APPENDIX I – Customer Action Plans

Component I – Systematics

1a. Insect and Mite Identification, Taxonomy, and Systematics

1b. Weed Systematics and Taxonomy

1c. Microorganisms Associated with Insects and Weeds

Component II – Protection of Agricultural and Horticultural Crops

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2c. Nut Crops

2d. Pome Fruit

2e. Stone Fruit

2f. Vegetables

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2l. Cotton

2m. Legumes

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Component I: Systematics and Identification

1a. Insect and Mite Identification, Taxonomy, and Systematics

(U.S. Value 1906-1991: $93 billion)

Problem Statement: Insect and mite systematists confront on a daily basis the challenge of identifying new, potentially invasive species that affect biological diversity and the agricultural landscape, as well as developing effective systems of names, descriptive and identification tools, and predictive genetic relationships for these organisms with the following targeted research programs:

- Diagnostic Detection Technology
- Genetic Relationships and Identities of Insects and Mites

***Research Needs*:**

1. **Diagnostic Detection Technology**

   Importance: Insects and mites enter the United States every day with the potential to become invasive pests or, perhaps, as beneficial arthropods in the control of noxious weeds and other insects, or as pollinators. Accurate identification of insects and mites is required before action can be determined. Efficacious exclusion of invasive plant pests, successful detection and management of those already established in the United States, and the selection of appropriate biological control agents all require the accurate identification of these insects and mites.

   Research Gaps: For most insect and mite groups [particularly for weevils, gypsy moths, scale insects, gall midges, plant-feeding true bugs, bark beetles, metallic wood-boring beetles, scarab beetles, plant-feeding flies (non-agromyzids), click beetles, and gelechioid moths] and animal feeding mites, our customers and stakeholders do not have expertise to do in-house identification. ARS fills this gap.

   Actions: ARS will:

   - Identify insects and mites (over a million species comprising 85 percent of all known organisms) for: regulatory officials in the U. S. Department of Agriculture/Animal and Plant Health Inspection Service/ Plant Protection and Quarantine (USDA/APHIS/ PPQ), the U.S. Department of Homeland Security, and state departments of agriculture; researchers in USDA/Agricultural Research Service (USDA/ARS) and universities implementing biological control programs; pest managers, conservation biologists, pest control services, homeowners, physicians, medical laboratories, and entomologists in the United States and foreign countries.
   - Maintain a database of insects and mites entering U.S. ports.

2. Genetic Relationships and Identities of Insects and Mites

Importance: Insects and mites are the most diverse groups of organisms on the planet; however, the number of unknown species may be greater than the number known. Lineages need to be determined to show the genetic relationships among known species with human impact. This will provide predictive power and help anticipate future and/or potential pest status of related species. Because new species that may have human impact will more likely be closely related genetically to species that already have human impact, the more we know about the current species, the better scientists can predict potential problem species. Newly developed molecular methods will be particularly useful in this work.

Research Gaps: For several insect groups [weevils, gypsy moths, scale insects, gall midges, plant-feeding true bugs, bark beetles, metallic wood-boring beetles, scarab beetles, plant-feeding flies (non-agromyzids), click beetles, and gelechioid moths, some groups of native bees] and animal feeding mites, there are currently no scientists working on the genetic relationships among these species. Much work remains for other taxa, particularly for ones that contain newly introduced invasive species.

Actions: ARS will:

- Create original scientific treatments describing the genetic relationships among species in the following groups:
  - aphids;
  - mites;
  - termites;
  - thrips;
  - fruit flies;
  - pest leaf-mining flies;
  - tachinid fly parasitoids of moth pests;
  - flower flies predacious on pest aphids,
  - whiteflies and other plant lice;
  - soldier flies and flower flies useful as nutrient recyclers;
  - fergusoniid flies that are weed biological control agents;
  - longhorned beetles that attack living trees, woody plants and timber, particularly those that are potentially invasive and commonly transported through commerce;
  - flea beetles, including known crop pests as well as prospective biological control agents of noxious introduced weeds;

- predatory ladybeetles that feed on plant lice and mites;
- wasps for biological control that are parasitic on pests or are plant feeding pests in their own right;
- native pollinator bees;
- plant-feeding caterpillars such as leafrolling moths, armyworms, and snout moths;
- predatory plant bugs; and
- leafhoppers.

***Anticipated Products*:**

- Enhancement and greater efficacy of the Systematic Entomology Laboratory Identification System (SELIS).
- Print and electronic databases of identified insects and mites.
- Increased specimen representation of insect and mite species in the U.S. National Insect Collection (Smithsonian Institution).
- New identification tools, accurate systems of names, and predictive genetic relationships of insect and mites.
- Print and electronic databases of host plants, geographic distributions, and vectors of plant diseases.
- Species inventories for use in conservation and management of native landscapes and natural habitats.
- Online interactive identification systems such as web pages and/or expert systems.
- Catalogs of important groups of insects and mites.

Potential Benefits (Outcomes):

- More accurate and timely identifications of key insect and mite species for SEL customers.
- Reduced risk of invasion from non-native insect and mite species.
- More accurate target in management and conservation using insect and mite species for biological control.

***USDA ARS Resources*:**

- Systematic Entomology Laboratory, Beltsville, Maryland
- Systematic Entomology Laboratory Identification System (SELIS), Beltsville, Maryland

Component I: Systematics and Identification

1b. Weed Systematics and Taxonomy (U.S. Value 2007: $27 billion)

Problem Statement: Successful control and management of noxious weeds on over 100 million acres of agricultural, public lands, right-of-ways, and native natural habitats is limited by confusion over basic knowledge of:

- Identification of Weed Species
- Genetic Relationships of Weeds to Other Plant Species
- Hybridization/Introgression Involving Weed Species
- Population Structure of Weeds
- Unknown Origin of Genetically Distinct Populations of Weeds

Research Needs:

1. **Identification of Weed Species**

   Importance: The identification of several key weed species is challenging and in some cases the species name is unknown or controversial. Without proper identification of weeds, it is difficult to determine their distributions, impacts, and origins. This lack of information leads to increased environmental impacts when weeds are not efficiently controlled, wasted economic resources when management is focused on the wrong target, and damaged desirable plant species when they are incorrectly identified as weed species.

   Research Gaps: For many plant groups, identification can be outsourced to experts of that taxonomic group, but for some genera and species, for which ARS is conducting research, there are no non-ARS experts and ARS botanists must fill in those gaps.

   Actions: ARS will:

   - Clarify identification of key or newly detected weed species.

2. **Genetic Relationships of Weeds to Other Plant Species**

   Importance: Biological control of weeds requires knowledge of a weed's relationship to other native and non-native plant species in order to be able to accurately assess the host-specificity of potential control agents (insects, pathogens). If relationships are unknown, there is the potential to incorrectly affect non-target organisms.

Research Gaps: For many taxonomic plant groups that are subjects of ARS research, knowledge of genetic relationships has not been adequately resolved. Recently, many systematic classifications based on morphology alone have been radically altered by molecular evidence.

Actions: ARS will:

- Use the best available analysis methods, such as molecular methods, to determine genetic relationships of key weed species.

3. Hybridization/Introgression Involving Weed Species

Importance: When species are introduced to new areas, there is risk that they may hybridize with other closely related species in the area. Novel hybrids may be created, or through introgression (back-crossing with parental species), native species may be polluted with non-native genetic material. Many invasive weeds are the result of hybridization events, which remix genetic material and potentially produce a wide array of genotypes. Some of these genotypes may have enhanced invasive properties.

Research Gaps: Many hybrids are physically indistinguishable from nonhybrids and putative hybrid events usually require DNA analysis to determine identity and abundance. When hybrid events are detected, it is not always known how much the plants are more like one parent species or the other, which may affect biological control efforts. Additionally, when non-natives hybridize with other species, DNA analysis is needed to determine how much of the non-native DNA exists in subsequent generations (introgression).

Actions: ARS will:

- Identify and quantify the abundance of hybridization events involving key weed species and determine levels of introgression in generations following hybridization.

4. Population Structure of Weeds

Importance: Within a weed species there can be many genetically distinct populations that vary in characteristics such as invasiveness and drought or cold resistance, as well as resistance to herbicides and highly host-specific, biological control agents. Molecular methods are usually required to obtain this population structure information and may be critical to efficient control methods in some weed systems.

Research Gaps: The distribution of genetically distinct populations of key weed species across the United States is often unknown.

Actions: ARS will:

- Use DNA analyses to determine the population structure of key weed species.

5. **Unknown Origin of Genetically Distinct Populations of Weeds**

Importance: Biological control depends in part on locating insect or microbial agents that have co-evolved with the target weed. Control agents that are chosen without knowledge of the weed's origin may be ineffective, especially when the agents are highly host-specific, even to the point of preferring a genetically distinct population within a single species. Weed origins can be determined through careful study of historical herbarium records and DNA analyses.

Research Gaps: The precise origin (e.g., country) of weed species is often unknown, and complicated by controversial species names.

Actions: ARS will:

- Determine origins of key weed species or genetically distinct populations of weeds using existing herbarium collections, field surveys, and/or DNA analyses.

***Anticipated Products*:**

- Increased specimen representation of key weed species in herbarium collections.
- Original scientific treatments showing the genetic relationships among groups of weed species and clarifying controversies involving species names.
- Original scientific treatments describing existence and distributions of hybridization events involving key weed species.
- Original scientific treatments describing population structure and geographic shifts of key weed species.
- Knowledge of origins of key weed species and/or genetically distinct populations of weeds.

Potential Benefits (Outcomes):

- More accurate identifications of key weed species.
- More rapid implementation of biological control agents.
- Enhanced efficacy of biological control agents used on key weed species.
- Determination of species-based ecological range expansion potential.
- Species-specific control methodology based on taxonomic relationships.

***USDA ARS Resources*:**

- Pest Management Research Unit, Sidney, Montana
- Plant Science Research Unit, Fargo, North Dakota
- Southern Weed Science Research Unit, Stoneville, Mississippi

Component I: Systematics and Identification

1c. Microorganisms Associated with Insects and Weeds (U.S. Value 2007: $ 202 billion)

Problem Statement: The full potential of microbes as biological control agents has not been realized because our knowledge of the relationships between microorganisms and other organisms is limited by confusion over a basic understanding of:

- Species and Strain Identification, Discovery, and Description
- Genetic Relationships
- Environmental and Biological Effects on Geographic Distribution and Dispersal
- Fundamental Biology of Microorganisms Associated with Arthropods and Weeds

***Research Needs*:**

1. **Species and Strain Identification, Discovery, and Description**

   Importance: Strains and species of agriculturally important microorganisms must be identified, and newly discovered ones need to be described. New isolates are accessioned into the core ARS national culture collections, and then distributed to ARS scientists, customers, partners and stakeholders. These new microorganisms can lead to innovations in biological control of insects, mites and weeds, improvements to methods for rearing insects (especially those currently difficult or impossible to rear in the laboratory), improvements to agricultural crops and commodities, and advancements in a number of other increasingly important areas of agricultural research (e.g., biofuels).

   Research Gaps: Current definitions of what constitutes a species are inadequate to describe microorganisms so the identity and naming of many species of microorganisms is controversial. Methods are lacking for culturing "uncultivable" microorganisms, which, if manipulated more easily in the laboratory, could possibly be used for agricultural applications.

   Actions: ARS will:

   - Develop new and/or improved analytical methods of data analysis as well as bioinformatic tools that enhance species and strain identification.
   - Refine existing criteria and develop novel ones for the recognition of species and strains from the following groups of microorganisms: insect-associated bacteria; insect-associated fungi (including insect-associated microsporidia); insect-associated viruses; weed-associated bacteria; weed-associated fungi; and weed-associated viruses.

- Develop novel methods for the growth and culture of fastidious and/or currently "non-cultivable" microorganisms.
- Distribute insect- and weed-associated reference strains to customers, partners and stakeholders via the following: core National Culture Collections; the ARS Culture Collection at Peoria (Illinois), a general culture collection housing over 90,000 type and reference stains (Peoria, Illinois); and the ARS Collection of Entomopathogenic Fungal Cultures at Ithaca (New York), which comprises more than 9,000 type and reference strains.
- Transfer strains of potential or demonstrated agricultural value to the above core National collections.

2. Genetic Relationships

Importance: Rapid diagnostic tests designed to differentiate species and strains of pathogens and their potential impact on agricultural and natural resources are based on their genetic relationships with well-understood species and strains. Scientists or regulators identify target species or strains as well as other closely related species or strains in order to predict properties such as toxigenicity and virulence.

Research Gaps: The number and diversity of species and strains of microorganisms whose genetic relationships are unknown is immense. For example, most genetic relationships among insect- and weed-associated microorganisms have not been demonstrated with modern methods of analysis. This is compounded by the lack of easily identified physical characteristics of microorganisms and the recent discovery that certain genes used extensively to assess the genetic relationships among microorganisms, such as the 16S ribosomal RNA gene of bacteria, are inadequate for comparing all species and strains.

Actions: ARS will:

- Characterize the utility of alternative genes for resolving genetic relationships among species and strains of microorganisms with different levels of relatedness.
- Determine genetic relationships of insect- and weed-associated microorganisms, including (but not limited to): insect-associated bacteria (*Bacillus, Enterobacter, Serratia, Spiroplasma* and *Pseudomonas*); insect-associated fungi (*Beauveria, Candida, Cordyceps, Cryptococcus, Isaria, Metarhizium, Nomuraea, Paecilomyces, Verticillium*), including microsporidia; insect-associated viruses; weed-associated bacteria; weed-associated fungi (*Fusarium*); weed-associated viruses.
- Develop rapid, molecular-based diagnostic tests to detect and differentiate crop pathogens vectored by insects and/or weeds.

3. Environmental and Biological Effects on Geographic Distribution and Dispersal

Importance: Study of the environmental and biological processes that shape the geographic distributions of genetic lineages of insect- and weed-associated microorganisms across time has been neglected, but is extremely important for a number of agricultural purposes. This knowledge will help predict future changes in the spread of plant-diseases brought about by climate change. As an example, the end of the last ice age brought about rapid and substantial changes in climate and available habitat due to retreating glaciers, which in turn allowed for the northward expansion of temperate deciduous forests and warm grasslands. Likewise, today's pattern of global climate change will allow more southerly species of fungal pathogens to expand northward by being carried along with the concomitantly expanding ranges of southerly species of weeds and insect vectors.

Research Gaps: We lack an examination of the population structure within a geographic context of various weed and insect-associated microorganisms, particularly, plant pathogens that have been listed as a high priority for customers, partners and stakeholders. In addition, the time when contemporary populations became genetically isolated is undetermined, and the factors affecting the separation unidentified.

Actions: ARS will:

- Determine how genetic diversity is partitioned within and between populations of insect-associated and weed-associated microorganisms.
- Clarify the historical timeframe for the separation of genetically distinct North American insect-associated and weed-associated populations of microorganisms from populations in other regions of the world and identify the factors that maintain or disrupt this separation.
- Identify the historical environmental and biological processes that facilitate transmission of plant pathogens from weed reservoirs to crops in North America.

4. Fundamental Biology of Microorganisms Associated with Arthropods and Weeds

Importance: The toxicity of a microorganism is a product of the chemical interactions between the microorganism and its host. These interactions are key targets for new intervention and implementation strategies for effective weed and arthropod control because production of these chemicals is genetically controlled and can be artificially exploited in a laboratory. This type of study, however, is only possible with microorganisms for which the genetic code is largely or entirely known.

Research Gaps: Several fungi and bacteria have been commercially registered as biological control agents, but little genetic information from this group of agricultural pathogens is available.

Actions: ARS will:

- Identify the genes and their chemical products driving the association between agriculturally-relevant microorganisms and their host systems.
- Determine specific virulence and pathogenicity factors in microorganisms important for biological control.
- Identify secondary metabolites from microorganisms that may lead to new chemistries for agricultural use.

***Anticipated Products*:**

- Expanded knowledge of the diversity of microorganisms associated with insects and weeds.
- Improved methods for identifying microorganisms associated with insects and weeds.
- Accurate genetic relationships and names of insect- and weed-associated species and strains of microorganisms.
- Novel and enhanced species identification databases for insect- and weed-associated microorganisms.
- Improved knowledge of the environmental and biological factors that influence the geographic dispersal of microorganisms.
- Diagnostic methods providing the ability to rapidly and accurately identify beneficial microorganisms.
- Accurate and confident post-release identification of pathogens approved and released for biological control.
- New reference strains for research and industrial or commercial use.

***Potential Benefits (Outcomes)*:**

- Reductions in crop losses from plant diseases transmitted by insect pests of citrus.
- Improved ability to accurately identify insect- and weed-associated microorganisms.
- Improved prediction of biological control potential of new strains.
- Development of molecular diagnostic assays for tracking releases of biological control strains.
- Availability of information to regulatory agencies for risk assessment and approval of petitions for release of biological control strains.
- Ability to culture and preserve "difficult" microorganisms and microorganisms currently classified as "non-cultivable."
- Distribution of microbial strains from core ARS national collections to customers, partners and stakeholders for research and development.

***USDA ARS Resources*:**

- ARS Collection of Entomopathogenic Fungal Cultures (http://arsef.fpsnl.cornell.edu)
- Biological Integrated Pest Management Unit, Ithaca, New York
- Foreign Disease-Weed Science Research Unit, Ft. Detrick, Maryland

Component II: Protection of Agricultural and Horticultural Crops

2a. Rangeland/Pasture and Arid Land Crops (U.S. Value 2007: $103 billion)

***Problem Statement*:** Our Nation's grass and shrub lands, including range, pastures, hay and turf lands, provide forages, open spaces and ecological services that contribute significantly to our agricultural, environmental, economic, and social well-being. Forage-livestock systems are the foundation of an animal industry that contributes more than $90 billion in farm sales annually to the United States economy. The estimated value of production from the 61 million acres of land providing grass and alfalfa hay is $13.5 billion. Rangeland, pasture, and forages together comprise about 55 percent of the total land surface of the United States, about a billion acres. Privately owned lands comprise about 45 percent of this total, or about 640 million acres. Rangeland, pasture and arid lands do not produce optimum yields and quality due to the following gaps in the biology, ecology and integrated management approaches for invasive and noxious weeds and destructive insects:

- Growth and Development of Perennial Weeds
- Delayed Response to New Invasions That Can Result in a Long Term Pest Problem
- Restoration of Invaded Sites
- Biological Control of Perennial Weeds
- Outbreaks of Grasshoppers and Mormon Crickets

***Research Needs*:**

1. **Growth and Development of Perennial Weeds**

   Importance: Leafy spurge and Canada thistle are noxious perennial weeds in many temperate regions of North America. In four northern Plains states, leafy spurge causes an estimated $130 billion in damage by reducing cattle carrying capacity on rangeland and is displacing an endangered plant species. White top or hoary cress is another widely distributed threat to rangelands, croplands and riparian habitats and has been declared a noxious weed in 14 United States and three Canadian provinces. Hawkweeds, recent invaders in the western United States that adapts to pastures, hayfields and a wide variety of other habitats, are expanding their range at about 16 percent per year. Canada thistle is widely distributed and is invasive in many ecosystems.

   Research Gaps: For most weed species the key biological characteristics governing reproduction, dispersal, and establishment need to be described and the mechanisms, pathways, and factors that control their expression need to be defined and clarified.

Long-term genomics research is needed to understand weedy characteristics and the growth and development of noxious and invasive weeds.

Actions: ARS will:

Control, Fundamental Biology

- Define and clarify biological factors, mechanisms, and pathways that regulate reproduction and dormancy in vegetative propagules of perennial weeds needed to enhance biologically-based weed management.
- Define and clarify biological factors, mechanisms, and pathways that regulate seed development, dormancy and germination in weeds needed to manipulate the production and destruction of weed seeds.

2. Delayed Response to New Invasions and Pest Outbreaks

Importance: Canada thistle, leafy spurge, and other established invasive weeds continue to impact the productivity of rangelands and the stability of associated natural areas. Newly introduced invasive weeds, if not rapidly controlled, will exacerbate the problems associated with established invasive weeds. Organic ranchers and farmers identified better weed and pest management as a top research need. Dependable, fast-acting, environmentally safe natural herbicide formulations for weed management are needed for a comprehensive, biologically based IPM program designed to control pests in rangeland and associated natural areas.

Research Gaps: A number of microbially produced phytotoxins have been identified and characterized, several of which have modes of action that are different from currently available synthetic herbicides. In addition, several microbial products with surfactant qualities have been isolated and described. In a number of cases, the potential for use of these natural compounds either alone or in combination for the control of weeds in agricultural systems has not been fully evaluated.

Actions: ARS will:

Control, Natural Herbicides and Formulations

- Identify genes involved in the regulation of microbially produced phytotoxins and develop methods to utilize that knowledge to enhance phytotoxin production to levels that meet commercial production needs.
- Develop formulations of natural herbicide and natural surfactant combinations and assess their efficacy on the major weeds of agricultural production systems and natural areas.

3. Restoration of Sites Degraded By Perennial Weed Infestation

Importance: Invasive species alter soil biological, chemical, and physical features and thereby native plant communities of rangelands. To return grazing lands to or maintain them at an economically viable level of productivity requires knowledge of the effects of weed infestations on biotic properties of soils supporting these rangeland plant communities. The after-effects of weed control measures can include shifts in soil and rhizosphere microbial communities. If populations of species of fungi and bacteria that cause seedling diseases are stimulated by such control measures, reestablishment of native or other desirable forbs and grasses may be impaired. Strategies to improve restoration may require practices that mitigate deleterious plant pathogen inoculum levels.

Research Gaps: How the presence of invasive species alters soil biology and affects key orbs and grasses in rangeland plant communities has not been investigated in short and mixed grass rangelands. Additionally, the shifts in soil microbial community structure as a consequence of infestations of invasive weeds has not included identification of predominant fungal and bacterial species within such microbial communities and their effects on native and other desirable species. For example, insect herbivory occurring as a consequence of the release and establishment of insects for biological control can alter root physiology and rhizosphere microbial ecology, especially when root herbivory is involved. Identification and characterization of species that are favored by insect herbivory (or long-term residence) of invasive weeds would lead to more effective restoration programs for rangelands.

Actions: ARS will:

Control, Fundamental Biology

- Identify species in soil microbial communities that predominate as a result of weed invasion or after successful biological control and investigate their effects on native and other desirable species.

Control, Ecological Interactions

- Investigate the structure of soil and rhizosphere microbial communities associated with long-term infestations.
- Identify and test the effects of soilborne fungi and bacteria associated with insect root herbivory of perennial rangeland weeds.

4. Biological Control

Importance: Biological control is by consensus the primary tactic for managing exotic invasive perennial weeds on rangelands that are typically of low monetary value but that provide significant ecological services. However, past and potential ecological risks associated with releases of too many agents and/or agents of low impact or effectiveness has made the release of fewer agents with documented higher impacts preferred. Most priority perennial rangeland weeds do not have insects among their most promising biological control agents, necessitating an increased emphasis on plant pathogens as biological control agents.

Research Gaps: Criteria for selecting sites to release biological control agents are not well established. Also lacking is an understanding of how microbes and microclimatic factors impact establishing insects used in weed biological control. Procedures for pre-release testing of the potential of new biological control agents, especially combinations of insects and pathogens, have not been developed. Studies in the native range of the target invasive weed species can aid the determination of the potential effectiveness of candidate agents by their effects on weed density.

Actions: ARS will:

Control, Biological

- Identify and test possible plant pathogens that may be synergistic in combination with insects that are priority candidates for biological control of perennial rangeland weeds.

- Determine the diversity of plant pathogens occurring in both the native and invaded ranges of target rangeland weeds.

5. **Outbreaks of Grasshoppers and Mormon Crickets**

Importance: Grasshopper and Mormon cricket outbreaks have plagued farmers and ranchers for centuries, competing with livestock, wildlife, and humans for food supplies. Grasshoppers cause the loss of an estimated $1.25 billion per year in forage in western U.S. rangelands and are often the dominant rangeland herbivore in terms of biomass and vegetation consumed. Grasshopper and Mormon cricket outbreaks on rangeland or Conservation Reserve Program (CRP) land can also pose a severe threat to adjacent cropland. Pesticides have historically been the primary tools used to combat outbreaks, with over 13 million acres of Federal land sprayed in the last major grasshopper outbreak. Increased public concern over non-target effects of pesticides, combined with high costs of spraying large areas, has made it imperative to develop new cost effective and environmentally sustainable management tactics. Of additional importance, grasshoppers may contribute to grassland health in ways that are of interest to Federal, state, and private land managers, as well as conservation organizations.

Research Gaps: Little is known about the mechanisms and factors that underlie grasshopper and Mormon cricket population dynamics and dispersal. Extensive outbreaks are cyclical, but knowledge of how they are influenced by drought, food availability, predation, disease, climate change, and contemporary rangeland and agricultural practices is lacking. Further research on rangeland management approaches, including livestock grazing and fire, is needed. This research needs to be conducted in multiple ecosystems, as grasshoppers respond differently to grazing, fire, and weather in different ecosystems. To provide much-needed alternatives to pesticide control, research on cultural practices and development and enhancement of control with microbials will be critical. Finally, almost nothing is known about the influence of grasshoppers and Mormon crickets on grazing system sustainability, exotic plant invasions, and grassland restoration.

Actions: ARS will:

Control, Fundamental Biology

- Define biotic and climatic factors that influence the likelihood of outbreaks and migration to enhance predictions of when outbreaks and migration will occur.
- Analyze spatial orientation and dispersal in migrating grasshoppers and Mormon crickets.
- Determine the effects of rangeland management techniques such as livestock grazing, fire, and chemical control.
- Clarify how grasshoppers and Mormon crickets influence grazing system sustainability, grassland health, and the relationships between exotic and native grassland plants.
- Identify new, commercially acceptable microbial control agents and/or increase efficacy of existing agents to suppress outbreaks, especially as replacements for pesticides in environmentally sensitive areas.
- Define and clarify biological factors, mechanisms, and pathways that regulate locomotion, reproduction, and immunity to pathogens to enhance biologically-based grasshopper and Mormon cricket management.

***Anticipated Products*:**

- Increased applied and fundamental knowledge of seed dormancy, propagules for weed management, and other aspects of the weed vegetative reproductive biology in agroecosystems.
- Information on specific genes and gene-products involved in plant growth and development.
- Genomic resources for investigating biological characteristics of leafy spurge and Canada thistle.
- Knowledge of mechanisms by which microbial phytotoxin production can be modified to significantly increase yields.
- Knowledge of, and techniques for, the on-site production of natural herbicides.

- Recommendations for the selection and use of natural herbicides for the rapid control of invasive weeds in agricultural and natural areas.
- Characterization of soil and rhizosphere microbial community structure associated with perennial weed infestations of rangelands.
- Restoration practices that account for the accumulation of higher inoculum levels of plant pathogens and deleterious rhizosphere bacteria.
- Biological control agents for perennial weeds of rangelands including white top, leafy spurge and hawkweeds.
- Protocols for testing soilborne plant pathogenic synergists of insects released for the biological control of one or more target weed species.
- Increased applied and fundamental knowledge on the biology and ecology of crickets and grasshoppers.

Potential Benefits (Outcomes):

- Scientifically-based, cost-effective, environmentally-safe strategies for weed and insect management in rangeland agroecosystems.
- Preservation of rangeland and associated natural lands resulting from the rapid control of invasive plants.
- Reductions in crop losses to weed competition.
- Ecologically sound and economically beneficial methods of weed control that are compatible with organic and conventional production systems.
- New strategies and approaches for restoration of rangelands degraded by invasive species.

USDA ARS Resources:

- Invasive Insect Biocontrol and Behavioral Laboratory, Beltsville, Maryland
- Natural Products Utilization Laboratory, Oxford, Mississippi
- Northern Plains Agricultural Research Laboratory, Sidney, Montana
- Overseas Biological Control Laboratory, Montpelier, France
- Plant Science Research Unit, Fargo, North Dakota
- Sustainable Agricultural Systems Laboratory, Beltsville, Maryland

Component II: Protection of Agricultural and Horticultural Crops

2b. Citrus (U.S. Value 2007: $2.9 billion)

***Problem Statement*:** The principal commercial citrus species (oranges, grapefruit, lemons, and tangerines) do not produce maximum yields due to the following pests:

- Citrus Greening, Transmitted by the Asian Citrus Psyllid (Florida, all citrus species)
- Citrus Canker and the Increase in its Transmission by the Asian Citrus Leafminer (Florida and Texas, all citrus species)
- *Phytophthora*, Transmitted by the *Diaprepes* Root Weevil (Florida and Texas, all citrus species)
- Tristeza Virus and its Efficient Vector, the Brown Citrus Aphid (Florida and Texas, all citrus species)
- Citrus Rust Mite (Florida and Texas, all citrus species)
- Pink Hibiscus Mealybug (Florida, all citrus species)
- Glassy-Winged Sharpshooter (all citrus producing areas, all citrus species)
- Weeds that Compete with Citrus Tree Resources, Harbor Insect and Rodent Pests, Increase Cold Damage, Increase Disease Pressure, Impede Harvest, Interfere with Low Volume Irrigation Systems, and Intercept Soil-Applied Chemicals (all citrus producing areas, all citrus species)
- A Major Issue is the Loss of Biological Control Agents Due to the Use of Pesticides to Control Vectors of Pathogens (Florida and Texas, all citrus species)
- A Second Issue is Glyphosate-Resistant and Other Herbicide-Resistant Weed Biotypes (all citrus producing areas, all citrus species)

***Research Needs*:**

1. **Asian Citrus Psyllid and Citrus Greening Disease**

   Importance: The Asian citrus psyllid vectors a bacterium that causes a disease known as citrus greening, considered the world's worst citrus disease. The vector and disease are new to Florida, and are jeopardizing Florida citrus with the potential to jeopardize the entire U.S. citrus industry. The vector has spread to Puerto Rico and Texas, and reports indicating that the putative pathogen is present in Texas. Recently, the psyllid and greening disease were found in Louisiana. The psyllid has not yet been found in Arizona or California, but it has been spreading rapidly across Mexico over the last several years and will likely reach these two states. Since 2005 when the disease was first found in Florida, hundreds of thousands of citrus trees have been removed from groves in an effort to reduce disease inoculum.

Research Gaps: In order to save the citrus industry, immediate research is required to develop efficient pesticide treatments against the Asian citrus psyllid. To the extent possible, these methods should avoid damaging current biological control and IPM systems that successfully control other pests. Efficient monitoring methods for the psyllid and diagnostics for the pathogen would facilitate the targeting of control methods. Longer-term research objectives should focus on developing techniques for eliminating the disease regionally or controlling it sustainably. In addition to the gaps that can be addressed with current ARS resources, customers have identified the need for improved chemical controls for the vector, including approaches that minimize application rates through development of low volume, electrostatic methods.

Actions: ARS will:

Monitoring

- Improve sampling and monitoring methods for the vector.
- Apply improved sampling and monitoring techniques to determine host preference, particularly in dooryards where numerous host species and cultivars may serve as refuge habitats for the vector.

Control, Interference with Vector Olfaction

- Discover volatile attractants (pheromones and host-plant volatiles), and plant repellents or confusants that can be used for interfering with vector mating and host-location.
- Determining mating behavior, acoustic signaling, visual and olfactory orientation, and spatial dynamics (movement).

Control, Biological

- Explore for new biological control agents, devise methods for culturing, introducing, and conserving biological control agents, determine genetics of known biological control agents, and screen for microbial pathogens of the psyllid.
- Develop biological control strategies tailored to control the vector in residential areas, abandoned orchards, and other vector refuge areas where chemical controls may not be appropriate.

Control, Interference with Vector Biology

- Determine the role of endosymbionts in the biology and reproduction of the insect.
- Determine the mechanisms of pathogen acquisition and transmission.
- Understand the role of specific genes in important biological phenomena, i.e., development, feeding, reproduction, and pathogen transmission associated with greening expression.

Control, Insect Resistant Citrus

- Use conventional and molecular methods to develop citrus varieties resistant to psyllids (and the pathogen).

Control, Chemical

- Develop chemical control strategies that are acceptable in dooryards and residential areas.

2. Citrus Leafminer and Citrus Canker Disease

Importance: Injury to citrus leaves by the citrus leafminer is known to exacerbate citrus canker disease. Canker is an important disease of citrus due to the negative effects it has on tree productivity and yield. Perhaps more importantly, citrus canker is now endemic to the state of Florida which has severely reduced the State's citrus export market. This is because many potential customers live in regions where canker is currently not present, and trade embargoes have been established against the Florida fresh fruit market. It is also a problem in Texas. Bacteriologists are seeking improved methods for managing the disease, including: windbreaks, novel chemical control sprays, and even transgenic solutions.

Research Gaps: Urgent solutions to the canker problem are needed. This includes determining the extent to which the citrus leafminer exacerbates the incidence of canker, as well as methods for controlling the leafminer. In the short-term, control will likely be dependent on insecticides during the summer, although increased pesticide use for this purpose is undesirable. Concurrently, there is a need to initiate development of long-term, sustainable approaches to leafminer management.

Actions: ARS will:

Monitoring

- Improve sampling and monitoring methods for citrus leafminer and citrus canker disease.
- Investigate optimal pheromone component blends for attracting and monitoring leafminers in traps.

Damage Assessment

- Assess the quantitative relationship between leafminer damage to citrus and both the incidence and severity of citrus canker.

Control, Interference with Leafminer Olfaction

- Discover volatile attractants (pheromones and host-plant volatiles) and plant repellents or confusants that can be used to interfere with leafminer mating and host-location.

- Determine optimal pheromone component blends for mating disruption in order to reduce the spread of citrus canker.
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3. *Diaprepes* Root Weevil

Importance: The *Diaprepes* root weevil is an important pest of citrus and some ornamental plants in Florida and has spread to Texas and California. For a number of years this weevil was considered the most important invasive insect pest of Florida citrus (until the arrival of the Asian citrus psyllid and citrus greening disease). Progress has been made in managing *Diaprepes* root weevil in citrus and ornamentals in Florida. Biological control agents have been imported and successfully established but only in extreme southern areas of the state. Citrus germplasm with some resistance (tolerance) to feeding by larvae of the weevil has been identified. However, affordable, environmentally sound strategies for this pest are still lacking. Sampling methods have been developed for the adult stage of the weevil, but these are for the most part mediocre methods.

Research Gaps: Solutions to the Diaprepes problem in citrus are urgently needed. The most promising and sustainable strategies identified came about through advances in our knowledge of the chemical ecology of the weevil and the development of citrus with plant resistance to the weevil.

Actions: ARS will:

Attractants

- Discover plant kairomones, weevil pheromones and non-host plant allomones that can be used to attract, repel, or confuse *Diaprepes* root weevil.
- Identify and synthesize promising semiochemicals.

Monitoring

- Improve sampling and monitoring methods for the weevil using traps baited with an attractant.

Control, Interference with Weevil Olfaction

- Develop methods of using attractants for interfering with *Diaprepes* mating and host-location.

Control, Host Plant Resistance

- Develop a transgenic citrus rootstock with resistance to *Diaprepes* root weevil. (Fort Pierce, Florida: Shatters, Hall, Lapointe)

***Anticipated Products*:**

- Increased knowledge of pest biology, ecology, behavior, genetics, and biological control agents, and of plant traits conferring pest resistance.
- Discovery, characterization, and synthesis of insect attractants, repellents and confusants.
- New biological control agents.
- Increased knowledge of the genomics and basic biology and ecology of biological control agents.
- Information on specific genes and gene-products involved in the replication of plant disease organisms in vector insects.
- Information on endosymbionts associated with subtropical insect pests.
- Identification of plant traits that might be used to develop pest-resistant plants.
- Development of plants with pest resistance.
- Novel methods of reducing the impact of subtropical insect pests of citrus, vegetables and ornamental plants.
- Information on trap crops as potential tools for pest management.
- Improved pest sampling and detection methods.
- Mating disruption.

***Potential Benefits (Outcomes)*:**

- Strategies for improved IPM of subtropical insect pests.
- Reductions in crop losses to insect pests of citrus and the plant diseases they transmit.
- Reductions in expenditures to manage insect pests.
- IPM tactics that are ecologically sound.

