blaxter *et al*. 1995, Nature

## EPN Systematics

**Order -Rhabditida**

Family -Steinernematidae
Genus -*Steinernema* >80 species

Family -Heterorhabditidae
Genus -*Heterorhabditis* >35 species

## Family: Steinernematidae

**Genus: *Steinernema***

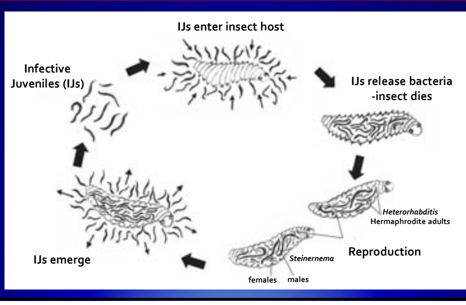
1. *S. krausse*
2. *S. glaseri*
3. *S. feltiae*
4. *S. affine*
5. *S. carpocapsae*
6. *S. arenarium*
7. *S. intermedium*
8. *S. rarum*
9. *S. kushidai*
10. *S. ritteri*
11. *S. scapterisci*
12. *S. caudatum*
13. *S. longicaudum*
14. *S. neocurtillae*
15. *S. riobrave*
16. *S. cubanum*
17. *S. puertoricense*
18. *S. bicornutum*
19. *S. monticolum*
20. *S. oregonense*
21. *S. abbasi*
22. *S. ceratophorum*
23. *S. karii*
24. *S. siamkayai*
25. *S. tami*
26. *S. thermophilum*
27. *S. sangi*
28. *S. loci*
29. *S. thanhi*
30. *S. pakistanense*

## Family: Heterorhabditidae

**Genus:** ***Heterorhabditis***

1. *H. bacteriophora*
2. *H. megidis*
3. *H. zealandica*
4. *H. indica*
5. *H. argentinensis*
6. *H. brevicaudis*
7. *H. marelatus*
8. *H. poinari*
9. *H. downesi*

