Appendix A. Regional Linkages Among Research Organizations And Major Pest Species

Table A1. Regional linkages among research institutions/organization with respect to biological control of aphids: (1) *Acyrothosiphon pisum*, (2) *Aphis craccivora,* (3) *Aphis gossypii*, (4) *Hyalopterus pruni*, (5) *Melanocallis caryaefoliae*, (6) *Moneilia caryella*, (7) *Monelliopsis pecanis*, (8) *Rentalunia nigroneruosa*, (9) *Tuxoptera citricida*, (10) Unspecified species.

Objective	AZ-AES	CA-AES	CA-DOA	GU-AES	HI-AES	ID-AES	NY-AES	UT-AES
1. Survey indigenous natural enemies				2,3,8,9		10	10	1
2. Conduct foreign exploration and ecological studies in native range of pest		4			3		10	
3. Determine systematics and biogeography of pests and natural enemies				2,3,8,9			10	
4. Determine environmental safety of exotic candidates prior to release		4		2,3,8,9				
5. Release, establish, and redistribute natural enemies		4,5,6,7	3	2,3,8,9	3	10		
6. Evaluate natural enemy efficacy and study ecological/physiological basis for interactions	5,6	4,5,6,7	3	2,3,8,9	3	10		1
7. Characterize and identify pest and natural enemy communities and their interactions				2,3,8,9			10	1
8. Identify and assess factors potentially disruptive to biological control				2,3,8,9	3		10	1
9. Implement and evaluate habitat modifications, horticultural practices and pest suppression tactics to conserve natural enemy activity	5,6			8,9	3	10		1
10. Assess biological characteristics of natural enemies			3	2,3,8,9	3		10	1
11. Conduct experimental releases to assess feasibility		7	3	2,3,8,9				
12. Develop procedures for rearing, storing, quality control and release of natural enemies				2,3,8,9				
13. Implement augmentation programs and evaluate efficacy of natural enemies								
14. Evaluate the environmental impacts of biological control agents		4		2,8,9				1
15. Evaluate the economic impacts of target pests and their biological control				2,8,9				

Table A2. Regional linkages among research institutions/organization with respect to biological control of gorse: (1) *Ulex europaeus*.

Objective	CA-DOA	OR-DOA
1. Survey indigenous natural enemies		
2. Conduct foreign exploration and ecological studies in native range of pest		
3. Determine systematics and biogeography of pests and natural enemies		
4. Determine environmental safety of exotic candidates prior to release		
5. Release, establish, and redistribute natural enemies	1	1
6. Evaluate natural enemy efficacy and study ecological/physiological basis for interactions	1	
7. Characterize and identify pest and natural enemy communities and their interactions		
8. Identify and assess factors potentially disruptive to biological control	1	1
9. Implement and evaluate habitat modifications, horticultural practices and pest suppression tactics to conserve natural enemy activity		
10. Assess biological characteristics of natural enemies		
11. Conduct experimental releases to assess feasibility		
12. Develop procedures for rearing, storing, quality control and release of natural enemies		
13. Implement augmentation programs and evaluate efficacy of natural enemies		
14. Evaluate the environmental impacts of biological control agents	1	1
15. Evaluate the economic impacts of target pests and their biological control		

Table A3. Regional linkages among research institutions/organization with respect to biological control of Hemiptera: (1) *Anasa tristis*, (2) *Erythroneura variabilis,* (3) *Leptoglossus clypealis*, (4) *Lygus hesperus*, (5) *Lygus* spp., (6) *Nezara viridula.*

Objective	CA-AES	CA-DOA	FR-ARS	KS-AES
1. Survey indigenous natural enemies	2,3,4,6			
2. Conduct foreign exploration and ecological studies in native range of pest	2		5	
3. Determine systematics and biogeography of pests and natural enemies				
4. Determine environmental safety of exotic candidates prior to release	2,4			
5. Release, establish, and redistribute natural enemies	2,6	4		
6. Evaluate natural enemy efficacy and study ecological/physiological basis for interactions	2,3,4,6	4	5	
7. Characterize and identify pest and natural enemy communities and their interactions	2,4		5	
8. Identify and assess factors potentially disruptive to biological control	2,4,6			
9. Implement and evaluate habitat modifications, horticultural practices and pest suppression tactics to conserve natural enemy activity	2,6			
10. Assess biological characteristics of natural enemies	2,3,4,6		5	1
11. Conduct experimental releases to assess feasibility		4		1
12. Develop procedures for rearing, storing, quality control and release of natural enemies	6			
13. Implement augmentation programs and evaluate efficacy of natural enemies	6			
14. Evaluate the environmental impacts of biological control agents	2,3,4,6			
15. Evaluate the economic impacts of target pests and their biological control				1

Table A4. Regional linkages among research institutions/organization with respect to biological control of knapweeds: (1) *Acroptilon repens*, (2) *Centaurea calcitrapa,* (3) *Centaurea diffusa*, (4) *Centaurea maculosa*, (5) *Centaurea solstitialis*, (6) *Centaurea squarrosa*, (7) *Centaurea virgata.*

Objective	CA-ARS	CA-DOA	FR-ARS	IT-ARS	MT-AES	MT-APHIS	NM-AES	OR-DOA	UT-AES	WA-AES	WY-AES
1. Survey indigenous natural enemies		5	4								1
2. Conduct foreign exploration and ecological studies in native range of pest	5		4	3,4							
3. Determine systematics and biogeography of pests and natural enemies		5	4								
4. Determine environmental safety of exotic candidates prior to release	5		4		1		1				
5. Release, establish, and redistribute natural enemies		2,3,4,5, 6			1,4	3,4	1	1,3,4,5	5,7	3,4,5	1
6. Evaluate natural enemy efficacy and study ecological/physiological basis for interactions	4	2,3,4,5, 6		3,4	1,4				5,7	3,4,5	1
7. Characterize and identify pest and natural enemy communities and their interactions											
8. Identify and assess factors potentially disruptive to biological control		4						1			1
9. Implement and evaluate habitat modifications, horticultural practices and pest suppression tactics to conserve natural enemy activity											
10. Assess biological characteristics of natural enemies					4		1		5,7		1
11. Conduct experimental releases to assess feasibility							1				1
12. Develop procedures for rearing, storing, quality control and release of natural enemies											
13. Implement augmentation programs and evaluate efficacy of natural enemies											
14. Evaluate the environmental impacts of biological control agents		5						1,3,4,5			1
15. Evaluate the economic impacts of target pests and their biological control								5			1

Table A5. Regional linkages among research institutions/organization with respect to biological control of Lepidoptera (1) *Acropsis muxnoriella*, (2) *Adoaophyes orana,* (3) *Amyelois transitella*, (4) *Anarsia lineatella*, (5) *Choristoneura rosaceana*, (6) *Cydia pomonella*, (7) *Heliothis zea*, (8) *Marmara* spp., (9) *Pandemis limitata*, (10) *Pandemis heparana*, (11) *Pectinophora gossypiella*, (12) *Phyllocnistis citrella*, (13) *Plutella xylostella*, (14) Unspecified species.

Objective	AZ-ARS	CA-AES	FR-ARS	HI-AES	NY-AES	WA-ARS
1. Survey indigenous natural enemies	11	3,5,8,12	2,10		14	9
2. Conduct foreign exploration and ecological studies in native range of pest	11	4,5	2,10		14	9
3. Determine systematics and biogeography of pests and natural enemies	11	8	2,10		14	
4. Determine environmental safety of exotic candidates prior to release	11	4,5, 12				
5. Release, establish, and redistribute natural enemies	11	1,4,5,7, 12				6
6. Evaluate natural enemy efficacy and study ecological/physiological basis for interactions	11	1,3,5,7, 8, 12	2,10	13		6,9
7. Characterize and identify pest and natural enemy communities and their interactions	11	12	2,10	13	14	6,9
8. Identify and assess factors potentially disruptive to biological control	11	5,12			14	9
9. Implement and evaluate habitat modifications, horticultural practices and pest suppression tactics to conserve natural enemy activity	11	5,12		13		9
10. Assess biological characteristics of natural enemies		3,5,8,12	2,10		14	6,9
11. Conduct experimental releases to assess feasibility		7,12				
12. Develop procedures for rearing, storing, quality control and release of natural enemies		12	2,10			
13. Implement augmentation programs and evaluate efficacy of natural enemies		4				
14. Evaluate the environmental impacts of biological control agents	11	4,5	2,10			
15. Evaluate the economic impacts of target pests and their biological control	11		2,10			

Table A6. Regional linkages among research institutions/organization with respect to biological control of other arthropods: (1) *Cacopsylla pyricola*, (2) *Cephus cinctus,* (3) *Eucayptolyma maideni*, (4) *Glycaspis brimblecombei*, (5) *Homalodisca coagulata*, (6) *Homalodisca homalodisca*, (7) *Liriomyza trifolii*, (8) *Scirtothrips perseae.* (9) *Tetranychus urticae*, (10) *Frankliniella occidentalis.*

Objective	CA-AES	CA-DOA	CA-APHIS	FR-ARS	HI-AES	KS-AES	WA-ARS
1. Survey indigenous natural enemies	3,4,8		5				
2. Conduct foreign exploration and ecological studies in native range of pest	3,4,8			2			
3. Determine systematics and biogeography of pests and natural enemies	4,8						
4. Determine environmental safety of exotic candidates prior to release	3,4,8		5				
5. Release, establish, and redistribute natural enemies	3,4,8	5	5		7		
6. Evaluate natural enemy efficacy and study ecological/physiological basis for interactions	3,4,6	5	5	2			1
7. Characterize and identify pest and natural enemy communities and their interactions	8		5	2			1
8. Identify and assess factors potentially disruptive to biological control			5				1
9. Implement and evaluate habitat modifications, horticultural practices and pest suppression tactics to conserve natural enemy activity			5		7	10	1
10. Assess biological characteristics of natural enemies	3,4,6,8		5	2	7	9,10	
11. Conduct experimental releases to assess feasibility	8	5	5			9,10	
12. Develop procedures for rearing, storing, quality control and release of natural enemies	3,84		5				
13. Implement augmentation programs and evaluate efficacy of natural enemies	8		5			9,10	
14. Evaluate the environmental impacts of biological control agents	8		5				
15. Evaluate the economic impacts of target pests and their biological control	3,4,8						

Table A7. Regional linkages among research institutions/organization with respect to biological control of other weeds: (1) *Arundo donax*, (2) *Cardaria draba,* (3) *Chondrilla juncea*, (4) *Conium maculatum*, (5) *Convolvulus arvensis*, (6) *Cynoglossum officinale*, (7) *Cytisus scoparius*, (8) *Delairea odorata*, (9) *Dipsacus laciniatus*, (10) *Galium aparine*, (11) *Genista* spp., (12) *Hypericum perforatum*, (13) *Isatis tinctoria*, (14) *Linaria dalmatica*, (15) *Linaria genistifolia*, (16) *Linaria vulgaris*, (17) *Peganum harmala*, (18) *Potentilla recta*, (19) *Salsola kali*, (20) *Salsola tragus*, (21) *Salvia aethiopis*, (22) *Salvinia molesta*, (23) *Senecio jacobaea*, (24) *Verbascum thapsus.*

Objective	CA-APHIS	CA-ARS	CA-DOA	FR-ARS	IT-ARS	MT-AES	MT-APHIS	NM-AES	OR-DOA	WA-AES	WY-AES
1. Survey indigenous natural enemies	22	1	7								
2. Conduct foreign exploration and ecological studies in native range of pest		1,8		2	2,5,9, 13,14						
3. Determine systematics and biogeography of pests and natural enemies		1,8	20	2		14,16					
4. Determine environmental safety of exotic candidates prior to release		1,8,19	20			2,3,6, 18		17			
5. Release, establish, and redistribute natural enemies	22	8,19	7,11,15 20,22			3,14,16	14, 16	5	3,5,6, 7,14	3,4,12, 15,24	14,16
6. Evaluate natural enemy efficacy and study ecological/physiological basis for interactions	22	8	7,11,15 20,22		2,5,9, 13,14	2,3,5, 14,16			14,21, 23	3	14,16
7. Characterize and identify pest and natural enemy communities and their interactions											
8. Identify and assess factors potentially disruptive to biological control			20			14,16					14,16
9. Implement and evaluate habitat modifications, horticultural practices and pest suppression tactics to conserve natural enemy activity								5			
10. Assess biological characteristics of natural enemies		1,8		2,10	5	2,5,14, 16			23		14,16
11. Conduct experimental releases to assess feasibility											14,16
12. Develop procedures for rearing, storing, quality control and release of natural enemies	22										
13. Implement augmentation programs and evaluate efficacy of natural enemies											
14. Evaluate the environmental impacts of biological control agents	22	1,8	20						6,7, 14,21, 23		
15. Evaluate the economic impacts of target pests and their biological control		1									

Table A8. Regional linkages among research institutions/organization with respect to biological control of purple loosestrife: (1) *Lythrum salicaria.*

Objective	CA-DOA	MT-APHIS	OR-DOA	WA-AES
1. Survey indigenous natural enemies				
2. Conduct foreign exploration and ecological studies in native range of pest				
3. Determine systematics and biogeography of pests and natural enemies				
4. Determine environmental safety of exotic candidates prior to release				
5. Release, establish, and redistribute natural enemies	1	1	1	1
6. Evaluate natural enemy efficacy and study ecological/physiological basis for interactions	1		1	1
7. Characterize and identify pest and natural enemy communities and their interactions				
8. Identify and assess factors potentially disruptive to biological control				
9. Implement and evaluate habitat modifications, horticultural practices and pest suppression tactics to conserve natural enemy activity				
10. Assess biological characteristics of natural enemies				
11. Conduct experimental releases to assess feasibility				
12. Develop procedures for rearing, storing, quality control and release of natural enemies				
13. Implement augmentation programs and evaluate efficacy of natural enemies				
14. Evaluate the environmental impacts of biological control agents			1	
15. Evaluate the economic impacts of target pests and their biological control				

Table A9. Regional linkages among research institutions/organization with respect to biological control of saltcedar: (1) *Tamarix ramosissima*, (2) *Tamarix* spp.