***USDA ARS Resources*:**

- Beneficial Insects Research Unit, Weslaco, Texas
- Subtropical Insects Research Unit, Fort Pierce, Florida

Component II: Protection of Agricultural and Horticultural Crops

2c. Nut Crops (U.S. Value 2007: $3.8 billion)

***Problem Statement*:** The principal commercial nut species (almonds, hazelnuts, macadamias, pecans, pistachios, and walnuts) do not produce maximum yields due to the following pests:

- Pecan weevil (in all pecan producing states except in the western United States, though it has been detected in New Mexico)
- Pecan Aphids (all pecan producing states)
- Navel Orangeworm (California but also some other western states, in almonds, pistachios, and walnuts)
- Peach Twig Borer (California, in almonds)
- Oriental Fruit Moth
- Obliquebanded Leafroller
- Filbert Worm and Filbert Weevil (primarily Oregon)
- Phytophagous Mites (all nut crops)
- Stink Bugs (all nut crops)
- Pecan Nut Casebearer (all pecan producing states)
- Weeds (nutsedges, vining weeds such as morningglory spp.) compete for resources in new orchards, interfere with irrigation, harbor insect and rodent pests, increase disease pressure, impede harvest, interfere with low volume irrigation systems, and intercept soil-applied chemicals (all orchards)
- Glyphosate-Resistant and Other Herbicide-Resistant Weed Biotypes (all orchards)

***Research Needs*:**

1. **Pecan Weevil**

   Importance: The pecan weevil is a key pest of pecans in many of the major pecan-producing states including Alabama, Arkansas, Florida, Georgia, Kansas, Louisiana, Mississippi, Oklahoma, South Carolina, and Texas. This economically important insect causes direct damage to the crop by feeding on and ovipositing in the developing nut. The pecan weevil infests more than 60 percent of managed pecan acreage; more than 300,000 acres are treated annually for this pest.

   Research Gaps: Current management practices rely solely on application of chemical insecticides for suppression of adult insects in the canopy during their feeding and oviposition periods. Application of these chemical insecticides can substantially reduce natural enemy populations causing outbreaks of other pests (such as aphids). Thus, due to potential pest resurgence as well as other environmental and regulatory issues, alternative control methods must be sought. Biological control agents (such as entomopathogenic nematodes and fungi) have shown some efficacy in suppressing pecan weevil larvae and adults, but additional research is required to integrate optimum biological control tactics with other management strategies. Additional innovations in pest suppression (such as using volatiles) should also be explored.

Actions: ARS will:

Control, Biological

- Determine the efficacy of biological and microbial control agents. Investigate the basic biology and ecology of these agents to enhance efficacy.
- Explore for new biological control agents with superior efficacy.
- Investigate improved methods of biological control agent production, formulation, and delivery.
- Integrate optimum biological control tactics with other management strategies.

Control, Other Alternative Approaches

- Additional innovations in pest suppression including the use of volatiles (such as for attract and kill) will be explored.

2. Pecan Aphids

Importance: Pecan foliage is attacked by three aphid species across the southern United States: black pecan aphid, blackmargined aphid, and yellow pecan aphid. Aphids feeding on pecan foliage can cause a reduction of leaf chlorophyll and leaf area, a decrease in leaf photosynthesis, depletion of carbohydrate reserves in stem tissue and even defoliation. Additionally, aphid feeding affects nut yield, nut quality, and return bloom. Aphid feeding also causes an indirect reduction in photosynthesis when black sooty mold grows on foliage covered with honeydew.

Research Gaps: The nature of the interaction between the aphids and the host pecan is poorly understood. More information is required regarding host plant resistance as related to cultivar susceptibility. Seasonal variation in constitutive levels of plant growth regulators appears important to aphid growth and damage to certain cultivars. Additionally, alternative and conventional management techniques are needed to insure continuous protection against aphid feeding.

Actions: ARS will:

Control, Host Plant Resistance and Interference with Aphid Feeding

- Assess seasonal impact of aphids on suspected susceptible and resistant cultivars.

- Assess the efficacy of different classes of plant growth regulators that disrupt normal development and feeding of aphids.

Control, Alternative and Conventional

- Assay natural enemy attractants under field conditions.
- Compare conventional and alternative aphid management plans.

3. Navel Orangeworm

Importance: In California the navel orangeworm (NOW), is a primary pest of almonds and pistachios and a secondary pest of walnuts (although in some years it causes more damage than any other insect). Direct damage by NOW can exceed 30 percent in almonds and 11 percent in pistachios, and infested nuts face an increased likelihood of mycotoxin (aflatoxins B1, B2, G1, G2) contamination, which is a serious food safety concern.

Research Gaps: Development of integrated control programs are needed on an area-wide level. Tactics that should be researched and integrated include: sanitation, mating disruption, and alternatives to chemical insecticides (such as use of entomopathogenic nematodes).

Actions: ARS will:

- Implement an area-wide IPM program that will reduce navel orangeworm damage,aflatoxin contamination, and broad-spectrum insecticide use.
- Collect baseline data characterizing the experimental plots in terms of NOW population density, historic levels of damage, sanitation efficacy, and the cost of current practices. Compare the efficacy of current and proposed NOW management programs using cost/benefit analysis.
- Identify key variables responsible for both consistent control and program failure and analyze the relative importance of these variables using epidemiological/epizootiological statistics.
- Expand an existing damage prediction model for Nonpareil almond damage that is based on Kern County data, to the other growing regions in the Central Valley; and develop a damage prediction model for pollenizer varieties of almonds and validate the model in the different growing regions.
- Determine the role played by NOW movement among multiple hosts on the efficacy of the new management practices demonstrated.
- Create NOW damage databases using grower-provided data that can identify high-risk areas for each commodity within a county and utilize these databases to develop a better understanding of the distribution of both NOW infestation and aflatoxin contamination within and between counties.

4. Glyphosate-resistant and Other Weeds

Importance: Weed control is a significant management issue in nut orchards. In young plantings, weeds compete with nut trees for nutrients, light, water, and space. Weeds can harbor insect and rodent pests, increase disease pressure, and interfere with irrigation systems. Additionally, because most nut crops are mechanically shaken from the tree and swept up from the orchard floor, complete control of weeds prior to harvest is essential for efficient harvest. Chemical weed control in tree nuts is dependant on relatively few herbicides: glyphosate (43-66 percent of acreage), paraquat (11-50 percent of acreage), and in some systems, oxyfluorfen (21-45 percent of acreage). Multiple applications of these herbicides are often needed each year. Recent identification of glyphosate-resistant weeds in some areas may lead to reduced weed control in these systems which, in turn, could lead to use of herbicides with less acceptable environmental impacts, decreased productivity, increased cold damage, or increased insect and pathogen problems.

Research Gaps: A greater understanding of the biology and physiology of weeds and alternative control strategies is needed.

Actions: ARS will:

Research directed toward controlling these resistant weeds is being addressed primarily in other ARS National Programs; no actions are proposed within National Program 304.

***Anticipated Products*:**

- Filling key knowledge gaps in basic insect pest and natural enemy biology and ecology such that our ability to develop effective methods of pest management will be enhanced.
- Novel alternative pest management tactics involving biological or microbial control agents, targeted volatiles, natural products or other innovative strategies.
- Improved methods for production, formulation, and delivery of biological control agents.
- Development of integrated orchard management systems.

***Potential Benefits (Outcomes)*:**

- New effective pest management strategies for nut crops that are ecologically and economically sound.
- Increased productivity and competitiveness in U.S. nut crops.
- Model systems of biological control agent production and application, and integrated pest management programs that are broadly applicable to other commodities.

USDA ARS Resources:

- Commodity Protection and Quality Research, Parlier, California
- Fruit and Nut Research Unit, Byron, Georgia

Component II: Protection of Agricultural and Horticultural Crops

2d. Pome Fruit [(U.S. Value 2007: $2.8 billion (apples and pears)]

Problem Statement: The principal commercial pome fruit species (apple and pear) do not produce maximum yields of high quality fruits at affordable costs due to the following pests:

- Codling Moth (apple and pear orchards; quarantine pest for exported pome fruits)]
- Pear Psylla (pear)
- Apple Maggot Fly (apple in eastern states, quarantine pest in western states)
- Secondary Pests of Apple and Pear Orchards: leafrollers (*Pandemis* leafroller, oblique banded leafroller, Oriental fruit moth, and light brown apple moth); aphids; scale insects; plant bugs; stink bugs; leaf miners; phytophagous mites; Japanese beetle (eastern states); dogwood borer (eastern states), and apple clearwing moth (potential new threat in Washington)
- Glyphosate-resistant and Other Weeds. (This problem statement is addressed in other subcomponents.)

Research Needs:

1. **Management of Codling Moth in Apple and Pear Orchards**

   Importance: Apple and pear growers need new and improved technologies and strategies to manage the codling moth, which infests fruit throughout the country. Growers struggle to respond to changes in pesticide regulations, economic issues, insect resistance to pesticides, and the pest complex in their orchards. Tolerance of codling moth in fruit is very low due to needs to meet consumer expectations and export criteria, while organophosphate insecticides are restricted, resistance to insecticides increases, and grower pest management costs increase. Management of codling moth by pheromonal mating disruption is difficult without compatible and complementary pest management methods to use to maintain high levels of pest control. Biological control of codling moth and other members of the pome fruit pest complex are disrupted by widespread use of insecticides.

   Research Gaps: Research is needed to develop, improve, and implement pest management methods that are affordable, effective, safe for people and the environment, and are compatible or complementary with mating disruption. To the extent possible, these methods should also be compatible with natural biological control of secondary pests. Information and methods are needed to foster or conserve natural enemies that are important biological control agents of orchard pests. In addition, better formulations are needed for application of pathogens and biopesticides to protect them from UV and dehydration. Formulations, knowledge of phenomenal chemistries, and strategies are also needed to reduce the costs and improve the efficacy of mating disruption.

Knowledge of pest biology, including behavior, ecology, physiology, genetics, and biochemistry, is needed to suggest and develop new approaches and technologies useful in pest management. Better techniques and genetic targets are also needed for genetic transformation of codling moth in support of sterile insect release (SIT) and other genetic strategies.

Actions: ARS will:

Knowledge of Pests and Pest Biology

- Develop methods for rapid screening of insect semiochemicals, using cloned pheromone receptor proteins, and identify novel chemical attractants and attractant analogs.
- Identify receptor proteins and their ligands that are critical to pest insect reproductive events and that might be exploited to control pest populations through biochemical and genetic manipulations.
- Determine the relative importance of different beneficial organisms in biological control of codling moth.
- Determine mechanisms and patterns of insect pathogen recycling and transmission in nature and in agro-ecosystems.
- Develop better understanding of pathogen development and infectivity within the insect pest host.
- Determine the behavior, ecology and population dynamics of codling moth in extra orchard habitats and assess the risks of these habitats to apple and pear orchards.

IPM and monitoring methods

- Develop applications for insect pathogens of the codling moth that are specific, cost-effective, safe, and environmentally-compatible.
- Develop attract-and-kill approaches and technologies based on pheromones, kairomones, and feeding attractants.
- Determine the impact of IPM practices, planting patterns, and orchard groundcovers on beneficial insects and on biological control of codling moth and secondary pests.
- Develop soft management programs for codling moth based on combinations of technologies and strategies.
- Develop improved semiochemical treatments for codling moth mating disruption, including combinations of pheromones and kairomones.
- Develop monitoring and management strategies to reduce the threat to commercial orchards from codling moth in extra orchard habitats.

2. Management of Pear Psylla in Pear Orchards

Importance: The pear psylla is a key pest of pear throughout the United States. It reduces tree vigor and fruit production, and direct damage to fruit occurs from the honeydew it produces and sooty mold that grows on the honeydew. Although biological control is adequate under some circumstances, the psylla is usually managed with pesticides that disrupt biological control methods used to control the pest. Growers need methods to enhance and conserve biological control agents, and monitoring tools to determine if control measures are needed.

Research Gaps: Better information is needed on the effects of the orchard ecosystem and landscape ecology on the dispersal and recruitment of predators, and the retention, survival and reproduction of predators in orchards. Predator species complexes also require taxonomic clarification. Better information is needed on the effects of soft pesticides on predator survival and reproduction. Such information will generate strategies to foster natural biological control. In addition, the identification of the sex pheromone of the pear psylla should provide a trapping system that growers can use to monitor the movement and changes in population densities of the insect, which will aid in pest management decision making.

Actions: ARS will:

IPM and monitoring methods

- Determine behavioral responses of the psylla to pheromones to aid in the identification, isolation, characterization, and development of the pheromone as a monitoring tool.
- Further define, using morphological, behavioral, and molecular approaches, the taxonomic status of forms of psylla predators in the genera *Anthocoris* and *Orius*.

3. Management of Secondary Insect Pests of Apple and Pear Orchards

Importance: Apple and pear growers need new and improved technologies and strategies to manage numerous insect pests. Biological control of leafrollers and other pests is disrupted by widespread use of insecticides. Apple maggot is increasing in distribution and prevalence in the Pacific Northwest and is a threat to the apple industry. A host of other insects must, at all times, be monitored and controlled to ensure good quality of harvested fruit.

Research Gaps: Research is needed to develop, improve, and implement pest monitoring and management methods that are affordable, effective, and safe for people and the environment, and are compatible with codling moth mating disruption. To the extent possible, these methods should also be compatible with natural biological control of secondary pests. Knowledge of pest biology, including behavior, ecology, physiology, genetics, and biochemistry, is needed to suggest and develop new approaches and technologies useful in pest management. Diagnostic methods, including biochemical approaches, are needed to identify some pest and beneficial species in orchards and in commerce, and to clarify the taxonomic status of some pest forms and populations.

Actions: ARS will:

Knowledge of Pests and Pest Biology

- Identify receptor proteins and their ligands that are critical to pest insect reproductive events and might be exploited to control leafroller populations.
- Develop methods for rapid screening of leafroller moth semiochemicals, using cloned pheromone receptor proteins, and identify novel chemical attractants and attractant analogs.
- Identify and improve chemical attractants for some pests, including lures for females of those pests, based on pest ability to locate foods, mates, and hosts.
- Develop diagnostic assays and use molecular methods to clarify the taxonomy of some pests and then beneficial insects.
- Determine the relative importance of different beneficial organisms in biological control of some pests, so as to prioritize work on the most effective biological control agents.
- Develop better understanding of pathogen development and infectivity within the host for the virus of *Pandemis* leafroller.

IPM and monitoring methods

- Develop applications for insect pathogens that are specific, cost-effective, safe, and environmentally-compatible.
- Determine the impact of IPM practices and orchard groundcovers on beneficial insects and on biological control of orchard pests.
- Develop combinations of technologies and strategies to provide soft management programs for insect pests.
- Develop mating disruption for dogwood borer.

4. Apple Maggot Fly

Importance: The recently (2003-2007) confirmed establishment of the apple maggot fly in central Washington State in wild hawthorn and non-commercial apple fruit represents a serious threat to the commercial apple industry. The fly, potentially, can infest commercial orchards there, as it does in the eastern United States and in western Washington State, and there is a zero tolerance for apple maggot larvae in exported apples. Apple maggot is a key production pest of apple throughout the eastern United States, and is largely controlled with pesticide sprays. The apple growing area impacted by apple maggot fly in central Washington may potentially be 45,000 acres, based on the areas of Kittitas and Yakima Counties that have been quarantined. To prevent further spread of apple maggot flies within these areas, local regulatory agencies rely on early detection and immediate control programs. Apple maggot flies caught near apple orchards pose a quarantine problem for apple export to California as well as virtually all of our export markets abroad.

Research Gaps: Alternatives to pesticide sprays are needed for control of apple maggot throughout its distribution. In Washington State, there is a strong need for a more sensitive detection method in support of requirements to document the absence of the fly from commercial orchards, or the possible development of fly free zones for exported fruit. Scale fruit volatile traps developed in the eastern United States are not effective in Washington and development of a specific fruit volatile that is attractive to apple maggot in the western United States is needed. Also, there is a need for identifying diagnostic traits that can be used to separate apple maggot fly from the nearly identical snowberry maggot fly, a non-pest species, and to clarify the genetic status of apple maggot in Washington in relation to other populations and to host use. Flies caught on traps cannot always be identified to species and cannot be identified to host race, so quarantines or control measures potentially may not be justified. In addition, there is a need to evaluate the environmental and physiological factors that could prevent apple maggot from the Pacific Northwest from reproducing and establishing in subtropical regions.

Actions: ARS will:

IPM and monitoring methods

- Improve detection of apple maggot fly using traps with fruit volatiles.
- Develop or improve attracticidal spheres for control of the fly.
- Provide diagnostic traits for identification of apple and snowberry maggot flies.
- Determine survival of apple maggot fly from Washington State exposed to simulated tropical, subtropical, and arid conditions.

5. Other Invasive Species of Apple and Pear

Importance: The distributions and status of insect pests continue to change at a rapid rate and the complex of pests that growers must deal with changes on a frequent basis. Detection and monitoring methods are usually not in place and management strategies must be developed as a rapid response to new threats. In some cases, we do not know the scope of the risk to orchard crops until after an invasive species is established, wherein options for eradication or slowing its spread are limited.

Research Gaps: Research is needed to develop and improve detection of pests that are likely to spread or expand their ranges within the United States. Examples are the false codling moth, marmorated stink bug, apple clearwing moth, plum curculio, light brown apple moth, and apple maggot. Pest management methods and strategies developed for established pests need to be adapted or evaluated for use against new pests, as needed. Knowledge is needed on environmental factors delimiting likely distributions and pestiferous populations of key pests and pests that pose a significant threat.

Actions: ARS will:

IPM and monitoring methods

- Identify semiochemicals such as pheromones and develop lures and trapping methods for insect pests that are newly introduced or are expanding geographic and host ranges.

6. Phytosanitary and Export Quarantine Pests

Importance: The presence of insects and other arthropods on and in fruit is generally not tolerated by the consumer, and often is of concern in relation to quarantines put into place to prevent the movement of pests with commodities. Two major export pest problems for U.S. apple and pear growers are the codling moth and apple maggot. The use of methyl bromide for dis-infestation of insects in fruits is under review by the Montreal Protocol for possible phase out or restriction of current use. Export markets are at risk when fruit cannot be shipped free of these pests. Solutions to these problems have changed from a strictly post-harvest situation to a systems approach, including the orchard environment and IPM program to reduce the probability of insects in fruit when packed.

Research Gaps: Research is needed to build a systems approach to ensuring the absence of pest insects in exported fruits. These needs include: understanding the impact of changes in IPM on risks of infestations of fruit, improved detection capabilities for finding infested fruits, mathematical models for assessing risks of infested fruit, and improved alternative post harvest treatments for dis-infesting fruit. A better understanding of the biology of the apple maggot in extra-orchard environments in the Pacific Northwest is needed to properly assess the risk of those populations to commercial apple production. [Also see Post-harvest subcomponents.]

Actions: ARS will:

IPM and monitoring methods

- Improve the applications of controlled atmosphere and temperature treatment systems (CATTS) for post harvest fruit treatment.
- Identify chemical markers for infested fruit that might be useful in the development of automated systems for detecting such fruit in packing houses.
- Determine infra-red patterns from fruit infested with codling moth and apple maggot, for possible application to packing line detection systems.

- Determine the host use pattern of the apple maggot in Washington and clarify the taxonomic status of this fly in relation to its threat to apple.

Anticipated Products:

- New and improved lures and trapping methods for detection and monitoring of pests.
- Management technologies and strategies for insect pests, including applications of pathogens, biological control, cultural methods, and semiochemicals for mating disruption and attract-and-kill technologies.
- The filling of key knowledge gaps in basic pest and natural enemy biology in relation to the application of methods of pest management.
- Development of optimal chilling regimes for reducing risk of infestation in fruit in storage.
- Diagnostic tools for separating apple and snowberry maggot flies and potentially other species complexes.

Potential Benefits (Outcomes):

- More effective IPM for apple and pear orchards.
- Grower cost savings from reduced pesticide use through improved IPM.
- Increased access of Pacific Northwest fruit to foreign markets.
- Reduced use of pesticides, along with reduced worker exposure to pesticides, and reduced pesticides in water and air.

USDA ARS Resources:

- Fruit and Vegetable Insect Research Unit, Wapato, Washington
- Beneficial Insect Introduction Research Unit, Newark, Delaware
- Innovative Fruit Production, Improvement and Protection Research Unit, Kearneysville, West Virginia

Component II: Protection of Agricultural and Horticultural Crops

2e. Stone Fruit (U.S. Value 2007: $1.3 billion)

***Problem Statement*:** The principal commercial stone fruit species (cherries, peaches, apricots, and nectarines) do not produce maximum yields of quality fruit due to the following pests:

- Cherry Fruit Fly
- Plum Curculio
- Peachtree Borers
- Oriental Fruit Moth
- Peach Twig Borer
- Phytophagous Mites
- Aphids
- Cherry Bark Tortrix
- Stink Bugs
- Thrips
- Root Feeding Weevils
- Japanese Beetle and Green June Beetle
- Glyphosate-Resistant Weeds

Research Needs:

1. **Cherry Fruit Flies**

   Importance: The western cherry fruit fly is a major quarantine pest of sweet cherries in the Pacific Northwest of the United States. There is a zero tolerance for cherry fruit fly larvae in fresh cherries whether for export or domestic sale, with specific phytosanitary requirements varying among countries. Methyl bromide fumigation of cherries against cherry fruit fly is required by several trading partners, though the cherry industry is actively seeking an alternative to this fumigant.

   Research Gaps: Research is needed to provide growers with better tools to determine the status of cherry fruit fly in their orchards and to reach fly-free status. This includes quantifying the densities of flies in unmanaged cherry trees and the risks of flies dispersing and infesting managed commercial orchards; determining the adequacy of current spray programs for control of the flies (in particular the use of different spray intervals and newer and safer insecticides at pre- and post-harvest); determining chilling regimes that are most effective in killing egg and larval stages of the fly in fruit; and determining if current methods used to detect fly larvae in harvested cherries in the warehouse are adequate to ensure a high level of assurance that fruit are free of infestation.

Actions: ARS will:

- Determine the efficacy of new and safer materials for use in spray programs for control of cherry fruit fly.
- Determine optimal chilling regimes for killing cherry fruit fly larvae in harvested fruit in the warehouse.
- Develop a better understanding of cherry fruit fly behavioral responses to attractants, baits, and traps.
- Develop new knowledge of cherry fruit fly phenology, host use, dispersal and orientation, and food sources.

2. Plum Curculio

Importance: The plum curculio has traditionally been a critically important pest of stone fruits (including peaches, plums, and cherries) as well as pome fruits, particularly in the eastern United States, as well as some other significant stone-fruit producing states. Due to potential changes in its distribution and host use, it threatens to be of importance throughout the entire country. The insect causes direct damage to the fruit by feeding and oviposition.

Research Gaps: Detection and monitoring of plum curculio is difficult and rarely conducted by growers, since chemical attractants perform poorly and traps are cumbersome. Isolation and identification of pheromones and host attractants, and a better understanding of plum curculio reproductive behaviors would lead to improved lures and traps. Current management of plum curculio relies on applications of broad spectrum chemical insecticides. Biological and microbial control agents have shown some efficacy in suppressing plum curculio larvae in the soil, but additional research is required to integrate optimum biological control tactics with other management strategies. Furthermore, research is needed to define this pest's ecology (particularly movement patterns) on a landscape scale.

Actions: ARS will:

- Determine efficacy of biological and microbial control agents.
- Integrate optimum biological control tactics with other management strategies.
- Develop improved attractants and trapping systems for the plum curculio.

3. **Peachtree Borers**

Importance: The peachtree and lesser peachtree borers are major pests of peach, plum, and cherry trees. Larvae cause severe damage to trees by boring into the trunk, limbs, and roots. These pests have increased in importance due to the removal of certain broad-spectrum insecticides used for control.

Research Gaps: Currently, there are no treatments available that produce acceptable levels of control, so alternative management solutions are needed for both of these pests. Entomopathogenic nematodes can kill the larvae, though desiccating conditions on the tree trunk or limbs limit the nematodes' efficacy. Advances and optimization in application technology and formulation of entomopathogenic nematodes are needed to facilitate effective implementation of this biological control solution. Mating disruption or an attract-and-kill strategy may provide a complementary or alternative management option.

Actions: ARS will:

- Investigate mating disruption for management of lesser peachtree borer.
- Investigate novel formulations and methods of application for use of entomopathogenic nematodes.
- Optimize the timing and rates of application for entomopathogenic nematodes and other biological control agents.
- Develop applications of target-specific insecticides.

4. **Integrated Pest Management of Secondary and Newly Invasive Insect Pests of Cherry, Peach and Nectarine Crops**.

Importance: Technologies and strategies are needed to manage insect pests of commercial cherry, peach and nectarine crops to reduce damage, reduce pesticides in the environment and on the commodity, improve worker safety and improve profitability.

Research Gaps: Alternative technologies, methods, and strategies are needed for management of numerous insect pests of stone fruits, in part to replace organophosphate insecticides that are increasingly restricted by regulation. New insect pests become problems on a frequent basis, either through introduction into the United State or changes in their geographic distribution.

Actions: ARS will:

- Develop improved attractants and trapping systems for brown marmorated stink bug.

- Identify, through foreign exploration in Asia, biological control agents of brown marmorated stink bug for evaluation and introduction into North America.
- Develop improved attractants, traps, and trapping strategies for monitoring and management of the brown stink bug.

5. Glyphosate-resistant and Other Weeds

Importance: Weed control is a significant annual management issue in *Prunus* fruit orchards. In young plantings, weeds compete with fruit trees for nutrients, light, water, and space. Weeds also can harbor insect and rodent pests, increase disease pressure, and interfere with irrigation systems. Glyphosate is the most common herbicide used in these orchards, though the recent identification of glyphosate-resistant weeds in some areas may lead to reduced weed control in these systems which, in turn, could lead to use of herbicides with less acceptable environmental impacts, decreased productivity, increased cold damage, or increased insect and pathogen problems.

Research Gaps: A greater understanding of the biology, ecology and physiology of weeds is needed as well as the development of alternative control strategies.

Actions: ARS will:

Research directed to managing glyphosate-resistance in other crops should have application to stone fruit systems.

***Anticipated Products*:**

- Novel alternative pest management tactics involving biological or microbial control agents, pheromonal mating disruption, and attract-and-kill.
- Improved methods for production, formulation, and delivery of biological control agents.
- Development of integrated orchard management systems.
- New and improved lures and trapping systems for use in detecting and monitoring pests.

***Potential Benefits (Outcomes)*:**

- New effective pest management strategies for stone fruit crops that are ecologically and economically sound, and that increase productivity and competitiveness in U.S. stone fruit crops.
- Model systems of biological control agent production and application, and integrated pest management programs that are broadly applicable to other commodities.

***USDA ARS Resources*:**

- Beneficial Insect Introduction Research Unit, Newark, Delaware

- Fruit and Vegetable Insect Research Unit, Wapato, Washington
- Fruit and Nut Research Unit, Byron, Georgia
- Invasive Insect Biocontrol and Behavior Laboratory, Beltsville, Maryland

Component II: Protection of Agricultural and Horticultural Crops

2f. Vegetables (U.S. Value 2007: $17 billion)

Problem Statement: The principal commercial vegetable crops (including potato, tomato, onion, leafy greens, cucurbits, crucifer crops) do not produce maximum yields due to the following pests and gaps in knowledge:

- *Bemisia tabaci* and Whitefly Transmitted Viruses (U.S.: tomato, watermelon, squash, snap beans, and other crops)
- Onion Thrips and Iris Yellow Spot Virus
- Thrips and Tomato Spotted Wilt Virus in Tomatoes and Other Vegetable Crops (U.S.: tomato, peppers)
- Chilli Thrips (diverse vegetable crops in Florida, Georgia, Texas)
- Beet Leafhopper in Potatoes and Other Vegetable Crops
- Potato Psyllid (in potatoes and other solanaceous crops, including tomato) and Zebra Chip Disorder in Potatoes
- Wireworms in Potatoes and Other Vegetable Crops (U.S.: potato, sweet potato, sweet corn)
- Colorado Potato Beetle in Potato and Other Solanaceous Vegetables (eastern United States)
- Pale Cyst Nematode *(Globodera pallida)* and *Globodera* n. sp., a New Species of Cyst Nematode, in Potato (in Pacific Northwest)
- Diamondback Moth in Crucifers
- Striped and Spotted Cucumber Beetles in Vegetables (especially cucurbits and sweet potatoes) and Flowers, including Organic Operations (all States)
- Regional Differences in Pest Status of Insects in Vegetables and/or Effectiveness of Natural Enemies
- Improved Use and Rearing of Biological Control Agents (predators and parasitoids)
- Improved Development and Use of Insect-Specific Pathogens
- Annual and Perennial Weeds
- Other Important Pests include: Potato Tuberworm (Washington: potatoes) and Other Moths, and Viruses Transmitted by Aphids (green peach aphid, soybean aphid, etc.) (U.S.: potato, squash, snap beans)

<u>Research Needs</u>:

1. ***Bemisia tabaci* and Whitefly Transmitted Viruses**

Importance: First described over 100 years ago, *Bemisia tabaci* has since become one of the most devastating tropical and sub-tropical agricultural pests worldwide. *B. tabaci* has been recorded from more than 600 plant species. Crop losses can occur not only from direct feeding damage but also from feeding induced plant physiological disorders, honeydew contamination and associated fungal growth, as well as plant diseases caused by whitefly transmitted viruses. *B. tabaci* is a vector of 111 recognized plant virus species in the genera *Begomovirus* (Geminiviridae), *Crinivirus* (Closteroviridae), *Carlavirus* and *Ipomovirus* (Potyviridae). There are more than 20 biotypes of this whitefly species, with two of the most damaging to plants, the B and Q biotypes, residing in the United States. Biotype B was first discovered in the United States in 1985 and biotype Q more recently in 2004. Biotype Q was detected during routine resistance monitoring efforts when resistance values of 1000-fold were observed for buprofezin (a commonly used insect growth regulator for whitefly control). Following the introduction of biotype B, new plant pathogenic begomoviruses began to appear and threaten tomato production in many U.S. tomato growing areas. Due to the broad host range and aggressive nature of biotype B, it is likely that this whitefly will continue to be a source of introduction of new viruses into tomato and other crops. Biotype Q is also a very efficient vector of plant viruses in the Mediterranean Basin which is considered its native range and may follow the same scenario if it makes the jump from ornamentals to field grown vegetables. Currently it has been detected in 25 U.S. states, on herb and ornamental hosts.

Research Gaps: Vital solutions to the *B. tabaci* problem in tomatoes are needed. Economic losses in tomatoes related to begomoviruses are currently negated through the use of costly and intensive pesticide treatments for whitefly control. Begomovirus-tolerant tomato varieties have been developed but insecticidal control of *B. tabaci* remains the major disease-control strategy. Growers rely almost exclusively on insect growth regulators and one chemical class of insecticides (neonicotinoid), yet resistance to these insecticides in *B. tabaci* has been well documented overseas. With respect to varieties with resistance to begomoviruses, the mechanism of resistance and commercial stability of this resistance are unknown. Tomato growers will likely turn to such varieties if widespread insecticide resistance develops in *B. tabaci* stateside. If so, the reoccurrence of production problems related to disorders such as tomato irregular ripening would likely occur. Research should address vector-pathogen interactions and insect-plant interactions, role of endosymbionts, aspects of population ecology, and rapid methods of biotype detection. Research should aim at identifying the genetic basis of tomato resistance to plant viruses and transmission of these viruses by *B. tabaci* as well as novel biotechnology strategies for overcoming whitefly/virus resistance. This information would in turn be used to develop new and improved methods for reducing whitefly mediated crop losses in tomato.

Actions: ARS will:

Vector-pathogen Interactions

- Determine molecular phenomena involved in transmission.
- Insect-plant Interactions and Host Plant Resistance
- Use conventional methods to develop resistant crop hosts.
- Determine heritability of resistance in melons and watermelon.
- Develop novel host plant resistance through interdiction of important biological processes (RNAi, Bt, etc.).
- Understand causes of physiological disorders in host plants.

Endosymbionts

- Determine primary and secondary role of endosymbionts in whitefly physiology.
- Investigate role of *Wolbachia* in reproduction, fitness, and virus transmission.

Population Ecology

- Understand U.S. population dynamics in context of global phylogeny.
- Determine extent of gene flow among mixed biotype populations and influence on fecundity and insecticide resistance.

Detection

- Develop simple rapid PCR-based detection of biotypes – including field applicable protocols.

Monitoring

- Develop trapping methods using pheromones and kairomones.
- Evaluate LED-modified traps for whitefly control.

Control, Biological

- Assess the importance of biological control agents in reducing whitefly populations.
- Investigate the effect of alternative host plants on parasitoids of whiteflies.
- Determine the overwintering ability of whitefly predators in order to develop methods to conserve and augment natural populations.

2. Onion Thrips and Iris Yellow Spot Virus

Importance: Onion thrips is the vector of iris yellow spot virus (IYSV), which is an emerging threat to the United States onion industry. Iris yellow spot has been present in the Pacific Northwest for over 15 years, but has now spread to all major onion producing

States. The reasons for the sudden development and dissemination of IYSV on onion bulb and seed crops in the United States remain unclear. Projected economic impacts, if the rate of spread and damage by IYSV and thrips continue unchecked in the western United States, could reach $80 million (10 percent loss) to $120 million (15 percent loss in farmgate value), in addition to environmental and economic costs associated with additional pesticide sprays that have limited efficacy ($7.5 to 12.5 million dollars for 3 to 5 additional sprays applied to 120,000 acres per year). Onion growers in the western United States currently rely almost exclusively on insecticides for thrips management. Problems with insecticide resistance in western populations of onion thrips have been reported for over 15 years. Reliance on insecticides alone to control thrips in onions is not sustainable.

Research Gaps: The epidemiology of IYSV and its thrips vector are largely unknown, and the literature is devoid of IYSV management recommendations. Studies of the biology and epidemiology of IYSV and onion thrips are needed to establish economic injury levels for onion thrips when IYSV is a threat and develop appropriate ecologically-based IPM programs for this pest complex. There is also need to determine how these IPM programs would affect management of other pests and production practices. There is a critical need to develop onion germplasm and cultivars with improved levels of resistance or tolerance to IYSV and onion thrips. Improved diagnostics for detecting the virus in thrips and plants would facilitate monitoring and other fundamental studies of this pathosystem.

Actions: ARS will:

Host Range

- Determine reproductive hosts vs. adult feeding hosts for onion thrips.
- Determine potential sources of thrips and virus.

Population Ecology

- Characterize relationships between IYSV incidence and thrips populations on onions and weed hosts in the field.

Monitoring

- Improve sampling and monitoring methods for the vector.

3. Thrips, Tomato Spotted Wilt Virus in Tomatoes, and Other Vegetable Crops

Importance: Over the past two decades, outbreaks of tomato spotted wilt have increased greatly on a number of crops, such that tomato spotted wilt virus (TSWV) is now considered one of the most important pathogens globally, with estimated losses exceeding $1 billion dollars annually. The principal vegetable crops at risk from tomato spotted wilt are tomatoes, peppers, lettuce, eggplant, and potatoes. The primary vector of TSWV is the western flower thrips, although at least two other thrips species present in the United States are known vectors. Management of thrips and tomato spotted wilt on tomatoes has relied on high input control measures, including extensive use of conventional synthetic pesticides. Not only do these chemicals not provide satisfactory disease control, but they also pose threats to consumers, growers, and the environment, and they can disrupt management programs for other pests, leading to secondary pest outbreaks.

Research Gaps: In order to safeguard the tomato industry and other vegetables, immediate research is required to develop efficient management programs for flower thrips and tomato spotted wilt. To the extent possible, these methods should avoid disrupting current programs that successfully control other pests. Alternative control methods that need to be addressed include improved use of naturally occurring biological control agents and methods to limit dispersal of thrips into crop fields. Efficient monitoring methods for the viruliferous thrips, and forecasting of disease severity would facilitate the targeting of control methods. Achieving these goals will require a better understanding of sources of infectious thrips and how thrips disperse into crops. Therefore, research is needed to understand season to season variation in populations of infectious thrips and their dispersal behavior. In addition, customers have identified the need for improved disease resistant varieties.

Actions: ARS will:

Population Ecology

- Conduct long-term studies of thrips population dynamics, with a focus on factors affecting the abundance of infectious thrips.
- Determine non-crop sources of infectious thrips.

Vector-pathogen interactions

- Investigate ability of thrips to acquire and transmit different virus strains from and to different host plants.

Control, Biological

- Characterize interactions between thrips and their predators, including host plant effects on interactions.
- Develop methods to conserve and augment naturally occurring populations of thrips predators.

Control, Interference with Host Plant Location

- Investigate new methods and materials to deter and/or repel thrips from entering crop fields.

4. Chili Thrips

Importance: The chili thrips (*Scirtothrips dorsalis*) is widespread across its natural range in tropical Asia and has recently been detected in the United States in Florida and Texas. The pest threatens to expand its range to most of the southern United States.