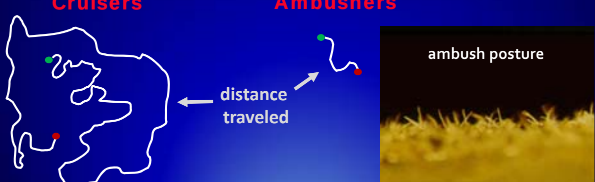
## EPN Life Cycle

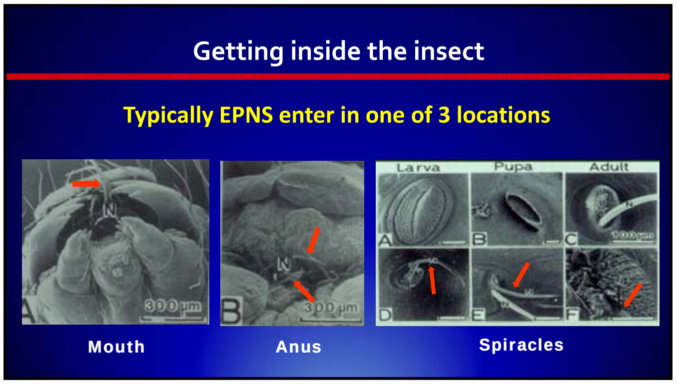


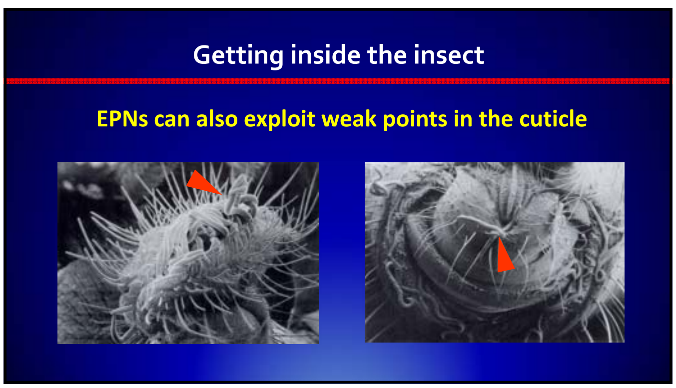

## Host finding

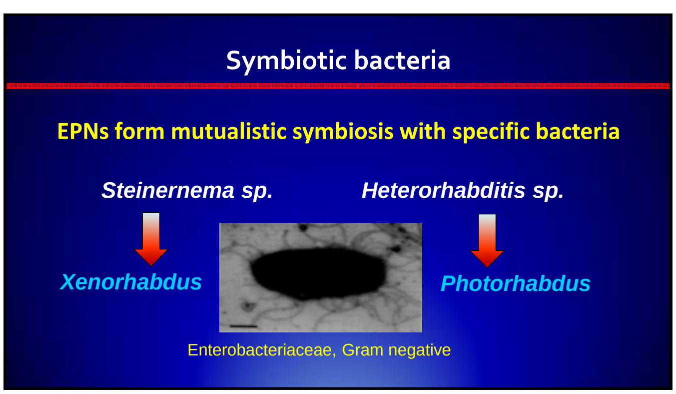
**Infective juvenile movement**

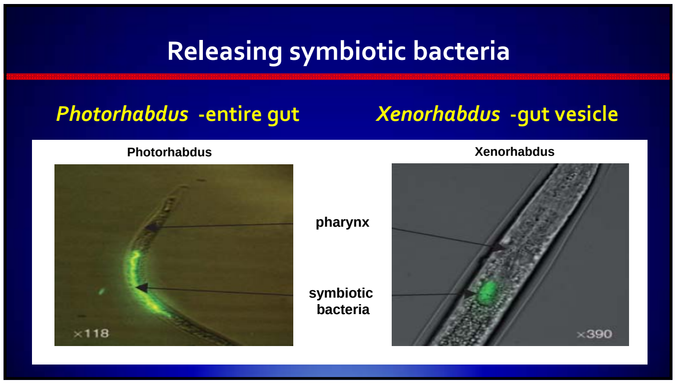
**Cruisers** **Ambushers**

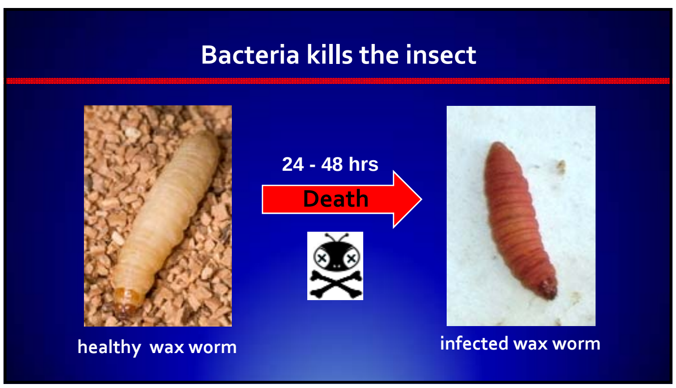


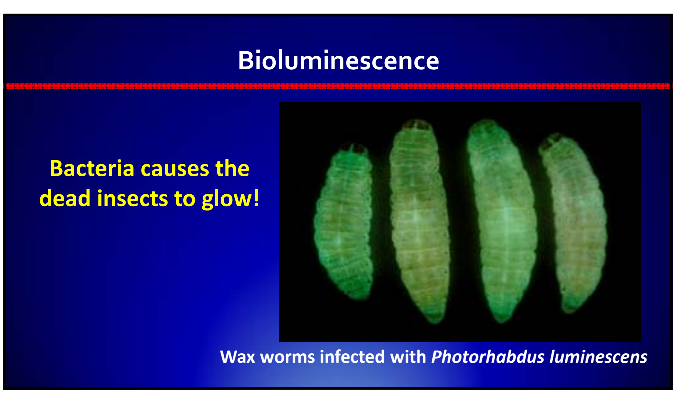

Getting inside the insect
Typically EPNS enter in one of 3 locations
Larva
Pupa
Adult
Mouth
Anus
Spiracles