Objective	AZ-APHIS	CA-ARS	CA-DOA	CA-Other	FR-ARS	NM-AES	OR-DOA	TX-ARS	WY-AES
1. Survey indigenous natural enemies		2				1		1	
2. Conduct foreign exploration and ecological studies in native range of pest		2			1			1	
3. Determine systematics and biogeography of pests and natural enemies								1	
4. Determine environmental safety of exotic candidates prior to release	2	2				1		1	
5. Release, establish, and redistribute natural enemies	2	2	1			1	1	1	1
6. Evaluate natural enemy efficacy and study ecological/physiological basis for interactions	2	2				1		1	1
7. Characterize and identify pest and natural enemy communities and their interactions						1		1	
8. Identify and assess factors potentially disruptive to biological control		2				1		1	1
9. Implement and evaluate habitat modifications, horticultural practices and pest suppression tactics to conserve natural enemy activity						1			
10. Assess biological characteristics of natural enemies		2			1	1		1	1
11. Conduct experimental releases to assess feasibility		2				1		1	1
12. Develop procedures for rearing, storing, quality control and release of natural enemies								1	
13. Implement augmentation programs and evaluate efficacy of natural enemies									
14. Evaluate the environmental impacts of biological control agents	2	2					1	1	1
15. Evaluate the economic impacts of target pests and their biological control	2	2		1				1	

Table A10. Regional linkages among research institutions/organization with respect to biological control of other weeds: (1) *Aonidiella aurantii*, (2) *Coccus pseudomagnoliarum,* (3) *Dysmicoccus brevipes*, (4) *Dysmicoccus neobrevipes*, (5) *Glycaspis brimblecombei*, (6) *Maconellicoccus hirsustus*, (7) *Planococus ficus*, (8) *Pseudococcus maritimus*, (9) *Pseudococcus viburni*, (10) *Quadraspidiosus perniciosus*, (11) *Saissetia oleae*, (12) Unspecified species.

Objective	CA-AES	CA-APHIS	CA-DOA	HI-AES	NY-AES
1. Survey indigenous natural enemies	7,8,10		5,6,7		12
2. Conduct foreign exploration and ecological studies in native range of pest	1,9				12
3. Determine systematics and biogeography of pests and natural enemies	7,8,9				12
4. Determine environmental safety of exotic candidates prior to release					
5. Release, establish, and redistribute natural enemies	1,7,8		5,6,7		
6. Evaluate natural enemy efficacy and study ecological/physiological basis for interactions	1,2,7,8, 9,10		6,7	3,4	
7. Characterize and identify pest and natural enemy communities and their interactions	1		6		12
8. Identify and assess factors potentially disruptive to biological control	1,2,7,8, 9,10		6	3,4	12
9. Implement and evaluate habitat modifications, horticultural practices and pest suppression tactics to conserve natural enemy activity	7,8				
10. Assess biological characteristics of natural enemies	2,7,9, 10,11	6		3,4	12
11. Conduct experimental releases to assess feasibility	2,8,9,1 0	6		3,4	
12. Develop procedures for rearing, storing, quality control and release of natural enemies	2,8		6	3,4	
13. Implement augmentation programs and evaluate efficacy of natural enemies	2,7,9, 10,11			3,4	
14. Evaluate the environmental impacts of biological control agents	8		6		
15. Evaluate the economic impacts of target pests and their biological control	1,8			3,4	

Table A11. Regional linkages among research institutions/organization with respect to biological control of spurges: (1) *Euphorbia esula*, (2) *Euphorbia virgata*.

Objective	CA-DOA	IT-ARS	IT-Other	MT-AES	MT-APHIS	NM-AES	OR-DOA	UT-AES	WY-AES
1. Survey indigenous natural enemies									
2. Conduct foreign exploration and ecological studies in native range of pest		1	2						
3. Determine systematics and biogeography of pests and natural enemies				1					
4. Determine environmental safety of exotic candidates prior to release						1			
5. Release, establish, and redistribute natural enemies	1			1	1	1	1	1	1
6. Evaluate natural enemy efficacy and study ecological/physiological basis for interactions	1	1	2	1		1		1	1
7. Characterize and identify pest and natural enemy communities and their interactions									
8. Identify and assess factors potentially disruptive to biological control				1					1
9. Implement and evaluate habitat modifications, horticultural practices and pest suppression tactics to conserve natural enemy activity						1			
10. Assess biological characteristics of natural enemies		1	2	1				1	1
11. Conduct experimental releases to assess feasibility									1
12. Develop procedures for rearing, storing, quality control and release of natural enemies									
13. Implement augmentation programs and evaluate efficacy of natural enemies						1			
14. Evaluate the environmental impacts of biological control agents			2	1			1		
15. Evaluate the economic impacts of target pests and their biological control									

Table A12. Regional linkages among research institutions/organization with respect to biological control of tephritids: (1) *Bactrocera cucurbitae*, (2) *Bactrocera dorsalis,* (3) *Bactrocera latifrons*, (4) *Bactrocera oleae*, (5) *Ceratitis capitata*

Objective	FR-ARS	HI-AES	HI-ARS	IT-Other
1. Survey indigenous natural enemies			1	
2. Conduct foreign exploration and ecological studies in native range of pest	4,5	1,2,3, 4,5	1	5
3. Determine systematics and biogeography of pests and natural enemies		1,2,3, 4,5	1	
4. Determine environmental safety of exotic candidates prior to release		1,2,3, 4,5	1	
5. Release, establish, and redistribute natural enemies		1,2,3, 4,5	1	
6. Evaluate natural enemy efficacy and study ecological/physiological basis for interactions	4,5	1,2,3, 4,5	1	5
7. Characterize and identify pest and natural enemy communities and their interactions	4,5		1	5
8. Identify and assess factors potentially disruptive to biological control		1,2,3, 4,5	1	
9. Implement and evaluate habitat modifications, horticultural practices and pest suppression tactics to conserve natural enemy activity		1,2,3, 4,5	1	
10. Assess biological characteristics of natural enemies	4,5	1,2,3, 4,5	1	
11. Conduct experimental releases to assess feasibility		1,2,3, 4,5	1	
12. Develop procedures for rearing, storing, quality control and release of natural enemies		1,2,3, 4,5	1	
13. Implement augmentation programs and evaluate efficacy of natural enemies			1	
14. Evaluate the environmental impacts of biological control agents		1,2,3, 4,5	1	
15. Evaluate the economic impacts of target pests and their biological control			1	

Table A13. Regional linkages among research institutions/organization with respect to biological control of thistles: (1) *Carduus nutans*, (2) *Carduus tenuiflorus,* (3) *Centaurea solstitialis*, (4) *Cirsium arvense*, (5) *Cirsium vulgare*, (6) *Onopordum acanthium*, (7) *Salsola kali*, (8) *Salsola* spp.

Objective	CA-ARS	CA-DOA	CA-Other	FR-ARS	IT-ARS	KS-AES	NM-AES	OR-DOA	UT-AES	WA-AES
1. Survey indigenous natural enemies										
2. Conduct foreign exploration and ecological studies in native range of pest	3			8	3,7					
3. Determine systematics and biogeography of pests and natural enemies										
4. Determine environmental safety of exotic candidates prior to release	3	6								
5. Release, establish, and redistribute natural enemies	3	1,5						1,2	4	4,6
6. Evaluate natural enemy efficacy and study ecological/physiological basis for interactions	3	1,5			3,7	1	1		4	
7. Characterize and identify pest and natural enemy communities and their interactions										
8. Identify and assess factors potentially disruptive to biological control	3	5				1				
9. Implement and evaluate habitat modifications, horticultural practices and pest suppression tactics to conserve natural enemy activity										
10. Assess biological characteristics of natural enemies	3			8	3	1		1	4	
11. Conduct experimental releases to assess feasibility										
12. Develop procedures for rearing, storing, quality control and release of natural enemies										
13. Implement augmentation programs and evaluate efficacy of natural enemies										
14. Evaluate the environmental impacts of biological control agents	3	1,5				1	1	1,2		
15. Evaluate the economic impacts of target pests and their biological control			3							

Table A14. Regional linkages among research institutions/organization with respect to biological control of whiteflies: (1) *Bemisia agrifolia*, (2) *Bemisia argentifolii,* (3) *Bemisia tabaci*, (4) *Bemisia* spp., (5) *Aleurodicus bugesii*, (6) *Paraleyrodes* spp.

Objective	AZ-AES	AZ-ARS	CA-AES	CA-APHIS	CA-DOA	NY-AES
1. Survey indigenous natural enemies		2	1,4,5,6	4	2	4
2. Conduct foreign exploration and ecological studies in native range of pest			5,6			4
3. Determine systematics and biogeography of pests and natural enemies			1,4,5,6			4
4. Determine environmental safety of exotic candidates prior to release			5,6			
5. Release, establish, and redistribute natural enemies		2	5,6		2	
6. Evaluate natural enemy efficacy and study ecological/physiological basis for interactions		2	5,6	4	2	
7. Characterize and identify pest and natural enemy communities and their interactions		2,3	5,6		2	4
8. Identify and assess factors potentially disruptive to biological control		2,3			2	4
9. Implement and evaluate habitat modifications, horticultural practices and pest suppression tactics to conserve natural enemy activity		2,3			2	
10. Assess biological characteristics of natural enemies	3	2	1,4,5,6			4
11. Conduct experimental releases to assess feasibility		2	5,6			
12. Develop procedures for rearing, storing, quality control and release of natural enemies			5,6			
13. Implement augmentation programs and evaluate efficacy of natural enemies		2	5,6		2	
14. Evaluate the environmental impacts of biological control agents			5,6	4	2	
15. Evaluate the economic impacts of target pests and their biological control						

Table A15. Regional linkages among research institutions/organization with respect to biological control of beetles: (1) *Hypera postica.*

Objective
1. Survey indigenous natural enemies
2. Conduct foreign exploration and ecological studies in native range of pest
3. Determine systematics and biogeography of pests and natural enemies
4. Determine environmental safety of exotic candidates prior to release
5. Release, establish, and redistribute natural enemies
6. Evaluate natural enemy efficacy and study ecological/physiological basis for interactions
7. Characterize and identify pest and natural enemy communities and their interactions
8. Identify and assess factors potentially disruptive to biological control
9. Implement and evaluate habitat modifications, horticultural practices and pest suppression tactics to conserve natural enemy activity
10. Assess biological characteristics of natural enemies
11. Conduct experimental releases to assess feasibility
12. Develop procedures for rearing, storing, quality control and release of natural enemies
13. Implement augmentation programs and evaluate efficacy of natural enemies
14. Evaluate the environmental impacts of biological control agents
15. Evaluate the economic impacts of target pests and their biological control

Appendix B. Regional Activities Among Research Organizations Relative to Four Major Goals and Major Pest Groups.

Table B2. Summary of Goals by Institution or Research Organization.

State	Affiliation	Goal A	Goal B	Goal C	Goal D
AZ	AES	2	2	1	0
AZ	APHIS	3	0	0	2
AZ	ARS	9	9	3	2
CA	AES	101	25	53	16
CA	APHIS	5	0	3	2
CA	ARS	23	2	5	6
CA	DOA	54	10	6	7
CA	Other	0	0	0	2
FR	ARS	24	6	12	4
GU	AES	20	10	12	6
HI	AES	32	17	25	7
HI	ARS	6	3	4	2
ID	AES	3	1	0	0
IT	ARS	21	0	3	0
IT	Other	4	1	1	1
KS	AES	1	2	5	2
MT	AES	22	3	6	1
MT	APHIS	4	0	0	0
NM	AES	12	5	5	1
NY	AES	20	16	8	0
OR	DOA	19	2	2	16
TX	ARS	6	2	3	2
UT	AES	14	6	7	2
WA	AES	16	0	0	0
WA	ARS	6	7	2	0
WY	AES	11	5	10	3

Table B2. Summary of Pest Groups by Institution or Research Organization.

State	Affiliation	Aphids	Beetles	Gorse	Hemiptera	Knapweed	Lepidoptera	Other arthro	Other weed	Purple Loosestrife	Saltcedar	Sessile Homoptera	Sessile Hompotera	Spurges	Tephritids	Thistles	Whiteflies
AZ	AES	2															1
AZ	APHIS										1						
AZ	ARS						1										2
CA	AES	4			4		9	4				7	1				4
CA	APHIS								1			1					1
CA	ARS					2			3		1					1	
CA	DOA	1		1	1	5		1	5	1	1	3		1		3	2
CA	Other										1					1	
FR	ARS				1	1	2	1	2		1				2	1	
GU	AES	4															
HI	AES	1					1	1				2			5		
HI	ARS														1		
ID	AES	1															
IT	ARS					2			5					2		2	
IT	Other													1	1		
KS	AES				1			2								1	
MT	AES					3			7					1			
MT	APHIS					3			2	1				1			
NM	AES					1			2		1			1		1	
NY	AES	2					2					2					2
OR	DOA			1		4			7	1	1			1		2	
TX	ARS										1						
UT	AES	1	1			3								1		1	
WA	AES					3			5	1						2	
WA	ARS						2	1									
WY	AES					1			2		1			1			

Appendix C. Regional Activities Among Institutions or Research Organizations by Pest Group and Research Protocol.

Table C1. Survey indigenous natural enemies (Objective 1).

State	Affiliation	Aphids	Beetles	Hemiptera	Knapweed	Lepidoptera	Other arthro	Other weed	Saltcedar	Sessile Homoptera	Tephritids	Whiteflies
AZ	ARS					1						1
CA	AES			4		6	3			3		4
CA	APHIS							1				1
CA	ARS							1	1			
CA	DOA				1			1		3		1
FR	ARS				1	2						
GU	AES	4										
HI	ARS										1	
ID	AES	1										
NM	AES								1			
NY	AES	2				2				2		2
TX	ARS								1			
UT	AES	1	1									
WA	ARS					1						
WY	AES				1							

Table C2. Conduct foreign exploration and ecological studies in native range of pest (Objective 2).