Chili thrips are highly polyphagous and have been recorded from more than 100 plant species spread across 40 different families. As with other plant feeding thrips, damage is caused by sucking sap from individual epidermal cells leading to necrosis of the tissue. Damage is most severe at growing tips, on young leaves and shoots, or on flowers and young fruits. On chilies, large numbers of thrips have been found causing young leaves to shrivel or curl badly; leaves may be shed and crop loss can reach 90 percent. Damage to roses and other ornamental hosts can be devastating with plants becoming completely defoliated, resulting in death. Chili thrips have also been reported to vector a number of plant viruses in peanut and tobacco, but it is unclear if *S. dorsalis* can transmit tomato spotted wilt virus.

Research Gaps: When invasive pests enter the United States, rapid and accurate taxonomic characterizations of the invader, as well as a determination of its genetic diversity and position in the global phylogeny of the species are crucial information. This information is a fundamental requirement to plant quarantine and biological control programs, as well as development of classical IPM control strategies. Furthermore, this information has proven useful in international trade negotiations with respect to quarantine, and plant material movement limitations. Currently, there are many taxonomic questions that need to be answered with this chili thrips species. Morphological variation has made species and subspecies determinations very difficult and many researchers believe that *S. dorsalis* may contain multiple biotypes or could be a cryptic species complex. Information regarding this invasive species is limited and research should be broad, including population genetics, general biology, host range (including crops and weeds), virus transmission potential, pesticide control and resistance monitoring, biological control, development of thresholds, and effect of cultural measures.

Actions: ARS will:

Population Genetics

- Investigate U.S. population thrips dynamics in context of global phylogeny to determine origin of U.S. thrips populations.
- Assess gene flow among thrips populations in the United States to determine complexity of genetic structure.

General Biology

- Determine thermal limitations and developmental times.
- Monitor movement between commodities.
- Identify key thrips pupation sites.
- Improve identification and taxonomy, using both classical and molecular technology.

Host Range (crops and weeds)

- Determine damage potential.
- Determine reproductive hosts vs. adult feeding hosts.

Virus Transmission

- Determine vector potential for tomato spotted wilt and other important viruses affecting vegetables.

Control, Insecticide

- Identify effective products.
- Determine residual activity.
- Determine optimal timing, frequency and method of application.
- Establish baseline data for resistance management.

Control, Biological

- Identify predators, parasitoids, pathogens and nematodes that could be effective biological control agents.
- Investigate rearing methodology to improve quantity and quality of biological control agents.
- Determine impact of pesticides on beneficial insects.
- Assess predator needs for pollen or alternate foods
- Assess host plant impacts on efficacy of biological control agents (i.e., tomato vs. ornamental hosts).
- Investigate soil controls against thrips pupae.

Develop Commodity Thresholds

- Greenhouse (herbs, vegetables, and potted plants)
- Field Vegetables

Impact of Cultural Practices

- Investigate the effect of fertility, pruning, flowering, watering, etc., on the pest and biological control agents.

5. **Beet Leafhopper in Potatoes and Other Vegetable Crops**
   Importance: Potatoes and other vegetable crops are attacked by the beet leafhopper, *Circulifer tenellus*. The beet leafhopper has been identified as the vector of beet leafhopper-transmitted viresence agent (BLTVA) phytoplasma, a causal agent of the potato purple top disease, which has recently been causing serious outbreaks in the Columbia Basin of Washington and Oregon. The disease is becoming increasingly important and damaging in the Pacific Northwest, causing significant yield losses to potato fields and reduction in tuber processing quality. It is difficult to effectively

manage the beet leafhopper and purple top disease in potatoes. The difficulty arises from the fact that there is very low to zero tolerance for several insect-vectored plant pathogens in potatoes, especially for potato seed growers and the processing industry, making acceptable control strategies difficult to growers, even with conventional means. There is a need to develop an improved way for growers to accurately assess the degree and timing of the beet leafhopper threat for effective control.

Research Gaps: It is crucial to understand the source and movements of the beet leafhopper to determine if infectious leafhopper populations are local or are originating from more distant locations. In addition, since the incidence of BLTVA phytoplasma within potatoes is a function of vector dispersal from weedy habitats to potatoes, this aspect also warrants investigation. There is incomplete knowledge of the relationship between crop and non-crop habitats and abundance of beet leafhoppers in adjacent potato crops. Moreover, there is incomplete understanding of beet leafhopper movement, overwintering, and the relationship of these traits with incidence of leafhopper-vectored diseases in potatoes. Furthermore, there is a lack of action thresholds and information on how insecticides should be timed to most effectively target this insect pest.

Actions: ARS will:

Population Ecology

- Determine the relationship between weed community and abundance of the beet leafhopper.
- Determine the source and the importance of the overwintering and spring/summer beet leafhopper populations in potatoes.
- Elucidate the local spatial
- Ecology of leafhoppers in circumpolar agroecosystems.

IPM

- Develop action thresholds and information on how insecticides should be timed to most effectively target the beet leafhopper.

6. Potato Psyllid (in potatoes and other solanaceous crops, including tomato) and Zebra Chip Disorder in Potatoes

Importance: The potato psyllid is indigenous to the southwestern United States and northern Mexico and is known to migrate long distances to exploit its solanaceous host plants, including potatoes, tomatoes, and peppers. Potatoes and other vegetable crops are attacked by the potato psyllid, *Bactericera cockerelli*, which has recently been identified as associated with zebra chip, a new disease (or disorder) of potato in the southwestern United States, Mexico, Central America, and New Zealand. Zebra chip was first noted in the United States in the Lower Rio Grande Valley of Texas in 2000. In Texas, potato production was valued at $91.6 million in 2005, but the crop is at risk since all the major potato production areas in Texas and parts of Mexico have experienced outbreaks of zebra chip. Zebra chip leads to lower yields, and also to the rejection of chips processed from infected potatoes. Chips processed from infected tubers have a dark color defect and are commercially unacceptable. Tubers infected with zebra chip generally do not sprout, or if they do, produce hair sprouts or weak plants. Mechanisms by which the potato psyllid induces zebra chip are not known. The potato psyllid is suspected to inject pathogens and/or toxins in plants when feeding. Recently, a new species of bacterium has been associated with zebra chip infected plants and potato psyllids. However, the role of this bacterium in zebra chip symptom expression is not yet clear.

Research Gaps: There is a need to increase the understanding of the role of the potato psyllid in zebra chip. In addition, little is known on the etiology and epidemiology of the disease. More studies on the ecology and population dynamics of this insect pest are needed to develop effective management strategies. Further research is needed to: investigate the role of native solanaceous plants as refuges for the pathogen; characterize the genotypes of *B. cockerelli* in Central and North America and evaluate their ability to vector zebra chip; compare the phenology of *B. cockerelli* with other pest psyllids, such as the Asian citrus psyllid. Grower difficulties in managing the potato psyllid with available tools have led to a need for research to develop effective alternative control methods that are compatible with current growing practices and IPM programs. Monitoring tools that are effective, acceptable, and used by growers are needed. This information is needed to refine the IPM program recently developed for this pest.

Actions: ARS will:

Vector Biology

- Assess the role of the potato psyllid in zebra chip by conducting transmission studies under laboratory and field conditions.

Population Ecology

- Study the phenology and population dynamics of the potato psyllid.
- Conduct additional field research to determine the potential refuges of the zebra chip pathogen.
- Assess environmental factors that influence zebra chip symptom expression, including planting time and plant growth stage.

Population Genetics

- Collect insect material for the genetic evaluation of *B. cockerelli*. ARS will conduct this research in tandem with research directed at the Asian citrus psylla.

Monitoring

- Develop effective and improved monitoring tools for the potato psyllid.

IPM

- Refine existing IPM program strategies for the potato psyllid, including chemical, biological, and cultural controls.

- Collaborate with the Texas Agrilife Extension Service to implement the IPM program developed by ARS.

7. Wireworms in Potatoes and Other Vegetable Crops

Importance: Potatoes and other vegetable crops are attacked by a complex of wireworm species. Problems caused by these soil-dwelling pests in irrigated crops appear to be increasing in severity. Current difficulties in managing these pests are due to a combination of factors: incomplete understanding of wireworm biology, the subterranean life cycle of the damaging life stage, multi-year development times, a paucity of effective insecticides, poor understanding of the relationship between wireworm numbers and damage potential, and a lack of effective monitoring tools.

Research Gaps: Grower difficulties in managing wireworms with available tools have led to a need for research to develop alternative control methods that are compatible with current growing practices and IPM programs. Monitoring tools that will be accepted and used by growers are needed. Research to develop synthetic attractants for the subterranean larval stage or the adult click beetle stage would lead to new monitoring tools and possibly to new control technologies (i.e., attract-and-kill methods). Biological studies to assess how larvae or adults are affected by putative attractants are also required. A poor understanding of how wireworm density predicts damage potential requires research to define this relationship quantitatively. Research that defines the environmental and biological factors that affect wireworm densities and distribution in fields would allow growers a means for assessing risk before planting of the crop.

Actions: ARS will:

Monitoring/Prediction of Damage

- Assess wireworm or click beetle response to putative attractants.
- Develop and improve monitoring tools.
- Determine the relationship between wireworm densities and damage potential.
- Define how field characteristics (e.g., soil type, growing history) predict wireworm infestation.

Control, Semiochemicals

- Develop methods to use synthetic attractants in control programs.

Control, Host Plant Resistance

- Identify sources of resistance.
- Determine heritability of resistance.
- Facilitate incorporation of resistance into advanced sweetpotato breeding lines and new cultivars.

8. Colorado Potato Beetle, in Potato and Other Solanaceous Vegetables

Importance: This key pest is most important east of the Rocky Mountains but is an occasional problem in the West as well. Starting around 1990, it has been controlled in many areas almost exclusively with nicotinoid insecticides, principally imidacloprid, but in the past few years, control failures have been documented as well as cross-resistance to related, more recently-registered insecticides.

Research Gaps: An integrated management system is critical to the longevity of any given pesticide class, thus a system should include cultural controls such as breeding and cultural tactics to increase crop resistance, crop rotation and timing (including trap cropping), conservation and deployment of microbial and arthropod biological controls, and application of semiochemical attractants and antifeedants. An integral component to any integrated management system is understanding the phenology of the potato beetle. Diapause is the chief physiological mechanism underlying insect phenology

Actions: ARS will:

Control, Semiochemicals

- Evaluate best strategies for use of plant volatile attractants (kairomones) and beetle pheromones, as well as antifeedants related to trapping, trap cropping, and crop timing. Strategies will likely differ by region.

Control, Biological

- Determine best practices for conservation and augmentation of natural enemies native to North America, including identification of limitations to biological control in potato and other agroecosystems.
- Identify and apply microbial (bacterial and fungal) controls that are selectively effective controls for the pest. One important component of this is to determine the role of endosymbionts and gut physiology in pathogen defense by the pest.

Control, Plant Breeding

- Enhance constitutive resistance against pest feeding and damage through conventional breeding. (Link to Madison: Vegetable Crops Research Unit)
- Pursue pest-induced expression of plant defenses as a mechanism for durable resistance.

Control, Cultural

- Determine factors responsible for cover-crop, mulch and manure effects on pest population suppression.

Biology

- Develop an understanding of diapause development and termination in the potato beetle.

9. Pale Cyst Nematode *(Globodera pallida)* and *Globodera* n. sp., a New Species of Cyst Nematode, in Potato

Importance: Two cyst nematodes new to the United States have recently been identified in the Pacific Northwest. In March, 2006, the Nematology Laboratory received and subsequently identified the pale cyst nematode *(Globodera pallida)* from soil collected at a potato processing plant in Idaho. This discovery represented the first detection of this major quarantine pest in the United States. Regulatory action was initiated, including the implementation of a survey designed to sample all U.S. potato-growing fields. Another species of cyst nematode, new to science, has been identified from a potato field in Oregon by the Nematology Laboratory. In May, 2008, the Laboratory received cysts from potato-growing acreage in Oregon and concluded that the cysts represent a new species of round cyst nematode (i.e., *Globodera* sp.). The host range of this new species and its ability to infect potato are obviously unknown. Species of *Globodera* have limited host ranges. APHIS has been notified through usual channels. If this species proves to be pathogenic on potato, significant regulatory impact will undoubtedly follow.

Research Gaps: As both of these species are new to the United States, and one is new to science, there is a need for more information on their biology, ecology, taxonomic status, host range, pathogenicity, and distribution in the United States.

Actions: ARS will:

- Conduct research on these cyst nematodes under National Program 303 – Plant Diseases.

10. Diamondback Moth in Crucifers

Importance: The diamondback moth *(Plutella xylostella)* is a major pest of crucifers (e.g., broccoli, cabbage, cauliflower, collard, mustard greens, radish and turnip). Major crucifers grown in the United States include broccoli (54,777 ha), cabbage (32,222 ha), and Brussels sprouts (1,174 ha). The diamondback moth occurs across the continental United States as well as Hawaii, and was recently detected in interior Alaska. Control failures for this pest have occurred in several states including Florida, Georgia, North Carolina, New York, South Carolina, Texas, and Wisconsin. Because of its resistance to many insecticides, the management of this insect pest is particularly problematic.

Research Gaps: Long- and short-term integrated management solutions against the diamondback moth are needed for growers of crucifer crops.

Actions: ARS will:

Ecology

- Improve the understanding of seasonality, population dynamics, and ecology of the diamondback moth, and the potential impact of natural enemies on diamondback moth populations.

Control

- Explore environmentally friendly management tools against the diamondback moth.
- Assess virulence of insect pathogens against the diamondback moth.
- Improve efficacy of biopesticides for control.

11. Striped and Spotted Cucumber Beetles in Vegetables (especially cucurbits and sweet potatoes) and Flowers, Including Organic Operations (all States)

Importance: Striped and spotted cucumber beetles, *Acalymma* (*A. vittatum* and *A. trivittatum*), and *Diabrotica* (*D. undecimpunctata* subspecies and *D. balteata*, but not including *D. virgifera* and *D. barberi*) respectively, are serious pests of many high-value crops including vegetables, peanuts, cut flowers, and diversified organic operations in the United States. Surveys of organic growers by the Organic Farming Research Foundation have found this group to be the most frequently cited group of pests for organic vegetables. *Acalymma*, the striped cucumber beetles, are cucurbit specialists which are a key threat to seedling cucumbers, squash, melons, and pumpkins, in many states. Spotted cucumber beetles, *D. undecimpunctata*, and in the South, banded cucumber beetle, *D. balteata*, are widespread polyphagous pests, which in addition to cucurbits, feed on leafy vegetables, sweet potatoes, peanuts, soybean, corn, flowers, etc. Cucumber beetles cause losses to cucurbits and other vegetables by chewing young plants, blossoms, and fruit. Root damage to sweet potatoes, peanuts, cucurbits, corn, soybeans, and other crops is caused by the larvae. Cucumber beetles also vector a serious bacterial wilt of cucurbits, which is caused by *Erwinia tracheiphila*, an incurable cucurbit pathogen. Current practices rely mainly on pesticide applications in vegetable crops.

Research Gaps: Detection and rapid, effective control methods are needed, particularly for organic plantings. Most promising is the combination of cucurbit-derived specific feeding stimulants for cucumber beetles with environmentally-friendly toxins as the basis for baits or other attract-and-kill tactics. However, the best formulations and deployments of cucurbitacins still need to be determined. Volatile attractants, including plant-derived kairomones and sex and aggregation pheromones, are known to influence cucumber beetle behavior, but specific means to apply these to pest management are not clear. Knowledge of the dynamics of bacterial wilt transmission and of effects of root feeding on various crops also is needed to place the damage in an IPM perspective. Adult parasitoids (braconid wasps and tachinid flies) are poorly known, as is the guild of predators and other mortality factors for larvae in the soil.

Actions: ARS will:

Control, Semiochemicals

- Develop knowledge of chemistry of cucurbitacins from plant sources, and how to quickly and economically measure and concentrate these feeding stimulants for field use in baits or other controls for cucumber beetles.

- Develop knowledge of emission dynamics of cucurbitacins and other attractant semiochemicals.
- Develop effective traps to determine pest abundance in the field.
- Compare and optimize field deployment of best formulations for attract-and-kill methods in vegetable crops.
- Develop a synthetic method for vittatalactone, the known aggregation pheromone for *Acalymma vittata* (eastern striped cucumber beetle). Currently, the active enantiomer is not available in pure form, and various racemic mixtures need to be tested in combination with novel chemical syntheses, to determine the best approach for an economic production of the attractant.

Control, Biological

- Evaluate larval (root) feeding and mortality, using molecular predation detection techniques and possibly plant biochemistry to look at larvae using phytochemicals to defend against natural enemies.
- Evaluate parasitoids of adults as a source of mortality for striped and spotted cucumber beetles.
- Examine non-target effects on natural enemies and pollinators, of novel baits and controls discussed above.
- Test novel microbial controls and toxins for larval and adult suppression.

Control, Cultural

- Evaluate trap cropping, barriers and row covers, possibly in combination with cucurbitacin-containing baits, to mitigate effects on affected crops, particularly susceptible cucurbits.

Control, Host Plant Resistance

- Identify sources of resistance.
- Determine heritability of resistance.
- Facilitate incorporation of resistance into advanced sweetpotato breeding lines and new cultivars.

12. Regional Differences in Pest Status of Insects in Vegetables and/or Effectiveness of Natural Enemies

Importance: The occurrence and pest status of some insect pests varies among regions or changes with passage of time. Management methods that work well in some areas or for certain periods of time, including biological control, may be unsatisfactory in others.

As a result, management techniques must often be tailored or modified according to these regional differences. In some cases, reasons for the differences may be known but often the underlying reasons are not well understood, making it difficult to improve management tools.

Research Gaps: Changes in regional pest distribution and status require greater understanding of pest biology, ecology and movement, as well as the development or modification of scouting and control methods. Research is needed to more fully understand the factors that determine such regional differences. There are many potential causal factors in need of further study, such as genetic differences among regional populations, development of insecticide resistance, climate or weather-related factors, and basic biological and other biotic factors such as competition and differences in natural enemy complexes.

Actions: ARS will:

Monitoring

- Improve sampling and monitoring methods to account for regional differences in pest status and distribution, including the appearance of insecticide resistance.

Ecological Research

- Conduct comparative ecological studies of pests in different regions, including invasive pests in their native range.

Control, Host Plant Resistance

- Develop and evaluate new and improved varieties tailored for better pest resistance in specific regions.

Control, Cultural

- Develop and evaluate cultural management tactics appropriate for specific regions.

Control, Biological

- Develop improved methods of foreign exploration for more efficacious populations of natural enemies of invasive pests.
- Develop methods to improve natural enemy conservation of resident natural enemy populations.

13. Availability of Pesticides for Minor Crops

Importance: There is low availability of herbicides, insecticides, and miticides that are registered for use on minor acreage crops such as most vegetable crops, which are affected by a wide range of arthropod and weed pests. Pesticides registered for use on the major crops such as cotton, corn, soybeans, and small grains are not generally available to growers of minor crops because of the economic disincentives for pesticide registrants. Croplife America industry analysts, in 2000, estimated the development of a new crop protection chemical costs in excess of $180 million and takes over 9 years.

First registrations are for major crops such as: corn (76 million acres), soybean (75 million acres), wheat (47 million acres), and cotton (13 million acres). The acreage of vegetable crops is generally too small for manufactures to add the cost of vegetable use to the labels.

Research Gaps: Short term integrated pest management solutions are needed for growers of minor crops because few or no options are available when needed. Reduced risk and biopesticides options are especially needed. The EPA crop grouping scheme provides a mechanism to obtain food use tolerances by the use of a few representative crops on an entire crop group. However, pesticide registrants are reluctant to add the crops to the label in many instances because of a lack of performance and safety data on the crops where data were not obtained for the tolerance. The IR-4 program functions as a public sector registrant and is the only publicly funded program which conducts research and petitions EPA for the registration of suitable control compounds.

14. Improved Rearing Systems for More Robust Biological Control Agents (predators and parasitoids)

Importance: Concerns about the impact of agricultural practices on environmental quality are continuing to increase. Also, the effectiveness of traditional chemically-based insect and weed control measures has decreased due to resistance. These two major problems have increased the need for biologically-based IPM strategies that include the use of beneficial insects for the control of pest insects and invasive plants. However, there are substantial obstacles to the successful implementation of biological control programs. One is the difficulty and expense of rearing beneficial insects in sufficient numbers for release at the appropriate times. Most beneficial insects are reared on their natural host, which is an inefficient approach. Consequently, artificial rearing and storage methods are needed for economical production of consistent populations of natural enemies. However, formulations of artificial diets have problems associated with the nutritional quality and other parameters that affect the quality of beneficial insects.

Research Gaps: To make augmentative biological control a more viable option for vegetable crops, improved mass rearing systems for the cost-effective production of high quality predators and parasitoids must be developed. Development of rapid, sensitive and accurate detection methods for the measurement of the quality of mass produced beneficial insects will help ensure that mass produced beneficials consistently meet high quality standards. Information is lacking on the impact of plant and environmental factors on the effectiveness of beneficial insects in the field.

Actions: ARS will:

Control, Biological

- Invent new or improved diet formulations and rearing technologies for production and storage of insects to enhance the use of beneficial insects and to improve and preserve their natural qualities.

- Identify and develop attractants for key predators and parasitoids, and protocols to utilize semiochemicals for detecting beneficial insects and promoting predation and parasitism in agroecosystems.
- Develop molecular methods (PCR and/or immunoassays) for use in detection of predation and parasitism in agroecosystems, including released strains.
- Identify genetic and biochemical factors involved in health, fitness and production of insects and develop those factors as accurate, high-speed biomarkers of those traits.
- Conduct foreign and domestic exploration for predators and parasitoids that may be candidate biological control agents.
- Improve non-target safety and effectiveness of biological control agents.

15. Improved Development and Use of Insect-Specific Pathogens

Importance: Control of insect pests in vegetables has relied predominately on synthetic insecticide sprays. Many of these pesticides are under increasing regulatory pressure, and are of concern in relation to pesticide residues in food and water, environmental concerns for pesticides in air and water, and worker safety. Research is needed to develop non-insecticidal means for controlling these pests and to reduce the need for pesticides in vegetables.

Research Gaps: Although insect pathologists have identified numerous pathogenic microbial agents that show good potential for use as biopesticides, there is a need to continue exploration for new species and strains of insect-specific pathogens including entomopathogenic nematodes, viruses, fungi and bacteria. Few of the currently known microbial agents have been commercially developed as biopesticides. A significant constraint to the commercial use of microbial agents in agriculture is the lack of low-cost, large-scale methods for producing and formulating stable, effective microbial products. Additional research is needed to develop quantitative assay methods for quantification of virulence of insect-specific pathogens. The commercial use of microbial control agents will be facilitated through improved application and formulation of pathogens to better target pest insects and improve persistence of pathogens in the environment. The ongoing concerns regarding environmental effects of biological control demand that quantitative assessments of the environmental impact of insect specific pathogens be improved, especially their effects on non-target organisms and other biological control agents.

Actions: ARS will:

Control, Biological

- Conduct foreign and domestic exploration for new and more virulent insect-specific pathogens. Foreign exploration would be in cooperation with ARS overseas laboratories (in France, Argentina, Australia, China).

- Improve production methods of pathogens including improved fermentation and development of new in-vivo methods.
- Invent new and improve existing methods of bioassay of pathogens against pest and non-target insects.
- Develop formulation additives for improved application, attractiveness (to pest insects), and persistence of insect-specific pathogens.
- In combination with other control methods, develop an integrated approach to insect control that maximizes the efficacy of insect pathogens and minimizes their effects on other components of integrated control including other biological control agents.

16. See IS4 Program for Minor Crops and Host Plant Resistant Section

17. Annual and Perennial Weeds

Importance: Annual and perennial weeds lower the quantity and quality of vegetable crops through direct competition for resources (light, water, nutrients), harboring other insect and nematode pests and plant pathogens, and by impeding harvest. Perennial weeds, including yellow and purple nutsedge, are extremely difficult to manage in certain vegetable cropping systems. Methyl bromide is effective on several weeds and has been utilized in some vegetable production systems, but is no longer available for use in most cases. Most vegetable crops have a limited number of herbicides registered for use, some of which are older herbicide chemistries with user concerns such as herbicide resistance in weeds and/or less favorable environmental profiles. Weed management systems, including the use of non-chemical approaches, must buffer against the failure of an individual tactic. Handweeding or hand-hoeing is frequently used; however, high labor costs can be prohibitive. Moreover, demand for organically produced vegetables is increasing and weed control costs in organic vegetable production can exceed $1,500/acre.

Research Gaps: Factors controlling seed/tuber dormancy, regulation of dormancy, and germination are unknown. Why specific weeds are a pest in certain regions and crops is largely unknown. There is a need for new herbicides to kill weeds, vegetable crops with greater tolerance to herbicides, and pest management alternatives to methyl bromide. Weed hosts of important vegetable root crop pests need to be identified and the impact of these weeds on insect, disease, and nematode pests needs to be determined. The effect of weed host presence in the landscape on disease and insect dynamics is largely unknown. Also, an understanding of multitrophic interactions among weeds, insects (beneficial and pest), pathogens, the crop, and how various crop production practices influence these interactions is needed. Integrated systems to control weeds need to be improved. Cropping systems that target not only seedling control, but also seed rain, seed bank, and emergence, are needed. In addition, systems that utilize multiple control tactics, such as crop rotation, weed suppressive cultivars, cover crops, soil amendments, and cultivation should be developed to reduce the risk of weeds in vegetable production.

Actions: ARS will:

Control

- Provide safe and effective pest management solutions for vegetables through the IR-4 program.
- Explore the feasibility of enhancing herbicide tolerance in specific vegetable crops.
- Identify new opportunities to improve weed management by a greater understanding of vegetable crop/weed ecology.
- Determine biotic and abiotic factors that contribute to weed seedbank fate.
- Develop methods to manage specific problem weeds in vegetable crops.
- Identify successful elements of cropping systems utilizing cultural, mechanical, and chemical weed suppression tactics for meeting weed management objectives.

Anticipated Products:

- Increased knowledge of pest biology, ecology, behavior, genetics, interactions with host plants, and geographic variation.
- Increased knowledge of invasion biology of insect pests.
- Increased knowledge of the ecology of insect vectors of plant pathogens, including knowledge of vector and pathogen sources and dispersal into crops, and disease epidemiology.
- Information on endosymbionts associated with vegetable pests, and their effect on pest physiology.
- Characterization of insect semiochemicals (attractants, repellents and confusants).
- Behavioral manipulation of pest and beneficial insects through the use of semiochemicals.
- Improved pest sampling and detection methods.
- Development of economic threshold and injury levels based on quantitative relationships between pest populations and crop damage.
- Facilitation of registration of pesticides for insect, mite and weed pests on minor crops.
- Discovery of new biological control agents.
- Increased knowledge of the genetics, basic biology, and ecology of biological control agents.

- Improved production and application of mass reared biological control agents.
- Improved methods for conservation and augmentation of biological control agents.
- Novel methods of incorporating pest resistance into vegetable crops.
- Development of crop varieties resistant to major pests.
- Increased knowledge of the effect of horticultural practices on pest and beneficial populations.
- Increased knowledge of weed biology and ecology that leads to enhanced control.
- Identification of weed hosts of insect, nematode, and plant pathogens of vegetables.
- Novel methods of reducing the impact of weeds on vegetable crops.

***Potential Benefits (Outcomes)*:**

- Sustainable, biologically-based IPM practices to manage pests of vegetable crops more effectively.
- Reduced economic losses from insect pests of vegetables and the plant diseases that they transmit, as well as weed pests of vegetables.
- Reduced reliance on synthetic pesticides.
- Reductions in expenditures to manage insect and weed pests.
- Weed management tactics that are ecologically and economically sound.

USDA ARS Resources:

- Applications Technology Research, Wooster, Ohio
- Beneficial Insects Research Unit, Weslaco, Texas
- Biological Control of Pests Research Unit, Stoneville, Mississippi
- Crop Protection and Management, Tifton, Georgia
- Fruit and Vegetable Insect Research, Wapato, Washington
- Insect Behavior and Biological Control Research Unit, Gainesville, Florida
- Invasive Weed Management, Urbana, Illinois
- Insect Behavior and Biological Control Research Unit, Gainesville, Florida
- Pest Management and Biological Control Research Unit, Maricopa, Arizona
- Subtropical Insect Research Unit, Fort Pierce, Florida
- Sustainable Agricultural Systems, Beltsville, Maryland
- Vegetable and Forage Crops Research, Prosser, Washington
- Vegetable Research Unit, Charleston, South Carolina

Component II: Protection of Agricultural and Horticultural Crops

2g. Sugar Beets (U.S. Value 2006: $1.5 billion)

***Problem Statement*:** Sugar beet production does not produce maximum yields due to the following pests:

- Sugar Beet Root Maggot
- Beet Leafhopper
- Wireworms
- Cutworms and Armyworms
- Collembola
- Sugar Beet Root Aphid
- Weeds (including kochia, pigweed, nightshade spp., nutsedge, foxtail spp., wild millet and oats, sowthistle and Canada thistle, common lambsquarter, common mallow, cocklebur, dodder spp., and barnyardgrass)

***Research Needs*:**

1. **Sugar Beet Root Maggot**

   Importance: This insect is considered the most serious sugar beet pest in the western United States, including the states of North Dakota, Minnesota, Montana and Idaho, as well as Colorado and Oregon. Heavy infestations cause severe stand loss, particularly with small plants, because the maggots feed upon and sever the taproot, resulting in wilted or dead plants, reduced plant vigor, and damaged plants that may be more susceptible to root diseases. Primary control tools are synthetic chemicals, and without treatment sugar production in the most severely infested regions would be reduced by 40 to 80 percent.

   Research Gaps: Efficacious and commercially acceptable biological control agents or conservation/augmentation methods for managing root maggot populations need to be developed. In this regard, rearing methods for the insect need to be developed to facilitate screening of microbial agents and screening of traditional or transgenic hybrids for efficacy. Current models used to predict sugar beet root maggot impact were developed for the Snake River Valley of Idaho, and need to be adapted to the other growing regions. In addition, current economic thresholds need to be refined, particularly for maggot-affected areas outside Idaho, and, for all areas, better adjustments for rapid fly buildup need to be factored into the decision-making process.

Actions: ARS will:

Biology

- Develop an understanding of diapause development and termination in the root maggot.

Control, Biological

- Develop microbial control agents and methods for their use within the framework of integrated pest management of the sugar beet root maggot.

Control, Host Plant Resistance

- Develop traditional or transgenic resistant lines of sugar beets, within the framework of relevant National Program 301 and National Program 302 programs.

2. Beet Leafhopper

Importance: Beet leafhoppers feed upon sugar beet plants, though they seldom reach densities to cause economic damage. Beet leafhoppers, however, are the sole vector of curly top virus, an extremely serious pathogen of sugar beets, and it is the leafhopper's ability to vector the curly top virus that makes it a critical insect pest. The virus overwinters in adult leafhoppers, which become a source of infection the following year. Curly top virus is so devastating to sugar beets that it almost eliminated the sugar beet industry in Idaho and Washington prior to the development of virus-tolerant cultivars.

Research Gaps: The biology of the beet leafhopper and curly top virus epidemiology is poorly understood. There is a need to develop and/or refine cultural practices that can reduce leafhopper densities. There is an additional need to develop area-wide pest management approaches that reduce sources of both vector and pathogen in overwintering sites outside of sugar beet growing acreage.

Actions: ARS will:

Control, Interference with Vector Biology

- Develop integrated management practices to control the beet leafhopper, thereby reducing the incidence of curly top virus in sugar beets, within the framework of projects within National Program 303.

3. Wireworms

Importance: Wireworm larvae are sporadic but serious pests in sugar beets, feeding on the germinating seed and/or the developing root, working below the soil surface, attacking and killing the seedlings, and causing stand reduction. Under a heavy infestation, bare spots may appear in fields making reseeding necessary. Wireworm infestations are more likely to develop where grasses, including grain crops, are growing or were grown in the previous year.

Research Gaps: Integrated approaches for wireworm management utilizing trap crops, microbial control agents, and natural attractants (like pheromones) need to be developed. A better understanding of the mechanisms that confer wireworm resistance in unique potato germplasm derived from wild potato species might be useful in developing resistant cultivars of sugar beets.

Actions: ARS will:

Monitoring

- Develop and improve monitoring tools aimed at wireworms in sugar beets and other crops attacked by wiremworms.

Control, Trapping

- Identify attractants of larval wireworms to facilitate development of a synthetic bait for trapping.

Control, Host Plant Resistance

- Identify and develop genetic traits that could be incorporated into sugar beets and confer resistance to wireworms, within the framework of National Program 301 and National Program 302.

4. Cutworms and Armyworms

Importance: A variety of lepidopterans are problematic in sugar beets. Armyworms are considered a major problem in the western half of Idaho and a sporadic problem in Montana, Wyoming, and parts of North Dakota. Sugar beet plantings adjacent to armyworm-infested alfalfa hay fields or cereals may be completely defoliated by armyworm larvae that migrate and disperse from these crops when hay is cut or the grain crop is harvested. Cutworm infestations, while sporadic, can severely decimate the sugar beet crop. Some cutworm species primarily feed underground, cutting plants off below the soil line, while other cutworm species feed aboveground, cutting plants off at or above the soil line. In either case, sugar beet stands may be significantly reduced. Current control measures rely upon prophylactic use of fast-acting chemical insecticides.

Research Gaps: Economic injury thresholds for both cutworms and armyworms are needed to reduce prophylactic insecticide use. Biological control agents (particularly parasitoids and microbials) need to developed and refined to fit within an integrated pest management framework.

Actions: ARS will:

Control, Attractants

- Extend discoveries about adult moth attract-and-kill strategies developed in potatoes to the lepidopteran complex in sugar beets. (See Vegetable Component)

5. Collembola (springtails)

Importance: Recently, subterranean springtails have become sporadic pests of sugar beets in the central and southern Red River Valley of Minnesota and North Dakota, as well as the sugar beet-growing areas of eastern Montana. Springtails are usually regarded as benign or even beneficial, since they feed on decaying plant material and improve soil structure. However, certain environmental conditions in the early spring can result in high populations of springtails and these infestations can cause major sugar beet stand reductions and yield losses. Springtail populations become most problematic in high organic matter, fine-textured soils like clays, and damaging infestations have often occurred in fields where small grains (barley or wheat) were previously grown. No insecticides are specifically labeled for springtail management in sugar beet.

Research Gaps: Management tactics based upon a better understanding of springtail biology are needed. Biological tools compatible with or even complementary to those for the other sugar beet pests need to be developed. These tools could be either resistant/tolerant lines or microbial agents.

Actions: ARS will:

Control, Biological

- Develop biobased tools for management of Collembola in parallel to main efforts targeting sugar beet root maggot and wireworms, as well as seedling pathogens.

6. Sugar Beet Root Aphid

Importance: Sugar beet root aphids feed upon the small secondary roots of sugar beets. Their feeding interferes with plant growth by inhibiting nutrient and water uptake and transport. Severe infestations cause leaf yellowing and wilting and the damage results in yield and quality losses. Some adult aphids leave sugar beet fields and overwinter on cottonwood trees, while other root aphids remain in the soil in the fall and overwinter. These aphids are capable of beginning new infestations on sugar beets the following spring. Given their cryptic habits but near universal occurrence in every sugar beet field every year, the economic importance of sugar beet root aphids likely has been underestimated across the West. The best current option for managing the sugar beet root aphid is the use of resistant sugar beet cultivars.

Research Gaps: Economic thresholds for the sugar beet root aphid need to be developed. Biologically-based control strategies are lacking as only varietal resistance is currently available.

Actions: ARS will:

- National Program 304 does not have sufficient resources to address this insect pest.

7. **Weeds**

Importance: Troublesome weeds including including kochia, pigweed, nightshade spp., nutsedge, foxtail spp., wild millet and oats, sowthistle and Canada thistle, common lambsquarter, common mallow, cocklebur, dodder spp., and barnyardgrass impact sugar beet production. The widespread adoption of glyphosate-resistant sugar beets in 2008 has radically transformed the weed control situation in the crop. Nevertheless, transgenic beets present new problems in prevention of weed resistance to this important herbicide, given the large number of weed species in sugar beet fields, particularly weeds related to the crop.

Research Gaps: The potential of gene flow from transgenic sugar beets to weeds needs to be evaluated, accompanied by analysis of the ecological effects and the persistence of those genes.

Actions: ARS will:

- ARS currently has no resources to address weed management in sugar beets.