Getting inside the insect
EPNs can also exploit weak points in the cuticle

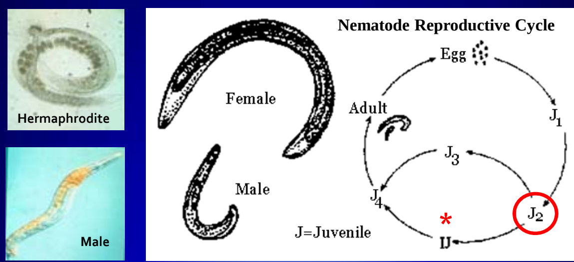

Symbiotic bacteria
EPNs form mutualistic symbiosis with specific bacteria
*Steinernema sp.*
*Heterorhabditis sp.*
*Xenorhabdus*
*Photorhabdus*
Enterobacteriaceae, Gram negative


Releasing symbiotic bacteria
Photorhabdus -entire gut
Xenorhabdus -gut vesicle
Photorhabdus
Xenorhabdus
pharynx
symbiotic bacteria
×118
×390


Bacteria kills the insect
24 - 48 hrs
Death
healthy wax worm
infected wax worm

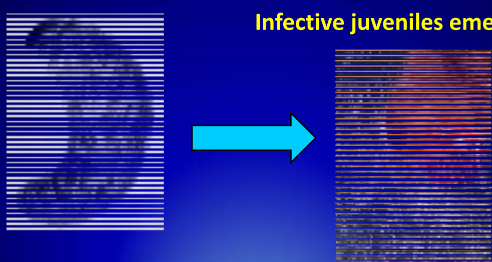

Bioluminescence
Bacteria causes the dead insects to glow!
Wax worms infected with Photorhabdus luminescens

## EPN Reproduction




## Emergence from host

Infective juveniles emerging



## Part II

Applications of EPNs

## EPNs have a broad host range


## Pests controlled by EPNs

| Sector | Nematode | Target pest |
|---|---|---|
| Citrus | *S. riobravae*<br>*H. bacteriophora* | Citrus root weevil |
| Turfgrass | *S. carpocapsae* | Hunting billbug, Black cutworm<br>Sod webworm, Fall armyworm |
| | *S. scapterisci* | Mole crickets |
| | *H. bacteriophora* | White grubs |
| Greenhouse | *S. feltiae* | Fungus gnats, Black vine weevil |
| Mushrooms | *S. feltiae* | Sciarid flies |
| Cranberries | *S. carpocapsae* | Cranberry girdler |
| Nursery | *H. bacteriophora*<br>*H. megidis* | Black vine weevil |
| Pet vet | *S. carpocapsae* | Dog flea |

## Commercial production of EPNs

**Production of beneficial nematodes in Israel**

## Consumer products containing EPNs

Variety of products targeted for different insect pests

white grubs


black vine weevil

soil dwelling pests

citrus root weevil

Lepidoptera

## Suppliers of EPNs

| Company | Address | Website | Nematodes |
|---|---|---|---|
| BioBest | 2020 Fox Run Road, RR 4<br>Leamington Ontario N8H 3V7 | www.biobest.be | Sc Sf Sk Hb |
| BioLogic Grows | P.O. Box 177<br>Willow Hill, PA. 17271 | www.biologicco.com | Sc Sf |
| BASF | 801 Dayton Ave<br>Ames, Iowa 50010 | www.beckerunderwood.com | Sc Sf Sk Hb |
| Hydro Gardens | P.O. Box 25845<br>Colorado Springs, CO 80936 | www.hydro-gardens.com | Sc Sf Hb |
| Koppert | 28465 Beverly Road<br>Romulus, MI 48174 | www.koppertonline.com | Sf Hb |
| Natural Insect Control | 3737 Netherby Rd.<br>Stevensville, ON L0S 1S0 | www.naturalinsectcontrol.com | Sc Sf Hb |
| Sierra Biological | 19730 Forest View Cir.,<br>Pioneer, CA, 95666 | www.sierrabiological.com | Sc Sf Sr |
| Southeastern Insectaries | 606 Ball Street P.O. Box 1546<br>Perry, GA 31069 | www.southeasterninsectaries.com | Sc Hb Hi |
| The Environmental Factor | 85 Chambers Drive, Unit 8<br>Ajax, ON L1Z 1E2 | www.environmentalfactor.com | Sc Sf Sg |