State	Affiliation	Aphids	Hemiptera	Knapweed	Lepidoptera	Other arthro	Other weed	Saltcedar	Sessile Homoptera	Spurges	Tephritids	Thistles	Whiteflies
AZ	ARS				1								
CA	AES	1	1		2	3			2				2
CA	ARS			1			2	1				1	
FR	ARS		1	1	2	1	1	1			2	1	
HI	AES	1									5		
HI	ARS										1		
IT	ARS			2			5			2		2	
IT	Other									1	1		
NY	AES	2			2				2				2
TX	ARS							1					
WA	ARS				1								

Table C3. Determine systematics and biogeography of pests and natural enemies (Objective 3).

State	Affiliation	Aphids	Knapweed	Lepidoptera	Other arthro	Other weed	Saltcedar	Sessile Homoptera	Spurges	Tephritids	Whiteflies
AZ	ARS			1							
CA	AES			1	2			3			4
CA	ARS					2					
CA	DOA		1			1					
FR	ARS		1	2		1					
GU	AES	4									
HI	AES									5	
HI	ARS									1	
MT	AES					2			1		
NY	AES	1		1				1			1
TX	ARS						1				

Table C4. Determine environmental safety of exotic candidates prior to release (Objective 4).

State	Affiliation	Aphids	Hemiptera	Knapweed	Lepidoptera	Other arthro	Other weed	Saltcedar	Spurges	Tephritids	Thistles	Whiteflies
AZ	APHIS							1				
AZ	ARS				1							
CA	AES	1	2		3	3						2
CA	ARS			1			3	1			1	
CA	DOA						1				1	
FR	ARS			1								
GU	AES	4										
HI	AES									5		
HI	ARS									1		
MT	AES			1			4					
NM	AES			1			1	1	1			
TX	ARS							1				

Table C5. Release, establish, and redistribute natural enemies (Objective 5).

State	Affiliation	Aphids	Gorse	Hemiptera	Knapweed	Lepidoptera	Other arthro	Other weed	Purple Loosestrife	Saltcedar	Sessile Homoptera	Spurges	Tephritids	Thistles	Whiteflies
AZ	APHIS									1					
AZ	ARS					1									1
CA	AES	4		2		7	3				3				2
CA	APHIS							1							
CA	ARS							2		1				1	
CA	DOA	1	1	1	5		1	5	1	1	3	1		2	1
GU	AES	4													
HI	AES	1					1						5		
HI	ARS												1		
ID	AES	1													
MT	AES				2			3				1			
MT	APHIS				3			2	1			1			
NM	AES				1			1		1		1			
OR	DOA		1		4			5	1	1		1		2	
TX	ARS									1					
UT	AES				3							1		1	
WA	AES				3			5	1					2	
WA	ARS					1									
WY	AES				1			2		1		1			

Table C6. Evaluate natural enemy efficacy and study ecological/physiological basis for interactions (Objective 6).

State	Affiliation	Aphids	Beetles	Gorse	Hemiptera	Knapweed	Lepidoptera	Other arthro	Other weed	Purple Loosestrife	Saltcedar	Sessile Homoptera	Spurges	Tephritids	Thistles	Whiteflies
AZ	AES	2														
AZ	APHIS										1					
AZ	ARS						1									1
CA	AES	4			4		8	4				6				2
CA	APHIS								1							1
CA	ARS					1			1		1				1	
CA	DOA	1		1	1	5		1	5	1		2	1		2	1
FR	ARS				1		2	1						2		
GU	AES	4														
HI	AES	1					1					2		5		
HI	ARS													1		
ID	AES	1														
IT	ARS					2			5				1		2	
IT	Other												1	1		
KS	AES														1	
MT	AES					2			5				1			
NM	AES										1		1		1	
OR	DOA								3	1						
TX	ARS										1					
UT	AES	1	1			3							1		1	
WA	AES					3			1	1						
WA	ARS						2	1								
WY	AES					1			2		1		1			

Table C7. Characterize and identify pest and natural enemy communities and their interactions (Objective 7).

State	Affiliation	Aphids	Beetles	Hemiptera	Lepidoptera	Other arthro	Saltcedar	Sessile Homoptera	Tephritids	Whiteflies
AZ	ARS				1					2
CA	AES			2	1	1		1		2
CA	DOA							1		1
FR	ARS			1	2	1			2	
GU	AES	4								
HI	AES				1					
HI	ARS								1	
IT	Other								1	
NM	AES						1			
NY	AES	2			2			2		2
TX	ARS						1			
UT	AES	1	1							
WA	ARS				2	1				

Table C8. Identify and assess factors potentially disruptive to biological control (Objective 8).

State	Affiliation	Aphids	Beetles	Gorse	Hemiptera	Knapweed	Lepidoptera	Other arthro	Other weed	Saltcedar	Sessile Homoptera	Spurges	Tephritids	Thistles	Whiteflies
AZ	ARS						1								2
CA	AES				3		2				6				
CA	ARS									1				1	
CA	DOA			1		2			1		1			1	1
GU	AES	4													
HI	AES	1									2		5		
HI	ARS												1		
KS	AES													1	
MT	AES								2			1			
NM	AES									1					
NY	AES	2					2				2				2
OR	DOA			1		1									
TX	ARS									1					
UT	AES	1	1												
WA	ARS						1	1							
WY	AES					1			2	1		1			

Table C9. Implement and evaluate habitat modification, horticultural practices and pest suppression tactics to conserve natural enemy activity (Objective 9).

State	Affiliation	Aphids	Beetles	Hemiptera	Lepidoptera	Other arthro	Other weed	Saltcedar	Sessile Homoptera	Spurges	Tephritids	Whiteflies
AZ	AES	2										
AZ	ARS				1							2
CA	AES			2	3				2			
CA	DOA											1
GU	AES	2										
HI	AES	1			1	1					5	
HI	ARS										1	
ID	AES	1										
KS	AES					1						
NM	AES						1	1		1		
UT	AES	1	1									
WA	ARS				1	1						

Table C10. Assess biological characteristics of natural enemies (Objective 10).

State	Affiliation	Aphids	Beetles	Hemiptera	Knapweed	Lepidoptera	Other arthro	Other weed	Saltcedar	Sessile Homoptera	Spurges	Tephritids	Thistles	Whiteflies
AZ	AES													1
AZ	ARS													1
CA	AES			4		5	4			5				4
CA	APHIS									1				
CA	ARS							2	1				1	
CA	DOA	1												
FR	ARS			1		2	1	2	1			2	1	
GU	AES	4												
HI	AES	1					1			2		5		
HI	ARS											1		
IT	ARS							1			1		1	
IT	Other										1			
KS	AES			1			1						1	
MT	AES				1			4			1			
NM	AES				1				1					
NY	AES	2				2				2				2
OR	DOA							1					1	
TX	ARS								1					
UT	AES	1	1		3						1		1	
WA	ARS					2								
WY	AES				1			2	1		1			

Table C11. Conduct experimental releases to assess feasibility (Objective 11).

State	Affiliation	Aphids	Hemiptera	Knapweed	Lepidoptera	Other arthro	Other weed	Saltcedar	Sessile Homoptera	Spurges	Tephritids	Whiteflies
AZ	ARS											1
CA	AES	1			2	1			4			2
CA	APHIS								1			
CA	ARS							1				
CA	DOA	1	1			1						
GU	AES	4										
HI	AES								2		5	
HI	ARS										1	
KS	AES		1			1						
NM	AES			1				1				
TX	ARS							1				
WY	AES			1			2	1		1		

Table C12. Develop procedures for rearing, storing, quality control and release of natural enemies (Objective 12).

State	Affiliation	Aphids	Hemiptera	Lepidoptera	Other arthro	Other weed	Saltcedar	Sessile Homoptera	Tephritids	Whiteflies
CA	AES		1	1	3			2		2
CA	APHIS					1				
CA	DOA							1		
FR	ARS			2						
GU	AES	4								
HI	AES							2	5	
HI	ARS								1	
TX	ARS						1			

Table C13. Implement augmentation programs and evaluate efficacy of natural enemies (Objective 13).

State	Affiliation	Hemiptera	Lepidoptera	Other arthro	Sessile Homoptera	Spurges	Tephritids	Whiteflies
AZ	ARS							1
CA	AES	1	1	1	5			2
CA	DOA							1
HI	AES				2			
HI	ARS						1	
KS	AES			1				
NM	AES					1		

Table C14. Evaluate the environmental impacts of biological control agents (Objective 14).

State	Affiliation	Aphids	Beetles	Gorse	Hemiptera	Knapweed	Lepidoptera	Other arthro	Other weed	Purple Loosestrife	Saltcedar	Sessile Homoptera	Spurges	Tephritids	Thistle	Whitefly
AZ	APHIS										1					
AZ	ARS						1									
CA	AES	1			4		2	1				1				2
CA	APHIS								1							1
CA	ARS								2		1				1	
CA	DOA			1		1			1			1			2	1
FR	ARS						2									
GU	AES	3														
HI	AES													5		
HI	ARS													1		
IT	Other												1			
KS	AES														1	
MT	AES												1			
NM	AES														1	
OR	DOA			1		4			5	1	1		1		2	
TX	ARS										1					
UT	AES	1	1													
WY	AES					1					1					

Table C15. Evaluate the economic impacts of target pests and their biological control (Objective 15).

State	Affiliation	Aphids	Hemiptera	Knapweed	Lepidoptera	Other arthro	Other weed	Saltcedar	Sessile Homoptera	Tephritids	Thistles
AZ	APHIS							1			
AZ	ARS				1						
CA	AES					3			2		
CA	ARS						1	1			
CA	Other							1			1
FR	ARS				2						
GU	AES	3									
HI	AES								2		
HI	ARS									1	
KS	AES		1								
OR	DOA			1							
TX	ARS							1			
WY	AES			1							

Summary Table:

Pest Group	Family	Genus	Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Aphids	Aphididae	Acyrthosiphon	pisum	1	0	0	0	0	1	1	1	1	1	0	0	0	1	0
		Aphis	craccivora	1	0	1	1	1	1	1	1	0	1	1	1	0	1	1
		Aphis	gossypii	1	1	1	1	3	3	1	2	1	3	2	1	0	0	0
		Hyalopterus	pruni	0	1	0	1	1	1	0	0	0	0	0	0	0	1	0
		Melanocallis	caryaefoliae	0	0	0	0	1	2	0	0	1	0	0	0	0	0	0
		Moneilia	caryella	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
		Monellia	caryella	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
		Monelliopsis	pecanis	0	0	0	0	1	1	0	0	0	0	1	0	0	0	0
		Rentalunia	nigroneruosa	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1
		Tuxoptera	citricida	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1
		Unspecified	Unspecified	1	0	0	0	1	1	0	0	1	0	0	0	0	0	0
	Unspecified	Unspecified	Unspecified	2	2	1	0	0	0	2	2	0	2	0	0	0	0	0
Total Aphids				9	6	8	9	16	20	14	16	16	19	17	16	13	19	18
Beetles	Curculionidae	Hypera	postica	1	0	0	0	0	1	1	1	1	1	0	0	0	1	0
Gorse	Fabaceae	Ulex	europaeus	0	0	0	0	2	1	0	2	0	0	0	0	0	2	0
Hemiptera	Cicadellidae	Erythroneura	variabilis	1	1	0	1	1	1	1	1	1	1	0	0	0	1	0
	Coreidae	Anasa	tristis	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1
		Leptoglossus	Clypealis	1	0	0	0	0	1	0	0	0	1	0	0	0	1	0
	Miridae	Lygus	hesperus	1	0	0	1	1	2	1	1	0	1	1	0	0	1	0
		Lygus	spp.	0	1	0	0	0	1	1	0	0	1	0	0	0	0	0
	Pentatomidae	Nezara	viridula	1	0	0	0	1	1	0	1	1	1	0	1	1	1	0
Total Hemiptera				4	2	0	2	3	6	3	3	2	6	2	1	1	4	1
Knapweed	Asteraceae	Acroptilon	repens	0	0	0	1	3	1	0	1	0	0	0	0	0	1	0
		Centaurea	calcitrapa	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
		Centaurea	diffusa	0	0	0	0	4	2	0	0	0	0	0	0	0	1	0
		Centaurea	macuiosa	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
		Centaurea	maculosa	0	0	0	0	5	4	0	1	0	0	0	0	0	1	0
		Centaurea	repens	1	0	0	1	2	1	0	1	0	2	2	0	0	1	1
		Centaurea	solstitialis	1	1	1	1	4	3	0	1	0	1	0	0	0	2	1
		Centaurea	squarrosa	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0

Pest Group	Family	Genus	Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		Centaurea	virgata	0	0	0	0	2	2	0	0	0	2	0	0	0	0	0
	Compositae	Centaurea	diffusa	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
		Centaurea	maculosa	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0
Total Knapweed				3	4	2	4	19	17	0	4	0	6	2	0	0	6	2
Lepidoptera	Gelechiidae	Amyelois	transitella	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0
		Anarsia	lineatella	0	1	0	1	1	0	0	0	0	0	0	0	1	1	0
		Pectinophora	gossypiella	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1
	Gracilcariidae	Marmara	Unspecified	1	0	1	0	0	1	0	0	0	1	0	0	0	0	0
		Phyllocnistis	citrella	1	0	0	0	1	1	0	0	0	1	1	0	0	0	0
		Phyllocnistis	citrella	1	0	0	1	1	1	1	1	1	1	0	1	0	0	0
	Noctuidae	Heliothis	zea	0	0	0	0	1	1	0	0	0	0	1	0	0	0	0
	Plutellidae	Plutella	xylostella	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0
	Pyralidae	Acropsis	muxnoriella	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
	Tortricidae	Adoaophyes	orana	1	1	1	0	0	1	1	0	0	1	0	1	0	1	1
		Choristoneura	rosaceana	2	1	0	1	2	2	0	1	2	1	0	0	0	1	0
Lepidoptera	Tortricidae	Cydia	pomonella	0	0	0	0	1	1	1	0	0	1	0	0	0	0	0
		Pandemis	heparana	1	1	1	0	0	1	1	0	0	1	0	1	0	1	1
		Pandemis	limitata	1	1	0	0	0	1	1	1	1	1	0	0	0	0	0
	Unspecified	Unspecified	Unspecified	2	2	1	0	0	0	2	2	0	2	0	0	0	0	0
Total Lepidoptera				12	8	5	4	9	14	9	6	6	11	2	3	1	5	3
Other arthropods	Agromeidae	Liriomyza	trifolii	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0
	Cephidae	Cephus	cinctus	0	1	0	0	0	1	1	0	0	1	0	0	0	0	0
	Cicadellidae	Homalodisca	coagulata	0	0	0	0	1	1	0	0	0	0	1	0	0	0	0
		Homalodisca	homalodisca	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
	Psyllidae	Cacopsylla	pyricola	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0
	Spondyliaspididae	Eucayptolyma	maideni	1	1	0	1	1	1	0	0	0	1	0	1	0	0	1
		Glycaspis	brimblecombei	1	1	1	1	1	1	0	0	0	1	0	1	0	0	1
	Thripidae	Scirtothrips	perseae	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1
Total Other arthro				3	4	2	3	5	7	3	1	2	6	2	3	1	1	3
Other weed	Apiaceae	Conium	maculatum	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
	Asteraceae	Chondrilla	juncea	0	0	0	1	3	2	0	0	0	0	0	0	0	0	0
		Delairea	odorata	0	1	1	1	1	1	0	0	0	1	0	0	0	1	0