Anticipated Products:

- Increased knowledge of biology, ecology, behavior, and genetics of the key pests.
- More effective and commercially-acceptable sugar beet varieties with resistance to insect pests, esp. root maggot, root aphid, and wireworm.
- Improved pest management systems for insect pests of sugar beets.

Potential Benefits (Outcomes):

- Reduced crop losses and increased profitability for sugar beet growers.
- Significant reduction in the prophylactic use of the synthetic insecticides to control root maggot and wireworms in sugar beets.

***USDA ARS Resources*:**

- Fruit and Vegetable Insect Research, Wapato, Washington
- Insect Genetics and Biochemistry Research Unit, Fargo, North Dakota
- Molecular Plant Pathology Laboratory, Beltsville, Maryland
- Northwest Irrigation and Soils Research Laboratory, Kimberley, Idaho
- Pest Management Research Unit, Sidney, Montana
- Sugar Beet and Potato Research Unit, Fargo, North Dakota
- Sugar Beet Research Unit, Fort Collins, Colorado

Component II: Protection of Agricultural and Horticultural Crops

2h. Tropical / Subtropical Crops (U.S. Value 2007: $0.6 billion) (avocado, banana, cocoa, coffee, date, kiwi, macadamia nut, olive, papaya, pineapple)

***Problem Statement*:** Expansion of tropical / subtropical crops is limited by quarantine restrictions, market factors, and maximum yields due to the following pests:

- Mediterranean Fruit Fly, Oriental Fruit Fly, Melon Fly, Malaysian Fruit Fly, Olive Fruit Fly, Peach Fruit Fly, Mexican Fruit Fly (Hawaii, California, Florida, and Texas) and Other Fruit Flies (Hawaii, California, Florida, and Texas).
- Light Brown Apple Moth (California), Banana Moth, Nettle Caterpillar and Other Invasive Moths
- Coffee berry borer (Puerto Rico)
- Other Insect Pests: Cocoa Pod Borer (Micronesia), Coffee Berry Borer, (worldwide) Red Palm Mite (Florida), Macadamia Borer (Hawaii), Sweet Potato Weevil (Hawaii), Pink Hibiscus Mealybug (Florida), Glassy-winged Sharpshooter (Florida and California)

***Research Needs*:**

1. **Fruit Flies** *(Please see the Fresh Commodities section for coverage of this important group of pests).*

2. **Light Brown Apple Moth, Banana Moth, Nettle Caterpillar and Other Invasive Moths**

   Importance: Moths, such as light brown apple moth (LBAM) (*Epiphyas postvittana*), banana moth (*Opogona sacchari*), and nettle caterpillar (*Darna pallivitta*), are pests of various tropical /subtropical crops, limiting production, and may severely disrupt trade if not detected and allowed to become established in primary growing areas. LBAM also attacks temperate crops and has recently been identified in California as a new invasive species. Because LBAM threatens a multibillion dollar industry in California, alone, CDFA and APHIS, have asked ARS scientists to help develop methods for LBAM control.

   Research Gaps: Effective management of moth pests of tropical /subtropical crops requires the development of: 1) user-friendly, economical, and environmentally acceptable technologies; 2) area-wide integrated pest management (IPM) systems for moth suppression; and 3) systems approaches to prevent pest movement on export commodities.

   Actions: ARS will:

Basic Biology

- Conduct studies of population dynamics and moth interactions with their natural enemies, host plants, and other pests in Hawaii and other ecosystems.

- Provide baseline information for development of low prevalence and/or moth-free zones, detection, control, containment, suppression, and eradication technologies for use on the United States mainland.

Surveillance, Detection and Monitoring

- Identify attractants from host and non-host plants, and determine physiological and environmental factors affecting or modulating moth behavior.
- Improve lure and trapping systems for surveillance, detection, and control of moths.

Control, Biological

- Assess the efficacy of sterile insect technology for control of moths and determine factors limiting its effectiveness.
- Evaluate field behavior of sterile moths.
- Improve quality of laboratory-reared insects compared to wild counterparts.

Areawide IPM Systems

- Develop areawide IPM approaches to reduce the economic impact of moths.

Commodity Movement

- Develop systems approaches for movement of commodities infested with moths. *Also see Subcomponent 4a: Fresh Commodities*

3. **Coffee Berry Borer**
Importance: The insect feeds solely on the coffee seed and causes worldwide losses estimated at more than $500 million on a yearly basis. It was detected in Puerto Rico in August of 2008, and has quickly spread throughout coffee plantations in the island.

Research Gaps: Due to the cryptic nature of the insect inside the coffee berry, it is imperative to develop user-friendly, economical, and environmentally acceptable technologies that can be effectively implemented throughout extensive areas. These include the use of traps, cultural practices, natural enemies, and fungal biocontrol agents.

Actions: ARS will:

Basic Biology

- Search for new natural enemies of the coffee berry borer in its endemic areas in Africa

4. Other Insect Pests

Importance: Cocoa pod borer (Micronesia), red palm mite (Florida), mirids (Africa), the macadamia borer (Hawaii), sweet potato weevil (Hawaii), pink hibiscus mealybug (Florida), glassy-winged sharpshooter (Florida and California) and a variety of other invasive insects can severely limit tropical/subtropical crop production, may severely disrupt trade, and if not detected become established in primary growing areas. Effective prevention and management strategies are needed to reduce their economic impacts.

Research Gaps: Expansion of the markets for tropical/subtropical crops necessitates development of effective pest management strategies that provide: 1) novel environmentally sound chemicals for pest control; 2) user-friendly, economical, and environmentally acceptable surveillance, detection and monitoring techniques; 3) sustainable economical area-wide integrated pest management systems for pest suppression; and 4) systems approaches for movement of export commodities.

Actions: ARS will:

Basic Biology

- Conduct studies of population dynamics and pest interactions with their natural enemies, host plants, and other pests in Hawaii and other ecosystems.
- Provide baseline information for development of low prevalence and/or insect-free zones, detection, control, containment, suppression, and eradication technologies for use in Hawaii and the United States mainland.

Surveillance, Detection and Monitoring

- Identify attractants from host and non-host plants and determine physiological and environmental factors affecting or modulating pest behavior.
- Improve lure and trapping systems for surveillance, detection, and control.

***Anticipated Products*:**

- Increased knowledge of the biology, ecology, behavior, genetics, and biological control of pests and their biological controls and of plant traits conferring pest resistance.
- Discovery, characterization, and synthesis of insect attractants, repellents, and disruptants.
- Identification and release of new biological control agents.
- Identification of plant traits that might be used to develop pest-resistant plants and development of plants with pest resistance.
- Novel methods of reducing the impacts of insect pests of tropical/subtropical fruits, vegetables, and ornamental plants including the use of trap crops for pest management.

- New or improved methods for pest sampling, detection, and mating disruption.
- Novel and environmentally friendly insecticides

***Potential Benefits (Outcomes)*:**

- New and/or improved tools for use in the detection, delimitation, control/eradication, and quarantine treatments for these pests that will allow for trade to continue.
- New attractants and formulations, knowledge of SIT and mating disruption, specific mitigations that could be included into systems approaches to quarantine.
- IPM tactics that are ecologically sound.
- Strategies for improved IPM of subtropical insect pests.
- Economical and sustainable area-wide IPM systems.
- Reductions in crop losses to insect pests of specialty crops and the plant diseases they transmit.
- Reductions in expenditures to manage insect pests.

USDA ARS Resources:

- Postharvest Tropical Commodities Research Unit, Hilo, Hawaii
- Subtropical Insects Research, Fort Pierce, Florida
- Sustainable Perennial Crops Laboratory, Beltsville, Maryland
- Tropical Plants Pest Research Unit, Hilo, Hawaii
- San Joaquin Valley Agricultural Sciences Center, Parlier, California;
- Kiki de la Garza Research Center, Weslaco, Texas;
- Center for Medical, Agricultural, and Veterinary Entomology, Gainesville, Florida

Component II. Protection of Agricultural and Horticultural Crops

2i. Small Fruits – Berries and Grapes (U.S. Farmgate Value 2007: 4.6 billion, however, grapes (and wine) contribute $52 billion to the economy)

***Problem Statement*:** The following pests cause significant economic losses during the production of small fruit crops (grapes, blackberries, blueberries, cranberries, raspberries) due to direct feeding damage, plant diseases caused by insect-transmitted plant pathogens, pest (insects, diseases, weeds) management costs, and reduced yields.

- Glassy-winged Sharpshooter (*Homalodisca vitripennis*)
- Vine Mealybug (*Planococcus ficus*)
- Light Brown Apple Moth (*Epiphyas postvittana*)
- Black Vine Weevil (*Otiorhynchus sulcatus*)
- Garden Symphylan (*Scutigerella immaculata*)
- Two-spotted Mite, *Tetranychus urticae*
- Perennial Broadleaf Weeds

Research Needs:

1. **Glassy-winged Sharpshooter, *Homalodisca vitripennis***

   Importance: The glassy-winged sharpshooter (GWSS) is the principal vector of the bacterial pathogen, *Xylella fastidiosa*, the causal agent of Pierce's disease (PD) of grapevines (as well as diseases of other agronomic and horticultural crops, and ornamental and landscape plants). This disease threatens the entire California grape and wine industry. Of secondary concern, feeding by this large leafhopper may rarely cause significant plant damage, although adult insects do excrete copious amounts of liquid that can make leaves and fruit appear whitewashed when dry. During hot weather, this feeding may cause small plants to wilt.

   Research Gaps: National and regional long-term solutions are needed for effective, sustainable protection of table and wine grapes and raisins against PD. New or innovative methods must be developed for long-term sustainable management of GWSS in order to reduce the incidence of PD and its threat to the United States grape industry. Research needed for biological- and systems-based GWSS management includes: developing grape rootstock and scion varieties that are resistant/tolerant to PD; elucidating insect–pathogen interactions within the native ranges of the GWSS and *X. fastidiosa* that have optimal growing conditions for grapes; evaluating long-term sharpshooter densities in experimental plantings to quantify the pressure of this vector and pathogen; developing mass rearing systems for the cost-effective production of high quality insects for research and parasitoid production; developing detection methods for the sensitive, accurate, and rapid measurement of the quality of mass produced insects; assessing plant and environmental factors that affect insect-symbiont relationships; and development of economic, effective, biologically-based, and environmentally-sound GWSS management strategies.

Actions: See the "Pierce's Disease Strategic Plan" (http://www.ars.usda.gov/research/programs/programs.htm?np_code=304&docid=14767) for the comprehensive plan on GWSS research at ARS.

ARS will:

Control, Host Resistance (This work is included in National Program 301 and National Program 303)

- Identify and develop GWSS-resistant/-tolerant grape germplasm.
- Develop and evaluate new rootstock and scion grape varieties for their resistance/tolerance to GWSS.

Control, Biological

- Develop new or improved diet formulations and rearing technologies for production and storage of insects to enhance research and the use of beneficial insects.
- Develop methods for short- and long-term cold storage of GWSS.
- Develop molecular genetic markers and DNA fingerprinting methods to identify and track GWSS and GWSS natural enemies.

Control, Interference with Vector Biology

- Identify chemical and biochemical factors involved in GWSS-host interactions (i.e., feeding, oviposition, dormancy, etc.).
- Identify genetic and biochemical factors involved in health, fitness, and production of insects, and develop those factors as accurate, high-speed biomarkers of those traits.
- Determine the impact of nutrition, immunity, and behavior on the symbiont complex within GWSS.
- Develop semiochemical approaches to managing GWSS.

2. Vine Mealybug, *Planococcus ficus*

Importance: The vine mealybug (VMB) was first reported in the Western Hemisphere in 1994 in the Coachella Valley of California in table grape vineyards. VMB has a wide host range that includes 23 plant species in 17 families. The mealybug can feed on ornamental, temperate, subtropical, and tropical crops including grapes, figs, apples, oleander, citrus, dates, bananas, avocados, and mangos. In addition, the VMB transmits grapevine leafroll viruses. By 2002, the VMB spread to Kern County, California and is now a serious pest of table and wine grapes in Santa Barbara, Napa, and Sonoma Counties. Since its detection in 1994, the VMB has spread to 17 counties in California.

Biological control is the most effective management option. ARS, from its laboratory in France, is assisting APHIS in the biological control of the VMB through collection, identification, quarantine clearance, and delivery of parasitoids from Eurasia.

Research Gaps: Solutions are urgently needed to effectively manage the VMB in grapevines. The most sustainable strategies are likely to be biologically-based systems developed through advances in our knowledge of the biology, ecology, behavior, genetics, biological control agents, and host plant resistance. Research needs to develop biological- and systems-based VMB management include: identification and evaluation of additional biological control agents; knowledge of the species diversity of native parasitoids in the Middle East; knowledge of the relationships of VMB populations from Asia (Pakistan, India) with Eurasian and California populations; and knowledge of the process(es)/mechanism(s)/nature of transmission of leafroll viruses to grapevine by VMB in California vineyards compared to the VMB in Europe.

Actions: ARS will:

Plant Pathology

- No actions proposed in National Program 304

Control, Biological

- Improve and conduct foreign exploration of new strains of parasitoids in areas not surveyed yet, such as the Middle East, India, and Pakistan.

3. **Light Brown Apple Moth, *Epiphyas postvittana***

Importance: The first detection of the light brown apple moth (LBAM) in the continental United States was confirmed in California in 2007. LBAM is considered to be a High-Risk pest by APHIS and a Class A pest by CDFA. Accordingly, State (California) and Federal (APHIS) quarantine orders restrict intra- and interstate movement of plant material from counties where LBAM has been detected. Currently, LBAM is known to occur in the San Francisco Bay Area counties of Alameda, Contra Costa, Marin, Napa, San Francisco, Santa Clara, San Mateo, and Solano; in the Central Coast counties of Monterey and Santa Cruz; and in Los Angeles County. International quarantines, prohibitions against shipments, or phytosanitary certification have been implemented against fresh plant products from LBAM-infested areas within California. LBAM has a wide host range that includes many trees and ornamental species, and is known to be a serious pest of grapes, caneberries and strawberries, as well as tree nuts, citrus, pome fruits, stone fruits, and kiwifruit in areas that have climates similar to that in California. Research on LBAM management strategies in California will be difficult under quarantine regulations. If LBAM becomes permanently established in California, the most important impact on growers/producers will likely be trade restrictions on crop exports. Trade restrictions for certain LBAM host species (e.g., almonds) affect 60 percent of the crop. Increased concerns regarding management of LBAM have recently resulted in court orders to halt the use of aerosolized LBAM pheromone for mating disruption. The use of broadly applied pheromone was one of the more promising control measures available in light of the highly restricted use of pesticides in urbanized areas. Recent progress in sterile insect technologies for LBAM is another promising approach.

Research Needs: In order to enhance and ensure the maintenance of export markets for horticultural crop products (including small fruits); immediate research is urgently needed to develop sustainable LBAM eradication, management, and postharvest commodity treatment strategies. These strategies need to be environmentally-sound and ecologically-safe. Research needs to develop biological- and systems-based LBAM management include: IPM strategies to suppress LBAM populations in areas not yet under intensive eradication; traditional IPM strategies to manage LBAM if eradication efforts are not successful; sterile insect technique (SIT) and release; pheromone mating disruption alternatives (to ones halted by court order); new or improved monitoring techniques; classical biological control tactics; areawide pest management systems; and postharvest commodity treatment(s) to meet domestic and international phytosanitary requirements.

Actions: ARS will:

Control, Interference with Insect Biology

- No actions proposed in National Program 304

Control, Postharvest Treatment

- Evaluate the effectiveness of available postharvest chemicals and fumigants to treat small fruits to meet domestic and international phytosanitary requirements for LBAM. See National Program 308.

4. **Black Vine Weevil, *Otiorhynchus sulcatus***

Importance: The black vine weevil (BVW) is a serious pest of a number of small fruit crops including strawberry, blueberry, cranberry, grape, and caneberries. Many small fruit crops are grown perennially, allowing for weevil populations to build over time. Weevil larvae feed on plant roots and can cause loss of vigor and even plant death. Defoliation by BVW adults can also be a serious problem particularly in young plantings. Current management strategies rely primarily on the use of chemical insecticides to target pre-ovipositional adults. Timing of chemical applications is difficult due to the nocturnal behavior of the insects and the preharvest interval required following insecticide application.

Research Gaps: Due to the increased consumer demand for organic fruits, there is an urgent need for developing alternatives to chemical insecticides. Research needs to develop biological- and systems-based BVW management include: monitoring strategies for adults (traps, host plant volatiles, etc.); improved application technologies of microbial control agents; and conservation practices that maintain natural enemies in the field.

Actions: ARS will

Monitoring

- Develop monitoring techniques for adult BVW. (Corvallis, Oregon: Bruck)

Control, Microbial

- Develop new application technologies for applying microbial control agents against the weevil. (Corvallis, Oregon: Bruck)
- Integrate microbial control agents into existing IPM programs. (Corvallis, Oregon: Bruck)
- Identify new, more effective microbial isolates if necessary. (Corvallis, Oregon: Bruck)

Control, Biological

- Determine the role that predators play in controlling BVW populations in the field. (Corvallis, Oregon: Lee)
- Identify cultural practices that enhance predator numbers in the field. (Corvallis, Oregon: Lee)

5. **Garden Symphylan, *Scutigerella immaculata***

Importance: Garden symphylans are serious pests of the below-ground parts of numerous fruit crops in the western United States. They are white, soft-bodied "centipede-like" arthropods which are related to insects. Garden symphylans are omnivorous and are commonly found in a wide range of agricultural systems. The damage caused in these systems varies greatly. Severe losses commonly occur in some organically grown strawberries, where damage is believed to be associated with secondary stresses from root diseases such as verticillium wilt (*Verticillium* spp.). Economic damage also frequently occurs in hop and mint crops, and somewhat less frequently in raspberry crops.

Research Gaps: Garden symphylan management is based on preventive treatment (e.g., soil fumigation, soil-applied insecticides, and cultural practices). Accordingly, reliable monitoring techniques to detect the presence and to estimate population sizes of symphylans in the field are needed. Research needs to develop biological- and systems-based garden symphylan management include: sampling protocols for effective estimation of population size; economic thresholds for the various susceptible crops; and effective control measures (biological, cultural and chemical).

Actions: ARS will

Monitoring

- Develop monitoring techniques for detecting the presence and estimating the population size of symphylans in the field. (Corvallis, Oregon: Bruck)

Economic Thresholds

- Determine the economic thresholds of various small fruit crops to symphylans. (Corvallis, Oregon: Bruck)

Control, Cultural Practices

- Develop cultural techniques (cultivation, crop rotation, etc) for effectively managing symphylan populations.

Control, Chemical

- Identify reduced risk chemicals for effective symphylan management. (Corvallis, Oregon: Bruck)

Control, Biological

- Integrate biological control agents into existing IPM programs. (Corvallis, Oregon: Bruck)

6. **Two-spotted Spider Mite, *Tetranychus urticae***

Importance: The two-spotted spider mite is a persistent pest in strawberry, grape, blackberry and raspberry. Feeding by the mite can reduce plant vigor, yield, and cause leaves to drop off. Extensive defoliation in blackberries can reduce yield by 25 percent during the following season. Mite infestations are exacerbated by dry and dusty conditions, and by insecticide treatment for other pests that subsequently kill their natural enemies. Practices that maintain and attract predators to the field can improve control of the mite while reducing the use of insecticides and miticides.

Research Gaps: Predators (e.g., predatory mites, lady beetles, minute pirate bugs, thrips, and lacewing larvae) are very important in regulating mite populations. Research needs to develop biological- and systems-based mite management include: conservation practices and non-toxic semiochemical attractants (herbivore-induced volatiles) to maintain predators in the field.

Actions: ARS will:

- No actions proposed in National Program 304

7. **Perennial Broadleaf Weeds**

Importance: Perennial broadleaf weed control is a significant annual management issue in small fruits (berries and grapes). Weeds compete with small fruits for nutrients, light, water, and space. Weeds can harbor insect and rodent pests, increase disease pressure, and interfere with irrigation systems. Significant amounts of herbicides are applied to small fruit acreage annually. In other cases, cultural practices to manage weed (e.g., disking and hoeing) are expensive and/or labor intensive. Herbicide use and cultural practices in some areas may not effectively and economically control weeds, and/or lead to unacceptable environmental impacts, decreased due to use of herbicides crop productivity, increased cold damage, or increased insect and pathogen problems.

Research Gaps: While weeds are an annual consideration for small fruit (grapes and caneberries) producers and are difficult to control, no ARS resources are currently directed to research related to weed management, biology, or ecology in small fruit production systems in this National Program. Research needs to develop biological- and systems-based weed management include: greater understanding of the biology and physiology of weeds; and alternative control strategies.

Actions: ARS will:

- No actions proposed in National Program 304

Anticipated Products:

- Economic, effective, biologically-based, environmentally-sound arthropod pest management strategies.
- Improved arthropod pest sampling and detection methods.
- Increased knowledge of arthropod pest biology, ecology, behavior, genetics and arthropod pest-plant host interactions.
- New species or new strains of biological control agents.
- New knowledge of the diversity of parasitoid species for arthropod pests.
- New knowledge about transmission of grapevine leafroll viruses by the VMB in the New World.

Potential Benefits (Outcomes):

- Improved IPM strategies for arthropod pests of small fruits (grapes and caneberries).
- Additional pest management tools for arthropods in small fruit organic production systems.
- Reduced arthropod pest management costs.
- Reduced losses due to arthropod pests during production of small fruit crops (grapes and caneberries).
- Increased grower/producer profitability.
- Maintenance and enhancement of natural resources.

USDA ARS Resources

- Beneficial Insects Research Unit, Weslaco, Texas
- Biocontrol of Insects Research Unit, Columbia, Missouri
- Commodity Protection and Quality Research Unit, Parlier, California
- Crop Diseases, Pests and Genetics Research Unit, Parlier, California
- Horticultural Crops Research Laboratory, Corvallis, Oregon
- Insect Genetics and Biochemistry Research Unit, Fargo, North Dakota
- Subtropical Insects Research Unit, Fort Pierce, Florida

Component II: Protection of Natural Ecosystems

2j. Greenhouse, Nursery, Turf (U.S. Value 2007: $17 billion)

Problem Statement: The ability of American producers of floral and nursery crops to maintain the high product quality needed to compete with world wide markets is severely hampered by the following insect and mite pests and issues:

- White Grubs *(Nursery Crop)*
- Black Vine Weevils *(Nursery Crop)*
- Ambrosia Beetles *(Nursery Crop)*
- Leafhoppers *(Nursery Crop)*
- Emerald Ash Borer *(Nursery Crop)*
- Whiteflies *(Greenhouse Crop)* [see "Vegetables" subcomponent]
- Chili Thrips *(Greenhouse Crop)* [see "Vegetables" subcomponent]
- Plant Parasitic Mites *(Greenhouse Crops, and Nursery Roses especially near almond)*
- Invasive Species
- Application Technology
- Specialty Crop Pesticide Label Expansion (IR-4) [see Cross-cutting Issues]
- Insect Pests of Bedding Plants

Research Needs:

1. **White Grubs**

   Importance: White grubs are the larvae of scarab beetles and there are a number of exotic species that are pests of nursery crops. Japanese beetle, Oriental beetle, and European chafer are pests of nursery crops and turf; the larvae feed on roots, stunting or killing their hosts. Oriental beetles appear more inclined to feed on woody ornamental roots than Japanese beetle and have caused considerable damage in the Northeast and Midwest. In addition, because the larvae are found in the soil, they may be spread by shipping plants with soil or soilless substrate around the roots. Since Japanese beetle is also a quarantine pest, growers in infested states must follow specific control procedures in order to ship plants to non-infested states. Most states east of the Mississippi are infested with Japanese beetles, while the Oriental beetle and European chafer occur in Northeastern, Midwestern, and some Atlantic states.

   Research Gaps: Information on interactions between the nursery ecosystem and many invasive scarabs are lacking. Management programs are based primarily around broadcast sprays of chemical insecticides. Research is needed on alternative application techniques for chemical control agents. Biological and microbial control agents have shown promise as management tools against Oriental beetle, European chafer and Japanese beetle, but techniques for application of biological and microbial controls that are practical on a commercial scale are needed. Preliminary data shows that some essential oils have potential as control agents for white grubs and further testing of various oils and application methods are needed. Acceptable quarantine treatments for shipping nursery crops from states infested with Japanese beetles to non-infested states are limited. Further research is needed on developing application techniques and more environmentally acceptable control agents for quarantine treatments.

Actions: ARS will:

Pest Biology and Host Interactions

- Examine the biology and ecology of Oriental beetle and other exotic scarabs in ornamental nurseries.
- Determine the performance of Oriental beetle on a variety of woody ornamental species.
- Examine the response of ornamental trees and shrubs to feeding by Oriental beetle and European chafer.
- Examine the performance of plants attacked by scarab larvae and the attraction of attacked plants to other pests such as ambrosia beetles.

Control, Chemical

- Determine efficacy of essential oils for control of white grubs in ornamental nurseries.
- Test new insecticides as they become available.

Control, Application Techniques

- Determine efficacy of chemical insecticides (including new materials) and biological/microbial control agents applied through drip irrigation in ornamental nurseries.
- Determine efficacy of various application techniques for entomopathogenic nematodes for control of white grubs in ornamental nurseries.
- Evaluate various treatment methods and reduced-risk materials as quarantine treatments for Japanese beetles.

2. Black Vine Weevil, *Otiorhynchus sulcatus*

Importance: The black vine weevil is a serious pest of a wide variety of container and field-grown ornamentals. Perennially grown ornamental crops allow weevil populations to build over time. Economic losses are mostly associated with poor plant growth due to larval root feeding and lost shipments due to quarantine issues. Other losses are associated with the cost of control, the destructive sampling needed for larval scouting, and cosmetic quality reduction due to leaf feeding (adult notching of leaves). The control program currently implemented by a large percentage of growers centers on the use of broad spectrum insecticides to target adults prior to oviposition. However, even when implementing an extensive insecticidal spray program, growers often discover plant material infested with mature larvae in the winter or in the spring prior to shipping. Infested plants can not be sold, and, if infested plants are shipped, the grower risks buyer refusal of the plants and potential loss of future sales. Timing of chemical applications is difficult due to the nocturnal behavior of the insects and the preharvest interval required following insecticide application.

Research Gaps: Development of improved monitoring strategies for adults is needed, including new traps containing host plant volatiles. For microbial control of black vine weevil, identification of new microbial agents, improved application technologies (both preventative and curative), and an improved understanding of the biology of the microbes are needed. In addition, research gaps need to be filled in determining the role and importance of predators in managing weevil populations in the field.

Actions: ARS will:

Monitoring

- Develop monitoring techniques for adult black vine weevil.

Control, Microbial

- Develop new application technologies for applying microbial control agents in the field.
- Integrate microbial control agents into existing IPM.
- Identify new more effective microbial isolates if necessary.)
- Study the biology of microbial control agents and use this knowledge to better integrate these microorganisms into the nursery ecosystem.

Control, Biological

- Determine the role that predators play in controlling black vine weevil populations in the field.
- Identify cultural practices that enhance predator numbers in the field.

3. Ambrosia Beetles

Importance: Exotic ambrosia beetles are increasingly being recognized as key pests of field-grown nursery crops. The East Asian introductions, *Xylosandrus germanus* and *X. crassiusculus*, are two of the most economically important ambrosia beetles in U.S. nurseries. Both *X. germanus* and *X. crassiusculus* have wide host ranges, but deciduous hosts are preferred for colonization over coniferous tree species. Both species have traditionally been viewed as secondary pests of stressed, dying, or dead trees. They are hypothesized to use stress and other host-derived volatiles, rather than aggregation pheromones, to locate suitable trees. A growing body of evidence indicates apparently healthy trees may also be attacked. Control tactics currently rely on repeated trunk applications of insecticides to prevent ambrosia beetle colonization. Ambrosia beetles cannot utilize wood as a source of nutrition; symbiotic fungi provide a source of nourishment. Thus, systemic insecticides, which concentrate in wood, have not been particularly effective for managing the beetles.

Research Gaps: Trees that are apparently healthy may in fact have been predisposed to ambrosia beetle attacks by a stress event that went unnoticed. A large number of abiotic and biotic factors can affect the attractiveness and susceptibility of trees to ambrosia beetles, including climatic events, insect and pathogen stressors, and nursery management practices. Understanding the influence and interaction among such factors for triggering attacks by ambrosia beetles is critical to improving management practices. Such information will also aid in developing a technique for reliably triggering attacks by ambrosia beetles, thereby allowing for the evaluation of mass trapping techniques, repellents, attractants, and reduced-risk insecticides.

Low molecular weight volatile compounds represent primary host-location cues for generalist ambrosia beetles. The dose-response and synergism associated with ethanol and other stress volatiles, such as acetaldehyde, acetone, ethyl acetate, and ethylene warrants additional studies. Studies contributing to our understanding of the attractiveness of stress and host-derived volatiles would be extremely useful for closely timing insecticide applications with the flight activity of ambrosia beetles. Modeling the spatial dynamics of ambrosia beetles within the nursery agroecosystem is also critical. Degree day models are also needed to compare tree phenology and ambrosia beetle flight activity within the nursery agroecosystem.

Ambrosia beetle fungal symbiont pathogenicity to trees and the interaction of fungus with stress factors has yet to be fully examined and warrants additional study, particularly in nursery stock. The geographical variability in fungal symbionts of *X. germanus* and *X. crassiusculus* needs to be addressed, along with the impact of such pathogens on the attractiveness of host trees to ambrosia beetles.

Synthetic insecticides, particularly pyrethroids, applied as trunk sprays are commonly used to protect vulnerable nursery stock from ambrosia beetle colonization. It is presently unknown how long insecticides remain effective on the bark after application, and such information is critical for maintaining a barrier against ambrosia beetle colonization. Investigations into the delivery methods, coverage, and longevity of insecticides for ambrosia beetle management are warranted. Evaluating the efficacy of chemigation tactics of insecticides and fungicides is also necessary. Reduced-risk insecticides and microbial agents also need to be evaluated. Microbial control agents are available that may be useful against either beetles or their fungal symbionts. In addition, information on ambrosia beetle repellents and attractants will ultimately be used to develop a "push-pull" management strategy, whereby ambrosia beetles are "pushed" or repelled away from vulnerable nursery stock and "pulled" or attracted into destructive traps.

Actions: ARS will:

Pest Biology and Host interactions

- Determine the impact of flood and water stress on the pathogenicity of ambrosia beetle fungal symbionts.
- Determine identity of, and genetic diversity among strains of ambrosia beetle fungal symbionts.
- Understand the interaction among abiotic and biotic stress factors for triggering attacks by ambrosia beetles.
- Model the spatial dynamics of ambrosia beetles within the nursery agroecosystem.
- Use degree day models to compare tree phenology and ambrosia beetle flight activity within the nursery agroecosystem.

Control, Test new materials

- Evaluate reduced-risk insecticides and repellents for protecting vulnerable trees from ambrosia beetle attacks.
- Characterize the attractiveness of stress and host-derived volatiles for monitoring and mass trapping ambrosia beetles in the nursery agroecosystem.
- Determine the residual activity of commonly-used insecticides and reduced-risk products and repellents.
- Determine effectiveness of available microbial control agents against beetles or their fungal symbionts.

Control, Application Techniques

- Develop a reliable technique for triggering attacks by ambrosia beetles in living trees.
- Assess the ability of chemigation and novel trunk application tactics for delivering insecticides and fungicides into vulnerable nursery stock.
- Incorporate repellents and attractant trap trees into a push-pull management strategy.

4. Potato Leafhopper, *Empoasca fabae*

Importance: The potato leafhopper is a major pest of red maple grown in ornamental nurseries. Overwintering occurs in the southern United States, followed by adults migrating north in mid to late spring. The potato leafhopper uses a lacerate-and-flush style of feeding, which disrupts vascular bundles and constricts the phloem fibers. The combination of mechanical damage and deposition of salivary components results in leaf chlorosis, necrosis, cupping and deformation, stunting of internodes, and death of apical tissues. The resulting symptoms, called "hopperburn," prolong the amount of time maples must be held in nurseries, require additional pruning, and reduce tree market value.

Research Gaps: A number of contact insecticides are commonly used for controlling the potato leafhopper, but few studies have addressed the use of systemic insecticides. Information is needed on the timing, rates, and efficacy of systemic insecticides delivered through drip irrigation for controlling potato leafhoppers. Reduced-risk insecticides and defense elicitors also need to be evaluated. In addition to insecticides, more sustainable management tactics are needed. Host plant resistance could be incorporated as a component of an IPM program. Maple cultivars vary in their degree of resistance to the potato leafhopper, and a few resistant cultivars have been identified. However, the basis for resistance is poorly understood and should be determined to aid in germplasm development programs. Resistance levels as well as physiological and defense responses need to be compared across existing maple cultivars and germplasm. Leafhopper performance and feeding behavior should also be characterized to determine resistance mechanisms. The ability to use molecular markers also needs to be assessed to aid in future breeding programs aimed at developing resistant cultivars.

Actions: ARS will:

Pest Biology and Host Interactions

- Screen existing maple cultivars and advanced lines for resistance to potato leafhoppers, and damage thresholds.
- Characterize resistance mechanisms by measuring plant physiological and defense responses, plant injury levels, and potato leafhopper performance and feeding parameters.

Control, Test new materials

- Evaluate reduced-risk insecticides, defense elicitors, and new insecticides for controlling potato leafhoppers in nurseries.

Control, Application Techniques

- Determine the timing, rates, and efficacy of systemic insecticides delivered via drip irrigation for controlling potato leafhoppers in nursery-grown maples.

5. Application Technology

Importance: Insecticide application has not been optimized for either conventional chemical pesticides or for natural enemies on greenhouse and nursery crops. The current lack of systems for effective delivery of pest-control agents, into these crops, (including potting substrates for container-grown crops) leaves the nursery or greenhouse industries vulnerable to possible crop loss or damage, rendering the crop unmarketable either due to appearance or quarantine.

5a. Matching Pesticide Application with Canopy Characteristics

Research Gaps: Nursery and floral crop canopies and growth habits differ as much as the numbers of species and cultivars that exist in the industry. Canopy penetration and coverage of insecticides or natural enemies continues to be an issue for both floral and nursery crops. Precision sprayers with intelligent decision systems are needed to match sprays with plant canopy characteristics and sizes, for precision sprayers are also needed so that pest control agents are precise and uniform coverage. In addition, off-target loss reduction technologies are required for use in nurseries to meet increased needs for environmental protection, including water and worker safety.

Actions: ARS will:

- Provide innovative new spray systems for efficient and economical pest control with minimal off-target loss.

- Develop innovative, new precision spray nozzles to horticulturally fit the application to the species.

5b. Enhancing Delivery of Pesticide to Target Area

Research Gaps: Pest control efficiency with less pesticide use is dependent upon residue pattern formation on intended target areas and length of time that spray droplets remain on the target. However, validation of this hypothesis is conditional upon the fact that the residual pattern and droplet evaporation time on intended targets also vary with application system performance, formulation of pest-control agents, fine structure of plant surfaces, and microclimate conditions. Thus investigation of spray droplet impaction, retention, evaporation and residual pattern formation and determining the fate of droplets in order to develop strategies for enhancing delivery to target areas are needed. The dynamic effects of droplet size and velocity spray solution physical properties, leaf morphology and surface fine structure on spray impaction, retention and coverage also need to be determined. This research is needed to provide fundamental knowledge and guidance for developing and selecting optimal spray application techniques and chemical formulations for targeted plants with maximal spray application efficiency and minimal pesticide use.

Actions: ARS will:

- Measure evaporation time, spread factor and chemical residual pattern coverage area of individual droplets containing spray additives on various floral and nursery crop foliage via sequential imaging under controlled conditions.

5c. Drip Irrigation Systems

Research Gaps: The wide variety of plant stock grown in nurseries imposes special constraints above and, below ground for soil injection systems. Drip irrigation systems (chemigation) facilitate the delivery of insecticides in field or in containers, are efficient methods for applying chemicals into target zones, can eliminate drift problems caused by the spraying of pesticides, and are less costly than pesticide application with sprayers. However, the deliverability and treatment uniformity of many other additives have not been evaluated under controlled conditions before they are released for field use. The efficacy of synthetic insecticide distribution patterns have not been evaluated and the distribution patterns of water soluble or insoluble materials across drip lines and in the soil under different emitter flow capacities and rates are poorly understood. Active agents in organic or other surface material may make surface applied biopesticides less effective. Consequently, excessive levels of application are required to achieve efficacy, at greater expense and risk to the environment. Injected applications for container nurseries are normally placed above the surface or at controlled shallow depths for more effective targeting of the pest to be controlled.