## Application techniques -Sprayers

EPNs are generally mixed in water and applied by spraying.

backpack sprayer

towed spray array

self-propelled boom sprayer

## Application techniques –Irrigation

EPNs can also be added to irrigation mixtures.

side roll system

pivot / linear system

## Environmental conditions

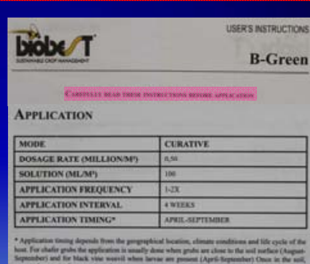
Important to apply EPNs under the right conditions

- EPNs require moisture.
- Cannot survive direct sunlight.
- Apply at temperatures above 60°F.
- Require proper host insects.


## Follow the directions!

For best results –

Follow the manufacturer's recommendations.



USER'S INSTRUCTIONS

B-Green

CAREFULLY READ THESE INSTRUCTIONS BEFORE APPLICATION

APPLICATION

| MODE | CURATIVE |
|---|---|
| DOSAGE RATE (MILLION/M²) | 0,50 |
| SOLUTION (ML/M²) | 100 |
| APPLICATION FREQUENCY | 1-2X |
| APPLICATION INTERVAL | 4 WEEKS |
| APPLICATION TIMING* | APRIL-SEPTEMBER |

* Application timing depends from the geographical location, climate conditions and life cycle of the host. For chafer grubs the application is usually done when grubs are close to the soil surface (August-September) and for black vine weevil when larvae are present (April-September). Once in the soil, nematodes persist for up to 6 weeks.

**Part III**

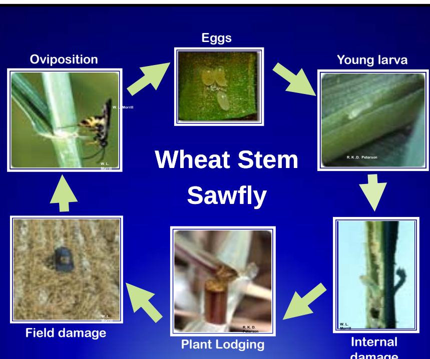
EPNs against sawfly and wireworms

## Wheat stem sawfly (*Cephus cinctus*)


**MT > $30 Million Losses**

**Problem since 1920's**

**Dozens of Researchers**



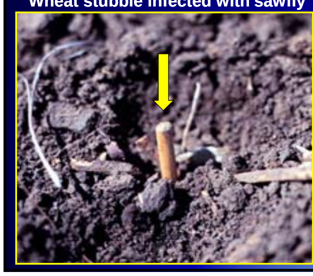
## Sawfly larvae are well protected

Wheat stubble infected with sawfly

Insect protected from chemicals and natural enemies

## Sawfly larvae are well protected

Wheat stubble infected with sawfly



Insect protected from chemicals and natural enemies

Exploit the plug

## Combine EPNs with carrier solutions

Chemicals that counteract the plug's hydrophobic properties.

- Surfactants (Alypso)
- Detergents (Trition-X, Tween 80)
- Ionic Compounds (Urea)

## Different species of EPNs against sawfly

% Mortality *Cephus cintus* larvae (N=20)

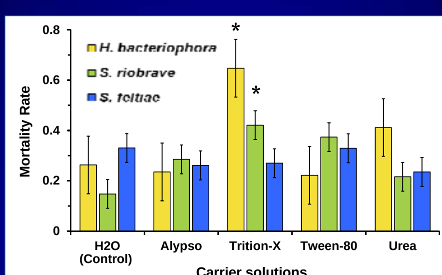
| Test Solution | Steinernema feltiae | Steinernema riobrave | Heterorhabditis bacteriophora | Steinernema carpocapse | Steinernema glaseri | Steinernema krausei |
|---|---|---|---|---|---|---|
| H2O | 31.3 | 11.1 | 26.3 | 0.0 | 0.0 | 16.7 |
| Alypso | 22.2 | 44.4 | 5.9 | 6.3 | 15.4 | 12.5 |
| Triton-X | 22.2 | 47.1 | 61.1 | 0.0 | 0.0 | 11.8 |
| Tween 80 | 23.5 | 52.9 | 22.2 | 0.0 | 0.0 | 5.6 |
| Urea | 10.5 | 20.0 | 41.2 | 0.0 | 5.9 | 6.7 |