Pest Group	Family	Genus	Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		Senecio	jacobaea	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0
	Boraginaceae	Cynoglossum	officinale	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0
	Brassicaceae	Cardaria	draba	0	1	1	1	0	1	0	0	0	2	0	0	0	0	0
	Chenopodiacae	Salsola	kali	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
		Salsola	tragus	0	0	1	1	1	1	0	1	0	0	0	0	0	1	0
	Clusiaceae	Hypericum	perforatum	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Other weed	Convolvulaceae	Convolvulus	arvensis	0	1	0	0	2	2	0	0	1	2	0	0	0	0	0
	Cruciferae	Cardaria	draba	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
		Isatis	tinctoria	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
	Dipsacaceae	Dipsacus	laciniatus	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
	Fabaceae	Cytisus	scoparius	1	0	0	0	2	1	0	0	0	0	0	0	0	1	0
		Genista	monsp	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
	Lamiaceae	Salvia	aethiopis	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0
	Poaceae	Arundo	donax	1	1	1	1	0	0	0	0	0	1	0	0	0	1	1
	Rosaceae	Potentilla	recta	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	Rubinaceae	Galium	aparine	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	Salviniaceae	Salvinia	molesta	1	0	0	0	2	2	0	0	0	0	0	1	0	1	0
	Scrophulariaceae	Linaria	dalmatica	0	1	0	0	2	3	0	1	0	1	1	0	0	1	0
		Linaria	genistifolia	0	0	1	0	2	1	0	1	0	1	0	0	0	0	0
		Linaria	vulgaris	0	0	1	0	2	2	0	2	0	2	1	0	0	0	0
		Verbascum	thapsus	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
		Linaria	genistifolia	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
	Zygophyllaceae	Peganum	harmala	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Total Other weed				3	8	6	9	24	23	0	5	1	12	2	1	0	9	1
Purple Loosestrife	Lythraceae	Lythrum	salicaria	0	0	0	0	3	3	0	0	0	0	0	0	0	1	0
Saltcedar	Tamaricaceae	Tamarix	ramosissima	2	1	1	3	6	4	2	3	1	3	3	1	0	4	3
		Tamarix	spp.	1	2	0	1	1	1	0	1	0	2	1	0	0	1	1
Total Saltcedar				3	3	1	4	7	5	2	4	1	5	4	1	0	5	4
Sessile Homoptera	Coccidae	Coccus	pseudomagnoliarum	0	0	0	0	0	1	0	1	0	1	1	1	1	0	0
		Saissetia	oleae	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
		Saissetia	oleae	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
	Diaspidae	Quadraspidiosus	perniciosus	1	0	0	0	0	1	0	1	0	1	1	0	1	0	0

Pest Group	Family	Genus	Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		Aonidiella	aurantii	0	1	0	0	1	1	1	1	0	0	0	0	0	0	1
	Pseudococcidae	Dysmicoccus	brevipes	0	0	0	0	0	1	0	1	0	1	1	1	1	0	1
		Dysmicoccus	neobrevipes	0	0	0	0	0	1	0	1	0	1	1	1	1	0	1
		Maconellicoccus	hirsustus	1	0	0	0	1	1	1	1	0	1	1	1	0	1	0
		Planococus	ficus	2	0	1	0	2	2	0	1	1	1	0	0	1	0	0
		Pseudococcus	maritimus	1	0	1	0	1	1	0	1	1	0	1	1	0	1	1
		Pseudococcus	viburni	0	1	1	0	0	1	0	1	0	1	1	0	1	0	0
	Psyllidae	Glycaspis	brimblecombei	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
	Unspecified	Unspecified	Unspecified	2	2	1	0	0	0	2	2	0	2	0	0	0	0	0
Total Sessile Homoptera				8	4	4	0	6	10	4	11	2	10	7	6	8	2	4
Spurges	Euphorbiaceae	Euphorbia	esula	0	2	1	1	6	6	0	2	1	4	1	0	1	2	0
		Euphorbia	virgata	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0
Total Spurges				0	3	1	1	6	7	0	2	1	5	1	0	1	3	0
Tephritids	Tephritidae	Bactrocera	cucurbitae	1	2	2	2	2	2	1	2	2	2	2	2	1	2	1
		Bactrocera	dorsalis	0	1	1	1	1	1	0	1	1	1	1	1	0	1	0
		Bactrocera	latifrons	0	1	1	1	1	1	0	1	1	1	1	1	0	1	0
		Bactrocera	oleae	0	2	1	1	1	2	1	1	1	2	1	1	0	1	0
		Ceratitis	capitata	0	3	1	1	1	3	2	1	1	2	1	1	0	1	0
Total Tephritids				1	9	6	6	6	9	4	6	6	8	6	6	1	6	1
Thistles	Asteraceae	Carduus	nutans	0	0	0	0	2	3	0	1	0	2	0	0	0	4	0
		Carduus	tenuiflorus	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0
		Centaurea	solstitialis	0	1	0	1	1	1	0	1	0	1	0	0	0	1	1
		Cirsium	arvense	0	0	0	0	2	1	0	0	0	1	0	0	0	0	0
		Cirsium	vulgare	0	0	0	0	1	1	0	1	0	0	0	0	0	1	0
		Onopordum	acanthium	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
	Chenopodiaceae	Salsola	kali	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
		Salsola	spp.	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0
	Compositae	Centaurea	solstitialis	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0
Total Thistles				0	4	0	2	8	8	0	3	0	6	0	0	0	7	1
Whiteflies	Aleyrodidae	Aleurodicus	bugesii	1	1	1	1	1	1	1	0	0	1	1	1	1	1	0

Pest Group	Family	Genus	Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		Bemisia	agrifolia	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0
		Bemisia	argentifolii	2	0	0	0	2	2	2	2	2	1	1	0	2	1	0
		Bemisia	tabaci	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0
		Bemisia	Unspecified	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0
		Paraleyrodes	spp.	1	1	1	1	1	1	1	0	0	1	1	1	1	1	0
		Unspecified	Unspecified	3	2	2	0	0	0	2	2	0	3	0	0	0	0	0
Total Whitelfies				9	4	5	2	4	5	7	5	3	8	3	2	4	4	0

Appendix D
Publications of W-185 Members (1997-2001)

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Appendix E: Critical Review of Regional Research Project W-185, 1996-2000

Executive Summary

Accomplishments

Research accomplishments by W-185 scientists from 1996-2000 are presented in accordance with the goals and objectives developed in 1995. The details of this work are presented in appendex XX. Included are accomplishments by members of W-185 on miscellaneous pest groups not covered under the main objectives. Herein we summarize this review, highlighting the major accomplishments and areas needing additional study.

Substantial progress was made towards the utilization of biological control for the suppression of both arthropod and weed pests through introduction (classical), conservation, and augmentation. Scientists participating in W-185 have been extremely productive, with XXX scientific papers (journal articles, technical papers, book chapters, and books) published in association with research conducted under project objectives. Underlying these many accomplishments were the critical interactions and collaborations that transcended state and institutional boundaries and were made possible through this regional research project.

Under Objective A, introduction of natural enemies, surveys of resident natural enemies were completed for more than a 15 insect pests and three weed pest species. Systematics on the parasitoids of the pink hibiscus mealybug, silverleaf whitefly, knapweeds, thistles, and spurges are being developed using both traditional and newer, molecular techniques. More than 40 species of biological control agents are currently in quarantine and/or were introduced into quarantine during the last five years. Host specificity testing has been completed for redgum lerp psyllid. More than 38 species/strains of natural enemies were released against insect pests and 75 bioagents were released or redistributed against weed pests. Establishment was confirmed for a number of these species. Successful biological control through the introduction of natural enemies was demonstrated for silverleaf whitefly, red-gum lerp psyllid, pink hibiscus mealybug, cotton aphid, and Lygus hesperus.

Under Objective B, conservation of natural enemies, surveys to identify indigenous natural enemies were completed for many important pest species, including cotton aphid, vine mealybug, and silverleaf whitefly. Studies to identify and assess factors potentially involved in disruption of biological control have been completed for various pest groups. Factors such as hyperparasitism, interference by ants and other predators, pesticide sensitivity, and crop sanitation were found to be important deterrents to successful biological control of several important pests. A variety of non-crop plants have been surveyed to determine their role in supporting a number of new mealybug pests. Perennial hedgerows are being investigated as year-round sources for natural enemies of silverleaf whitefly.

Significant progress was also made under Objective C, augmentation of natural enemies. Researchers identified viable augmentative biological control agents of sessile and non-sessile Homoptera and Lepidoptera. Small-scale augmentative release studies were completed for parasitoids of the silverleaf whitefly and codling moth and fruitflies. Results were encouraging but more work is need on rearing to make this approach economically feasible. Some progress was made towards implementation of augmentative biological control for scales, whiteflies, aphids, and the codling moth.

Breakthroughs on the biology *Encarsia*, an important group of whitefly parasitoids, suggest that symbionts (i.e. Wolbachia) and ovicidal behavior on the part of adult females can influence parasitism rates. New marking technologies and wind-tunnel studies are revealing detailed information on the dispersal of whitefly parasitoids, important to understanding the potential for augmentative biological control.

Finally, several systems have been examined in relation to Objective D, evaluation of environmental and economic aspects of biological control. Non-target and other environmental impacts of biological control activities were studied for sessile Homoptera, whiteflies, aphids, tephritid fruitflies, thistles, and spurges. Analyses of the economic benefits of biological control have been completed for the blue gum psyllid and knapweeds. In general, economic benefits from these and previous biological control efforts are in excess of millions of dollars annually, and provide a benefit to cost ratio exceeding 100.

Areas needing further investigation

Additional work needs to be done on a number of pest groups for which effective natural enemies have not been identified. These include yellow starthistle, other thistles?, cotton aphid. In addition, several new exotic pests have invaded Western United States. Those for which classical biological control is amendable and which currently lack any specialized natural enemies include glassy-winged sharpshooter, lemon lerp psyllid, a new strain of cereal leaf beetle, a new strain of citrus pealminer, olive fruit fly, salvinia and others.

Each of the above new pest species will require research on host rearing, host range studies and systematics for candidate natural enemies. Work on conservation of these newly imported natural enemies will be needed to determine which indigenous natural enemies attach them, and how to maximize the impact of introduced and indigenous natural enemies, i.e. environmental requisites, least harmful pesticides. If economically feasible rearing systems can be developed, some of these and other natural enemies could be considered for augmentative biological control. Studies are needed, retrospective, and pre-release, to determine the potential for introduced natural enemies to attack non-target organisms. Probably most needed are economic studies on the impact of past biological control projects.

CRITICAL REVIEW: OUTLINE

Goal A. Introduction (classical biological control) of natural enemies to control target pests

Objective 1. Survey indigenous natural enemies

a. Work accomplished (1996-2000)

1) Insect pests

Aphids

The native parasites and pathogens of the cotton aphid were surveyed in the San Joaquin Valley over multiple years prior to the introduction of exotic natural enemies. The native parasites were recovered throughout the year in all of the habitats that cotton aphid occupies. The genera represented included *Aphidius*, *Diaeretiella*, and *Lysiphlebus*. The native pathogens were recovered in the cooler, wetter times of the year (late fall through spring). The fungi recovered included *Erynia neoaphidis*, *Conidiobolus obscurus*, *Entomophthora planchoniana*, and *Pandora neoaphidis.*

Coccinellidae were surveyed in wheat, canola and lentil fields in northern Idaho in 1996 and 1997. *Hippodamia convergens* and *Coccinella septempunctata* were found to be dominant in all crops. Coccinellid abundance correlated with aphid abundance except early in the season, when aphids were scarce. At this time blooming canola supported the most coccinellids.

Coccinellid and aphid parasitoid abundance on Russian wheat aphid susceptible and resistant wheats were examined in northern Idaho. Resistant wheats with the Dn4 gene did not negatively impact the abundance of coccinellids or the rate of parasitism by *Diaeretiella rapae* or *Aphidius* spp.

On Guam, Saipan, and Tinian the aphidiid parasitoid complexes associated with introduced aphids were characterized. No aphidiids were present on Saipan. *Lipolexis oregmae* was observed attacking *Toxoptera citricida, Aphid craccivora, Aphis gossuypii and Pentalonia nigronervosa* on Guam, while *Lysiphlebus testaceipes* was widespread on *A. gossypii, A. craccivora*, *T. oregmae*, *P.nigronervosa* and four other aphid species. *L. testaceipes* was found attacking *A. gossypii* on Rota. Undentified Aphelinus sp. were observed on Guam, Saipan, Tinian, and Rota.