Actions: ARS will:

- Develop an engineering testing system for delivering agri-chemicals and bio-compounds through drip irrigation that can control the delivery of all individual delivery variables.
- Investigate the distribution uniformity of agri-chemicals and bio-compounds with different physical properties and particle sizes across drip lines and in soilless substrates and soil with various emitter sizes and flow rates.
- Conduct tests to determine emitter sizes and amounts of water needed to diffuse bio-compounds in soilless substrate in various size containers.
- Develop a new injection system to precisely deliver suspendable bio-compound materials through drip irrigation systems.

6. Insect Pests of Bedding Plants

Importance: Greenhouse production of ornamental bedding plants is constrained by a large complex of arthropod pests, including thrips, whiteflies, aphids, mites, fungus gnats, and shore flies. These pests are ubiquitous in greenhouse production systems throughout North America and the rest of the world. They cause direct feeding damage or vector virulent pathogens to an extraordinarily broad range of host plants.

Research Gaps: In the United States, control of these pests is currently dependent, to a great extent, on use of broad-spectrum chemical insecticides that carry considerable risk of selecting for resistance in pest populations. Resistance management programs call for rotation of pesticides with different modes of action, yet registration of novel chemicals for greenhouse use has slowed dramatically in recent years. Western flower thrips poses one of the most urgent problems, as emerging resistance is severely limiting control options. Virtually all of these pests have been found susceptible to microbial biological control agents (primarily the entomopathogenic fungi, which are capable of infecting insects that feed by sucking plant juices) and the novel modes of action of these agents combined with their general safety make them attractive options for integrated management of greenhouse pests. Most significantly, the safety of these agents translates to minimal re-entry and pre-harvest requirements. Despite these advantages, however, greenhouse markets for fungus-based biopesticides remain limited, a situation related primarily to the lower and less consistent efficacy of these products compared to available chemical insecticides. Experiences of agricultural researchers and commercial biocontrol producers indicate that expanding the use of microbial control agents will require a greater knowledge of the many environmental and other factors that regulate their activity in commercial greenhouses. Such knowledge will enable researchers to recommend specific modifications to crop production systems, which, if found economically and practically feasible, could greatly enhance biopesticide effectiveness. Knowledge of the roles of insect pests as vectors of oomycete and fungal pathogens of ornamental plants is also limited yet critical to the development of integrated crop management systems.
Actions: ARS will:

Efficacy Factors, Environmental

- Identify and quantify environmental conditions essential for effective activity of microbial control agents against bedding plant pests in greenhouse crops.
- Work with plant pathologists and growers to assess the scientific, economic, and practical feasibility of altering greenhouse environmental conditions to improve performance of microbial control agents without increasing risk of plant disease.

Efficacy Factors, Biotic

- Identify the specific stages in the development of greenhouse pests or pest populations that are most vulnerable to microbial control actions.

Insect Vector – Plant Pathogen – Host Plant Interactions

- Characterize the roles of insect pests in the transmission of oomycete and fungal pathogens and in the predisposition of plants to infection by these pathogens.

Control, Application Techniques

- Identify application technologies, methods, and strategies that optimize primary targeting or secondary pick-up of microbial control agents applied against pests in high-density cultures of greenhouse crops.

Control, Formulation/Packaging Technologies

- Elaborate mass production, formulation, and packaging technologies to preserve virulence and optimize commercial shelf life of fungus-based biopesticide products.

Control, Integrated

- Identify potential antagonistic or synergistic interactions between microbial control agents, other biological control agents, and agrochemicals used for greenhouse pest and disease management, and develop deployment methods/strategies to minimize negative and exploit positive interactions.
- Develop methods for integration of microbial control agents into existing greenhouse pest and disease management programs.

***Anticipated Products*:**

- Increased knowledge of pest biology, ecology, behavior, and biological control agents as related to management of insect pests.
- Improved biological control.
- Increased knowledge of the biology of microbial control resulting in increased and more consistent levels of microbial control.
- Novel methods for reducing the impact of soil-dwelling arthropod and leafhopper pests of container and field-grown ornamentals.
- Improved pest sampling and detection methods.
- New microbial isolates.
- Improved delivery of biological control agents to target surfaces.
- Enhanced crop quality.

***Potential Benefits (Outcomes)*:**

- Improved monitoring and detection techniques for white grub larvae, black vine weevil, ambrosia beetles, and potato leafhoppers.
- Improved IPM strategies for arthropod pests of container and field-grown ornamentals.
- Additional management tools for arthropods in organic production systems.

- Increased profitability.
- Reduced pesticide use and cost.
- Reduced environmental contamination.

USDA ARS Resources:

- Application Technology Research Unit, Wooster, Ohio.
- Beneficial Insects Introduction Research Unit, Newark, Delaware
- Beneficial Insects Research Laboratory, Weslaco, Texas
- Biological Integrated Pest Management Research Unit, Ithaca, New York
- Horticultural Crops Laboratory, Corvallis, Oregon.
- Horticultural Research Laboratory, Fort Pierce, Florida.

Component II: Protection of Agricultural and Horticultural Crops

2k. Corn (U.S. Value 2007: $52 billion)

***Problem Statement*:** Control costs and losses from insects and weeds in the United States corn crop add to over $2 billion annually. Growers are unable to increase corn production with emerging control technologies because of the following pests, weeds and issues:

- Pest Resistance to Bt Corn and Chemical Insecticides and Glyphosate Tolerant (GT) Weeds in GT Crops
- System Level Problems with Pests Associated with New Types of Corn, Cropping Systems and Management System Diversity
- Environmental Stewardship: Impact of Pest Control Systems
- Developing and Using New Technologies
- Emerging Pest Problems and Issues Related to Biofuel Production
- Key Insect Pests and Weeds:
  - Corn Rootworm (*Diabrotica* spp.) (throughout Corn Belt and southern states)
  - Corn Borers: European corn borer (Corn Belt states); Southwestern Corn Borer (Kansas, Missouri and southern states); Sugar Cane Borer (Louisiana and Texas)
  - Corn Earworm and Fall Armyworm (primarily southern Corn Belt states)
  - Western Bean Cutworm (emerging pest in Nebraska, Iowa, Illinois)
  - Spider Mites (Texas and Kansas) [no ARS work planned]
  - Kernel Feeding Pests: Brown and Green Stink Bugs, Sap Beetles, Pink Scavenger Caterpillar (primarily southern states)
  - Annual Local Grass Weeds: Broadleaf Signalgrass, Browntop Millet, Junglerice, and Shattercane (southern Corn Belt, especially regarding herbicide sensitivity; e.g., resistance to ALS-inhibitor herbicides)
  - Annual Broadleaf Weeds: Giant Ragweed and Horsetail (marestail) (evolved resistance to glyphosate throughout Corn Belt); Palmer Amaranth (evolved resistance to glyphosate in central to southern Corn Belt); waterhemp (evolved resistance to glyphosate in central to northern Corn Belt); Benghal dayflower (natural resistance to glyphosate, southern Corn Belt); Asiatic dayflower (natural resistance to glyphosate, central Corn Belt); lambsquarters (rapidly increasing frequency of poor control by glyphosate throughout Corn Belt)
  - Perennial Grass Weeds: Johnsongrass (resistance to ALS-inhibitor herbicides in southern Corn Belt); cogongrass (southern Corn Belt); Quackgrass (northern Corn Belt organic production)

- Perennial Broadleaf Weeds: Canada thistle (northern Corn Belt organic production); White Cockle and Pokeweed (northern Corn Belt)

***Research Needs*:**

1. **Pest Resistance**

   Importance: Collectively, corn rootworm, European corn borer, southwestern corn borer, corn earworm, fall armyworm, western bean cutworm and a number of kernel feeding insects reduce corn grower yields at least 5-10 percent and impact grain quality. Damaged corn tissue, especially ears, can lead to fungal infections (molds) and the development of mycotoxins, especially aflatoxin and fumonisin which are unsafe to livestock and humans. Weeds cause growers to incur costs directly through yield losses and herbicide and equipment purchases, but also indirectly through increased labor, application (fuel) expenses, harvesting difficulty, and grain contamination. Weeds also serve as alternate hosts for some important crop diseases and insects.

   U.S. growers are becoming more and more dependent on transgenic crops for insect and weed control. Widespread use of this technology, however, increases the likelihood that pests will become resistant to these corn products. Fall armyworm larvae in Puerto Rico have become resistant to Cry1F Bt corn and a number of weeds have become resistant to glyphosate. Resistance management programs are necessary to prolong the use of these environmentally friendly and popular products. Additionally, growers in the South and sweet corn producers are threatened by the development pyrethroid resistant corn earworm. Besides evolved resistance, some pests are naturally tolerant to some commonly used pesticides. The term "species shift" describes encroachment into an agroecosystem of naturally tolerant pests in response to repeated use of the same or related pesticides. Species shifts are increasingly noticeable and troublesome in systems dominated by glyphosate-resistant crops.

   Research Gaps: Problems with resistant weeds and insects have created an urgent need to better understand the biology, ecology, and genetics of these pests. In particular, there is a need to understand the mechanisms and inheritance of resistance, factors that influence the adaptation of these traits, and movement of resistance genes across landscapes. Increased knowledge in these areas can be used to mitigate resistance issues as they appear and can be used in the development of future management products. For insect resistance management (IRM) of Bt corn, growers are required to plant 20 percent refuge (i.e., non Bt corn) but this is becoming increasingly more difficult as seed companies stack multiple insect and weed control products together. However, there is an opportunity with new types of Bt corn to make IRM easier for growers. Smaller refuges and even seed blending might be possible but there are many questions related to insect movement that influence the development of insect resistance. Evolution of resistance often is accompanied by changes in behavior, development, physiology, and responses to the environment and host plant. Identification and understanding of these changes are important because they affect how resistance spreads and persists in populations, and this influences strategies for mitigation. There also is a need to develop more efficient monitoring systems for detecting insects resistant to transgenic corn and chemical insecticides and weeds resistant to various herbicides.

Actions: ARS will:

Control

- Utilize stable carbon isotope techniques to identify potential differences in source crops for pyrethroid-resistant and susceptible corn earworms.
- Improve and expand pyrethroid resistance monitoring for corn earworm.
- Develop and incorporate new control strategies into an IRM plan that includes rotation of insecticide chemistries.
- Develop lines of the western corn rootworm selected to survive transgenic corn, utilize these rootworm lines toward an understanding of rootworm survival on transgenic corn, and if possible, evaluate these lines on other transgenic maize lines for potential cross resistance.
- Improve knowledge of corn rootworm (adults and larvae) ecology, genetics, and behavior in relation to the efficiency of IRM plans and European corn borer.
- Examine changes in flight behavior and development times of insects selected in the laboratory for Bt resistance.

2. System Level Problems with Pests

Importance: Solutions to specific challenges with pest management can influence the decision-making process of other farm management practices. Systems-level understanding of the implications of pest management decisions provide a real-world test of how specific decisions influence farm productivity. These systems-level projects are particularly important in understanding the ecological impacts of genetically enhanced crops, consequences of low- vs. high-diversity cropping and management systems, key differences between organic and conventional approaches to farming and managing pests, and the effects of landscape level processes on within-field distributions of pests and natural enemies.

Research Gaps: A basic tenet of IPM systems is that technology to control pests should be applied only when economic and environmental return justifies the control. The implications of prescriptively planting and managing genetically enhanced crops (Bt-expressing or herbicide-tolerant) on environmental (biodiversity, other pest management options) and economic (costs and returns) aspects of crop production relative to other pest management strategies need to be evaluated using systems-level approaches in ways meaningful to growers. Organic producers are faced with unique pest management challenges including a limited number of options when it comes to managing weeds and insects. A solution to this problem involves understanding how specific farm management practices and their various combinations promote crop health and natural enemies and minimize pest populations and damage. Predicting spatial patterns of pest pressure between and within fields, farms, and regions must be developed to make prescription planting, rotations, and cover crops effective alternatives to maximum planting of transgenic corn across larger regions. The occurrence of pest insect populations (notably corn earworm and stink bugs) on wild host plants and the dispersal of these pests on a landscape scale are poorly understood, as are effects of differing sequences of rotation crops on the patterns and dispersion of major weed species.

Actions: ARS will:

Biology

- Determine biological, landscape, topographic, agronomic, and weather factors that impact the spatial distribution of natural enemies, as well as corn borer, rootworm and earworm abundance and damage among and within cornfields.
- Quantify the reliability of identified risk factors to predict the spatial distribution of pest pressure.
- Identify previous host plants of adult stink bugs found in corn.
- Characterize the dispersal of adult corn earworms and stink bugs at within-field and landscape spatial scales.
- Understand how cover crops affect weed dynamics.

Control

- Network with organic producers, identify key research needs, and evaluate solutions compatible with organic production practices.
- Examine the economic implications of herbicide-intensive production systems on arthropod diversity, insect management decisions, and the productivity of the entire cropping system relative to other weed management systems.
- Develop new control tactics that integrate appropriately with either organic or traditional corn management systems.

3. Environmental Stewardship

Importance: One of the long-term goals of ARS is to achieve sustainable agriculture that minimizes environmental impacts. Numerous services are provided by non-pest arthropods and plants within agroecosystems, and pest management practices that disrupt the functioning of these non-target species can be costly. There is a need to evaluate possible effects of new types of corn on non-target organisms compared with traditional forms of pest control so that growers are preserving natural ecosystem functions within their farmland while minimizing the impacts of pest species. Similarly, pesticides used in corn must be evaluated in terms of fate, transport, and non-target effects to preserve the high pest efficacy and low environmental impact that corn growers and the public have come to expect. To limit the frequency of resistance development, soil-applied herbicides now are recommended widely by extension and industry for use in glyphosate-resistant corn. These herbicides often include the older chloroacetamides (e.g., acetachlor) and triazines (atrazine) which commonly impact water supplies, and other newer residuals (e.g., flufenacet, isoxaflutole, mesotrione) about which we know much less. These herbicides may have carry-over that influences choice of rotation crops and they may move off-site, either above ground via runoff or wind or below ground in shallow aquifers. Whatever the case, their fate and transport are dependent upon a myriad of biotic and abiotic factors.

Research Gaps: There is a fundamental need to establish better tests to evaluate non-target effects of new types of corn and corn pesticides. In particular, there is a need to develop limit-dose laboratory tests for representative beneficial insect species that can be reared easily in the laboratory. Also, there is a need to develop efficient field tests to assess impact of various corn systems on non-targets that provide valuable ecosystem services. Despite a general understanding of how synthetic chemicals degrade and move through an environment, many aspects of fate and transport remain unknown. Moreover, the ultimate long-term consequences to the environment of the presence of temporally-varying concentrations of differing herbicides still require analysis. Movements and metabolites of newer pesticides are studied rigorously prior to labeling by manufacturers, but once in widespread use in highly heterogeneous environments across large regions, unanticipated fates are to be expected and must be examined critically to minimize unintended consequences.

Actions: ARS will:

Control

- Develop laboratory-based tests to evaluate stressor compounds (usually proteins) produced by genetically engineered corn on various insects.
- Identify ecological pathways through which beneficial arthropods interact with genetically enhanced corn and corn ecosystems as a means to assess their exposure to potentially harmful aspects of these crops.
- Establish how genetically enhanced corn affects food webs compare with other pest management systems.

4. Developing and Using New Technologies

Importance: New technologies and techniques are needed to conserve the efficacy of insecticides and transgenic crops that have a narrow range of target pests. Laboratory studies show that many corn pests can evolve resistance to Bt proteins. New sources of native plant resistance traits to these pests can be stacked with Bt genes to delay the onset of resistance, or can be used alone to protect non-Bt refuge and organic corn. Development of resistance in corn insect pests to transgenic Bt proteins is the most recent example of an ongoing arms race in plant defense and insect herbivore counter-defense. Unraveling the molecular basis for these interactions is critical to devising sustainable pest management strategies. Microarray analysis and genetic mapping of pests will allow identification and potential manipulation of the genes in insects responsible for resistance and key life-history traits that can be exploited as weak links. Use of genetic markers for insect pests makes it possible to understand spatial patterns and the extent of insect pest movement over long distances, and the ability to develop good markers will increase as DNA sequencing projects are conducted on ESTs or entire insect genomes.

Weed control in corn is dominated by application of synthetic herbicides, an activity that has been enormously successful. Even organic producers can appreciate the efficacies of these products, which is why there is an incipient market for organic herbicides. Many natural plant and microbial chemicals have phytotoxic activities. Some of these chemicals can be used in their original forms as herbicides, or they can be used as templates and possibly modified for enhanced effectiveness.

Research Gaps: New plant resistance traits are needed to enhance Bt-corn IRM, and as an alternative control option for non-Bt corn. Although a number of corn inbred lines and partial inbred lines are known to confer resistance against single insect species, few have been assessed for native resistance to multiple key insect pests at multiple growth stages of the plant. Additional low-input pest control technologies and techniques are critical as an alternative or as a complement to current pest control technology, especially for organic and non-Bt refuge corn production. Though difficult to study, we need a much better understanding of long distance insect movement, which is necessary for predicting pest population dynamics. Subgroups of insect pests that prefer different host plants, or interact with host plants in different ways, often exist without our knowledge based on monitoring data. This hinders efforts to accurately assess the threat posed to a crop at a given time and place. Little or no microarray data are available for most corn insect pests and this data will be critical to deciphering the molecular mechanisms of interaction between pests and corn, and the genes that are involved. This effort will require much more DNA sequence data, genetic mapping, and gene discovery for the pests than are currently available.

Only a few of the vast array of natural plant and microbial products that are phytotoxic have been identified and isolated, with one of the most recent highly-active moieties being the simple nonprotein amino acid, m-tyrosine, from fescue grasses. For most of these chemicals their identity and associated biochemistry and molecular biology are entirely unknown, as are their potential roles in plant defense and crop protection.

Actions: ARS will:

Control

- Characterize newly-discovered native plant resistance traits of corn earworm, southwestern corn borer, and corn rootworm by understanding their genetic control and determining chemical/biochemical, physiological and/or morphological bases of resistance.
- Identify and characterize the genes for these traits at the molecular level for genetic enhancement in corn and for genetic engineering of alternative crops.

- Screen and develop corn germplasm that confers root-, leaf- and ear-feeding insect resistance at multiple locations from Midwest, Mid South, and South Atlantic Regions.
- Develop and use molecular genetic markers to characterize gene flow, and therefore dispersal patterns, of insect pests of corn at different spatial scales.
- Use genetic markers to reveal potential host races or other distinct races or variants.
- Develop and use molecular markers to construct genetic linkage maps for corn pests.
- Understand the dynamic nature of the molecular basis for plant-insect interactions in corn.
- Derive and test natural products from plants and microbes that have potential as natural pesticides in corn, other crops, and elsewhere.

5. Emerging Pest Problems and Issues

Importance: Corn management system changes have increased the frequency of emerging pest issues, and expanded commerce has increased the introduction rate and spread of invasive species. Western bean cutworms are increasing their geographic range to the eastern portion of the Corn Belt. Most varieties of Bt-corn do not adequately control this pest. Western bean cutworm may be evolving resistance to the few varieties that do partially control this insect, threatening growers' investments in the Bt-technologies. Reduced use of insecticides on Bt-cotton and -corn has resulted in increases in brown, green, and southern green stink bug populations, which contribute to an increase of corn ear damage and associated ear rot and aflatoxin/fumonisin contaminations. Further, a new invasive moth species called the chocolate milkworm infests high numbers of ears on pre-harvest corn in Louisiana and Georgia. In addition, aflatoxin reduction research is critically needed because ethanol production from corn will significantly increase aflatoxin levels as high as three times in the dry distiller grains (DDGs).

New management systems in corn and associated rotational crops have not only selected for glyphosate-resistant populations of previously common weed species, but also for species that are naturally tolerant to glyphosate. Examples of these “species shifts” include Benghal dayflower in the southeastern United States and Asiatic dayflower in the southwestern and central Corn Belt. Furthermore, new introductions, such as apple-of-Peru, may pose additional problems for weed management in corn. Not only are control procedures poorly understood for these species, but their effects on crops, basic biology and ecology, and propensity as hosts for diseases and insects are largely unknown.

Research Gaps: The tendency of western bean cutworm to spread into new geographic areas and its potential to evolve resistance to Bt-corn need to be studied. Little is known about the population dynamics and economic injury levels of the stink bug complex and chocolate milkworm in southern corn production regions. Ecological interactions among these insect pest populations, the severity of all key ear- and kernel-feeding insect damage, and ear rot infection rate, as well as mycotoxin (aflatoxin and fumonisin) contamination levels in pre-harvest corn is not well defined. Also, the influence of pre- and post-harvest insect pest damage on aflatoxin levels in corn grains is not well understood.

New weed species not only enter the United States regularly, but naturalized and native weeds evolve and adapt to new conditions. For instance, the evolution of resistance to glyphosate in giant ragweed populations was mentioned earlier, but equally important is the evolution of other traits important to management. An excellent example involves delayed seedling emergence in giant ragweed. Giant ragweed traditionally was amongst the earliest of summer annual species to emerge in spring, which allowed for easy control through seed bed preparation. With the advent of corn hybrids tolerant to early planting, populations of giant ragweed with delayed emergence now are common in Ohio and Indiana. Nearly identical behavior was observed recently with kochia in the northern Great Plains. Delayed emergence is but one of many weed traits that critically affect management decisions. Broadscale research and understanding of these characteristics will be required to permit better management of these types of species in the future.

Actions: ARS will:

Biology

- Conduct flight mill studies and population genetic research to assess movement and gene flow in the western bean cutworm.
- Examine stink bug and chocolate milkworm biology, population dynamics and economic injury levels.
- Conduct detailed research to examine ecological interactions between the severity of ear- and kernel-feeding insect damage and ear rot infection rate, as well as mycotoxin (aflatoxin and fumonisin) contamination levels in pre-harvest corn.
- Conduct flight mill studies to assess dispersal activity of adult stink bugs.

Control

- Selection experiments and resistance monitoring research will assess the risk of evolution for resistance to Cry1F-expressing corn in the Western bean cutworm.

***Anticipated Products*:**

- Information on specific genes and gene-products involved in insect resistance to genetically enhanced corn.
- Identification of plant traits that might be used to develop pest-resistant plants.
- Development of plants with pest resistance.
- Improved pest sampling and detection methods.

- Diagnostic markers to distinguish races or variants of pest species that attack corn.
- Markers for determining origin of migrant pests and characterizing their movement.
- Production of linkage maps that can be used for locating genes of interest, such as resistance genes or novel targets for control.
- Procedures using predictive criteria to guide grower decisions on where it will be cost-effective to plant transgenic corn among and within fields on a farm.
- Anticipate patterns and speed of resistance spread through pest populations.
- Increased knowledge of pest biology, ecology, behavior, genetics, and biological control agents, and of plant traits conferring pest resistance.
- Increased knowledge of the genomics, and basic biology and ecology of biological control agents.
- Improved understanding of how weeds respond to agroecosystem modifications, such as but not limited to cover crops and rotations.
- New weed control products appropriate for organic and conventional cropping systems.
- Novel weed control tactics appropriate for organic and conventional cropping systems.

***Potential Benefits (Outcomes)*:**

- Strategies for improved IPM of corn insect pests and weeds.
- Reductions in crop losses due to insect pests of corn and the plant diseases they transmit.
- Reductions in expenditures to manage insect pests and weeds.
- IPM tactics that are ecologically sound.
- Gains in farmer profitability could be made if transgenic corn targeting pests like corn borers and rootworms could be planted only where needed.
- Fewer acres planted to transgenic corn will reduce selection pressure on the insect pests, and slow development of resistance.
- Provides critical information for designing effective resistance mitigation strategies.
- Development of pest-resistant corn lines that can be used as low-input alternatives to transgenic Bt-corn in refuges or organic production.
- Development of Bt-corn with stacked native resistance to slow evolution of resistant populations of insects.
- Ability to monitor spread of races or variants into new regions.
- Ability to better assess real-time threat to corn from migrant pests, including races with different behaviors and host preferences.

- Recommendations for appropriate rotation frequencies of both crops and herbicides to stymie evolution of weed resistance and shifts to naturally tolerant weed species, and cause a general reduction in weed populations.
- Enhanced arsenal of weed control tactics appropriate for organic and conventional corn.

USDA ARS Resources:

- Areawide Pest Management Research Unit, College Station, Texas
- Corn Insects and Crop Genetics Resarch Unit, Ames, Iowa
- Crop Protection and Management Research Unit, Tifton, Georgia
- Insect Genetics and Biochemistry Research Unit, Fargo, North Dakota
- Invasive Weed Management Research Unit, Urbana, Illinois
- Natural Products Research Unit, Oxford, Mississippi
- New Crops and Processing Technology Research Unit, Peoria, Illinois
- North Central Agricultural Research Laboratory, Brookings, South Dakota
- North Central Soil Conservation Research Laboratory, Morris, Minnesota
- Northern Plains Agricultural Research Laboratory, Sidney, Montana
- Plant Genetics Research Unit, Columbia, Missouri
- Soil and Water Management Research Unit, St Paul, Minnesota
- Southern Insect Management Research Unit, Stoneville, Mississippi
- Southern Weed Science Research Unit, Stoneville, Mississippi
- Sustainable Agricultural Systems Laboratory, Beltsville, Maryland
- Water Management Research Unit, Fort Collins, Colorado

Component II: Protection of Agricultural and Horticultural Crops

2l. Cotton (U.S. Value 2007: $5.2 billion)

***Problem Statement*:** Cotton does not produce maximum yields in the United States because of realized and potential constraints characterized by the following insect pests, weeds, and knowledge gaps:

- Piercing-sucking insects (e.g., lygus bug, cotton fleahopper, stink bugs, green mirid, cotton aphid, whiteflies) that cause about one third of all insect damage to cotton
- Development of resistance to insecticides or to bacterial toxins in transgenic (Bt) cottons by cotton insect pests
- Continued presence of the boll weevil and pink bollworm, necessitating ongoing research support to ensure eradication progress and efforts are sustained
- New introductions of invasive arthropod species requiring improved detection, monitoring, and remediation methods
- Herbicide-resistant native weeds (e.g., morningglories, redvine, trumpetcreeper, spreading dayflower, smartweeds), exotic weeds (e.g., Benghal dayflower, nutsedges), and naturally herbicide-tolerant weeds (e.g., pigweeds, horseweed) requiring improved knowledge of weed biology and management
- Weed propagule persistence and dispersal of weed populations (seedbanks) and implications for weed management (e.g., black nightshade, browntop millet, prickly sida, barnyardgrass, florida pusley, wild poinsettia, spurges, Texas millet)
-

***Research Needs*:**

1. **Piercing-sucking Insects**

   Importance: Plant bugs and stink bugs have become the most important pests of cotton in the United States. Although the speciescomposition of individual complexes of these pests vary regionally, key species or groups of species produce economic losses annually in western (western tarnished plant bug), southwestern (cotton fleahopper, green mirid), mid-South (tarnished plant bug) and southeastern (stink bugs) production regions. The importance of plant bugs as pests has increased, at least in part, because the adoption of insecticidal transgenic varieties and progress in eradicating the boll weevil have led to reductions in the use of insecticides that once provided incidental control of piercing-sucking pests. Other piercing-sucking pests, such as whitefly and aphids, continue to be problematic in several regions of the United States cotton belt. This insect complex has long been associated with a variety of impacts on cotton lint yield and quality, including lint contamination by honeydew, production of immature fibers, discoloration from boll feeding and associated boll rot, and delayed crop maturity resulting from early- and mid-season square loss.

Research Gaps: Sucking insects in many cotton production systems have received relatively little research attention compared to more traditional cotton pests such as the boll weevil, cotton bollworm, tobacco budworm, and pink bollworm. Consequently, knowledge of certain aspects of the basic ecology, population dynamics, and crop-pest interactions, as well as fundamental knowledge of sampling methods, economic thresholds, and control efficacy are lacking. Increased knowledge of these factors will be necessary for development of ecologically-sound and sustainable management strategies that focus on a broader landscape-level perspective. Because the economics of commercial agriculture dictates continual changes in production practices, increasingly sophisticated knowledge of ecological mechanisms driving population and landscape-level processes will be needed to ensure the durability of management strategies. For example, the USDA, ARS Area-Wide Control Program for Tarnished Plant Bug demonstrated that treating marginal areas (turn rows, ditches, roadsides, etc.) with a selective herbicide to control broadleaf hosts of the pest reduced in-season cotton insecticide costs by $5.90 per acre. Recent market-driven increases in acreages of alternate cultivated hosts (corn, soybean), however, have reduced the benefits of the program. Development of more cost-effective, environmentally-sound, and durable management strategies for the complex of piercing-sucking insects will, therefore, require extensive knowledge of spatial and temporal population patterns occurring in a landscape containing a mosaic of hosts. Interpretation of landscape-level data will require increased understanding of sampling methods and their limitations. We need to elucidate crop responses to infestation, improve sampling methods, and assess the risk and status of pesticide resistance to construct more reliable action thresholds that maximize profitability of production. (Also, see the Legume subcomponent for additional information on lygus and stink bug research.)

Actions: ARS will:

Monitoring/Decision Aids

- Evaluate and calibrate standard and novel sampling methods for plant bugs in cotton.
- Develop and refine economic thresholds for sucking insects in cotton.
- Develop and validate GIS map-based risk-rating systems for stink/leaf-footed bugs at whole farm and field levels.
- Define spatial and temporal distributions of pests and natural enemy populations.
- Identify pheromones (sex, aggregation, defensive) with application in monitoring and mating disruption of piercing-sucking pests.

Host-Insect Interactions

- Examine host plant responses to plant bug injury on species- (Pima or Upland) and cultivar-specific bases.

- Examine virus-vector relationships and identify plant pathogens vectored to cotton by stink bugs and cotton fleahoppers.

Basic Biology/Ecology

- Identify endogenous and exogenous factors influencing diapause in plant bugs and define the ecological implications of the diapause phenomenon.
- Characterize dispersal of plant and stink bugs between and within multiple hosts using mark-recapture and pollen identification.
- Identify neuropeptides that regulate critical life processes of stink bugs.
- Illuminate the process of hormonal regulation of development and reproduction in plant bugs.
- Study and implement novel molecular-based control strategies for whitefly and plant bugs.
- Identify and functionally characterize genes/proteins in sucking cotton pests with application for disruption of key physiological processes.
- Develop molecular phylogeny of lygus bugs

Control, Biological

- Evaluate selected insect pathogens for incorporation into an ecologically-based management strategy for plant bugs.
- Develop and test habitats of nectar-producing plants for conservation of stink bug natural enemies and bees in conventional and organic production of cotton.
- Evaluate release strategies of the stink bug egg parasitoid, *Trissolcus basalis*, for augmentative biological control in cultivated crops acting as sources of stink bug populations.
- Develop DNA-based methods for studying and quantifying predation on piercing-sucking pests.

Control, Chemical

- Evaluate insecticides for selectivity for piercing-sucking pests and minimal impact on natural enemy complexes.

Control, Landscape Management

- Elucidate relationships and interactions between landscape structural parameters, and pest biology and dispersal behavior.
- Develop and evaluate trap cropping systems for stink/leaf-footed bug management that are adaptable to conventional and organic production systems.
- Evaluate non-crop hosts for use as trap environments.

- Identify plant volatiles used in host attraction and recognition.
- Conduct flight mill studies of the flight behavior and activity of plant and stink bugs.
- Develop methodologies to use elemental isotopies or genetic markers to better understand the ecology of plant bugs, thereby improving delivery of areawide control methods and novel insecticide resistance management strategies.
- Develop and apply computer simulation models of IPM strategies over large landscape scales.

2. Insecticide Resistance and Management

Importance: Insecticides remain a primary tactic of pest control in most cotton IPM programs throughout the United States, and insecticide resistance remains a continual threat to the sustainability of these management programs. Tarnished plant bugs in the mid-south have, or are developing resistance to a range of insecticide classes. Whiteflies have a long history of insecticide resistance, and it is possible for the Q biotype, which is resistant to most current insecticides used in whitefly management, to become established. Also, several caterpillar pests have shown the capacity to evolve resistance to Bt proteins in the laboratory. Therefore, field-evolved resistance to Bt-cotton is a critical concern. New strategies for managing insecticide resistance are needed to delay or prevent the onset of resistance and sustain the current arsenal of pest management tools.

Research Gaps: Critical research needs include improved methods for resistance monitoring, as well as development of new insecticide resistance management strategies and control tactics to augment the limited selection of insecticides currently effective against major cotton pests. New information is needed on the population ecology/genetics of Bt-targeted pests so that resistance management strategies can be optimized, and new control methods can be integrated in a way that improves the quality and duration of this pest control technology.

Actions: ARS will:

Resistance monitoring

- Continue to monitor the development of insecticide resistance in the tarnished plant bug and characterize the mechanisms of resistance. This will aid in the development of new control methods with unique modes of action and assist in the implementation of optimal insecticide rotation schemes to delay the evolution of resistance.

Control, Biological

- Develop and enhance the use of a new biotype of the fungus *Beauveria bassiana* for control of tarnished plant bug in the areawide program and as a rescue treatment during the cotton growing season.

- Study movement and mating behavior of Bt-targeted pests in diverse cotton agroecosystems to optimize the management of Bt susceptibility in the pest populations.

Control, Resistance

- Use existing genetic markers and develop new, more informative, genetic markers to study population parameters such as gene flow of rare resistance alleles, to improve resistance management strategies for Bt cotton.
- Provide expertise and support of programs for monitoring pink bollworm resistance to Bt cotton.
- Characterize Bt intoxication and mode of action processes in pink bollworm, tobacco budworm, and cotton bollworm.
- Study transposable elements derived from pink bollworm and adapt novel molecular tools used for increased gene drive and transformation systems in other insect systems for improved control options.
- Examine the influence of plant allelochemicals on insecticide resistance expression in the polyphagous sweetpotato whitefly.
- Refine chemical control strategies for sweetpotato whitefly to manage resistance and enhance natural enemy conservation.

3. Sustaining Eradication of Boll Weevil and Pink Bollworm

Importance: Over a period of about 30 years, the boll weevil eradication program has eliminated the insect as an economic pest from nearly 14.9 million acres of U.S. cotton; it is still active in 1.45 million acres. Despite considerable progress in eradicating the boll weevil, low-level infestations remain in many production regions of the South and Southwest. Occasional captures of weevils in suppressed or eradicated zones trigger expensive and labor-intensive remediation measures to preserve prior program investments. The pink bollworm eradication program was initiated in early 2000 in Texas and has spread west to Arizona and California, with eradication activities in the United States as a whole scheduled to end in 2010. Both eradication programs represent vast investments of producer, state, and Federal resources, and both programs are subject to the continual threat of reinfestation from Mexico, where both pests remain established.

Research Gaps: There is need for research support of maintenance programs, especially regarding detection and monitoring of re-infestations that jeopardize the substantial investments in these eradication programs. The current economic environment dictates reductions in the cost of maintenance programs concurrent with improved capacity to detect and remedy re-infestations. These needs are particularly urgent for program areas that abut international borders. Elimination of low-level populations in active programs, and efficient detection of local and distant sources of re-infestation, will require improvements in monitoring technology and interpretation of trapping data, and increased understanding of biotic and abiotic mechanisms governing insect movement and subsequent colonization. Determination of the origin of reinfestations is crucial to effective eradication maintenance strategies. Monitoring remaining populations of boll weevils for susceptibility to organophosphates in the United States or Mexico is important to ensure that effective control can be achieved in potentially re-infested zones.

Actions: ARS will:

Identification and Detection

- Determine if molecular markers can be used to identify populations of remaining boll weevils in the United States and Mexico.
- Develop technology and techniques for rapid identification and biochemical characterization of pollen attached to boll weevils.
- Develop techniques to detect and map uncultivated areas of volunteer cotton plants using remote sensing.

Monitoring

- Monitor remaining populations of boll weevils for susceptibility to organophosphates, and develop alternate control strategies in the event of resistance development.

Control

- Evaluate and develop new technologies and strategies for managing pests in post boll weevil eradication zones.

4. Introduction of Invasive Arthropod Species

Importance: Invasive species are a growing problem in the United States. In 2000, it was estimated that invasive arthropods caused $20.5 billion dollars in losses and control costs annually. It is estimated that approximately 40 percent of all crop pests are exotic and many agricultural commodities are at risk from invasive species. Vigilance is required to identify and act on emerging exotic pest issues before they become problematic.