## Different species of EPNs against sawfly

% Mortality *Cephus cintus* larvae (N=20)

| Test Solution | Steinernema feltiae | Steinernema riobrave | Heterorhabditis bacteriophora | Steinernema carpocapse | Steinernema glaseri | Steinernema krausei |
|---|---|---|---|---|---|---|
| H2O | 31.3 | 11.1 | 26.3 | 0.0 | 0.0 | 16.7 |
| Alypso | 22.2 | 44.4 | 5.9 | [illegible] | [illegible] | [illegible] |
| Triton-X | 22.2 | 47.1 | 61.1 | [illegible] | [illegible] | [illegible] |
| Tween 80 | 23.5 | 52.9 | 22.2 | [illegible] | [illegible] | [illegible] |
| Urea | 10.5 | 20.0 | 41.2 | 0.0 | 5.9 | 6.7 |

## Mortality of sawfly larvae

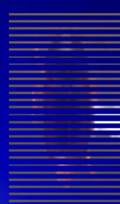


## Wireworms (Family: Elateridae)



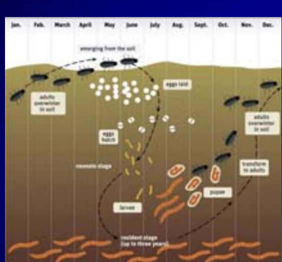
## Two problem species for Montana grain growers

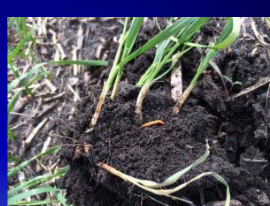

*Limonius californicus*



*Hypnoidus bicolor*

## Wireworm lifecycle





wireworm feeding on wheat

## *Tenebrio* larvae similar to wireworms

*Tenebrio molitor* larvae

wireworm larvae

## Tested three EPN species

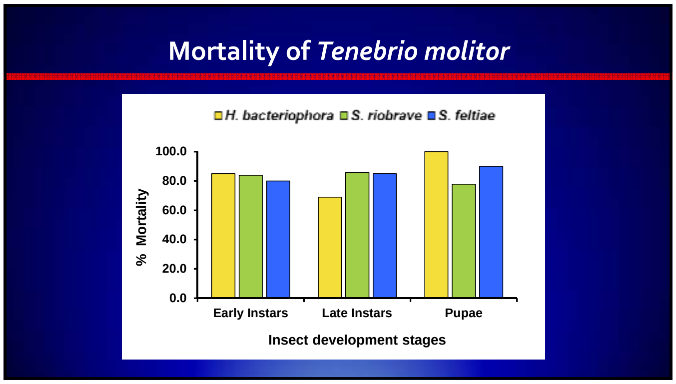
**Added ~2400 EPNs to deli cups containing 10 immature *T. molitor.***

- ***H. bacteriophora***
- ***S. felitiae***
- ***S. ribrave***

## Experimental design

**Tested EPNs with different development stages of *T. molitor***

| | Number of *T. molitor* | | |
|---|---|---|---|
| development stage | *Heterorhabditis bacteriophora* | *Steinernema feltiae* | *Steinernema riobrave* |
| Early Instar | 20 | 20 | 20 |
| Late Instar | 20 | 20 | 20 |
| Pupa | 10 | 10 | 10 |


Mortality of *Tenebrio molitor*
*H. bacteriophora* *S. riobrave* *S. feltiae*
% Mortality
100.0
80.0
60.0
40.0
20.0
0.0
Early Instars
Late Instars
Pupae
Insect development stages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