Sessile Homoptera (mealybugs)

Natural levels of parasitism of the vine mealybug (VMB), *Planococcus ficus,* have been studied in the San Joaquin Valley of California vineyards. Indigenous parasites attacking the pink hibiscus mealybug

(PHM), *Maconellicoccus hirsutus*, and several other common mealybug species are being surveyed in Imperial Valley, CA. The PHM has not been found to be parasitized by any resident primary parasoid species, however, it is hyperparasitized by the resident species, *Marietta* sp. (family Aphelinidae)

Whiteflies
Several undescribed species of *Encarsia, Eretmocerus* and *Neopomphale* have been reared from *Bemisia tabaci* and native whitefly species that occur on desert host plants in southern CA and AZ. Native predators include a species of *Semidalis* (Neuroptera: Coniopterygidae). Survey work on desert host plants is continuing (AZ-USDA-APHIS). Extensive surveys in cucurbit growing areas of Guam since 1997 have failed to detect any aphelinid parasitoids attacking whiteflies. *Encarsia* spp. were regularly observed prior to 1997 and it is thought that severe weather events, drought and other factors are involved (Guam-AES).

True Bugs
Beetles—nothing to report
Lepidoptera
Psyllids
Red gum lerp psyllid (*Glycaspis brimlecombei* Moore) We observed predation by birds on sticky traps used for monitoring in California. Birds have been seen frequently feeding on foliage infested with the psyllids as well. Syrphid, brown lacewing, anthocorid, and coccinellid adults were found on traps, but were not common. However, on foliage these predators are frequently seen.

Pear psylla natural enemies were monitored throughout 1998-2000 in over 50 orchards in the Yakima River drainage. *Campylomma verbasci, Deraeocoris brevis*, green and brown lacewings, and spiders were the dominant natural enemies observed. Campylomma appears to be the dominant predator in pear orchards using IPM.

2) Weed pests
Knapweeds –nothing to report
Thistles
A two-year pre-introduction survey of the entomofauna associated with Scotch thistle (*Onopordum acanthium*) by WA-AES in southeastern Washington and northwestern Idaho revealed no damaging arthropod associates.

Spurges
Surveys for aerial and soilborne pathogens of leafy spurge were conducted and *Fusarium* and *Rhizoctonia* spp. were isolated. Host range tests

conducted in MT (AES) on the soilborne pathogens collected in the U.S. revealed that non-target plant effects were negligible.

Purple Loosestrife

Gorse (no work to report, drop as target)

c. Degree to which objective has been accomplished

d. Incomplete work or areas needing further investigation

Objective 2. Undertake foreign exploration

a. Work accomplished (1996-2000)

1) Insect pests

Sessile Homoptera (mealybugs)

Vine mealybug parasites (family Encyrtidae) have been imported, including two biotypes of *Anagyrus pseudococci* and *Leptomastidea abnormis*. Foreign exploration for pink hibiscus mealybug parasites has been undertaken in Egypt and Australia. One species (*Allotropa* sp.) is currently in quarantine, a biotype of *Anagyrus kamali* from Egypt is anticipated. Two encyrtid parasitoids (*Pseudaphycus flavidulus* and *Leptomastix epona)* were imported and released for obscure mealybug control.

Whiteflies

Collectively, 25 countries worldwide have been explored for natural enemies of *Bemisia tabaci* since 1991. Efforts have resulted in the importation of dozens of species/strains of aphelinid wasps in the genera *Eretmocerus* and *Encarsia* (USDA-ARS, Montpellier). Searches for natural enemies of *Paraleyrodes* whiteflies in El Salvado, Hondurus, and Costa Rica resulted in the importation of new parasitoids on a number of new whitefly host species (CA-R-AES).

True Bugs

Beetles –nothing to report

Lepidoptera

Psyllids

Red gum lerp psyllid: Exploration in southern Australia in August 1999 in resulted in eight parasitoids (encrytid wasps) being imported for this pest for study in quarantine.

Pear psylla (mixture of Psylla vasylevi and Cacopsylla spp.) mummified by parasitoids were collected in the Kyrgyz portion of the Fergana valley in the late summer of 1996 and imported to quarantine in Washington in spring of 1997.

2) Weed pests

Knapweeds

Turkey, Uzbekistan, and Kazakhstan were thoroughly explored and many promising natural enemies were found on Russian knapweed. A field test in Uzbekistan, with collaboration of MSU, Cabi Switzerland, and Uzbek Academy of Sciences in Uzbekistan, was conducted to evaluate four insect species (two seed feeders, one stem-gall maker, and one root feeder) for biological control of Russian knapweed. The results look good but are not completed yet.

Thistles—nothing to report
Spurges—nothing to report
Purple Loosestrife
Gorse (no work to report, drop as target)

c. Degree to which objective has been accomplished
d. Incomplete work or areas needing further investigation

Knapweeds
Evaluation of the natural enemies found on Russian knapweed needs several more years.

Objective 3. Determine systematics and biogeography of pests and natural enemies

a. Work accomplished (1996-2000)
   1) Insect pests

Sessile Homoptera (mealybugs)
Using molecular techniques to characterize a newly collected pink hibiscus mealybug parasitoid, *Allotropa* specimens from Egypt as well as others collected in Puerto Rico, Malaysia and Australia were determined to be the same species (i.e., *A. mecrida*).

Whiteflies
Specimens of *Encarsia meritoria,* a parasitoid of a *Bemisia tabaci*, were contributed to morphological and molecular taxonomic studies of the *Enc. hispida* group; taxonomic revision resulted in the renaming of the commercially cultured whitefly predator *D. pusillus* to *D. catalinae* (AZ-USDA-APHIS) The phylogenetic relationships of *Encarsia* (Hymenoptera: Aphelinidae) were studied using molecular information from the 28S-D2 region and morphological characteristics. A total of 67 strains and 24 species encompassing 10 species groups were surveyed and a robust hypothesis produced. The gene regions also proved to be useful in sorting morphologically indistinct species, *E. formosa* and *E. luteola*. The molecular studies coincided with completion of a project on the discrimination of species in the *Encarsia strenua* group, and publication of an online catalog of species (CA-R-AES).

True Bugs
Beetles—nothing to report

Lepidoptera

Psyllids

Red gum lerp psyllid: Populaton monitoring was begun in 1999, and is now being done in 13 counties in California. The psyllid is confirmed in 42 counties in California. We have found very high populations in many areas when weather is moderate, but low populations in winter and with very hot temperatures. Sex ratio (% female) is in the 30-50% range with moderate weather, and very low in cold or very hot weather.

Psyllids on lemon-scented and spotted gum: Spotted gum psyllid (*Eucalyptolyma maidenii*), and *Cryptoneossa triangula,* a free living brown-colored psyllid, are being monitored (from Nov. 2000) in Anaheim, California.

Eugenia psyllid: Monitoring continues in cooler, coastal areas of California, including San Francisco (1996-1998), and the UC Berkeley campus (1999-2001).

2) Weed pests

Knapweeds

Many promising natural enemies collected on the Russian knapweed have been identified. Samples of Russian knapweed were collected in Eurasia and sent to Mission, TX, for DNA analysis to match these samples with samples collected in the U.S. The results showed that the genetic characterization of the Uzbek population of the weed was most similar to the samples collected in the U.S.

Thistles

On September 22, 1998, CDFA recovered the musk thistle rust, *Puccinia carduorum*, on musk thistle, *C. nutans*, located near Mt. Shasta in northern California. On August 12, 1999, this rust was recovered from musk thistle plants near Mogul, Nevada. Teliospores of the rust were found to contain the same ITS2 sequence as that from the Turkish isolate originally released in Montgomery County, Virginia, from 1987-90, as a potential biological control agent for musk thistle. Identification of these rusts were preformed by USDA-ARS, Frederick, MD. These are the first recoveries of this rust disease west of the Rocky Mountains and suggests that it has spread unaided the continent.

An investigation of the genetic variation in the widespread alien plant Russian thistle, *Salsola tragus*, in California using isoenzymes and random amplified polymorphic DNA (RAPD) assays was performed by USDA-ARS-HCRL and CDFA. Results indicated the existence of three genetic entities, named Type A, Type B, and Type C. Examination of chromosome number shows that Type A has 36 chromosomes, Type B has 18 chromosomes and Type C has 54 chromosomes. In addition, examination of a related species, *Salsola paulsenii*, in California also has revealed two genetic entities with each having different chromosome numbers. Estimates of genetic similarity of the foreign (Turkey and France) and domestic plant samples showed that plants obtained from France were similar to domestic biotype A while plants obtained from Turkey were not similar to any domestic biotypes. Thus, while Type B plants are exotic to North America, its current only known location worldwide is California. Efforts are underway to locate its native homeland, probably in central Asia. A common garden of these five genetic entities was planted in 2000 and observations of plant morphology and development were made during growth. It is hoped that reliable morphological characters can be discovered to aid in identification of these genetic entities in the field.

Spurges
AFLP (Amplified Fragment Length Polymorphism) and multivariate analysis techniques were used by MT-AES to enable the leafy spurge phytophages *Aphthona cyparissiae, A. czwalinae, A. flava, A. lacertosa*, and *A.* nigriscutis to be genetically distinguished from one another. Such approaches were also used to assess genetic variability within and among beetle populations (MT-AES) and within and among populations of leafy spurge (ND-ARS, MT-AES, WY-AES).

Purple Loosestrife
Gorse (no work to report, drop as target)

c. Degree to which objective has been accomplished
d. Incomplete work or areas needing further investigation

Objective 4. Quarantine of exotic natural enemies and pre-release studies

a. Work accomplished (1996-2000)
   1) Insect pests

Sessile Homoptera (mealybugs)
Allotropa mecrida from Egypt is currently in quarantine. Host range studies are pending.

Whiteflies Nothing to report

True Bugs
Beetles-- Nothing to report

Lepidoptera
Psyllids
Red gum lerp psyllid: Of eight parasitoids imported for this pest for study in quarantine, several were found to be hyperparasitoids, and one, *Psyllaephagus bliteus,* was determined to be specific to red gum lerp psyllid in a series of host specificity tests. It appears to be a good

biological control candidate.

Pear psylla: Twelve species were reared from mummies imported from Kyrgyzstan including *Trechnites* sp., *Psyllaephagus sp.* and hyperparasitoids. None of the identifiable primary parasitoids were successfully reared on *Cacopsylla pyricola* in quarantine.

2) Weed pests

Knapweeds

Field tests of Russian knapweed agents were conducted in Uzbekistan; and host specificity tests on two Tephritid flies, *Urophora xantipes* and *U. Kazakhstanoca,* were almost completed at MSU quarantine. A petition for their release will be submitted to TAG soon.

Thistles

Pre-release studies examining the phenology and fecundity of Scotch thistle, *Onopordum acanthium,* in eastern Oregon (ODA) and northeastern California (CDFA) were performed.

Australian scientists have performed foreign exploration of natural enemies of Scotch thistle in Eurasia and have identified almost ten species as potential biological control agents. Host specificity testing of these potential agents for release in the western United States was begun by USDA-ARS Albany. Three insect taxa (*Lixus cardui* Greek biotype, *Lixus cardui* French biotype, and *Trichosirocalus* n. sp.) have been tested to date. All caused damage to NA native *Cirsium* species and will not be pursued further. The remaining potential biological control agents will be host tested in the future.

Spurges

Screening tests were conducted for the scolytid *Thamnurgus ephorbiae* (ARS-MT). Host specificity studies were completed for the shoot tip gall midge, Spurgia capitigena, collected from leafy spurge associated with mesic areas in France.

Purple Loosestrife

Gorse (no work to report, drop as target)

c. Degree to which objective has been accomplished

1) Insects
2) Weeds

Knapweeds

Host specificity tests on two Russian knapweed agents are almost complete.

c. Incomplete work or areas needing further investigation

1) Insects
2) Weeds

Knapweeds

Several promising natural enemies found on Russian knapweed need further investigation.

Objective 5. Release and disseminate natural enemies

a. Work accomplished (1996-2000)

1) Insect pests

Aphids

Work accomplished – Approximately 6,400 *Aphelinus* near *paramali* (ANP) and 9,200 *Aphelinus gossypii* (AG; Hymenoptera: Aphelinidae) were released in four nursery sites in the northern San Joaquin Valley, and approximately 29,775 ANP and 54,030 AG were released at nine sites in the southern San Joaquin Valley. The parasites have been recovered at all sites.

Aphidius colemani (Aphidiidae) obtained from western Australia was released (and established) on three Hawaiian islands on populations of the melon aphid, *Aphis gossypii.*

Approximately 13,000 Aphidius colemani (Chilean strain) and 3,000 *Diaeretiella rapae* (from Washington State) were released on Guam and Saipan. About 600 *A. colemani* were also released on Rota. Both aphidiids were initially recovered on Guam, as was *A. colemani* on Saipan. Establishment has not been determined on any of the islands.

Sessile Homoptera (mealybugs)

Two vine mealybug parasitoids have been released in Coachella and San Joaquin Valleys (*Angyrus pseudococci* and *Leptomastidea abnormis*). Two parasitoid species have been introduced for the pink hibiscus mealybug in Imperial Valley, CA.. Over 167,000 *Anagyrus kamali* and 230,000 *Gyranusoidea indica* were release at 400 sites in Imperial Valley in 2000. For the obscure mealybug, approximately 150,000 P. flavidulus and 50,000 L. epona have been release. Recoveries of both have been made.

Whiteflies

Eight distinct species/strains of *Eretmocerus* and 7 species of *Encarsia* from 13 countries have been released in AZ and CA desert valleys. Large scale releases were made between 1997-2000 of *Eretmocerus emiratus*, *E.* nr. *emiratus*, *E. mundus*, *E. hayati*, and *Encarsia sophia* into citrus in the San Joaquin Valley, CA and in melons, cotton and ornamentals the desert valleys of CA and AZ. *Encarsia sophia* (=*transvena),* was released against the whitefly in the San Joaquin Valley and near Mexicali, Mexico. Several species have exhibited within-season reproduction and at least three species have been successfully established. *E. mundus* has been most frequently recovered in CA. Establishment of *Eretmocerus emiratus* was documented in the southern San Joaquin Valley, CA using sentinel plants (CA-DFA, USDA-APHIS-AZ). *Delphastus catalinae* has been successfully established as a biological control agent against the giant whitefly in San Diego. Populations of the giant whitefly parasitoid *Entenonecremnus krauteri* also have increased (CA-DFA).