Research Gaps: In many cases, monitoring techniques, such as using sex pheromone and floral volatile lures, are available. Therefore, early detection of certain key exotic species (e.g., *Helicoverpa armigera*, cotton bollworm; *Spodoptera littoralis*, Egyptian cotton leafworm; and *S. litura*, cotton leafworm) is important so that control strategies can be implemented while populations are low and amenable to eradication. Both exotic species of *Spodoptera* attack several crop plants, and *S. litura* has been found in south Florida where it presumably was imported on ornamental plants from Asia. These species have wide host ranges and it is conceivable that these species could invade subtropical areas of the United States (Florida, Texas, Arizona, and California) on crops other than cotton and then expand their range to include cotton-growing areas.

Cooperative research between ARS and APHIS scientists will be needed to monitor these exotic lepidopteran species.

Actions: ARS will:

Monitor

- Monitor for populations of key exotic species.

5. Management and Biology of Herbicide-resistant and Herbicide-tolerant Weeds

Importance: Herbicides are the primary means of controlling weeds in cotton. The use of glyphosate (Roundup, among others) in Roundup Ready cotton has altered crop production practices, allowing for greater adoption of reduced tillage and more efficient weed control of many previously troublesome species (such as sicklepod and Johnsongrass). However, this selection pressure has caused shifts in weed species composition towards weeds that are naturally tolerant of or resistant to glyphosate, or that can develop from seedling to maturity, from layby to harvest. This issue is further complicated by the co-occurrence of weeds resistant to other herbicides used in cotton (and crops commonly used in rotation with cotton), which could potentially lead to the evolution of weeds resistant to multiple herbicides. If herbicide-tolerant and herbicide-resistant weed biotypes are allowed to spread, there will be a clear reduction in the ability of the grower to effectively manage weeds. The presence of herbicide-resistant weeds threatens the use of reduced tillage systems, which promotes soil conservation, but precludes an alternative control option (i.e., cultivation). Many of the weed species that are troublesome in cotton are also difficult to manage in summer crops (e.g., corn, soybean, and peanut) that are commonly rotated with cotton and planted in the same fields. This is especially true of herbicide resistant weeds, as these crops use herbicides with similar modes of action. In addition to use in cotton, ALS-inhibiting herbicides, dinitroanilines, PPO-inhibiting herbicides, chloracetemides are also used in corn, soybean, and peanut. Glyphosate, ureas, and triazines are also used in both corn and soybean. Further complicating this issue is the disappearance (e.g., cyanzaine/Bladex) or threat of disappearance (e.g., MSMA) of tools commonly used to manage weeds prior to the introduction of herbicide-tolerant crops.

Research Gaps: There is great variability in the mechanisms of resistance and tolerance in many of the troublesome weeds that have developed in our agroecosystems. Some species have the ability to restrict herbicide movement within the plant, but the mechanisms for this are not understood. With other species, such as glyphosate-resistant pigweeds and glyphosate-tolerant Benghal dayflower, the means of resistance and tolerance have not been fully understood. Resistance to other herbicides used in cotton has been documented worldwide, for example, ALS-inhibiting (e.g., Staple), dinitroaniline (e.g., Prowl), PPO-inhibiting (e.g., Relfex), organoarsenicals (e.g., MSMA), and bipyridilium (e.g., Paraquat) herbicides. However, as the occurrence of glyphosate-resistant weeds increases, alternatives to glyphosate-only applications are replaced with tank-mixes that include alternative herbicides. The use of glyphosate will likely continue, even in areas with resistant weeds, due to its high efficacy against numerous common weeds. Selection of tank-mix partners to which resistance does not compromise control will have limited application. Alternative weed management options to be used in place of, or in conjunction with, glyphosate in cotton and its rotation crops need further exploration. In addition, while herbicide resistance mechanisms are presently unknown in many of these resistant weeds, it is unlikely that these mechanisms would prevent the infectivity mechanism and mode of action of a bioherbicide that is pathogenic to non-herbicide resistant weed biotypes.

Actions: ARS will:

- Determine basic mechanisms of herbicide-tolerance or resistance in troublesome species, such as horseweed, ragweeds, johnsongrass, pigweeds (e.g., waterhemp and Palmer amaranth).
- Investigate basic biology of vines with herbicide-tolerance or -resistance, such as morningglories and redvine.
- Evaluate various herbicide and cultural crop production practices to suppress herbicide-resistant and herbicide-tolerant weed species, and weeds developing late season between layby and post-harvest.
- Investigate the use of plant pathogens as bioherbicides for weed species [e.g., horseweed, pigweeds (including Palmer amaranth and waterhemps), ragweeds, morningglories, redvine, and trumpetcreeper] that have become resistant or are naturally tolerant of commonly used herbicides.

6. Persistence and Dispersal of Weed Populations (weed propagule) and Implications for Weed Management (seedbank)

Importance: Current weed management strategies focus on controlling emerged weeds or reducing seedling emergence. These efforts will effectively reduce emerged weed population densities. However, these results are temporary, and treatments must be repeated throughout the season to minimize crop yield losses from weeds. To improve efficiency of these strategies, greater understanding of the factors and mechanisms that govern the reproduction, dispersal, and establishment of weeds in cotton production systems is needed. Reproduction and dispersal of seed and vegetative propagules (e.g., nutsedge tubers) with differing types and levels of dormancy and longevity lead to a reserve in the seedbanks and propagule-banks for future weed populations. Factors that regulate seedbank and propagule-bank dynamics are not well understood in cotton agroecosystems. Greater knowledge concerning the fate of weed propagules and factors that regulate propagule dispersal and viability will assist in developing strategies to reduce weed populations for greater long-term weed control and will assist in improving weed management efficiency.

Research Gaps: Comprehensive understanding of weed reproduction is lacking for most weeds that commonly occur in cotton production systems. Because of the limited basic and applied knowledge of factors that affect weed establishment, growth, reproduction, dispersal, and seed fate, there has been limited success in minimizing weed population densities in the soil seedbank. More information is required concerning factors that govern weed seedling establishment, pollination efficiency, seed development, seed rain and dispersal, and seed dispersal within and between fields, especially for weeds without specialized dispersal mechanisms.

Actions: ARS will:

- Investigate the seedbank dynamics and factors that regulate seed persistence of troublesome weeds (e.g., Benghal dayflower, pigweeds, browntop millet, and nutsedges) of cotton and its common rotational crops.
- Evaluate the dispersal mechanism(s) of Texas weed, croton species, vetch species, wild geranium, and other principal weeds of fields in the mid-South that eject their seeds from the capsule and investigate inhibitors of these processes for potential field use.

***Anticipated Products*:**

- Increased knowledge of sucking pest biochemistry, biology, ecology, behavior, dispersal, and genetics.
- Increased knowledge of biological control agents, sampling methods, decision aids, host plant interactions, and other potential control tactics such as trap cropping.
- GIS methods, computer simulation, and various genetic and marking techniques for all cotton production areas of the United States that exploit an understanding of the landscape ecology of piercing-sucking pests and their natural enemies.
- Increased knowledge of pest semiochemicals and their use in monitoring and management.
- Understanding of the pest biology and behavior (attractants/repellents), and plant injury relationships between piercing sucking pests and their host plants.
- Identification of potential pathogens useful in plant bug control and better understanding of potential plant-pathogen/pest relationships.
- Improved/new insect pathogenic biological control agents
- Strategy for augmentative biological control for management of stink/leaf footed bugs.
- Improved methods for the detection and study of predation on sucking pests.
- Improved conservation of natural enemies through use of selective insecticides and provisioning of nectar and other non-prey resources.
- Improved monitoring systems for tracking insecticide resistance and resistance to transgenic Bt cotton.

- Improved resistance management systems for delaying resistance and sustaining important insecticides and transgenic technologies.
- Increase knowledge of the underlying genetics and behavior of resistance.
- Improved monitoring of eradicated pests to allow more efficient remedial actions.
- Improved monitoring of potential exotic invasive pest species.
- Determination of the mechanism(s) by which resistance and tolerance to glyphosate is achieved and possible alternative treatments that would allow for control of these species.
- Effective weed management strategies for minimizing the impact of herbicide-tolerant/resistant weed species in conservation tillage and conventional tillage agroecosystems.
- Improved long-term weed management systems that incorporate knowledge of soil seedbanks and seed longevity into the design of crop production systems and weed control decisions.
- Knowledge of the mechanism(s) of seed dispersal will allow development of seed dispersal process inhibitors and treatments that would affect cotton boll opening and seed shatter in soybean and rape.
- Development of a broad-spectrum bioherbicidal fungus tactics that provide good to excellent control of the cotton weed species and include directed spray application technologies and/or preplant applications for use in row crops such as soybeans and cotton.

Potential Benefits (Outcomes):

- Strategies for more efficient, sustainable and ecologically-based IPM systems for all pests of cotton.
- Reductions in crop and quality loss from insect pests of cotton.
- Reductions in insecticide use and in overall costs of pest management.
- Improved quality of rural communities.
- Reduced impact of weeds, especially those that tolerate or are resistant to current weed control options, on cotton production systems through improved weed management strategies.
- Improved control and management of troublesome species due to a greater understanding of the population dynamics of herbicide-resistant and herbicide-tolerant weeds.
- Greater efficiency in weed management systems due to improved knowledge of weed reproductive biology and factors that regulate seed longevity in the soil propagule/seedbank.
- Improved bioherbicide performance due to optimization of mass production, improved formulation and application technologies, and increased knowledge of

ecological/climatological effects, e.g., weed and crop densities, rainfallfastness of pathogen formulations, and weed growth stage.

- Tactics for optimal application timing of candidate bioherbicide and models for predicting bioherbicide efficacy due to an understanding of weed and pathogen biology, ecology, and biochemistry.
- New and improved commercial bioherbicide products available to the public for weed control.
- Reduction and minimization of weed shifts impacts resulting from continuous glyphosate usage.
- Improved resistance management strategies due to better understanding of resistance establishment pathways.

***USDA ARS Resources*:**

- Areawide Pest Management Research Unit, College Station, Texas
- Beneficial Insects Research Unit, Weslaco, Texas
- Crop Protection and Management Research Unit, Tifton, Georgia
- Insect Behavior and Biocontrol Research Unit, Gainesville, Florida
- Pest Management and Biocontrol Research Unit, Maricopa, Arizona
- Southern Insect Management Research Unit, Stoneville, Mississippi
- Southern Weed Science Research Unit, Stoneville, Mississippi
- Western Integrated Cropping Systems Research Unit, Shafter, California

Component II: Protection of Agricultural and Horticultural Crops

2m. Legume Field Crops [U.S. Value 2007: $38 billion (peanuts, alfalfa, dry bean, pea, lentil)]

Problem Statement: The principal legume field crops (soybeans, peanuts, and alfalfa) do not produce maximum yields due to the following pests.

- Lygus and Alfalfa Plant Bugs (alfalfa, especially seed alfalfa in the northwestern United States)
- Soybean Aphid (soybeans)
- Brown Marmorated Stink Bug and Other Stink Bugs (soybeans and peanuts in southern states)
- Sporadically and Regionally Important Pests (including; various Lepidoptera species; several species of alfalfa aphids; thrips which vector diseases; planthoppers; alfalfa weevil; slugs, grubs, millipedes, and other soil pests; bean leaf beetle, pyrethroid-resistant corn earworm, and other foliar feeders; and native *Dectes* stemborers)

Research Needs:

1. **Lygus and Alfalfa Plant Bugs**

   Importance: Several lygus bug species (tarnished plant bugs) are among the most economically damaging insects for many crops in North America. They reduce the yield and quality of seed alfalfa and many other important food, fiber, and seed crops. The importance of lygus has increased because of the development of pest resistant bioengineered crops and area-wide management programs that reduce the impact of other key pests, and development of lygus resistance to widely used insecticides. The introduced European alfalfa plant bug damages seed alfalfa and other forage legumes throughout the United States. Native natural enemies do not cause significant mortality in plant bug populations.

   Research Gaps: A better understanding is needed regarding the movement of lygus between host plants. Research is needed regarding the role of landscape ecology in governing the increase and dispersal of plant bug populations and their natural enemies. New management tools, especially biological control agents adapted to specific climatic regions and integrated areawide approaches, are needed to combat resurgent lygus populations in many parts of the United States.

Actions: ARS will:

Basic Biology

- Study and implement novel molecular-based control strategies for whitefly and plant bugs.
- Identify and functionally characterize genes/proteins in sucking pests with application for disruption of key physiological processes.

Monitor, Dispersal Behavior

- Determine the extent to which lygus bugs and their associated natural enemies disperse between key cropping systems including alfalfa, cotton and new cropping systems such as lesquerella and guayule.

Control, Biological

- Conduct foreign exploration in Europe, Africa and Asia for new biological control agents of lygus and alfalfa plant bug, based on host specificity and climatic tolerances for establishment in the United States.
- Determine the impact of introduced biological control agents on lygus in alfalfa and other host crops in the United States.

Genetics

- Use molecular genetic markers to clarify the relationships among lygus species and populations and assist in biological control agents with their hosts.

2. **Soybean Aphid**

Importance: The invasive Asian soybean aphid (SBA) was detected in 2000 in the northern United States and rapidly spread throughout soybean production regions in the United States and eastern Canada, resulting in major changes in soybean insect management and increased use of pesticides. Aphid populations vary regionally, with the north central states experiencing the greatest levels of damage. SBA outbreaks often correspond to potyvirus outbreaks in other legume crops including dry beans and snap beans, and other crops including vine crops and potato, thus extending the overall impact of this species beyond soybeans. Soybean aphid overwinters on several introduced buckthorn species that are widespread in North America, but the influence of this landscape interaction on SBA populations in soybean is not well understood.

Research Gaps: Environmentally sustainable management methods are needed to reduce soybean aphid populations and reduce management costs to farmers. Biological control by natural enemies is one sustainable strategy with great promise. Efforts to introduce new biological control agents and to conserve native and naturalized natural enemies both contribute to this approach. Screening of candidates for biological control introductions, based on host specificity and climatic tolerances, introduction of the most promising species, and evaluation of impact on target and non-target species are necessary. In addition, efforts are needed to develop and evaluate cultural and host plant resistance management tactics. Research is also needed to understand the role of aphid dispersal and overwintering aphid populations on buckthorn in reinfesting soybeans the following season.

Actions: ARS will:

Landscape Ecology

- Determine the impact of resident biological control agents on soybean aphid populations in overwintering host reservoirs.

Control, Biological

- Determine the impact of resident biological control agents on soybean aphid populations in North American soybean production regions.
- Determine the microhabitat preferences, alternate prey or hosts, and dispersal behavior of effective natural enemies in relation to soybean aphid infestation patterns in time and space.
- Develop conservation biological control strategies for effective natural enemies.
- Conduct foreign exploration in Asia for new biological control agents . Screen, introduce, and evaluate the impact of candidates for biological control introductions, based on host specificity and climatic tolerances.

Control, Host Plant Resistance

- Develop and evaluate host plant resistance mechanisms and management tactics.
- Determine how aphid-resistant soybeans can be integrated with other management strategies, such as biological control.

Control, Organic Systems

- Develop organic management systems for controlling insect pests in soybeans.

Control, Fundamental Biology or Biological Controls

- Conduct research on behavioral and genetic determinants of host specificity.

3. **Brown Marmorated Stink Bug and Other Stink Bugs**

Importance: Several species of stink bugs are increasingly of concern as pests in soybeans and peanuts in southern states. Brown marmorated stink bug is a new invasive species of Asian origin with the potential to impact soybeans in the United States as its range continues to expand. The red-banded stink bug has been shown to cause ‘flat pod’ syndrome and delayed maturity. Stink bugs also occur in peanuts, where their impact is not yet clear.

Research Gaps: The biology and ecology of key stink bugs that occur in soybeans and peanuts need to be fully understood prior to the establishment of effective new or modified scouting methods and injury thresholds. This knowledge also is essential to the development of new environmentally sustainable management practices such as the introduction of biological control agents, conservation of native naturalized natural enemies, and establishment of effective cultural and host plant resistance-based management tactics. The status of brown marmorated stink bug a developing pest of soybeans needs to be monitored and prospects for its biological control evaluated.

Actions: ARS will:

Biology and Ecology

- Develop improved and novel methods for understanding the biology and ecology of stink bugs.
- Determine the impact of agricultural landscapes on populations of stink bugs and their natural enemies.
- Characterize dispersal and seasonal phenology of stink bugs and their natural enemies.
- Collaborate with plant pathologists to determine the ability of stink bugs to vector plant pathogens.

Attractants

- Identify and synthesize promising semiochemicals with activity for brown marmorated stink bug.

Monitoring

- Improve sampling and monitoring methods for stink bugs using traps baited with an attractant.

Control, Chemical

- Investigate the efficacy of lethal and sub-lethal doses of insecticides on management of stink bugs.

Control, Novel Methods

- Develop neuropeptide mimics that may be formulated as novel control agents for pest management.

Control, Biological

- Assess the impact of current pest intervention strategies on stink bugs and their natural enemies, and develop strategies that are less disruptive to natural enemies.
- Develop and enhance biological control strategies for suppression of stink bugs in area-wide pest control systems for southern row crops.
- Conduct foreign exploration in Asia for new biological control agents of brown marmorated stink bug and evaluate new agents for host specificity and efficacy.

- Determine the impact of resident biological control agents on brown marmorated stink bug populations in the Mid-Atlantic region.
- Cooperate in programs to establish new agents of brown marmorated stink bug and evaluate their impact on the target and monitor for impact on selected nontarget species.

Control, Germplasm Resistance

- Evaluate soybean germplasm for resistance to stink bugs.

Control, Organic Systems

- Develop organic management systems for controlling stink bugs in peanuts.

4. Sporadically and Regionally Important Pests

Importance: Various native and long-established pests are increasing in soybeans. Populations of soil pests (such as slugs, grubs, and millipedes) and foliar feeders (such as bean leaf beetle) are increasing in many regions. This is also true for the stemborer, *Dectes*. In addition, pyrethroid-resistant corn earworm abundance and distribution appears to be increasing in the eastern United States. Other legume crop pests are sporadically or regionally important, including several aphid species, leafhoppers (alfalfa) and planthoppers (alfalfa), alfalfa weevil, thrips (important as disease vectors), and various species of Lepidoptera.

Research Gaps: New or modified scouting methods, injury thresholds and management tools need to be develop that are able to adjust to changes in pest impact and distribution. Many of the pests in this category are not being actively addressed by ARS programs.

Actions: ARS will:

Control, Minor Use Pesticides

- Provide data to support registration/re-registration of minor use pesticides for legume forage crops.

Control, Organic Systems

- Develop organic management systems for controlling insect pests in peanuts and soybeans.

<u>Anticipated Products</u>:

- Increased knowledge of pest biology, ecology, behavior, genetics, and biological control agents, and of plant traits conferring pest resistance.
- Discovery, characterization, and synthesis of insect attractants, repellents and behavioral disruptants.
- New biological control agents.

- Increased knowledge of the genomics and basic biology and ecology of biological control agents.
- Identification of plant traits that might be used to develop pest-resistant plants.
- Development of crop plants with pest resistance.
- Novel methods of reducing the impact of insect pests of soybeans, peanuts and alfalfa.
- Information on trap crops as potential tools for pest management.
- Improved pest sampling and detection methods.
- Improved understanding of determinants of viral vector competency for pests.
- Mating disruption.

Potential Benefits (Outcomes):

- Strategies for improved IPM for insect pests of soybeans, peanuts and alfalfa.
- Reductions in crop losses to insect pests of soybeans, peanuts and alfalfa and the plant diseases they transmit.
- Reductions in expenditures to manage insect pests.
- IPM tactics that are ecologically sound.

USDA ARS Resources:

- Areawide Pest Management Research Unit, College Station, Texas
- Arid-Land Agricultural Research Center, Maricopa, Arizona
- Beneficial Insect Introduction Research Unit, Newark, Delaware
- Biological Control of Insects Research Unit, Columbia, Maryland
- Biological Control of Insects Research Unit, Stoneville, Mississippi
- Crop Protection and Management Research Unit, Tifton, Georgia
- European Biological Control Laboratory, Montpelier, France
- Fruit and Vegetable Insect Research Unit, Wapato, Washington
- Insect Behavior and Biocontrol Research Unit, Gainesville, Florida
- Insect Genetics and Biochemistry Research Unit, Fargo, North Dakota
- Integrated Cropping Systems Research Unit, Brookings, South Dakota
- Invasive Insect Biocontrol and Behavior Laboratory, Beltsville, Maryland
- Sino-American Biological Control Laboratory, Beijing, China
- Southern Insect Management Research Unit, Stoneville, Texas

Component II: Protection of Agricultural and Horticultural Crops

2n. Small Grains (Barley, Oats, Rice, Rye, Sorghum, and Wheat) (U.S. Value 2007: $19 billion)

Problem Statement: Production of small grains is reduced by pest insects and weeds. The most widespread and economically significant insect and weed problems are:

- Cereal Aphids (Russian wheat aphid, greenbug, barley yellow dwarf virus and its very efficient vector the bird cherry-oat aphid) in Wheat, Barley, and Sorghum.
- Hessian Fly in Wheat. *(This is addressed in National Program 301)*
- Wheat Stem Sawfly in Wheat.
- Other Insect Pests* include: Cereal Leaf Beetle, Lepidoptera (such as Army Cutworm, Western Pale Cutworm, True Armyworm, Fall Armyworm), and Wheat Streak Mosaic Virus and its vector the Wheat Curl Mite.
- Weeds include: Crop Mimics or Weedy Relatives with similar growth periods and/or genetics to grain crops such as Red Rice, Wild Oats, Johnsongrass, Jointed Goatgrass, and Downy Brome; and weeds of grains in conventional, organic or biofuels systems such as Ryegrass, Wild Oats, Barnyardgrass, Common Crupina, Field Bindweed, Himalaya Blackberry, Knapweeds, Medusahead, Mile-a-Minute, Milk Thistle, Musk Thistle, Russian Thistle, Teasel, Swallowworts, White Top (Hoary Cress), Horseweed, Pigweeds, and Sedges, Canada Thistle, Leafy Spurge, Quackgrass, Sweet Sorghum, Bermudagrass, Yellow and Purple Nutsedge, Kudzu, Hemp Sesbania, Sicklepod, Redvine, and Trumpetcreeper. *(Weeds of interest to growers of grains are also addressed in other subcomponents especially Rangeland/Pasture and Arid Land Crops, Citrus Nut Crops, Vegetables, Cotton, and Weeds in Natural Ecosystems as well as in National Programs 202, 211, 301, 302, 305, and 308).*

*No actionable item due to resources

Research Needs:

1. **Cereal Aphids**

Importance: Cereal aphids are key insect pests of wheat, barley, and sorghum throughout much of the United States due to their capability of explosive population growth and ability to cause severe damage to grains by their feeding. The Russian wheat aphid (RWA), for example, is an invasive pest of wheat and barley in the western United States that is especially important in the semi-arid High Plains region. RWA outbreaks occur somewhere in the High Plains almost every year with widespread outbreaks occurring periodically, resulting in heavy insecticide use and/or greatly reduced wheat and barley yields. Average losses to the wheat and barley industries from the RWA exceed $50 million annually. Similar statements can be made for the greenbug, which is an economic pest of sorghum in addition to wheat and barley, and has a more eastern range. Losses caused by cereal aphids present an impediment to the economic viability of grain production. Both the RWA and greenbug have overcome genetic resistance conferred by resistance genes bred into wheat varieties. Varieties are currently being bred that contain other resistance genes, but the potential for these insects to adapt to overcome new resistance sources is high, and our ability to stop or slow this process is limited due to lack of fundamental knowledge on insect and plant biology, genetics, and ecology.

Research Gaps: Solutions are needed to mitigate the economic losses caused by cereal aphids. The underlying basis for development of RWA and greenbug biotypes needs to be determined to guide breeding programs to develop new, durable, resistant wheat, barley, and sorghum varieties. Tools for more effective pest management decision-making are needed, as are techniques to quickly and inexpensively detect RWA infested grain fields. Regional monitoring programs to detect new and emerging biotypes and potential new invasive insect pests are also needed. In addition, methods to enhance the role of naturally occurring biological control are important in the long term for sustainable pest management.

Actions: ARS will:

Monitoring and Decision-Making

- Determine the potential for airborne remote sensing to detect RWA infested grain fields.
- Develop a computer based pest management decision support system for the RWA.

Biology, Genetics, and Ecology

- Determine the genetic and biochemical basis for biotype formation in the RWA and greenbug.
- Monitor cereals for biotypic diversity in aphids and new invasive insect species.
- Determine the ecology of RWA and greenbug on native hosts and the relationship to biotype formation and pest status in cereals.
- Design, produce and utilize molecular markers to answer pertinent questions about ecology and evolution of aphid biotypes and populations.

Control, Biological

- Assess the effectiveness of key biological control agents in traditional and emerging small grain crop production systems.
- Conduct foreign exploration in Eurasia for new biological control agents. Screen introduce, and evaluate the impact of candidates for biological control introductions, based on host specificity and climate tolerances.

- Conduct research on behavior and genetic determinants of host specificity in parasitoids of cereal aphids.

Control, Host Plant Resistance

- Identify new sources of resistance to cereal aphids and incorporate them into resistant wheat, sorghum, and barley germplasm. *This is addressed in National Program 301 Action Plan.*

2. Wheat Stem Sawfly

Importance: The wheat stem sawfly (WSS) is an important pest of wheat and other grain crops in the northern Great Plains. Damage to wheat occurs primarily in Montana, the Dakotas, western Nebraska, eastern Wyoming, and the Canadian Prairie Provinces. Field infestation levels of greater than 80 percent have been reported with yield losses of as much as 20 percent in some years and locations. Damage caused to wheat in Montana alone has been estimated at $25-30 million annually with regional losses in the United States greater than $100 million. Current management practices for WSS, including resistant wheat cultivars and various cultural practices, have not been effective in minimizing losses. Biological control, including natural, classical, conservation and augmentation approaches, may have potential for effective control of the pest.

Research Gaps: Classical biological control using exotic parasitoids has promise for effective and sustainable control of WSS, however exploration is needed to identify new candidate biological control agents. Research is needed on prospective agents to determine the potential of classical biological control for WSS in the northern Great Plains.

Actions: ARS will:

Control, Biological

- Find, identify, and evaluate WSS parasitoids from Asia.
- Evaluate candidate biological control agents in the insect quarantine laboratory.
- Release and evaluate promising candidate biological control agents.

3. Hessian Fly

Importance: The Hessian fly is a pest of wheat over much of the United States. The primary method of control is through genetically resistant wheat. However, resistance resources in wheat and wheat relatives are expected to be finite. Within 8-10 years of the release of a new wheat cultivar, the Hessian fly is able to overcome the resistance gene and can survive on cultivars that were formerly resistant. Thus, new sources of resistance genes must constantly be identified to replace ones that are no longer effective. Since it takes roughly 8-10 years to identify a new source of resistance and incorporate it into a cultivar, the wheat crop is constantly under threat.

Research Gaps: Knowledge of how the insect overcomes resistance in wheat is essential to continued control with genetic resources from wheat. Molecular markers for analysis of the genetic structure of field populations of the insect, an understanding of the molecular interaction between the insect and wheat, and identification of genes for resistance to transform into wheat will be important for continued effective and durable control of the Hessian fly.

Actions: ARS will:

Control, Resistance

- Devise deployment strategies that will lead to more durable resistance. *This is addressed in National Program 301 Action Plan.*
- Identify new sources of resistance and determine which genes will be effective in various parts of the United States. *This is addressed in National Program 301 Action Plan.*

4. Weed Management

Importance: Even with the array of herbicides available for producer use, weeds still remain a continuous problem for producers. Cost of weed management is often a major input for crop production, whereas resistance further increases difficulties with weed management in small grains.

Research Gaps: Producers are asking for alternatives to herbicide-centered weed management and for cropping systems that are not so dependent on herbicides. One approach is to expand weed management to include cultural tactics that disrupt weed population growth, and consequently, reduce weed community density in croplands. A key need is to identify cultural tactics that are effective in disrupting population growth of weeds and to integrate these tactics into production systems.

Actions: ARS will:

Control *This is addressed in National Program 202, 211 and 301 Action Plans.*

- Identify competitive crop cultivars that are also high yielding.
- Develop competitive crop canopies by combining several cultural practices together for crop management.
- Quantify the interaction between no-till and rotation design on long-term population dynamics of weeds.
- Measure the impact of crop rotations on weed seed survival in soil.
- Integrate cultural tactics that suppress weed population growth with the design of cropping systems to develop ecologically-based weed management.

Anticipated Products:

- Increased knowledge of pest biology, ecology, behavior, and genetics.
- More effective and durable grain varieties with resistance to insect pests.
- Improved pest early detection and monitoring at within field and regional scales.
- Improved pest management systems for insect pests of grains.
- Increased knowledge of the biology and ecology of key biological control agents and enhanced biological control of insect pests of grains.
- Increased knowledge of the biology, ecology, and genetics of problem weed species.
- New integrated weed management systems that include crop diversity.
- Increased knowledge of the interaction between crops and weeds.
- Information on weed seed survival in soil and weed density in following crops.

Potential Benefits (Outcomes):

- More effective strategies for managing insect pests of grain crops.
- Reduced crop losses to insect pests of grain crops.
- Reduced costs for managing insect pests of grain crops.
- Ecologically and economically sound (sustainable) pest management programs and systems for insect pests of grain crops.
- Strategies for improved IPM of pests in small grain crops.
- Reductions in crop losses to insect and weeds.
- Reductions in expenditures for pest management.
- IPM tactics that are ecologically sound.

USDA ARS Resources:

- Beneficial Insect Introduction Research Unit, Newark, Delaware
- Crop Production and Pest Control Research Unit, West Lafayette, Indiana
- Dale Bumpers National Rice Research Center, Stuttgart, Arizona (Weeds)
- Land Management and Conservation Unit, Pullman, Washington (Weeds)
- National Biological Control Laboratory, Southern Weed Science Research Unit, Stoneville, Mississippi (Weeds)
- Natural Products Utilization Research Unit, University, Mississippi (Weeds)
- Pest Management Research Unit, Sydney, Montana

- Plant Science and Entomology Research Unit, Manhattan, Kansas
- Subartic Agricultural Research Unit, Fairbanks, Alaska (Weeds)
- Sustainable Agricultural Systems Laboratory, Beltsville, Maryland (Weeds)
- Water Management Research Unit, Fort Collins, Colorado (Weeds)
- Wheat, Peanut, and Other Field Crops Research Unit, Stillwater, Oklahoma

Component II: Protection of Agricultural and Horticultural Crops

2o. Sugarcane (U.S. Value 2006: $0.9 billion)

***Problem Statement*:** The following weed and insect pests are most responsible for reducing yields in sugarcane:

- Perennial Weeds: Johnsongrass and Bermudagrass
- Annual Weeds: Morningglory and Itchgrass
- Stemborers: Sugarcane Borer and Mexican Rice Borer
- Sugarcane Aphid

***Research Needs*:**

1. **Weed Interference from Perennial Weeds Johnsongrass and Bermudagrass**

   Importance: Johnsongrass and Bermudagrass continue to be the most widespread and economically important perennial weeds of sugarcane. Integrated weed management practices need to be developed that provide season-long control of these perennial weeds that are capable of enduring the four- to five-year crop cycle, where competition from these weeds generally increases each year. Sugarcane is at a competitive disadvantage against these weeds during the critical establishment phase each spring due to the crop's slower spring growth, growth that can be further slowed by the application of glyphosate as a ripener in the previous season. Currently, there are no herbicides labeled for the selective and long-term control of these weeds once they are established and no attempts have been made to date to develop glyphosate-tolerant sugarcane which would afford some opportunity to selectively control and perhaps eliminate these weeds from sugarcane. Aggressive early generation (near wild) sugarcane varieties and related genera of high biomass producing traditional and non-traditional crops are being developed for a bioenergy industry which includes sugarcane. Weed control strategies within these crops, as well as an assessment of the weediness potential of some of these non-traditional crops to sugarcane need to be determined.

   Research Gaps: Reducing input costs is needed for the continued economical production of sugarcane which requires a better understanding of the value of cultivation and herbicide application. In addition, further evaluations of herbicides are needed in order to refine application timings throughout the growing season (fallow field, at planting, fall, spring layby) to target specific weed problems. If herbicide resistant sugarcane becomes available, application rates and timing will have to be identified for the control of both Johnsongrass and Bermudagrass. A better understanding of the effects of potential short-season rotational crops that could be planted in place of the traditional fallow season on weed infestation is needed. Development of reduced input weed control programs for energy cane is also needed as well as an assessment of dedicated energy crops being considered for the South for their potential to become weed problems.

Actions: ARS will:

Damage Assessment, Weed Interference

- Measure Johnsongrass interference in ratoon crops as influenced by residue management, ripener application, and asulam application.
- Measure the impact of Bermudagrass on sugarcane production as influenced by tillage frequency.

Control

- Evaluate fallow plus at-planting plus spring herbicide treatments for the control of Johnsongrass and Bermudagrass in sugarcane/energy cane.
- Develop management practices for the application of glyphosate in glyphosate resistant sugarcane if it becomes available.

2. **Evaluation of New Herbicide Chemistry for Annual and Perennial Weed Control in Sugarcane**

Importance: Sugarcane growers rely heavily upon multiple and high dosage applications of a small number of herbicides, the majority of which were developed many years ago and utilize only a few modes of action. With this reliance on multiple applications of just a few herbicidal modes of action, the buildup of weed resistance becomes likely. These herbicides applied preemergence and again one or more times post-planting in the same production year must control a broad-spectrum of seedling grass and broadleaf weeds including Bermudagrass, Johnsongrass, itchgrass, morningglory, pigweed, crabgrass, browntop millet, sprawling panicum, yellow and purple nutsedge, etc., that emerge throughout the year. Weeds interfere with sugarcane emergence and establishment after planting and in the spring as plant-cane and ratoon crops emerge following a period of winter dormancy. Vine-type weeds such as morningglory not only compete with sugarcane, but its twining vines can impede harvesting equipment. Once established, Bermudagrass can not be selectively controlled in the sugarcane crop with the herbicides currently registered for use in sugarcane.

Research Gaps: Additional herbicides for weed control in sugarcane continues to be limited by the lack of interest in developing selective herbicides or herbicide resistant crops by chemical manufacturers for the small domestic sugarcane industry. New herbicides need to be developed that are more environmentally friendly, use lower rates, and provide additional modes of action for weed control to help avoid development of herbicide weed resistance. In order for new herbicides to be adopted they must also be cost-effective, have a long residual due to the long growing season, and not delay growth and maturity of sugarcane. Additionally, there is a need to find an herbicide that will selectively control Bermudagrass postemergence in sugarcane. The utility of these herbicides for sugarcane varieties developed for use in the bioenergy industry "energy cane" will also have to be explored.

Actions: ARS will:

Control, Herbicide

- Cooperate with herbicide manufactures in identifying new herbicides with potential utilization in sugarcane to:
  - identify weed spectrum controlled;
  - evaluate crop injury potential; and
  - identify appropriate application timings.
- Develop and/or evaluate technologies to improve the crop safety of herbicides not currently registered for use in sugarcane and work with herbicide manufacturers in developing registrations for herbicides identified with potential utility in sugarcane. (Also See Minor Crops Cross-cutting Issues.)

3. Stemborers

Importance: Stemborers (sugarcane borer and Mexican rice borer) remain the most important pest insects of sugarcane in the continental United States. Biological control of the sugarcane borer is limited in Louisiana by its temperate climate while biological control of the Mexican rice borer is limited by the lack of effective parasites. Plant resistance is an important component for successful pest management of both species, but effective breeding strategies are lacking. Future adoption and planting of energy crops will likely increase area-wide problems with stemborers; however, these same plantings may also provide important refuge sites for overwintering beneficial insects. Transgenic sugarcane and energy crops are likely to have important implications in future stemborer IPM.

Research Gaps: Research suggests that a significant level of cross resistance exists between the two species, and current resistance mechanisms are strongly correlated with resultant lower sucrose yields. New sources of resistance that either are not correlated or less correlated with lower yields are needed. In addition, there is a need to identify potential new biological control agents of borers, determine important aspects of their biology, and evaluate their potential as biological control agents. Research on the potential area-wide impact of wide-spread planting of energy crops is also needed as well as continued research incorporating novel genes conferring resistance to stemborers.

Actions: ARS will:

Control, Host Plant Resistance

- Identify stemborer resistance in *Saccharum* and related species.

- Conduct a recurrent selection program to develop elite breeding canes for incorporating any new sources of identified resistance into new cultivars.