True Bugs

Beetles

Between 1996 and 1998 19,200 *Oomyzus gallerucae* (Fonscolmbe) [= *Tetrastichus gallerucae*] (Hymenoptera: Eulophidae) Grenada strain were released in Sacramento, CA to control the elm leaf beetle *Xanthogaleruca luteola* (Müller) (Coleoptera: Chrysomelidae). Although the parasites became established within the growing season in which they were released, they failed to overwinter in numbers sufficient to provide control (UC-Berkeley AES).

Lepidoptera

Psyllids

Red gum lerp psyllid: *Psyllaephagus bliteus* is being reared at the UCB insectary and CDFA insectary in California. Releases began in early summer 1999 and have been made at 19 sites throughout the state.

2) Weed pests

Knapweeds

OREGON: The following species were recovered: *Pterolonche inspersa* (1997, the only site in the US), *Larinus obtusus* (1998), *Chaetorellia acrolophi* (1999), and *Pelochrista medullana* (2000). Redistribution began with the following agents: *Cyphocleonus achates* (1997), *Terellia virens* (1997), *Subanguina picridis* (1999), and *Larinus obtusus* (2000). Declines in diffuse knapweed density, up to 90% reductions, were observed at several *Larinus minutus* and *Bangasternus fausti* release sites. Declines in yellow starthistle density, from 60-90% reductions, were observed at several *Eustenopus villosus* release sites.

MONTANA: The following five insects were released against spotted knapweed: *Agapeta zoegana*, *Cyphocleonus achates*, *Pelochrista medullana*, *Larinus minutus*, and *Bangasternus fausti*. Due to mass-rearing efforts, *A. zoegana* and *C. achates* were released at many sites. Follow-up studies on *Terellia virens*, *Chaetorellia acrolophi*, and *Larinus obtusus* were conducted.

WASHINGTON: The diffuse (*Centaurea diffusa*) and spotted (*C. maculosa*) knapweed phytophages *Urophora affinis*, *U. quadrifasciata*, *Larinus minutus*, *Metzneria paucipunctella*, *Cyphocleonus achates*, *Agapeta zoegana*, and *Chaetorellia acrolophi* were redistributed into many counties. A reintroduction of the diffuse knapweed seed head weevil *Bangasternus fausti* was made in northeastern WA in 2000. Yellow starthistle (*Centaurea solstitialis*) capitulum-infesting weevil adults *Bangasternus orientalis* (32,500) and *Eustenopus villous* (139,300) were extensively redistributed. Additional releases of *Chaetorellia australis* and *Larinus curtus* were also made.

UTAH: Releases of *Bangasternus fausti* (Coleoptera: Curculionidae), *Larinus minutus* (Coleoptera: Curculionidae), *Sphenoptera jugoslavica* (Coleoptera: Buprestidae), and *Urophora affinis* and *U. quadrifasciata* (Diptera: Tephritidae) were made on squarrose knapweed.

Thistles

Multiple annual releases of *Urophora cardui* and *Rhinocyllus conicus* were made against Canada thistle, *Cirsium arvense*, in Washington (WA-AES). Redistribution of *R. conicus* and *Trichosirocaulus horridus* on musk thistle, *Carduus nutans*, was also effected. In Oregon (ODA), the stem fly, *Cheilosia corydon,* was released on slender-flower thistle, *Carduus tenuiflorus*, Italian thistle, *C. pycnocephalus*, and musk thistle and has been recovered from slender-flower thistle and Italian thistle and not from musk thistle. This is the first record of establishment of this species in North America. Larvae of *C. corydon* will be collected for rearing in order to provide releases against musk thistle in other states. The rosette weevil, *T. horridus* was released and recovered from musk thistle in Oregon since 1998 and redistribution efforts are currently underway. The gall fly, *Urophora solstitialis*, was released on musk thistle in 1999, but has not been recovered in follow-up surveys. In California (CDFA) over 8,000 gall flies, *Urophora stylata* were released on bull thistle, *Cirsium vulgare*, at 46 sites. Follow-up surveys show recoveries at 25 of the 46 sites.

Spurges

The following insect species were introduced or redistributed against leafy spurge:

Aphthona abdominalis in CO, MT, ND, and OR; *A. cyparissiae* in CO, IA, ID, MI, MN, MT, ND, NE, NH, NM, NV, NY, RI, SD, UT, WA, WI, and WY; *A. czwalinae* in CO, IA, ID, MI, MN, MT, NE, ND, NH, NM, NV, NY, OR, RI, SD, UT, WA, WI, WY; *A. flava* in CO, IA, ID, MI, MN, MT, ND, NE, NH, NM, NV, NY, RI, SD, UT, WA, WI, and WY; *A. lacertosa* in CO, IA, ID, MI, MN, MT, ND, NE, NH, NM, NV, NY, OR, RI, SD, UT, WA, WI, and WY; *A. nigriscutis* in CO, IA, ID, MI, MN, MT, ND, NE, NH, NM, NV, NY, RI, SD, UT, WA, WI, and WY; *Chamaesphecia crassicornis* in OR; *Chamaesphecia hungarica* in MT; *Hyles euphorbiae* in MT; *Oberea erythrocephala* in CO, IA, ID, MI, MN, MT, ND, NE, OR, SD, WA, WI, WY; *Spurgia esulae* in CO, ID, IA, MI, MN, MT, ND, NE, NH, NM, NV, NY, OR, RI, SD, UT, WA, WI, and WY.

Purple Loosestrife

Gorse (no work to report, drop as target)

c. Degree to which objective has been accomplished

1) Insects
2) Weeds

Knapweeds

Thirteen insects have been introduced against spotted knapweed in Montana. Distribution of spotted and diffuse knapweed agents is 75% complete in Washington.

c. Incomplete work or areas needing further investigation

1) Insects
2) Weeds

Knapweeds

Redistribution of agents will continue against yellow starthistle, diffuse and spotted knapweed in WA, with emphasis being placed on establishing weevils.

Objective 6. Evaluate efficacy and study ecological/physiological basis for interaction

a. Work accomplished (1996-2000)

1) Insect pests

Aphids

Studies in California on the individual and combined effects of generalist predators on the biological control of the cotton aphid, *A. gossypii*, in cotton showed that biological control of the common green lacewing is disrupted by intense predation pressure by other generalist predators, including *Orias, Geocoris, Nabis, and Zelus*.

Sessile Homoptera (mealybugs)

Field cage evaluations are being conducted on the comparative impact of pink hibiscus mealybug parasitoids. *Anagyrus kamali* and *Gyranusoidea indica* have had similar levels of parasitism within cages, however this is in contrast with field monitoring which has demonstrated that *A. kamali* is much more effective. Two parasitoids of the vine mealybug were also tested against the pink hibiscus mealybug. PHM attack by these parasitoids (*Anagyrus pseudococci* and *Leptomastidea abnormis*) occurred to a very limited extent.

Whiteflies

Laboratory and field experiments examined the interactions between two parasitoids of the *B. tabaci*: *Er. eremicus*, a native primary parasitoid, and *En. transvena*, an exotic autoparasitoid. Results suggest *E. transvena* is a superior intrinsic competitor to *E. eremicus*. Further studies of interference competition among a group of related *Encarsia* spp. suggest that egg size is not necessarily a good predictor of competitive success. Results from field cages studies suggest that even when an autoparasitoids species negatively influences the reproduction of a primary parasitoid through interference competition, disruption of biological control of *B. tabaci* may not result. This supports the 'multiple introductions' perspective. A newly discovered, vertically transmitted bacterium unrelated to *Wolbachia* was found in 4 of 5 thelytokous populations of whitefly and armored scale parasitoids in the genus *Encarsia* and in 1 of 5 arrhenotokous populations. (AZ-AES).

Field-cage evaluations on cantaloupes identified four exotic *Eretmocerus* spp. with high reproductive potential; navel orange was evaluated as a developmental host for exotic *Eretmocerus* in Imperial Valley, CA, and cage evaluations on navel oranges in San Joaquin Valley were initiated to assess overwintering survival (CA-DFA, AZ-USDA-APHIS); life-table studies were initiated to estimate mortality factors affecting populations of *Bemisia* on *Hibiscus* in Phoenix; preliminary studies suggest that two exotic *Eretmocerus* are unable to complete development in *Trialeurodes vaporariorum* or *T. abutiloneus* (AZ-USDA-APHIS).

Studies examined interactions between generalist predators and parasitoids of *B. tabaci*. Adult female *Geocoris punctipes, Orius insidiosus* and *Hippodamia convergens* displayed a significant preference for parasitized hosts. In *G. punctipes* and *O. insidiosus*, this discrimination appears to be based on visual cues (AZ-USDA-ARS).

True Bugs

Beetles

The importance of aphid honeydew and alternative carbohydrate sources in influencing foraging behavior, longevity and fecundity of the foremost natural enemy of the alfalfa weevil in Utah, the parasitoid *Bathyplectes curculionis*, was investigated (UT-AES).

Although they attacked and consumed larvae of the alfalfa weevil, larval ladybird beetles were found to be much less successful in capturing and developing on a diet of weevil larvae than of their "preferred prey" in Utah alfalfa, pea aphids (UT-AES). Adults of these ladybird beetles produced eggs when provided mixed diets of alfalfa weevil larvae and sugar, but such egg production was much reduced in comparison to that when the predators fed on pea aphids (UT-AES).

Lepidoptera

Psyllids

Predation of pear psylla by an anthocorid and 2 mirids was studied to develop a molecular technique to estimate realized predation in the field. Two monoclonal antibodies to psylla were developed and more recently a PCR-based method was employed to estimate predation rates.

2) Weed pests

Knapweeds

In Montana, studies were conducted on the following: identification of optimum site characteristics for *A. zoegana*, assessment of methods of field-collecting *A. zoegana*, assessment of *A. zoegana* and *C. achates* impact on knapweed, integration of herbicides and root insects for knapweed control, assessment of integration of root insects and the fungus, *Sclerotinia sclerotiorum*, and development of degree-day model for *A. zoegana*.

Impact studies of *Chaetorellia australis*, *C. succinea*, and *Larinus curtus* on *Centaurea solstitialis,* and of *L. minutus* were undertaken on diffuse and spotted knapweed populations in WA.

Populations of seedhead flies (*Urophora* spp.) expanded rapidly upon initial release, to infest 17-30% of squarrose knapweed seedheads throughout central Utah. In seedhead samples from multiple sites during the first five years following introduction, fly galls were strongly aggregated among flowerheads in most instances, and the degree of gall aggregation at individual sites was positively correlated with mean flowerhead quality (i.e., number of seeds per flowerhead) and negatively correlated with mean fly density per flowerhead.

Thistles

Studies by UT-AES showed that the stem-mining weevil, *Ceutorhynchus litura*, increased in density from initially small numbers at the time of release, to infest 60-95% of Canada thistle stems at riparian sites in Utah, while thistle stems declined in number to approximately half their former densities.

Exclusion-type field experiments were performed by KA-AES to evaluate the individual and combined impact of the flower weevil, *R. conicus* and the rosette weevil, *T. horridus* on musk thistle, *C. nutans*. *T. horridus* caused a predictable increase in the initial number of flower heads, but were smaller compared to uninfested host plants. Flowering phenology was not influenced by *T. horridus* nor did *R. conicus* attack differentially plants damaged by *T. horridus*. While rosette damage by *T. horridus* did not reduce the amount of viable seed, it did not negatively impact attack by *R. conicus* which reduced viable seed in terminal flowers by 81% and lateral flowers during the first four weeks by 61% compared to uninfested plants.

Field studies were initiated by CDFA to evaluate the impact of the rust, *Puccinia carduorum*, on musk thistle near Mount Shasta, California. In spring just prior to bolting, the diameters of selected rosettes were measured and plants rated for rust infection. Plants were re-examined in September to compare the change over the season for both diseased and clean (un-infected) plants. The rusted plants proved less likely to bolt this season than clean plants of similar diameter (68% vs. 81%) suggesting that, despite having a relatively small degree of visible damage, the rust disease may have important effects on the seasonal development of the plant. This study is continuing.

Spurges

Habitat association models were developed for *Aphthona cyparissiae, A. czwalinae, A. flava, A. lacertosa,* and *A. nigriscutis* from soil, plant, and flea beetle information collected from Montana, North Dakota, and Wyoming (MT-AES). Flea beetle habitat association models, developed previously from European data, were compared statistically with similar models developed from U.S. data and were found to be statistically similar. This means that had pre-release habitat association studies been conducted in the native range of the flea beetles they could have correctly predicted the habitats and site requisites in which they have been most successful in establishing in and having an impact on leafy spurge. The impact of the flea beetles on plant species richness and diversity was evaluated using geostatistical analysis at leafy spurge sites in Montana and Wyoming (MT-AES). Over the period 1996-2000, population increases of *Aphthona lacertosa*, *A. nigriscutis*, and especially *A. flava* were documented in UT (UT-AES). Beetles increased explosively in number to almost completely eliminate a leafy spurge population that previously had formed a dense stand of several hectares in the foothills of northern Utah (UT-AES).

Purple Loosestrife

Gorse (no work to report, drop as target)

c. Degree to which objective has been accomplished

1) Insects
2) Weeds

Knapweeds

Studies on methods of *A. zoegana* field collection, and root insect-*S. sclerotiorum* integration were completed. Studies on most of the other spotted knapweed projects are approximately 50% complete in MT and 85% in WA.

c. Incomplete work or areas needing further investigation
    1) Insects
    2) weeds

Knapweeds

Additional work is needed to complete most of the above-mentioned projects in MT.
One additional year of data collection is required for the *L. minutus* impact investigation in WA.

Goal B. Conservation of natural enemies to increase biological control of target pests

Objective 7. Confirm identity of organisms involved in pest problem

a. Work accomplished (1996-2000)

1) Insect pests

Aphids

Work accomplished - *Endaphis maculans* (Diptera; Cecidomyidae) was confirmed as a parasitoid of *Aphis gossypii* and *Pentalonia nigronervosa* in Hawaii.