Control, Biological

- Conduct studies to determine important aspects of the biology of *Leptotrachelus dorsalis* (Coloptera: Carabidae), a native predator of the sugarcane borer.
- Enhance biological control by existing natural enemies through conservation or augmentative control.

Control, Cultural

- Conduct studies to determine the role of silica in enhancing resistance to stemborers.

4. Sugarcane Aphid

Importance: Identified in Louisiana in 1999, this aphid was initially a concern only for its ability to transmit the virus that causes yellow leaf disease (YLS). However, there is also a growing concern that the aphid, when present in sufficient numbers, is able to cause direct yield losses. Currently, YLS is not considered to be important in Louisiana, but concern remains that some varieties may be super-sensitive to the disease and may yet exhibit yield loss.

Research Gaps: Yield data is unavailable either from research done in the United States or elsewhere that relates sugarcane aphid densities to yield loss. In addition, little is known of the affect of plant resistance on the transmission of the virus that causes yellow leaf disease.

Actions: ARS will:

Damage Assessment

- Assess the quantitative relationship between aphid densities and yield loss.

Control, Host plant resistance

- Determine levels of aphid resistance in current and soon to be released sugarcane cultivars.

Monitoring

- Correlate aphid appearance and sugarcane infestation by YLS.
- Correlate aphid numbers to YLS spread and disease titers.

***Anticipated Products*:**

- New recommendations for the control of Johnsongrass and Bermudagrass with existing herbicides.
- New herbicides with different modes of action labeled for use in sugarcane.
- Information on rotational crops such as wheat and sweet sorghum that can be use in the sugarcane production cycle for food and bioenergy.
- Information and recommendations for the use of herbicide- and insect-resistant sugarcane if it becomes available.
- Increased knowledge of beneficial insect biology, ecology, and behavior.
- New sources of borer resistance.
- Identification of plant traits that might be used to develop pest-resistant plants.
- Enhancement of plant traits with the use of soil amendments.
- Information on the relationship of aphid numbers and YLS spread.
- Determine the economic impact of aphid feeding on sugarcane yields.

***Potential Benefits (Outcomes)*:**

- Increased knowledge and implementation of weed management practices may lower input costs while increasing production through less weed interference.
- Management strategies for companion crops dedicated to the production of bioenergy.
- Strategies of improved IPM of stemborers
- Reductions in crop losses to insect pests of sugarcane and the plant diseases they transmit.
- Reductions in expenditures to manage insect pests.
- Control tactics that are ecologically sound.

***USDA ARS Resources*:**

- Sugarcane Research Unit, Houma, Louisiana

Component III: Protection of Natural Ecosystems

3a. Terrestrial Forest Insects (U.S. Value: More than $670 billion threat from Asian Longhorned Beetle, alone)

***Problem Statement*:** Major tree species (ash, maples, oaks, pines, etc.) are threatened and/or sustain significant mortality due to the following insect pests:

- Longhorned Beetles (threaten many hardwood species if not eradicated)
- Emerald Ash Borer (killed millions of ashtrees in the Great Lakes Region and is spreading rapidly)
- Asian, European, and related Gypsy Mothspecies (represents a threat to many tree species if it becomes established)
- Lobate Lac Scale [attacks over 200 plant species in Florida, including rare native species in special habitats (Everglades' tree islands and tropical hammocks)]

Research Needs:

1. **Asian Longhorned Beetle and Citrus Longhorned Beetle** (*Anoplophora* spp.)

   Importance: The Asian longhorned beetle (ALB) is a polyphagous non-indigenous invasive insect pest species threatening an unusually wide variety of hardwood tree species in North America. ALB has successfully attacked and developed in nine maple species, four willow species, three elm species, three birch species, horse chestnut, and sycamore. These and other susceptible tree species make up approximately 33 percent of the tree cover in all urban areas in the eastern United States. One species, sugar maple, is the symbol of the Northeast and the backbone of the maple syrup and fall foliage tourism industries. ALB has been found infesting trees in New York, Chicago, Massachusetts and New Jersey in the United States, and Toronto, Ontario in Canada. To date, more than 18,000, 22,000, 1,771 and 25,000 trees have been removed in the New York, New Jersey, Illinois and Toronto infestations, respectively. However, while ALB has been declared eradicated in two localized infestations (Chicago and northern New Jersey), the larger ALB infestations in New York and New Jersey continue to pose a significant risk in the United States, and an adult was found in Chicago in August 2008, as well as a new infestation in Massachusetts.

   Potential economic losses to lumber, maple syrup, and tourism industries have been estimated at $670 billion in the United States, if the beetle is allowed to expand beyond its currently known infested areas. At risk are the forests covering approximately 48 million acres from New England westward beyond the Great Lakes. These forests are vitally important to the species diversity and ecological processes of natural and protected areas, and protect public drinking water quality (e.g., for New York City) and many rare species and natural communities. Therefore, ALB could drastically alter the makeup of North American forests and significantly impact natural forests and urban environments.

The citrus longhorned beetle (CLB) is a related polyphagous pest attacking living trees of over 100 species in 40 genera in 26 different families, including species of *Acer* (maple), *Aesculus, Alnus* (alders), *Betula* (birch), *Carpinus* (hornbeam), *Casuarina* (chestnut), *Citrus* (e.g., lime, lemon, oranges, tangor), *Corylus* (hazel), *Cotoneaster* (cotoneaster), *Crataegus (hawthorn), Cryptomeria japonica* (cedar), *Fagus* (beech), *Ficus* (fig), *Hibiscus, Lagestroemi* (crape myrtle), *Litchi, Mallotus, Malus* (apple), *Melia, Morus* (mulberry), *Platanus* (sycamore/plane tree), *Poncirus* (Trifoliate orange), *Populus* (poplar), *Prunus* (cherry laurel), *Pyrus* (pear), *Rosa* (rose), *Salix* (willow), *Ulmus* (elm), and *Zizyphus.* CLB was found in trees imported into Washington State, from Italy, the Netherlands and Germany. The beetle has infested and killed thousands of maple and other trees in Italy and was also recently discovered killing hundreds of thousands of citrus trees in south central China. CLB presents a significant threat similar to that of ALB, if not greater, due to the much broader range of tree species at risk, particularly citrus.

Research Gaps: Urgent solutions are needed for early detection of, and rapid response to, new introductions and incipient populations of ALB and CLB. The most promising strategies identified will be through advances in our knowledge of the host selection and colonization process at both the tree and landscape levels. Collectively, early detection and rapid response are the keys to preventing establishment and to containing established populations, thereby making eradication a viable option. Early detection of ALB and CLB will likely depend on development of strategies for implementation of existing technologies and development of new innovative technologies. Early detection would facilitate the targeting of control methods. Rapid response for containing ALB and CLB infestations may initially be dependent on insecticides, although increased pesticide use for this purpose is undesirable. Attract-and-kill and new strategies represent potential viable alternatives to the use of insecticides. Concurrently, there is need to begin development of long-term, sustainable approaches (e.g., IPM) for managing ALB should it become permanently established in North America, as well as to halt the spread of the existing CLB infestation in Italy. Among these approaches is biological control, developed through comprehensive faunistic and floristic assessments in the countries of origin and countries of invasion to provide a base of understanding for identifying biological control agents with desirable traits, e.g., no significant non-target effects and highly efficient host searching ability and parasitism. In addition, there is a need to expand research on invasive species in areas at the interface between urban and natural areas. More specifically, this includes research on the potential spread of ALB within and between natural ecosystems (e.g., South Korea) and urban areas (e.g., North America, Europe, China) and at their interface (e.g., North America, Europe, South Korea, China); and the potential spread of CLB in agricultural (e.g., citrus), urban, and natural ecosystems, and at their interface.

Actions: For ALB and CLB, ARS will:

Attractants

- Discover plant kairomones and insect pheromones that can be used to attract *Anoplophora* species.
- Identify and synthesize promising semiochemicals.
- Evaluate promising semiochemicals.

Monitoring

- Investigate optimal pheromone component blends for attracting and monitoring ALB and CLB.
- Develop protocols for using attractants in eradication and/or management programs.

Detection, Infested Trees

- Investigate new technologies for detection of trees infested by ALB and CLB.

Detection and Control, Attract-and-Kill

- Develop attract-and-kill strategies and protocols for use in eradication and/or management programs, especially for ALB.

Control, Biological

- Explore for new biological control agents for classical biological control of ALB.
- Explore for native natural enemies for enhancing biological control of ALB by existing natural enemies through conservation or augmentation biological control.

Control, Insecticide

- Evaluate promising insecticides for CLB.

2. Emerald Ash Borer

Importance: The emerald ash borer (EAB), *Agrilus planipennis*, is a buprestid beetle that feeds as larvae in the cambium layer between the bark and wood, producing galleries that eventually girdle and kill trees. Since 2002, when the insect was first found in southeastern Michigan, EAB has killed or infested tens of millions of ash trees in both managed and natural forests of nine northeastern and midwestern states. This relatively new pest spreads rapidly and kills all sizes and even very healthy ash trees. Ash is a "workhorse" species in urban forests, and comprises a substantial portion of forest communities that provide ash products to our local and national economies.

Research Gaps: Accelerated research is necessary to develop control strategies for EAB that can be used by homeowners and arborists. Augmentative and inundate biological control programs appear to be the most promising control strategies in areas where the EAB is firmly established. Research is needed to identify and evaluate exotic and native natural enemies, investigate their potential roles in suppressing EAB populations, develop effective rearing methods and technology for mass production of these parasitoids, and to develop life table methods for quantifying the efficacy of the natural enemies used as biological control agents.

Concurrently, other approaches need to be developed if biological control agents fail to provide a sustainable, long-term management strategy for the borer. The most promising of these appear to be host plant resistance and preservation of ash germplasm. Though all North American ash species are highly susceptible to EAB, the Asian ash species, especially Manchurian ash (*F. mandshurica*), appear to be much more resistant. It might be possible to introduce resistance genes into North American forests by developing Asian X American hybrids followed by backcrosses with North American ash species to retain the original characteristics. By preserving germplasm in the form of seeds, it would be possible to repopulate ash species after the existing trees and host specific EAB die out. Control tactics such as biopesticides, soil injection or drenches, and trunk injections with systemic insecticides also need to be developed to provide short term management.

A prerequisite for responding effectively to EAB infestations in new areas is being able to detect them as soon as possible. Although attractants for EAB are under investigation by Federal and state scientists, highly effective chemicals have not been identified. Research should continue into discovering attractant compounds emitted by the beetles and ash trees, followed by attractant synthesis, blending, and formulation for field use and optimum trap design. The roles that vision and other sensory modes play in attracting EAB also need to be investigated. While sensitive monitoring of adults would be the first priority, mass trapping for control could become feasible in the future. Finally, attractants could be important in other areas of research on EAB, for example, monitoring biological control agents. Research on how parasitoids of EAB find their hosts or mates could lead to new tools for detecting and monitoring these beneficial insects.

Actions: ARS will:

Attractants

- Isolate, identify, synthesize, and evaluate EAB attractants, e.g., sesquiterpenes, from host ash trees.
- Evaluate the behavioral effect of the putative pheromone of EAB, a sex-specific compound that was previously identified at ARS-Peoria, but for which no function has yet been established.
- Investigate volatiles from EAB eggs, larvae and host plants for attractiveness to EAB parasitoids, and seek to identify pheromones of the parasitoids.

Monitoring

- Improve sampling and monitoring methods for EAB using traps baited with an attractant.

- Develop an insect tracking system using harmonic radar to measure dispersal ability (flight range) for many insect pests, including EAB.

Control, Biological

- Search for new natural enemies in previously unexplored regions of the Far East.
- Determine impact (using a life table approach) of the most effective parasitoid and/or other key mortality factors in regulating populations of EAB.
- Conduct quarantine evaluation and host specificity studies on imported natural enemies.
- Develop effective mass rearing methods for producing host EAB eggs and larvae.
- Develop technology for effective parasitoid exposure, storage, and production of progeny for the most promising species.
- Conduct developmental research needed to implement an area-wide biological control program against EAB.

Control, Biopesticides

- Determine the effectiveness and feasibility of use of microbial control agents in an integrated program for EAB management. Host Plant Resistance *(This research is done by National Program 301)*
- Conduct research to determine if new resistant ash varieties can be identified for use in the landscape.
- Obtain accessions of Asian ash species for use in hybridization experiments.
- Do cytogenetics experiments to see which Asian and North American ash species are likely to have compatible ploidy levels.
- Conduct interspecies hybidizations to see if resultant cultivars are more resistant than native cultivars.
- Preserve ash germplasm.
- Design and organize collections of seed from wild ash populations to capture the biodiversity present over the range of ash species and store seed at National Center for Genetic Resources Preservation in Peoria.

3. Asian, European and Related Gypsy Moth Species

Importance: The Asian gypsy moth (AGM), ***Lymantria***. *dispar asiatica*, differs from the European gypsy moth (EGM) in several important respects: (1) AGM can attack more tree species (about 500 known hosts, including conifers), (2) they are larger, and (3) females fly and disperse. In addition, AGM can mate freely with the established EGM. These characteristics combine to make the AGM an even greater threat to North American forests than the devastating EGM has been. As a result, Federal policy has been to eradicate Asian gypsy moth infestations whenever and wherever they are found.

Several introductions of AGM to the Pacific Northwest and other U.S. regions have occurred in the last 15 years. To date, known infestations have been successfully eradicated, but the pest continues to pose an invasive species threat to North America. Several other pests in the genus *Lymantria* exist in Eurasia and also represent potential invasive threats to North America: nun moth, *L. monacha*; pink gypsy moth, *L. mathura*; Japanese gypsy moth, *L. dispar japonica*; Indian gypsy moth, *L.* obfuscata; and luna tussock moth, *L. lunata*. EGM continues to spread and move into Midwest and Southern United States regions containing highly vulnerable trees and continues to cause significant management and economic impacts.

Research Gaps: Although Asian gypsy moth species have been studied by ARS in terms of taxonomy and nomenclature, description and synthesis of the sex pheromones of most species, and characterization of parasitoid predator/pathogen complexes of two *L. dispar* species (*asiatica* and *japonica*), there are many gaps in research. Almost no genetic information exists for gypsy moths that would enable identification of genes associated with pesticide susceptibility or resistance and help develop novel targets for pest control. New management tools with improved persistence are needed to slow the movement of EGM and abate potential AGM introductions.

Actions: ARS will:

- Provide identifications of Lymantriid tussock moths as needed by APHIS.
- Provide quality control analyses of pheromones provided by industry for use by APHIS and state regulatory agencies.
- Characterize expressed gene profile of GM to identify genetic vulnerabilities.
- Develop new microbial GM management tools with improved persistence.

4. Lobate Lac Scale

Importance: The lobate lac scale (LLS), *Paratachardina lobata*, a recent introduction (discovered in the late 1990's) to Florida, is an extremely dangerous pest, because it is known to attack over 300 species of woody plants. Trees and shrubs in many important natural areas of southern Florida have been damaged, including Everglades National Park, Big Cypress National Wildlife Refuge, and Loxahatchee National Wildlife Refuge. High value indigenous and horticultural plants such as wax myrtle (*Myrica cerifera*) and coco plum (*Chrysobalanus icaco*) have been killed in many localities. Redbay (*Persea borbonia*), an attractive evergreen tree common along the coasts of the southeastern United States, is highly susceptible to the scale. LLS also occurs in the Bahamas, where a recent survey found that two-thirds of plant species examined were infested.

Research Gaps: Pesticides are not a control option in natural areas because of statutory restrictions, probable adverse effects on non-target organisms, and the large acreages involved. Many non-indigenous scale insects have been successfully controlled by importation of the natural enemies that suppress their populations in their land of origin.

The best long-term solution for controlling LLS is using its natural enemies. However, little is known about the identity and biology of most natural enemies of LLS and its close relatives. A chalcidoid wasp that parasitizes LLS was found in India; it also parasitizes true lac scales in its native range. Foreign exploration for additional co-adapted natural enemies needs to be conducted in India and Sri Lanka. Although these wasps have a very narrow host range, research must confirm the host specificity of these parasites before they can be used in Florida. Candidate natural enemies from overseas must be subjected to host specificity testing with native scales to determine their safety.

Actions: ARS will:

Control, Biological

- Conduct surveys in India and Sri Lanka to discover specialized natural enemies of LLS.
- Obtain natural enemies of LLS for quarantine evaluation and conduct host-specificity testing of candidate biological control agents for LLS to assess potential risk to non-target species.
- Develop techniques for mass rearing promising LLS natural enemies, and release approved agents.
- Evaluate post-release colonization, spread and impact of the biological control agents on LLS and non-target scales.

Anticipated Products:

- Development of practical lures, for use by land managers (local, state, and federal agencies) for detection of ALB, EAB and other invasive insect pests.
- New semio-chemicals for insect monitoring and control.
- Improved tools for studying dispersal ecology, host preference, and other epidemiological issues.
- Identification of plant traits that might be used to develop pest-resistant trees.
- Development of trees with pest resistance.

Potential Benefits (Outcomes):

- Strategies for improved control of insect pests in natural ecosystems.
- Reductions in damage to trees in natural ecosystems by insect pests.
- Improved technologies for detection of invasive species at ports of entry.
- Successful eradication of insect pests (ALB and AGM) with limited distribution or that are not yet established.

- Permanent biological control of established insect pests (EAB and LLS) by introduction of specialized natural enemies from the regions of their origin.
- Reductions in expenditures, including application costs, to manage insect pests.
- Management technologies that are biologically based and ecologically sound.
- Saving native tree species (e.g., ash) from extinction.

USDA ARS Resources:

- Application Technology Research Unit, Wooster, Ohio
- Beneficial Insects Introduction Research Unit, Newark, Delaware
- Biological Integrated Pest Management Research Unit, Ithaca, New York
- Crop Protection Research Unit, Peoria, Illinois
- European Biological Control Laboratory, Montpellier, France
- Invasive Insect Biocontrol and Behavior Laboratory, Beltsville, Maryland
- Invasive Plant Research Laboratory, Fort Lauderdale, Florida)

Component III: Protection of Natural Ecosystems

3b. Weeds in Terrestrial Ecosystems (U.S. Value: Over $1 billion)

***Problem Statement*:** Prevention of non-indigenous terrestrial invasive plant species in natural systems and reduction of economic and environmental harm caused by these weeds is limited by a lack of effective, affordable, and environmentally sound management strategies for:

- Prevention and Early Control of New Invasive Weeds
- Control of Widespread Invasive Weeds in Terrestrial Natural Systems

Research Needs:

1. **Prevention and Early Control of New Invasive Weeds**

   Importance: Non-indigenous invasive plant species (NIPS) threaten the function and integrity of terrestrial ecosystems throughout North America. The number of these species is increasing in the United States as is their abundance and distribution. Natural systems are often adjacent to managed systems such as rangelands and weeds therefore invade from natural ecosystems. Impacts of plant invasions in natural areas have become painfully clear and include: damaging shifts in fire and nutrient cycles; increasing erosion and declines in water quality; increasing negative effects on human and livestock health; reducing diversity and resilience of native plant communities; and altering trophic webs.

   The number of new NIPS has been growing due to increased trade and intentional or inadvertent movement of plants by people. Some of these species become invasive and add to already large economic and environmental impacts. Often the environmental impacts of these new species are unknown and are not recognized until they have spread too far to be easily controlled.

   Research Gaps: Prevention is the most cost-effective control strategy. Study of invasion pathways can be used to identify the most important sources of new plant species and aid in design of prevention strategies. Some NIPS are more invasive than others. As weed management budgets are small, it is important to determine which of these species could cause the greatest impacts. Methods must be developed to control new NIPS before they become widespread. Study of the biology of new invaders helps to predict ranges of invasions and aid in design of control strategies. Economic impacts of new NIPS need to be determined.

   Actions: ARS will:

   - Determine pathways that potential NIPS utilize to colonize new areas.
   - Determine evolutionary potential of NIPS to expand ranges
   - Determine impacts of NIPS.

- Develop integrated chemical and non-chemical control measures for NIPS. Study the biology of NIPS.
- Determine invasive potential of plant species proposed for use in biofuel production.

2. Control of Widespread Invasive Weeds in Terrestrial Natural Systems

Importance: Numerous NIPS have already established and are causing significant economic and environmental harm to natural systems. Populations are too large to allow for economic control using cultural or chemical methods. It may not be feasible to use these methods due to labeling problems, harm to non-target species, public concern, or labor.

Research Gaps: Economic impacts of NIPS in natural systems include environmental and aesthetic impacts which are difficult to measure and to assign economic value. Biological control agents are needed to manage widespread NIPS in natural systems where they have adapted and become widespread. Biological controls must be shown to be effective and must not harm non-target species. Research needs include: study of invasive weed biology to determine the most effective life stage and plant structure for biological control, identification of potential control agents, control agent biology and rearing studies, and screening for efficacy and effects on non-target species.

Actions: ARS will:

- Discover and collect potential biological control agents for non-indigenous invasive plant species from foreign and domestic ecosystems.
- Conduct invasive weed demography studies to determine most effective life history stages and plant parts for biological control.
- Conduct studies on agent biology to determine best rearing/production methods.
- Determine effectiveness of control agents and screen for non-target effects.
- Release and measure impacts of control agents on target and non-target plant species.
- Work to develop biological controls including agents for control of:
    - Australian Pine (*Casuarina* spp.)
    - Bermudagrass [*Cynodon dactylon* (L.) Pers.]
    - Brazilian Peppertree (*Schinus terebinthifolius* Raddi)
    - Canada Thistle [*Cirsium arvense* (L.) Scop.]
    - Cheatgrass (*Bromus tectorum* L.)
    - Dodder (*Cuscuta* spp.)
    - Garlic Mustard [*Allaria petiolata* (M. Bieb) Cavara and Grande]
    - Giant Reed (*Arundo* donax L.)
    - Hawkweeds (*Hieracium* spp.)

- Knapweeds (*Centaurea* spp.)
- Kudzu [*Pueraria montana* (Lour.) Morr.]
- Leafy Spurge (*Euphorbia esula* L.)
- Medusahead [*Taeniathernum caput-medusae* (L.) Nevski]
- Melaleuca [*Melaleuca quinquenervia* (Cav.) S. F. Blake]
- Old World climing fern
- Russian Thistle (*Salsola kali* L.)
- Salt Cedar (*Tamarix ramossima* Ledeb.)
- Skunk Vine (*Paederia foetida* L.)
- Small-leaf Climbing Fern [*Lygodium microphyllum* (Cav.) R. Br.]
- Swallow-worts (*Vincetoxicum* spp.)
- Whitetop (*Lepidium draba* L.)
- Yellow Starthistle (*Centaurea solstitialis* L.)

***Anticipated Products*:**

- Increased knowledge of pathways for NIPS colonization leading to strategies for prevention of new introductions.
- Increased knowledge of the effects of NIPS on other species and ecosystems, enabling prioritization of control efforts.
- Increased knowledge of NIPS biology and ecology, to predict potential distributions and to target early detection and control measures.
- Cultural and chemical methods to eradicate infestations of new NIPS.
- Increased knowledge of NIPS demography to better target control measures on the most susceptible life stages and plant parts.
- New biological control agents.
- Increased knowledge of genomics, basic biology and ecology of biological control agents.

Potential Benefits (Outcomes):

- Strategies for improved IPM of NIPS in natural systems.
- Reductions in economic and environmental harm to natural systems by NIPS.
- IPM tactics that are ecologically sound.
- Restoration of degraded habitats and improvement of wildfire management on western uplands.

USDA ARS Resources:

- Beneficial Insects Research Unit, Weslaco, Texas
- Biological Integrated Pest Management Unit, Ithaca, New York

- Center for Medical, Agricultural, and Veterinary Entomology, Tallahassee, Florida
- Crop Protection and Management Research Unit, Tifton, Georgia
- European Biological Control Laboratory, Montpellier, France
- Exotic and Invasive Weeds Research Unit, Albany, California and Reno, Nevada
- Foreign Disease-Weed Science Research, Fort Detrick, Maryland
- Insect Genetics and Biochemistry Research Unit, Fargo, North Dakota
- Invasive Plant Research Laboratory, Fort Lauderdale, Florida
- Invasive Weed Management Unit, Urbana, Illinois
- Beneficial Insects Research Unit, Weslaco, Texas
- Pest Management Research Unit, Sidney, Montana
- Plant Science Research Laboratory, Fargo, North Dakota
- Range and Meadow Forage Management Research Unit, Burns, Oregon
- Southern Weed Science Research Unit, Stoneville, Mississippi
- Subarctic Agricultural Research Unit, Fairbanks, Alaska

Component III: Protection of Natural Ecosystems

3c. Aquatic, Wetland, and Marine Weeds (U.S. Value annually: $2-3 billion/aquatic and wetland, $50 billion marine)

***Problem Statement*:** Comprehensive fully integrated environmentally and ecologically sustainable strategies for the prevention, eradication, control and management of aquatic weeds are not available for the following ecosystems:

- Submersed Weeds in Irrigation Systems/Flood Control Channels
- Weeds in Riverine and Freshwater Tidal Systems
- Wetlands Habitat Degraded by Woody Shrubs and Creeping Vines
- Weeds of Lakes and Ponds
- Invasive Marine Algae and Marine Plants Impacting U.S. Estuarine and Coastal Ecosystems.
- Invasive Marine Algae/Plant in Shellfish Production Systems.

Weed species that are detrimental to aquatic and wetland habitats and their uses include: hydrilla (*Hydrilla verticillata*); giant waterfern (*Salvinia molesta*); salt cedar (*Tamarix* various species); giant reed (*Arundo donax*); Chilian cordgrass (*Spartina densiflora*); Brazilian waterweed (*Egeria densa*); water hyacinth (*Eichhonia crassipes*); South American spongeplant (*Limnobium laetivagum*); watermillfoils (*Myriophyllum* spp); parrotfeather (*Myriophyllum aquaticum*); waterprimrose exotic species complexes [Uruguayan primrose-willow, Uruguay seedbox (*Ludwigia hexapetala*), large-flowered primrose (*L. grandiflora*), and creeping water primrose (*L. peploides* spp, *montevidensis, L. p*. spp. *Peploides)*]; purple loosestrife (*Lythrum salicaria*); melaleuca (*Melaleuca quinquenervia*); Old World climbing fern (*Lygodium microphyllum*); azolla *(Azolla mexicana)*; duckweed (*Lemna* spp., *Spirodela* spp., *Landoltia* spp.); Cape ivy *(Delairea odorata*); Japanese knotweed (*Polygonum cuspidatum*); torpedograss *(Panicum repens*); water lettuce *(Pistia stratiotes*); hygrophila (*Hygrophila polysperma*); oxygen weed (*Lagarosiphon major*); water chestnut (*Trapa natans*); Russian olive (*Elaeagnus angustifolia*); Chinese tallow (*Triadica sebifera*), and pondweeds (*Potamogeton* spp.).

Invasive algae and plant species that are detrimental to U.S. estuarine and coastal ecosystems and shellfish production systems and their uses include: *Caulerpa taxifolil, C. racemosa, C. mexicana* (Note: there are 9 species of *Caulerpa* banned in California); *Undaria pennatifida*; *Kappyphycus* spp.**;** *Codium fragile* spp. *tomentosoides*; *Zostera japonica*; *Sargassum muticum*; and *Gracilaria* spp.

Research Needs:

1. **Submersed Weeds in Irrigation Systems/Flood Control Channels**

Importance: Timely and adequate storage/transfer and delivery of water are critical to irrigated agriculture and to the health of rivers and streams that provide fish-spawning habitat. The persistence of key weeds in these systems is due to the weeds' ability to persist during winter de-watering (drawdown) periods. Few management tools are available to reduce growth and spread of rooted plants in moderate to high-velocity flowing water due to the difficulty in using herbicides, lack of biological control agents, and risk of spreading weeds downstream when physical cutting or removal is attempted.

Research Gaps: In order to protect and sustain water storage and delivery, research is needed to develop effective and safe integrated methods to reduce growth, reproduction and spread of key submersed and floating species of aquatic plants in high-flow habitats. Physiological mechanisms and environmental conditions that enable dormancy and longevity of over-wintering structures (tubers, rhizomes, and turions) are not well understood. Disrupting these functions could provide new approaches to control and reduce the dispersal of such weeds as *Hydrilla verticillata*, invasive pondweed species (sago pondweed, American pondweed, curlyleaf pondweed), and Western milfoil.

Actions: ARS will:

- Determine physiological mechanisms that impart dormancy (and longevity) of vegetative over-wintering tubers and turions in order to disrupt their formation or longevity.
- Investigate new potential aquatic herbicides for use in water and as soil applied systemic herbicides that can be used during seasonal drawdown (draining) of irrigation canals to prevent regrowth.
- Investigate plant growth regulators that may be effective in breaking dormancy of over-wintering structures.
- Develop models for strategically integrated weed management in irrigation systems.
- Search for new biological control insects in Asia.

2. Methods to Control/Eradicate Weeds in Riverine and Freshwater Tidal Systems

Importance: Exotic and invasive submersed, floating and emergent weeds drastically impair normal flows and ecological functions of natural rivers, seasonal flood-water conveyance channels, and streams, including the complex Sacramento-San Joaquin tidal estuary. Extensive population growths (high biomass) also impair access to these systems by waterfowl and reduce important fish spawning habitat (e.g., for salmon and other threatened/endangered fish). Dense weed infestations provide habitat for disease-bearing mosquitoes while simultaneously impeding actions for prevention and control of arthropod-borne diseases. The interactions between invasive plant and native plant populations, plant-fish interactions, and the role of seasonal flows and nutrient inputs are poorly understood; however, this information is needed to develop adaptive management methods to reduce threats from invasive weeds.

- ***Azolla*, Mexican Waterfern, Mosquito Fern (*Azolla mexicana, Azolla* spp.*):*** *Azolla* spp. are small floating aquatic ferns that recently have been out-breaking as invasive weeds in California's Butte Sink, the most significant area for water birds in the Pacific Flyway, supporting the highest densities of wintering waterfowl in North America. Further, the exotic *Azolla pinnata* has recently appeared in some southern Florida waterways. Thick floating *Azolla* mats reduce open water habitat critical to migratory birds, impede light penetration, create anaerobic conditions unfavorable to biodiversity, reduce fish populations, and compromise irrigation water deliveries. Research is needed to support restoration goals of the North American Waterfowl Management Plan and Central Valley Joint Venture.

  Research Gaps: The identity and origin of the problematic *Azolla* spp. is uncertain, and it is possible that both native and new exotic invaders may be responsible. The population dynamics and effectiveness of the *Azolla* weevil, a biological control agent, relative to environmental conditions are poorly understood. The need to understand population, biomass and nutrient cycling dynamics of problematic *Azolla* spp. in a food web context is critical for development of biologically-based management strategies.

  Actions: ARS will:

  - Identify and evaluate distributions of out-breaking *Azolla* weed species.
  - Assess *Azolla* growth and population dynamics relative to environmental conditions (photoperiod, temperature, nutrient regimes, and herbivore abundance) for rapid response management methods.
  - Assess food web associations and the general impact of herbivores regulating *Azolla* with emphasis on biological control of specific insect species relative to dynamic environmental conditions.
  - Investigate whether the native weevil *Stenopelmus rufinasus*, an herbivore that attacks the native *Azolla caroliniana*, will transfer to the exotic *A. pinnata* and whether damage by this insect affects the competitive balance between these two aquatic ferns.

- **Parrotfeather (*Myriophyllum aquaticum*):** Parrotfeather infestations have dramatically increased in the United States and especially western states over the past 20 years. This species is particularly competitive in sites with moderate to high nutrient inputs where it rapidly covers open water sites and displaces native plants, which results in increased habitat for disease carrying insects. Extensive rhizome systems also interfere with, and reduce fish and waterfowl habitat.

  Research Gaps: Parrotfeather is both a primary and increasingly an opportunistic secondary invader following control efforts towards eradication of aquatic weeds (such as *Ludwigia*, water hyacinth, E*geria*, and Eurasian watermillfoil). Knowledge of competitive interactions and ecological restoration strategies that take into account the potential emergence of parrotfeather are lacking for current environmental conditions in California and other Western states.

Actions: ARS will:

- Integrate knowledge of competitive interactions and succession pathways of closely associated weeds, and available biological and other control methods to optimize use of biological control agents and develop comprehensive weed management strategies.
- Investigate potential for integrating efficacious selective, systemic herbicides with water management regimes and with potential biological control agents.

- ***Egeria*, Brazilian Waterweed *(Egeria densa)*:** Over the past 15 years *Egeria* has expanded its range in the Sacramento-San Joaquin Delta from 2,000 acres to over 10,000 acres. Limited control programs (California Department of Boating and Waterways) currently cost $5 million annually but rely on a single systemic herbicide (fluridone). Management of this species is critical for reliable transfer of water for irrigation and potable water for 22 million Californians. Management is also essential for improvement and protection of spawning habitats for Chinook salmon, Delta smelt, Sacramento split tail, and for waterfowl habitat. Developing sustainable, integrated management can be achieved through understanding the responses of key ecological processes to alternative management and restoration actions.

Research Gaps: Relationships between *Egeria* and native plant population density/distributions on fish habitat is not well understood, yet this information is vital to establishing restoration goals. Responses of native plants to E*geria* management and the relative influences of *Egeria* and native plants on trophic pathways are also not known. Potential for the use of a newly registered herbicide is lacking, but will be essential to avoid risks of developing resistance. There are no biological control agents available for release, but at least one potential herbivore has been identified from E*geria's* native habitats in Argentina.

Actions: ARS will:

- Investigate mechanisms influencing succession and competitive interactions of E*geria* and native plants, and their implication for restoration of trophic pathways.
- Determine the efficacy and utility of new systemic herbicides for inclusion and improvement of current management programs.
- Examine the consequences of the current "single species" weed target approach compared to a fully "aquatic vegetation management" approach and strategies in the Sacramento-San Joaquin Delta.
- Conduct host-specificity and efficacy evaluations of herbivorous insects and potential pathogens using overseas laboratories (e.g., South American Biological Control Laboratory) and approved quarantine introductions.

- Test integration of potential approved biological and non-biological control methods to optimize *Egeria* management and to facilitate habitat restoration in the Sacramento-San Joaquin Delta.

- **Giant Reed (*Arundo donax*):** Giant reed, an aggressive rhizomatous grass has invaded a wide range of riparian ecosystems throughout the southwestern United States **including the Rio Grande River Basin** (over 130,000 acres), including California (over 30,000 acres). Giant reed is a prodigious water user, causes damaging erosion of stream banks, outcompetes native riparian vegetation and creates massive fire-fuel sources that threaten humans and wildlife.

  Research Gaps: Although successful modeling of growth has been done, habitat and environmental impacts are only partially known. Water use by *A. donax* as compared to native species is not well understood and is critical to understanding the impact of this invasive weed on water resources. Several biological control agents have been evaluated in the native range and in U.S. quarantine facilities. Two agents, the Arundo wasp and Arundo scale, are anticipated for release, and two others are under evaluation.

  Actions: ARS will:

  - Pursue further exploration, host specificity and efficacy evaluations, releases and field evaluations of biological control agents.
  - Refine weed growth and agent impact models. Use remote sensing to define weed density and distribution before and after release of agents. Investigate water use.
  - Define the Mediterranean origin(s) and distribution of invasive N. American genotypes.
  - Evaluate inundative releases of biological control agents. Evaluate herbicides for use alone and in conjunction with biological control agents. (Davis, California: Spencer; Weslaco, Texas: Moran)

- **Purple Loosestrife (*Lythrum salicaria*):** Purple loosestrife has spread across North America and degraded many prime wetlands resulting in large, monotypic stands that persist for decades, are difficult to control using conventional techniques (chemical, physical, and mechanical), and continue to spread into adjacent areas. Purple loosestrife has been declared a noxious weed in at least 19 states, has reduced water flow in western irrigation systems, and alters biogeochemical and hydrological processes. Where populations are long established, the weed is dominating seed banks. Native species richness temporarily returns following suppression of purple loosestrife through herbicide application, but without routine continued use of herbicides, purple loosestrife re-invades and re-establishes dominance within a few years. Biological control agents have proven to be successful in some areas, but have not been effective in many recently invaded areas of Pacific western states.

  Research Gaps: Purple loosestrife invasions can provide a model to help determine whether: (1) exotic species evolve stronger competitive ability over time (evolution of increased ability) or (2) competition decreases over time of co-occurrence (neighborhood effect). These are contrasting hypotheses that have direct relevance to management yet are still poorly understood. An increased understanding of these questions could fundamentally change the way we manage non-native purple loosestrife. In California, where invasions are relatively recent compared to the eastern United States, environmental factors correlated with purple loosestrife abundance and the potential for continued expansion of the invaded range are also not known.