Sessile Homoptera (mealybugs)

Vine mealy studies have shown the importance of ant control to improve parasitism. Chlorpyrifos applications and bait traps, with such materials as imidacloprid in a 25% sugar solution, are being investigated.

Whiteflies

Studies were conducted to identify native natural enemies *B. tabaci* in urban areas in AZ and CA (AZ-USDA-APHIS). Laboratory studies evaluated feeding behavior of five insect predators when exposed to various life stages of *B. tabaci*. The egg and immature stages of whitefly were not preyed on as frequently as the adult stage. Ethograms reveals that predators attack many prey over a short period of time followed by extended periods of starvation. Further studies showed that predators rarely feed at night with the highest rates of predation occurring during early morning hours. Life tables were constructed for *B. tabaci* over 14 generations in untreated Arizona cotton. Survival from egg to adulthood ranged from 0-27% and was < 10% in the majority of generations. Predation by sucking predators and dislodgment were major sources of egg and nymphal mortality; parasitism by aphelinid wasps was consistently low all years. Studies continued to identify predators of *B. tabaci* in the field using immunological methods. Laboratory studies evaluated the feeding behavior of adults and 3rd, 4th, and 5th nymphal instars of the two *Lygus* spp. when exposed to the various life stages of whitefly on cotton. Both species fed on whiteflies as well as on cotton plants. All stages of both species fed more on whitefly nymphs than on whitefly eggs (AZ-USDA-ARS)

True Bugs

Beetles—nothing to report

Lepidoptera

Psyllids

2) **Weed pests**

Knapweeds

Thistles

Spurges

Purple Loosestrife

Gorse (no work to report, drop as target)

c. Degree to which objective has been accomplished

d. Incomplete work or areas needing further investigation

Objective 8. Identify and assess factors potentially involved in disruption of biological control

a. Work accomplished (1996-2000)

1) Insect pests

Sessile Homoptera (mealybugs)

Vine mealy studies have shown the importance of ant control to improve parasitism. Chlorpyrifos applications and bait traps, with such materials as imidacloprid in a 25% sugar solution, are being investigated.

Whiteflies

Preference and suitability of the immatures of an autoparasitoid, *Encarsia transvena* and a primary parasitoid, *Eretmocerus eremicus* for development of the hyperparasitic male *E. transvena* were investigated; the window of vulnerability of *E. eremicus* is broader than that of *E. transvena*, and may lead to a greater rate of attack on these wasp hosts (AZ-AES).

Studies indicate that native and non-indigenous parasitoids in the genera *Eretmocerus* and *Encarsia* can develop in whiteflies on alfalfa and enough whitefly-infested alfalfa escapes cutting to provide a refuge; comparative whitefly control trials were conducted at 5 sites in AZ where there was one group of fields (alfalfa, melons, cotton) treated under an IPM regime and one group of fields treated under a conventional regime; a whitefly trap was highly selective for whitefly while preserving parasitoid populations (AZ-USDA-APHIS).

Comparative analyses of the effects of new insect growth regulators (IGRs) vs. conventional insecticides on the abundance and activity of native natural enemies of *B. tabaci* in cotton were conducted from 1997-1999. Results demonstrate that use of IGRs conserve natural enemies, particularly predators. Partial life table studies were conducted to identify sources and measure rates of mortality in cotton fields subjected to different management strategies. Predation and dislodgment were major sources of egg and nymphal mortality. IGRs function by initially contributing essential irreplaceable mortality of *B. tabaci* and conserving natural enemies, allowing season long control with a single application. Laboratory toxicology studies showed that *Geocoris punctipes*, *Orius insidiosus* and *Collops vittatus* were unaffected by the IGR buprofezin. The IGR pyriproxyfen caused some mortality to immatures and caused some inviability in *Collops* adults. Studies examined the effects of a new imidicloprid-like insecticide (NI-25) on generalist predators and whitefly parasitoids in cotton (AZ-USDA-ARS).

Development and reproduction of *Eretmocerus eremicus*, a native parasitoid of *Bemisia tabaci* was studied on cotton and sweet potato. Net reproductive rates on sweet potato were much lower and reflect, among other things, differences in female foraging and oviposition behavior relative to plant morphological features (CA-R-AES)

True Bugs

Beetles— nothing to report

Lepidoptera

Psyllids

Eugenia psyllid: we found that a cool, coastal climate reduces the effectiveness of the previously released parasitoid, *Tamarixia* sp., for biological control. This parasitoid is effective in warmer areas. Parasitoid populations lag psyllid populations significantly in early spring, allowing significant plant visual damage to occur.

Pear psyllids monitored in 50 orchards showed population trends largely explained by pre-bloom pesticide use. Control of spring psylla with strident chemicals in spring, before natural enemies entered orchards, was associated with low population levels through the summer. Use of organophosphates in summer was associated with higher psylla populations. Predators were positively associated with psylla. High tree vigor especially that associated with well fertilized Anjou and Bartlett pears supported higher psylla densities. Red Bartlett and Red Anjou, both less vigorous cultivars, showed lower psylla densities.

2) Weed pests

Knapweeds— nothing to report

Thistles-- nothing to report

Spurges--nothing to report

Purple Loosestrife

Gorse (no work to report, drop as target)

c. Degree to which objective has been accomplished

d. Incomplete work or areas needing further investigation

<u>Objective</u> <u>9.</u> Implement and evaluate habitat modification, horticultural practices and pest suppression tactics to conserve natural enemy activity

a. Work accomplished (1996-2000)

1) Insect pests

Aphids

The large-scale distribution of aphidophagous lady beetles in alfalfa fields was rapidly modified by localized applications of "artificial honeydew", suggesting that lady beetle dispersal can be effectively managed in pest management systems (UT-AES). As revealed by large-scale mark-release-recapture experiments, long-distance dispersal of beetles occurred readily when local densities of essential prey (aphids) were low and could be modeled using normal distributions of beetles over space with variance increasing linearly in time (UT-AES).

Sessile Homoptera (mealybugs)

Grass species (including sugarcane) and broadleaf weeds adjacent to pineapple plantings in Hawaii have been studied to determine there role in supporting source populations of pink pineapple mealybug and gray pineapple mealybug populations. Of 42 weedy sites surveyed adjacent to pineapple plantings, mealybugs were found in 22 sites, of which mealybugs were found in both the weeds and pineapple crop at 12 sites. Of plantings with no adjacent source population, no mealybug populations occurred in the plantings. Work continues on the project to develop a weed management program to reduce mealybug movements into pineapple.

Whiteflies

Field trials were conducted at an organic farm in Imperial Valley, CA to test a number of perennials and annual plant combinations as year round sources for natural enemies of *B. tabaci*. These plantings have already proved useful in the initial colonization of new natural enemies. We also hope these can help in the year round maintenance and enhancement of natural enemies near whitefly susceptible crops (CA-DFA).

True Bugs

Beetles

The potential for increasing alfalfa weevil parasitoid densities and levels of parasitism by application of "artificial honeydew" in alfalfa fields to provide supplemental nutrition for adults of the weevil parasitoid, *Bathyplectes curculionis*, was investigated. Such application was shown to be effective when aphids and naturally occurring aphid honeydew were not abundant (UT-AES).

Lepidoptera

Psyllids

Eugenia psyllid: we are studying effects of pruning on the effectiveness of the previously released parasitoid, *Tamarixia* sp., for biological control in cool, coastal climates.

Best IPM practices based on 3-year study have been presented to the industry and continue to be refined. A consortium of scientists in Washington, Oregon and California have begun a 3-4 year program to assess the effect of pesticides on key beneficial insects of apple and pear. The results of this work will be integrated into best practices (supported by IFAS grant).

2) Weed pests

Knapweeds— nothing to report

Thistles— nothing to report

Spurges— nothing to report

Purple Loosestrife

Gorse (no work to report, drop as target)

c. Degree to which objective has been accomplished

d. Incomplete work or areas needing further investigation

Goal C. Augmentation of natural enemies to increase biological control of target pests

Objective 10. Identify and study biological characteristics of candidate natural enemies (species and biotypes)

a. Work accomplished (1996-2000)

1) Insect pests

Sessile Homoptera—nothing to report

Whiteflies

Infection with parthenogenesis-inducing *Wolbachia* appears to have influenced the evolution of host selection behavior and development patterns in autoparasitoid *Encarsia* species. Studies on ovicide by Encarsia formosa indicates that females commonly locate eggs laid by other females within the whitefly host, and stab them with their ovipositor before laying their own egg. Results indicated that there was no time cost to this behavior, and in up to 75% of encounters that led to oviposition in parasitized hosts, females killed the conspecific egg before laying their own. Further, females engaged in ovicidal bouts did not just kill eggs incidentally in the normal process of probing the host, but probed consistently in the direction of the egg. Ovicide has been overlooked in a species that has served as a model system for the study of oviposition behavior and underscores the possibility that ovicide in parasitoids is a more general phenomenon than has been thought. Studies of *B. tabaci* parasitoid dispersal in vertical wind tunnels and in the field are in progress (AZ-AES).

Dispersal studies with the *B. tabaci* parasitoid, *Eretmocerus eremicus,* in cotton suggest that this parasitoid moves only small distances within a 6 day period; preliminary results indicate that reproductive capacity was greater for three exotic *Eretmocerus* than by the native *E. eremicus* on poinsettia (AZ-USDA-APHIS).

Eretmocerus were marked with protein and then released into either a cotton field or a cantaloupe field. Parasitoids were recaptured from 0530 to 1100 every day for 5 days after release using passive suction vacuum traps located in the cotton and cantaloupe fields. These data are currently being analyzed to determine the efficacy of the marker and to determine the dispersal patterns of *Eretmocerus* (AZ-USDA-ARS).

Studies were conducted on the reproductive biology and search behavior of *Amitus bennetti*, an exotic parasitoid of *Bemisia tabaci*. The parasitoid exhibited the highest intrinsic rate of increased ever measured for parasitoids of *B. tabaci* and it may be a suitable candidate for use in inundative control programs. Further partial life table studies on cotton and bean in field cages revealed that *A. bennetti* was responsible for marginal rates of parasitism of *B. tabaci* nymphs between 20-54% (CA-R-AES)

The effects of temperature were examined for 37 isolates of *Paecilomyces fumosoroseus* from various parts of the world infecting *Bemisia tabaci*. Intraspecific variability in optimal temperatures was partially related to the origin of the fungal biotypes. Thirty isolates of *P. fumosoroseus* were tested for efficacy against nymphs of *Bemisia tabaci*. In additional studies, 22 isolates of *P. fumosoroseus*, 14 isolates of *Beauvaria bassiana* and 5 isolats of *P. farinosus* were tested against *B. tabaci* nymphs. Both *P. fumosoroseus* and *B. bassiana* show good potential as an augmentative biological control agents. Studies examined the effect of plant allelochemicals on germination of conidia and blastospores, and growth of mycelia. Some compounds reduce fungal activity and may have implications for use of this agent concomitantly with resistant plants. Further studies demonstrated that activity of *Paecilomyces fumosoroseus* against *B. tabaci* was similar on cucumber, cabbage and 3 cultivars of tomato (Monpellier-USDA-ARS, WA-USDA-ARS, TX-USDA-ARS)

True Bugs

Beetles—nothing to report

Lepidoptera

Psyllids—nothing to report

2) Weed pests

Knapweeds—nothing to report

Thistles—nothing to report

Spurges—nothing to report

Purple Loosestrife

Gorse (no work to report, drop as target)

c. Degree to which objective has been accomplished

d. Incomplete work or areas needing further investigation

Objective 11. Conduct limited release studies to assess feasibility

a. Work accomplished (1996-2000)

1) Insect pests

Sessile Homoptera (mealybugs)

For the grape mealybug in the San Joaquin Valley, an augmentative release program has been tested with *Pseudaphycus angelicus*. With release rates of 10,000 parasitoids, an increase in parasitism and decline of mealybug densities and economic damage were observed. A second parasitoid is soon to be evaluated. Augementative biological control is also being investigated for the vine mealybug using *Anagyrus pseudococci* and *Leptomastidea abnormis*.

Whiteflies

An exotic *Eretmocerus emiratus* was released in a large-scale trial on spring melons in CA for control of *B. tabaci*; parasitoid release is compatible with use of imidacloprid and may contribute to stable and effective control of whitefly infesting spring melons; preliminary results indicate that high levels of parasitism were achieved in both the treated (pyrethroids) and untreated cotton. Whitefly parasitoids were released in spring melons using a tractor mounted metering device to distribute them in vermiculite. Of the five release rates used, there were no measurable differences, probably due to low survival of parasitoids (AZ-USDA-APHIS). Three fungi representing 2 genera effectively controlled *Bemisia* in Arizona cotton (AZ-USDA-ARS-AZ).

A new technique that uses transplants that have been inoculated with *B. tabaci* and their parasitoids, then placed into fields along with conventional transplants, have provided better than or equal control than when equal number of parasitoids are released by hand (CA-DFA, AZ-USDA-APHIS)

True Bugs

Beetles—nothing to report

Lepidoptera

Psyllids—nothing to report

2) Weed pests

Knapweeds—nothing to report

Thistles—nothing to report

Spurges—nothing to report

Purple Loosestrife

Gorse (no work to report, drop as target)

c. Degree to which objective has been accomplished

d. Incomplete work or areas needing further investigation

Objective 12. Develop procedures for rearing, storage, quality control and release of natural enemies

a. Work accomplished (1996-2000)

1) Insect pests

Sessile Homoptera (mealybugs)

Rearing procedures for pink and gray pineapple mealybugs have been refined. Innoculation procedures, preferred host stages, and optimal parasitoid to host ratios have been improved or identified for *Anagyrus ananatis* attacking the pink pineapple mealybug. For the grape mealybug, rearing procedures are being developed for the parasitoid, *Acerophagus notativentris.*

Whiteflies

greenhouse technique was developed to mass-rear 3 strains of exotic parasitoids (*Eretmocerus*) of *Bemisia tabaci* for release in AZ and the Imperial Valley, CA. The system uses eggplant as a whitefly host, and is capable of producing over 35 million parasitoids annually (AZ-AES).

Field trials were conducted 1998-2000 to assess the use of cantaloupe transplants as a means of delivering *Eretmocerus* nr. *emiratus*, a parasitoid of *B. tabaci*. The transplant method enhanced levels of parasitism in organic cantaloupe fields, but reductions in pest density were inconsistent (AZ-USDA-APHIS, CA-DFA). The effects of temperature, storage duration, and parasitoid developmental stage were studied for *Eretmocerus* from Ethiopia to determine viability and longevity. Four methods were tested for augmentative release of *E.* nr. *emiratus* against the *B. tabaci* in cotton and melons. A gel-cap method was superior in providing a much more even distribution of individuals throughout the field, especially in melons, but considerable time was necessary to prepare the gel-caps for release. Results suggest that releasing parasitoids in paper cups is best overall, but it is predicted that the parasitoids will have a more even distribution if four cups per 0.1 ha are released rather than one (AZ-USDA-APHIS).

A technique for assessing the efficacy of fungi against *Bemisia tabaci* was developed based on the use of rooted cabbage leaves. The method was used to discriminating doses of two isolates of *Paecilomyces fumosoroseus*. A liquid culture system for production of *P. fumosoroseus* was developed. The system that was shown to produce high concentrations of desiccant tolerant blastospores for 23 isolates that maintained their ability to infect and kill *B. tabaci* (Montpellier-USDA-ARS). The effects of storage temperature and duration on the survival of pupal *Encarsia formosa*, a parasitoid of *B. tabaci*, were examined. Exposure to 10C for periods of 3-13 days resulted in 90-55% emergence. Short exposures to 2 and 5C caused significant mortality. Result indicate some short-term storage of this agent is possible (Montpellier-USDA-ARS, CA-R-AES)

True Bugs

Beetles—nothing to report Lepidoptera

Psyllids

Red gum lerp psyllid: Rearing methods for the parasitoid *Psyllaephagus bliteus* have been under study since 1999. Rearing has been difficult and so far only relatively small numbers are available for release.

2) Weed pests

Knapweeds—nothing to report

Thistles—nothing to report

Spurges—nothing to report

Purple Loosestrife

Gorse (no work to report, drop as target)

c. Degree to which objective has been accomplished

d. Incomplete work or areas needing further investigation

Objective 13. Release natural enemies and assess their biological impact

a. Work accomplished (1996-2000)

1) Insect pests

Aphids

Work accomplished – The efficacy and establishment potential of four species of exotic natural enemies for the cotton aphid were evaluated in field cages and limited field releases. From these studies, two parasites, ANP and AG, were identified as potential components in an introduced natural enemy complex for the cotton aphid. In addition, the fungus, *Neozygites fresenii*, may have some potential for inclusion in the complex, but more study is required. Studies on the short distance movement of ANP and AG were also conducted to determine if the parasites would move with the cotton aphid throughout the year. Movement by the parasites of up to ¼ mile was detected. This objective is approximately 30% complete. More species of natural enemies will need limited field cage testing to determine efficacy and establishment potential.

Sessile Homoptera—nothing to report

Whiteflies—nothing to report

True Bugs

Beetles

Five hundred females of *Catolaccus grandis* were released weekly into cotton against the boll weevil at four locations (2,20,30 and 35A size plots) in the Mesilla Valley, New Mexico. Percent parasitism of the boll weevil from C. *grandis* ranged from 5-28%, averaging 20%. Mortality caused by females feeding on boll weevil larvae ranged from 5-6%, averaging 27% over time at all locations. *Catolaccus grandis* did not give satisfactory control of boll weevil at Las Cruces (NM-AES).

Lepidoptera

Psyllids

Red gum lerp psyllid: Releases of the parasitoid *Psyllaephagus bliteus* began in early summer 1999 and have been made at 19 sites throughout the state. Recovery has been made at two sites. Evaluation of its effectiveness is in progress.

2) Weed pests

Knapweeds—nothing to report

Thistles—nothing to report

Spurges—nothing to report

Purple Loosestrife

Gorse (no work to report, drop as target)

c. Degree to which objective has been accomplished

d. Incomplete work or areas needing further investigation

Goal D. Evaluation of the environmental and economic aspects of biological control target pests

<u>Objective</u> <u>14.</u> Evaluate the environmental aspects of biological control

a. Work accomplished (1996-2000)

1) Insect pests

Aphids

Long-term data on body size of individuals of native aphidophagous ladybird species in Utah show no decline in mean body size within species following the establishment of *Coccinella septempunctata*, thus providing no evidence that the invader's establishment has significantly increased scramble competition for food among immature ladybirds of native species (UT-AES).

Sessile Homoptera (mealybugs)

For the pink hibiscus mealybug project, collections of non-target mealybug species in Imperial Valley are being collected to determine if *Anagyrus kamali* or *Gyranusoidea idica* parasitize them as well. Thus far, none have been found parasitizing resident species.

Whiteflies

Surveys in desert valleys of Arizona and California have identified ca. 21 species of desert plants that frequently host *Bemisia argentifolii,* *Trialeurodes abutiloneus*, *Tetraleurodes mori*, *Tetraleurodes acaciae, Siphoninus phillyreae* and several species of *Aleuropleurocelus*; parasitoids reared from whitefly other than *Bemisia tabaci* on fourteen of these host plants include more than 6 species of *Encarsia*, at least 3 undescribed species of *Eretmocerus* and species of the eulophid *Neopomphale;* results have so far revealed no significant parasitism of non-target whiteflies by parasitoid introduced against *B. tabaci*. Surveys of ornamental plants surrounding parasitoid release sites have shown that exotic parasitoids travel to host whiteflies on woody and herbaceous plants up to 2 miles from the release location. In the Imperial Valley exotic parasitoids are being recovered throughout the area covered in the survey of urban areas (AZ-USDA-APHIS).

True Bugs

Beetles—nothing to report

Lepidoptera

Psyllids—nothing to report

2) Weed pests

Knapweeds—nothing to report

Thistles

Surveys for non-target impacts of the stem fly, *Cheilosia corydon*, on native Cirsium thistles was initiated in Oregon (ODA). Presently, no impacts have been recorded.

Field and laboratory studies were conducted between 1995 and 1999 by USDA-ARS, Albany to determine if *Rhinocyllus conicus* significantly impact rare native California thistles (*Cirsium* spp.). Populations of six rare native *Cirsium* species were surveyed and *R. conicus* was found attacking five of the six species. Infestation levels varied considerably between species, ranging from 32 to 100 % in early-season samples. Attack on *Cirsium fontinale* var. *fontinale* and *C. hydrophilum* var. *hydrophilum* (both federally listed as endangered species) represented new host records for *R. conicus*. Surveys of the target weed, Italian thistle (*Carduus pycnocephalus*), along a seven-mile transect perpendicular to the coast found that *R. conicus* attack rate was significantly higher in inland areas suggesting that native *Cirsiums* growing near the coast may be protected from attack. Studies on seed production by the endangered thistle *C. hydrophilum* var. *vaseyi* showed that the initial flowers were heavily attacked but the majority of late-season flowers were not. Thus, while seed production in initial flowers was reduced 82% compared to uninfested flowers, overall seed production was actually reduced only 21 % for the year.

Spurges

Studies by various federal, state, university, and other researchers have provided invaluable knowledge as to where various leafy spurge bioagents can establish and be most effective. These studies have strongly demonstrated the importance of matching the proper natural enemy with its host in the appropriate habitat type. Dramatic reductions of leafy spurge have occurred at numerous sites in MT, OR, ND, and WY. In OR sites with heavy volcanic clay soils have realized little impact from the flea beetles.

Purple Loosestrife

Gorse (no work to report, drop as target)

b. Degree to which objective has been accomplished

c. Incomplete work or areas needing further investigation

Objective 15. Evaluate the economic aspects of biological control

a. Work accomplished (1996-2000)

1) Insect pests

Sessile Homoptera

Whiteflies—nothing to report

True Bugs

Beetles—nothing to report

Lepidoptera

Psyllids

Blue gum psyllid: We completed a study on economic benefit of the biological control of this psyllid. We concluded that biological control has a benefit-to-cost ratio of 10-25:1 from reduced insecticide treatments alone. Additional benefits in terms of foliage yield, reduced health risks, and avoidance of insecticide resistance further increase this ratio.

2) Weed pests

Knapweeds

OREGON: Net economic losses due to knapweeds were estimated at $3.4 million in Oregon. Benefits will accrue as biological control becomes more evident and widespread.

Thistles—nothing to report

Spurges—nothing to report

Purple Loosestrife

Gorse (no work to report, drop as target)

c. Degree to which objective has been accomplished

d. Incomplete work or areas needing further investigation

Appendix A. Other progress made and research activities related to Regional Research Project W-185 – Biological Control in Pest Management Systems of Plants

Goal A. Introduction (classical biological control) of natural enemies to control target pests

Objective 1. Survey indigenous natural enemies

1) Insects

Fruitflies

Parasitoids of the two-spotted leafhopper, *Sophonia rufofascia*, were surveyed on 3 Hawaiian islands. *S. rufofascia* eggs were parasitized by *Chaetomymar* sp. nr *bagichi*; *Schizophragma bicolor* (Dozier); and *Polynema* sp. Haliday (Hymenoptera: Mymaridae).

Parasitoids of the newly invasive planthopper *Kallitaxila granulata* (Stal) (Homoptera: Tropidocadae) were surveyed on Kauai and Oahu: *Chaetomymar* sp. nr *bagichi* and an unidentified mymarid species were recovered.

Objective 2. Undertake foreign exploration

1) Insects

Fruitflies

Coffee plantations in Kenya were searched for parasitoids of the Mediterranean fruit fly, *Ceratitis capitata*. Ten species of parasitic Hymenoptera were reared from 3 tephritids. The assemblage was dominated by koinobiont endoparasitoids. One new species was discovered, and several new host records documented.

Cooperators in southern China reared 10 species of egg parasitoids in association with *Sophonia* leafhoppers, including *Chaetomymar hishimoni*, *Ufens rimatus*, *Hispidophila* spp.(new species), *Gonatocerus* spp., *Polynema* spp., and a trichigrammatid and an aphelinid.

Objective 3. Determine systematics and biogeography of pests and natural Enemies.

1) Insects

Fruitflies

The generic relationships of opiine braconid parasites of tephritid fruit flies were revised by our cooperator on the medfly project (Dr. Wharton, Texas A & M). One new species was described from Kenya (*Fopius ceratitivorous*), and synonymy of *Psyttalia concolor* and *P. humilis* was confirmed.

2) Weeds

Spurges

Host race studies of *Brachypterolus pulicarius,* an ovary-feeding nitidulid that attacks Dalmatian and yellow toadflax, were continued using AFLP and behavioral response techniques (MT-AES).

Objective 4. Quarantine of exotic natural enemies and pre-release studies

1) Insects

Fruitflies

Two species of medfly parasitoids (*F. caudatus* and *F. ceratitivorous*) from Africa are currently in the quarantine facility of our cooperators in Guatemala. A third medfly parasite (*Diachasmimorpha kraussii*) from Australia has passed through quarantine and been permitted for release. A fourth species (*Psyttalia humilis*) has passed through quarantine but is only permitted for laboratory and cage studies. Target and non-target species are being tested to establish host-range.

Objective 5. Release and disseminate natural enemies

1) Insects

2) Weeds

Spurges

The following natural enemies were released against Dalmatian or yellow toadflax: the noctuid moth, *Calophasia lunula* (AZ, ID, MT, NV, WY); the ovary-feeding nitidulid, *Brachypterolus pulicarius* (AZ, ID, MT, NV, WY); the root boring moths, *Eteobalea intermediella* and *Eteobalia serratella* (CO, MT); the Dalmatian toadflax-adapted strain of the seed capsule-feeding weevil, *Gymnetron antirrhini* (MT); the seed capsule-feeding weevil collected from yellow toadflax (ID, MT, WY); the root-galling weevil, *Gymnetron linariae* (CO, MT, SD, UT, WY); and the stem-boring weevil, *Mecinus janthinus* (CO, ID, MT, SD, UT, WY).

Objective 6. Evaluate efficacy and study ecological/physiological basis for Interaction

1) Insects

2) Weeds

Spurges

The effects of plant competition versus insect herbivory on seedling recruitment of Dalmatian toadflax was evaluated at two field sites in Montana (MT-AES). Plant competition played a more important role in reducing seedling recruitment of toadflax than insect herbivory.

Goal B. Conservation of natural enemies to increase biological control of target pests

Objective 7. Confirm identity of organisms involved in pest problem

Objective 8. Identify and asses factors potentially involved in disruption of biological control

Objective 9. Implement and evaluate habitat modification, horticultural practices and pest suppression tactics to conserve natural enemy activity

Goal C. Augmentation of natural enemies to increase biological control of target pests

Objective 10. Identify and study biological characteristics of candidate natural enemies (species and biotypes)

1) Insects

Fruitflies

Host finding attributes of several opiine fruit fly parasitoids were studied in laboratory and field experiments.

2) Weeds

Objective 11. Conduct limited release studies to assess feasibility

1) Insects

Fruitflies

Localized dispersal behavior of several mass-reared opiine braconids was tested in release sites on Kauai.

2) Weeds

Objective 12. Develop procedures for rearing, storage, quality control and release of natural enemies

Objective 13. Release natural enemies and assess their biological impact

1) Insects

Fruitflies

Mass-reared *Diachasmimorpha longicaudata* were released in a guava orchard to assess impact on Oriental fruit fly populaions.

2) Weeds

Goal D. Evaluation of the environmental and economic aspects of biological control of target pests

Objective 14. Evaluate the environmental aspects of biological control

Objective 15. Evaluate the economic aspects of biological control

1) Insects

Fruitflies

The impacts of introduced parasitoids of fruit flies were measured on both endemic and exotic (beneficial) non-target tephritids in Hawaii.

2) Weeds