Actions: ARS will:

- Determine environmental factors correlated with purple loosestrife abundance across a wide latitudinal and climate range in western states.
- Evaluate seed bank dynamics and potential methods to deplete seed banks for improved restoration success.
- With collaborators in the United States and Europe, determine the effects of neighborhood selection pressure on the evolution of competitive ability in purple loosestrife.

- **Exotic Waterprimrose Complexes: Uruguayan Primrose-willow, Uruguay Seedbox (*Ludwigia hexapetala*), Large-flowered Primrose (*L. grandiflora*), Creeping Water Primrose (*L. peploides* spp. *montevidensis, L. p*. spp. *peploides*):** *Ludwigia* spp. spread to form dense floating mats that displace native vegetation, degrade water quality, increase flood risk, impede irrigation water delivery, and inhibit mosquito control. Recent aggressive spread of creeping emergent/aquatic *Ludwigia* spp. has impacted both sensitive wetlands and water conveyance canals in six major watersheds of the Pacific western states, and has prompted regulation of this plant as a noxious weed in Washington. Thousands of acres from the Columbia River Basin south through California are now impacted, prompting multi-million dollar chemical control efforts that to date have been largely ineffective.

  Research Gaps: Because many *Ludwigia* taxa are invasive yet each may respond differently to management actions, and because *Ludwigia* taxa have invaded a wide range of aquatic ecosystem types, targeted research is needed to support integrated management specific to environmental conditions. Identification of effective non-chemical control measures are needed to support *Ludwigia* management in sensitive ecosystems where herbicide use is currently restricted or prohibited. Knowledge of food web ecology in the weed's native and invaded range is needed to develop biological control methods, and to understand how these methods may vary with ploidy level of *Ludwigia* taxa. Because environmental conditions of impacted habitat are expected to change due to both intentional, large scale water management actions and also inadvertent climate change, research is needed to gauge *Ludwigia* response and improve management effectiveness under dynamic growth conditions.

  Actions: ARS will:

  - Evaluate food web relationships associated with invasive *Ludwigia*, and determine how these relationships vary with ploidy level and environmental change, to improve biological control and to incorporate climate change impacts into management.

- Conduct experiments to inform development of best management practices specific to riverine emergent, palustrine floodplain, and managed seasonal wetlands; and also for management of *Ludwigia* in water canals.
- Investigate community level ecological interactions to develop preventative and adaptive management actions for *Ludwigia* invasion of wetland restoration sites.
- Evaluate how demographic and dispersal differences, and their variation with fluvial processes, contribute to spatial population dynamics, weed spread, and potential control.
- Continue overseas explorations for host-specific agents that can be used in an integrated management program for *Ludwigia* spp.

- **Chilean Cordgrass, Dense-flowered Cordgrass (*Spartina densiflora*):** Chilean cordgrass, native to South America, has aggressively dominated salt marshes of Humboldt Bay, California and has also invaded salt marshes in San Francisco Estuary and Oregon. Recently, this exotic cordgrass has been dramatically increasing its tidal range within salt marshes and directly threatens the extinction of rare and endangered native plants, National Wildlife Refuge habitat, and fisheries/aquaculture industries in California and Pacific Northwest estuaries. Chilean cordgrass has also invaded salt marshes in southern Spain, where it has compromised ecological restoration projects and the aquaculture industry.

  Research Gaps: Seedling recruitment of *Spartina densiflora* follows eradication efforts in restoration projects underway in both California and Spain, yet seed bank dynamics and dispersal mechanisms of Chilean cordgrass are poorly understood. There is a great need for methods of ecological restoration that both control Chilean cordgrass, and promote the demographic success of rare native halophytes. The success of future management efforts may be contingent on planning for climate change, yet existing research has only addressed static environmental conditions and the adaptive ability of the weed is unknown.

  Actions: ARS will:

  - Investigate dispersal mechanisms and seed bank dynamics to support ecological restoration.
  - Conduct life table response experiments to track the demographic response of native plants to cordgrass control actions.
  - Contribute to collaborative research in the native South American range, and invaded sites in California and Spain to investigate local adaptation vs. plasticity of invaded populations to inform sustainable management over dynamic climate gradients.

- **Eurasian Watermillfoil (*Myriophyllum spicatum*):** Eurasian watermillfoil has invaded every contiguous U.S. state, but is still spreading to new sites, most recently in Idaho and at Lake Tahoe (California/Nevada). Infestations degrade fish and waterfowl habitat in lake and river ecosystems. Infestations also restrict commercial and recreational vessel movement. The movement of this plant and attached invasive invertebrates (e.g., quagga and zebra mussel) pose serious threats to the vast network of water storage and conveyance systems in the 17 western states. Millfoil's continued expansion creates serious water resource management issues throughout the United States.

  Research Gaps: The efficacy and utility of new systemic herbicides are not well known, but limited data suggests they could be successfully used to reduce potential non-target impacts, and possibly in integrated programs with native herbivorous insects and pathogens. The relative invasiveness of various genotypes (hybrids) of *M. spicatum* is not known, nor is relative susceptibilities to herbicides or biological control agents. Recent (2007) discovery of the United States native weevil *Euhrychopsis lecontei* in California provides an important opportunity to determine its efficacy and population dynamics under mild winter conditions compared to previous studies of the weevil under more prevalent northeastern populations. The distribution of this weevil is unknown in many states, like Connecticut, and natural dispersal many need to be supplemented by distribution of cultured insects.

  Actions: ARS will:

  - Determine the efficacy of new herbicides on Lake Tahoe populations of *M. spicatum* and compare responses with known native *Myriophyllum* spp. in Lake Tahoe.
  - Conduct population/life history studies on *E. lecontei*, and evaluate impacts of *E. lecontei* on *M. spicatum* in the known California location.
  - Determine the distribution of *E. lecontei* in Connecticut and develop mass rearing techniques for supplementing natural populations to increase biological control efficacy.

3. **Restoration of Wetlands Habitat Degraded by Trees, Shrubs, and Creeping Vines**

   Importance: Emergent invasive shrubs, trees and vines are converting ecologically rich Everglades wetlands in southern Florida into "biological deserts" that are unsuitable to many native flora and fauna. Reduction in abundance and density of these invasive species, coupled with re-establishment of native vegetation, is essential to improvement and sustainability of these habitats and water resources.

- **Melaleuca (*Melaleuca quinquenervia*):** Melaleuca is an invasive tree of Australian origin that invades wetland (both seasonally and permanently inundated), pineland, and occasionally mangrove plant communities in southern and central Florida (also Puerto Rico, the Bahamas, and Hawaii), changing hydrologic regimes and displacing native vegetation and associated native wildlife. *Melaleuca* is one of the most aggressive Everglades invaders and currently infests about 400,000 acres in Florida.

Research Gaps: Three biological control insects have been released against this Everglades invader, two of which are established, well dispersed, and are substantially reducing the plant's reproductive potential. A fourth biological control insect has been approved for release, but strategies for establishing persistent and increasing populations need to be developed. Host range studies need to be completed on one or two more Australian insects that have been identified as having high potential for adding to current stresses on this invasive tree. Post-release evaluations are critical for evaluating agent dispersal, efficacy, and integration into existing IPM approaches. The ultimate goal of this project is to reduce this tree's reproductive potential, and thereby halt invasion of previously un-invaded habitat and prevent regeneration of *Melaleuca* populations treated by alternative control methods (herbicides, mechanical removal). Thus, evaluation of cumulative effects of biological control agents on dispersal and reproduction of this tree is needed as well.

Actions: ARS will:

- Conduct releases of the melaleuca gall midge *Lophodiplosis trifida* and monitor post-release population growth and dispersal.
- Assess the host fidelity of new potential biological controls of melaleuca.
- Evaluate the cumulative effects of released biological control insects on melaleuca population dynamics and reproductive success.

- **Brazilian Peppertree (*Schinus terebinthefolius*):** Brazilian peppertree (sometimes called Christmas berry or Florida holly) is purported to have appeared in Florida during the 1830s, and was recorded for sale as an ornamental shrub by 1880. Originally from South America, the plant forms dense thickets of woody stems that shade and displace native vegetation, including several rare plant species. Brazilian pepper has already spread to more than one million acres in Florida, Hawaii, Texas, and southern California. Success of the Comprehensive Everglades Restoration Project (CERP) requires dramatic reductions in Brazilian peppertree population expansion and reproductive potential as a means of promoting reestablishment of the biodiversity that once characterized the Everglades.

Research Gaps: Recent discoveries show that Brazilian peppertree genotypes present in Florida and Hawaii differ from genotypes surveyed for potential biological control agents in Brazil. This helps explain paradoxical outcomes of previous host fidelity studies by collaborators, but requires retesting of previously studied candidates. Further, there is need to locate Brazilian populations of the genotypes found in Florida and then to survey the herbivore and fungal fauna in these locations for potential biological control agents. Also, potential biological controls discovered during these surveys need to be assessed for host fidelity.

Actions: ARS will:

- Re-examine host fidelity of the Brazilian peppertree thrips.
- Conduct surveys in Brazil for herbivorous insects and pathogenic fungi on suitable genotypes of Brazilian peppertree.
- Assess host fidelity of new potential biological controls of Brazilian peppertree.
- Characterize the population dynamics of Brazilian peppertree in Florida to establish a baseline against which to measure biological control agent success.

- **Old World Climbing Fern (*Lygodium microphyllum*):** Old World climbing fern is an exotic species of Asian/Australian origins that invades wetland (both seasonally and permanently inundated) and pineland habitats in southern and central Florida, displacing native vegetation, changing fire regimes, and threatening rare arboreal species like bromeliads and orchids. It was first reported in the United States in 1965, and has since expanded to occur in over 125,000 acres and more than a dozen counties. Projections indicate that this species will blanket every tree island in the Everglades by the year 2050 if left unchecked.

  Research Gaps: Although three biological control agents have been approved for release against this invader, only one shows evidence of having established any self-perpetuating populations in the field. There is a critical need to determine whether this agent will persist, how rapidly it will disperse, and the levels of damage it will inflict. A second agent has proven difficult to culture in sufficient quantities for field release and there is need to identify the biological constraints that are restricting population growth as well as devise strategies to overcome these constraints. Additional agents are needed, as well.

  Actions: ARS will:

  - Monitor provisionally established field populations of the *Lygodium* moth *Neomusotima conspurcatalis* for persistence, dispersal, and population dynamics.
  - Develop rearing techniques for the *Lygodium* mite.
  - Conduct surveys in Asia for herbivorous insects on suitable genotypes of *Lygodium*.
  - Assess host fidelity of new potential biological controls of *Lygodium*.

- **Chinese Tallow (*Triadica sebifera*):** Chinese tallow is an aggressive woody invader of wetland, coastal, and disturbed habitats, and has been shown to reduce native species diversity and richness, and alter ecosystem structure and function in natural areas. This early successional tree has life history traits that enable it to thrive in unstable or unpredictable environments including; high fecundity, relatively small size, short generation time, and the ability to disperse propagules widely. Chinese tallow is also a superior competitor in its new range, has few natural enemies in the United States, can readily occupy “vacant niches”, and can alter ecosystem processes such as nutrient cycling and stand structure. In Texas, tallow has been shown to convert herbaceous coastal prairies into closed canopy tallow forests within a decade of establishment.

Research Gaps: Although numerous arthropod pests are known to attack Chinese tallow in its native range, preliminary surveys for potential biological control agents have begun only recently. These surveys need to be expanded and the most promising candidates imported into quarantine facilities for complete host fidelity testing. Further, research over the past decade has demonstrated the wisdom of searching for biological control candidates on plant genotypes within the native range that match the genotypes in the geographic range where control is desired.

Actions: ARS will:

- Use biochemical and molecular techniques to match U.S. genotypes to Asian genotypes.
- Survey in Asia for herbivorous arthropods damaging Chinese tallow.
- Assess host fidelity of new potential biological controls of Chinese tallow.

4. Weeds Deteriorating Water Resources in Lakes, Ponds, and Reservoirs

- **Water Hyacinth (*Eichhornia crassipes*):** Waterhyacinth infests tens of thousands of acres in the Gulf Coast states, and requires constant control within the Sacramento-San Joaquin Delta in California. It is acknowledged as one of the world's worst weeds. Excessive growths completely cover lakes, rivers and reservoirs; impair fish and waterfowl habitat; block critically important vessel movement; and interfere with timely delivery of potable and irrigation water.

Research Gaps: Although there are some aquatic herbicides registered for control of waterhyacinth, their continued exclusive use risks development of resistance. Efficacious herbicides with different modes and sites of action need to be integrated into single-herbicide programs. Similarly, only two herbivorous host specific insects, *Neochentina bruchi* and *N. eichhornai*, have had moderate success in reducing water hyacinth cover but these agents have not been effective in several sites. Additional biological control agents need to be introduced and evaluated for efficacy. Better matching of the biological control agents' environmental requirements with release-site/target population conditions should result in better efficacy. In addition, little is known about potential interactions (integration) of new herbicides with *Neochetina* species.

Actions: ARS will:

- Characterize biotic and a-biotic characteristics of problematic populations and source (South American) conditions to optimize fitness in release sites.
- Examine the potential for integration of new herbicides with biological control agents.

- Conduct expanded host-specificity testing for new agents.
- Survey South America for fungi with potential for use as mycoherbicides against waterhyacinth.

- **Fanwort (*Cabomba caroliniana*):** Native to the southeastern United States, fanwort is a non-native weed species in the northeastern and northwestern United States. It is a rooted, submersed plant that generally grows in areas up to 10 feet deep in ponds, lakes, and quiet streams. It has become a pernicious aquatic weed in several northeastern states, and a weed target of special concern to collaborators at the Connecticut Agricultural Experiment Station because it reduces biodiversity by displacing native vegetation (like eelgrass) and associated fauna.

  Research Gaps: Virtually nothing is known of the arthropod fauna and fungal diseases attacking fanwort in its native range (South America and southern United States). Surveys for potential biological control candidates are needed. Characterization of native United States pathogens associated with fanwort is needed to identify possible micoherbicide candidates. Also, the relationships between fanwort in the eastern United States and South America needs to be assessed.

  Actions: ARS will:

  - Conduct surveys in southeastern United States and South America for arthropods and fungi associated with fanwort.
  - Assess the genotypic diversity of fanwort in the United States and South America.
  - Develop vegetation maps documenting the incursion of fanwort in Connecticut waterways.

- **Waterlettuce (*Pistia stratiotes*):** Waterlettuce is a South American native that infests thousands of acres of waterways in Florida and the Gulf Coast states. Maintenance control of these populations costs several million dollars each year in Florida alone. Excessive growth completely covers lakes, rivers, and reservoirs, impairs fish and waterfowl habitat, blocks vessel movement, and interferes with timely delivery of irrigation water.

  Research Gaps: Two biological control insects were released in the 1980s and 1990s, but only one established persistent populations and demonstrated any efficacy. Unfortunately, control has been sporadic and inconsistent, highlighting the need for additional biological control candidates. Many herbivorous insect species are known from waterlettuce in South America but little is known of their biology or host fidelity.

  Actions: ARS will:

  - Survey South American waterlettuce populations for herbivores (known and unknown) with potential as biological control candidates and develop a better understanding of the biology of the most promising candidates.

- Assess host fidelity of new potential biological controls of waterlettuce.
- Evaluate effects of previously released biological control insects on waterlettuce population dynamics and reproductive success.

5. **Develop Effective Rapid Response Methods for Newly Introduced /Newly Discovered Aquatic Invasive Weeds**

Importance: Exotic and invasive marine algae and invasive marine flowering plants interfere with commercial production of fish and shellfish, degrade natural functions of near-shore and tidal habitats (e.g., native eelgrass beds and other seagrass beds), and threaten other high-value commercial uses of these areas. Pathways and "vectors" for the introduction of these species are well understood and include: commercial bait importations, un-regulated introductions for food/fiber/cultures in marine waters, marine aquarium trade (commercial and private), unregulated introduction/sale/trade of "live rock," commercial and private vessel hulls, and vessel transport systems (i.e., trailers). Newly introduced aquatic invasive plant species are reported each year and there is no reason to assume that those in the international aquarium and aquascape-trade pathways, such as oxygen weed (*Lagarosiphon major*), will not be found as either inadvertent or purposeful releases. Other species such as water chestnut (*Trapa natans)* and *Hygrophila polysperma* have not yet been introduced from eastern United States sites to western states. Having effective eradication tools for these species is essential for successful rapid responses within time-scales that will be both cost-effective and adequate to prevent their establishment and "naturalization" in un-infested areas. Effective rapid detection and response can save millions of dollars compared to the long-term management programs that become necessary when populations are allowed to establish and spread.

Research Gaps: Effective controls for known invaders (i.e., high risk introductions) are lacking. Similarly, effective infrastructures (rapid response teams and networks) are not established, nor are regulatory (permitting) needs identified. Thus, there is a multifaceted gap that encompasses research on effective tools as well as coordination and strategic planning with action agencies.

Actions: ARS will:

- Determine the suite of herbicides efficacious against *Trapa natans, Hygrophylla polysperma* and *Lagarosiphon major.*
- Assist state and Federal regulatory and action agencies to integrate research findings to transfer technologies for effective rapid response actions to eradicate newly introduced aquatic weeds.
- Integrate information that can assist in identifying and deploying effective rapid response actions for new invasive aquatic and wetland weeds.

6. **Invasive Marine Algae/Plant in Shellfish Production Systems.**

Importance: Mariculture (i.e., shellfish production) is growing in the United States and worldwide since the food produced is high-protein, high value, and usually cannot fully meet demand. Both algae and shellfish are cultured and can come from exotic (non-United States) sources. Thus, the industry can be both the vector (pathway) of introductions and also be negatively impacted by introductions of unwanted species. The grow-out stages to final harvest of shellfish production can be seriously impaired by proliferation of rapidly growing marine algae that attached to culturing structures. Some microscopic algae can produce toxins that reduce quality of harvest.

Research Gaps: To protect the U.S. shellfish culture industry, and associated grow-out habitat, methods for preventing the establishment of nuisance marine algae and marine plants are needed. A suite of methods and strategies are needed to control or eradicate invasive marine algae and plants that become established and interfere with production and harvest. Because the scope and scale of these impacts on shellfish production are poorly understood, better assessments are needed of the impacts and distributions of nuisance marine algae and marine plants within the United States mariculture industry. Trends in numbers of introductions and problems associated with these species are not well documented. Effects of these species on quality and harvestable production are not well known.

Actions: ARS will:

- Collaborate with the USDA-Economic Research Agency and mariculture stakeholders to develop quantifiable assessment of impacts.
- Collaborate with marine phycologists to help identify known and potential key nuisance marine algae/plants affecting mariculture activities.

7. **Invasive Marine Algae and Marine Plants Impacting U.S. Estuarine and Coastal Ecosystems.**

Importance: Several species of non-native marine algae and some marine flowering plants have invaded or could invade critical marine habitats along the approximately 80,000 miles of U.S. coastlines (coastal shoreline, bay, estuaries). Native seagrass meadows communities are threatened by: *Caulerpa taxifolia, Undaria pinnatifida* (California), *Zostera japonica* (Washington State), *Gracilaria* spp., and *Kappaphycus* (Hawaii). The cost of eradicating *Caulerpa taxifolia* was $7.2 million. Since these habitats are characterized by tidal changes, wave action and highly variable growing conditions (e.g., substrate), a suite of new approaches are needed to reduce the growing detrimental impacts. However, methods for managing and eradicating these species are practically non-existent. An increase in transport of non native marine algae and plants along with long-term marine ecosystem trends (e.g., increasing mean temperature, changes in salinity) suggest that this problem will only become more acute.

Research Gaps: To develop effective control methods, a better understanding of life-cycles and dispersal mechanisms of key invasive marine algae and marine plants are needed. There is no information on the potential to use herbicides and algicides that are already approved by the Environmental Protection Agency (EPA). No herbicides are registered for use in saline water, or for tidal marine waters. Similarly, little is known about the efficacy and non-target effects of physical removal (e.g., suction dredging, smothering with "bottom barriers"). A suite of tools (strategies, methods and regulatory guidance) are needed to respond to this threat. Virtually nothing is known about the susceptibility of major invasive marine algae and marine plants to the range of active ingredients in herbicides routinely used for managing freshwater weeds. Culture and testing protocols have not been established, nor are there federal or state facilities currently conducting these types of studies. The susceptibility of various stages in the life cycles of these species is similarly unknown. These are precisely the essential characteristics that must be understood to identify "weak" links and to assess the best timing of any control effort (chemical or physical).

Actions: ARS will:

- Facilitate technology transfer from known and successful tools for management of freshwater weeds for potential control of nuisance marine algae and marine plants.
- Collaborate with marine Federal and state research laboratories to establish protocols for assessing efficacy of control methods and the risk to non-target organisms.
- Conduct collaborative studies to identify candidate herbicides for use in controlling marine algae and marine plants.

Anticipated Products:

- Increased knowledge of the biology and ecology of aquatic and wetland weeds and native plants.
- Discovery of new effective management tools for use in a wide range of aquatic sites such as irrigation systems, lakes, rivers, fresh water tidal systems, flood control projects and related riparian ecosystems.
- New biological control agents for key invasive weeds.
- Increased knowledge of impacts of invasive aquatic weeds on fish and waterfowl habitat functions.
- Increased knowledge of physiological and environmental controls of dormancy in highly invasive aquatic plants.
- New tools for effective rapid response to newly introduced aquatic weeds.
- New understanding of life cycle, dispersal, and vulnerabilities of marine algae/plants.
- New registrations (via EPA) for efficacious products to control marine algae.

- Knowledge base to help assess the risk/benefits for various control actions.
- Tools for rapid responses to infestations of invasive marine algae and plants.

***Potential Benefits (Outcomes)*:**

- Contributions to the development of region-wide rapid response systems.
- Improvement in sustainable and effective weed management systems for a wide range of aquatic sites and impacted uses.
- New knowledge of ecosystem mechanisms operating and conditions needed for successful restoration following, and as a part of, invasive weed management.
- Reduced cost of managing new infestations and reduced the threat that these infestations serve as continuing sources of dispersal.
- Reduced non-target risk through integration of biological control agents.
- Reduced cost of water conveyance for irrigation, potable, and commercial uses.
- Increased coordination among federal, state, and local agencies for detection and responses to aquatic weed introductions.
- Improved mariculture productions.
- Improved biosecurity of products for domestic and export markets.
- Reduction in high risk pathways and vectors that lead to new introductions of invasive marine algae and marine plants.

***USDA ARS Resources*:**

- Australian Biological Control Laboratory, Brisbane, Queensland, Australia
- Beneficial Insects Research Unit, Weslaco, Texas
- Exotic and Invasive Weeds Research Unit, Davis, California
- Grassland Soil and Water Research Unit, Temple, Texas
- Invasive Plant Research Laboratory, Fort Lauderdale, Florida
- South American Biological Control Laboratory, Hurlingham, Buenos Aires Province, Argentina
- University of California, Davis, California Bodega Bay Marine Laboratory
- USFWS- USGS Western Fisheries Research Center, Seattle, Washington
- Other marine laboratories

Component IV: Protection of Postharvest Commodities and Quarantine

4a. Fresh Commodities

Problem Statement: There is the need to stop the geographical spread and adverse impacts of exotic fresh commodity insect pests by providing for the safe movement of commercial agricultural commodities from areas already invaded, reducing costs and damage to agriculture in those invaded areas, and developing environmentally acceptable and economically-efficacious systems to suppress and/or eradicate established populations of invasive species. Key pests of fresh commodities include:

- Fruit Flies (Mediterranean fruit fly, Oriental fruit fly, melon fly, Malaysian fruit fly, olive fly, Caribbean fruit fly, Mexican fruit fly, peach fruit fly, apple maggot, cherry fruit fly)
- Moths (codling moth, Oriental fruit moth, oblique banded leafroller, light brown apple moth, fall armyworm, banana moth, litchi fruit moth, nettle caterpillar)
- External Quarantine Arthropods (aphids, thrips, mealybugs, scale insects, leafminers, ants, spiders)
- Post-harvest Disease Management (gray mold, citrus green mold, brown rot, other post-harvest diseases)

Research Needs:

1. **Fruit Flies**

   Importance: Fruit flies have a severe economic impact on tropical and subtropical agriculture and pose an increased threat of establishment into new areas. When new fruit fly species are introduced into the United States mainland, they often require large-scale eradication programs at great public expense. In California, where the total annual value of the fruit and vegetable industry has been estimated at more than $14 billion, the California Department of Food and Agriculture estimated that an established Mediterranean fruit fly infestation would cost from $855 million to $1.4 billion during the first year of establishment. In Hawaii, production of fruits and vegetables is severely limited by fruit flies and other introduced alien insect pests.

   Invasive (and potentially invasive) tephritid fruit flies include: Caribbean fruit fly, *Anastrepha suspensa* (attacks guavas, peaches and grapefruit); Mexican fruit fly, *A. ludens* (principally attacks citrus); West Indian fruit fly *A. obliqua* (principally attacks mango); species of *Ceratitis* (primarily Mediterranean fruit fly, *C. capitata*, attacks a very broad host range); *Bactrocera* species, particularly the Oriental fruit fly, *B. dorsalis*; and melon fly, *B. cucurbitae* (principally attacks citrus, guava, mango, papaya); olive fruit fly (olives), and *Rhagoletis* species (attacks walnuts, cherries, apples, and blueberries).

Research Gaps: User-friendly, economical, and environmentally acceptable technologies are needed to control fruit flies. Area-wide pest management (AWPM) systems for fruit fly suppression are under development but are often, not always, sustainable and economical for farmers in all geographic areas and for all crops. Systems approaches for movement of export commodities are essential to expansion of specialty crops. More information is also needed to increase the practice of biological control for fruit flies, including information on ecology, physiology, and behavior of the pests and their natural enemies; mass-rearing techniques and strain development; and augmentative release strategies and tactics. Effective use of the sterile insect technique (SIT) requires an understanding of sexual behaviors and improved technology for genetic marking, sperm marking, genetic sexing (male-only) strains and male sterilization. Fundamental studies are needed in the areas of fly odorant and gustatory receptor gene identification and isolation, and identification of strain specific genetic markers in fruit flies.

Actions: ARS will:

Basic Biology

- Conduct studies of population dynamics and fruit fly interactions with their natural enemies, host plants, and other pests in the ecosystem.
- Provide baseline information for development of low prevalence and/or fly-free zones, and detection, control, containment, and suppression and eradication technologies for use in Hawaii and the United States mainland.
- Determine the responses of fruit flies to host plant volatiles, particularly in relation to oviposition and the maintenance of sexual signaling sites.
- Conduct full genome and specific EST sequencing projects in fruit flies to identify genetic reagents necessary for transgenic strain development, odorant/gustatory receptor gene identification and isolation, and highly specific strain identification.
- Create transgenic strains incorporating fluorescent protein markers for organismal detection and sperm detection in mated females.
- Create transgenic strains that allow conditional lethality specific to embryos of mass-reared females or progeny of released males.
- Use odorant and gustatory receptor genes for microarray analysis.

Surveillance, Detection and Monitoring

- Identify attractants from host and non-host plants and determine physiological and environmental factors that influence fruit fly behavior.
- Improve male lures and trapping systems for fruit fly surveillance, detection, and control.
- Develop automated methods for monitoring pest fruit flies and develop improved methods of trapping female fruit flies.

Biological Control and SIT

- Assess the efficacy of new and established parasites and predators and the sterile insect technique for fruit fly control, and determine factors limiting their effectiveness.
- Determine the best conservation and augmentation methods to improve the effectiveness of entomophagous insects to suppress fruit fly populations.
- Evaluate field behavior of parasitoids and sterile fruit flies.
- Improve quality of laboratory-reared fruit flies and their parasitoids compared with counterparts in nature.
- Explore for and investigate the characteristics of candidate fruit fly biological control agents..
- Explore tritrophic interactions among fruit flies, hosts, and natural enemies with the goal of developing new attractants and increasing biological control efficacy.
- Manipulate sex ratios in mass-reared parasitoids to produce more females.
- Determine the role of host and fruit fly host plant odors in the foraging of fruit fly parasitoids.
- Develop cultural control methods to reduce field populations of fruit flies.
- Create transgenic strains that allow conditional lethality specific to embryos of mass-reared females or progeny of released males.
- Conduct foreign exploration in Africa and Asia for biological control agents of olive fruit fly, and develop rearing methods for these agents.

Area-wide Integrated Pest Management (IPM) Systems

- Develop area-wide IPM approaches to reduce the economic impact of fruit flies.
- Enhance the role of natural enemies in IPM systems.
- Integrate environmentally friendly replacements for organophosphate pesticides used to control fruit flies.

Quarantine Treatments and Other Mitigation Approaches

- Develop heat, cold, irradiation, controlled atmosphere, and other post-harvest commodity treatments.
- Determine commodity tolerance and efficacy of controlled atmosphere plus heat and other combination treatments.
- Increase knowledge of pest biology and physiology as it relates to the development of quarantine procedures and risk of pest establishment.
- Develop multiple-component systems approaches to maintain current or establish new trade markets.

2. Moths

Importance: Moths are probably the second most significant pests of economic and quarantine concern for fresh fruits and vegetables. Moth pests can limit agricultural production and may disrupt trade if not detected and allowed to become established in major production areas. Codling moth is a serious economic pest of pome and stone fruits and a pest of quarantine concern to many Pacific Rim countries that import U.S. fruit. Oriental fruit moth is a quarantine pest for Mexico and Canada and light brown apple moth, an exotic pest, recently became established and is spreading in California, resulting in trade restrictions imposed by foreign countries. Fall armyworm overwinters in Texas and Florida and may migrate from more southerly locations in the Caribbean, Mexico and even South America serving as a model for exotic pests that migrate into the United States. False codling moth, a pest of 40 commodities, has recently been found in California.

Research Gaps: User-friendly, economical, and environmentally acceptable technologies are needed for control of moth pests. Sustainable economical area-wide pest management systems for suppression of moths need further development. Quarantine treatments and systems approaches for movement of export commodities are essential to expansion of specialty crops. More information is also needed to increase the practice of biological control for moths including information on ecology, physiology, and behavior of the pests and their natural enemies; mass-rearing techniques and strain development; and augmentative release strategies and tactics. Effective use of the sterile insect technique requires a better understanding of insect dispersal and improved technology for genetic sexing (male-only) strains and male sterilization. Little is known about the annual long-range movements of migratory pests and the potential for hemispheric migration.

Actions: ARS will:

Basic Biology

- Conduct studies of population dynamics and moth interactions with their natural enemies, host plants, and other pests in the ecosystem.
- Provide baseline information for development of low prevalence and/or moth-free zones, detection, control, containment, suppression and eradication technologies.

Surveillance, Detection and Monitoring

- Identify attractants from host and non-host plants and determine physiological and environmental factors affecting or modulating moth behavior.
- Improve lure and trapping systems for surveillance, detection, and control of moths.
- Identify genes and molecular markers to distinguish between species, strains or subpopulations.

Biological Control and SIT

- Assess the efficacy of SIT for control of moths and determine factors limiting their effectiveness.
- Evaluate the field behavior of sterile moths.
- Improve the quality of laboratory-reared insects compared to their wild counterparts.
- Develop area-wide IPM approaches to reduce the economic impact of moths.

Quarantine Treatments and Other Mitigation Approaches

- Improve pre-harvest procedures to reduce the incidence of moths in harvested fruit and packed boxes.
- Develop heat, cold, irradiation, controlled atmosphere, and other post-harvest commodity treatments.
- Determine commodity tolerance and efficacy of controlled atmosphere plus heat and other combination treatments.
- Increase knowledge of pest biology and physiology as it relates to the development of quarantine procedures and risk of pest establishment.
- Develop multiple-component systems approaches to maintain current or establish new trade markets.

3. External Quarantine Pests

Importance: External or surface feeding quarantine pests and hitchhiker pests are as important as internal quarantine pests in interrupting import/export marketing channels of fresh commodities. Although these pests can be detected through inspection and culled, many go undetected (e.g., when pests are hidden inside fruit clusters or protected within various plant parts in the exported commodity). A postharvest quarantine treatment or systems approach (pre- and/or post-harvest) may be required to treat external pests such as thrips, mealybugs, scale insects, leafminers, ants, mites, and spiders.

Research Gaps: Fundamental scientific information is lacking for most exotic surface feeding anthropod insect pests and is necessary in order to develop effective quarantine and safeguarding programs. This information also is necessary to develop basic detection and delimitation tools and to determine the types of systems approaches or commodity treatments that are appropriate to minimize the risk of their introduction and spread. The effectiveness of most current quarantine treatments against these external surface or hitchhiker pests is poorly understood.

Actions: ARS will:

Basic Biology

- Study the population dynamics and pest interactions of surface-feeding or hitchhiker pests with their natural enemies, host plants, and other pests in the ecosystem.
- Provide baseline information for development of low prevalence and/or pest-free zones, detection, control, containment, and suppression technologies, as needed.
- Target pest populations with the appropriate predators through genomic, physiological and comparative studies that define species-specific abundances and niches in greenhouses and in the field.

Surveillance, Detection and Monitoring

- Identify attractants from host and non-host plants and determine physiological and environmental factors affecting or modulating pest behavior.
- Improve lure and trapping systems for surveillance, detection, and control of the pest.
- Map the annual migration of populations of moth pests in North America in order to target control measures.

Biological Control and Sterile Insect Technique

- Assess the efficacy of new and established parasites and predators and determine factors limiting their effectiveness.
- Determine the best methods to improve the effectiveness of entomophagous insects in suppressing pest populations through conservation and augmentation.
- Identify nutritional components that will contribute to improved diets for rearing predators. (Gainesville, Florida: Shapiro, Shirk)
- Develop molecular and genetic methods for disrupting moth-larval physiology to be used in area-wide controls. (Gainesville, Florida: Meagher, Nagoshi, Shirk)
- Improve methods for mass-reared predator distribution and so increase efficacy.

Quarantine Treatments and Other Mitigation Approaches

- Develop heat, cold, irradiation, controlled atmosphere, and other post-harvest commodity treatments.
- Determine commodity tolerance and efficacy of controlled atmosphere plus heat and other combination treatments.

- Increase knowledge of pest biology and physiology as it relates to the development of quarantine procedures and risk of pest establishment.
- Develop multiple-component systems approaches to maintain current or establish new trade markets.

4. **Postharvest Disease Management** (gray mold, citrus green mold, brown rot, stem end rots, body rots, anthracnose, and other post-harvest diseases)

Importance: Postharvest diseases cause major losses due to spoilage and reduced shelf life. Papayas and other tropical fruits are susceptible to postharvest diseases with incidences in the range of 40-60 percent. Without postharvest disease control, fruit quality would be diminished with mild blemishes to severe rots resulting in poor consumer acceptance or marketability. In citrus, postharvest diseases that currently cause losses of 3 to 5 percent in retail trade can become much higher. These diseases occur early in the harvest season when fruit are de-greened with ethylene gas, later in packinghouse storage, or among fruit where sales were delayed. These diseases also make deliveries of sound fruit to certified organic buyers or distant foreign markets risky and difficult, particularly when customers reject the use of conventional fungicides or if pathogen resistance to these compounds has diminished their effectiveness.

Research Gaps: In order to deliver fresh agricultural products of high quality to satisfy the growing domestic demand for organic fruit and vegetables, or to reach distant but profitable foreign markets, the research capacity to develop new postharvest treatments and practices to prolong their shelf and shipping life are needed. Integrated disease control regimes are also needed with elements that employ OMRI (Organic Materials Review Institute)-approved treatments, generally recognized as safe compounds, biological control, and/or thermal treatments.

Actions: ARS will:

Monitoring

- Improve sampling and monitoring methods to detect and manage the development of pathogen fungicide resistance among postharvest pathogens.

Control, Chemical

- Discover treatments based on reduced risk compounds that can become elements in integrated postharvest disease control programs and, if applicable, to be elements in programs to minimize food safety risks as well.
- Monitor pathogen populations within packinghouses and fruit shipments to determine the extent of fungicide-resistance.
- Determine efficacy of chemical controls under various storage temperatures and using different packaging systems.

- Determine the efficacy of chemicals combined with postharvest quarantine treatments, such as heat, cold or irradiation.

Control, Biological

- Develop biological control agents, determine feasibility of their mass production, formulation, and tolerance to their use in current commercial practices.
- Determine efficacy of biological control agents under various storage temperatures and using different packaging systems.

5. **Post-harvest Commodity Quality**

Importance: Quarantine treatments for fresh commodities are urgently needed but often cause unacceptable injury to the commodity that reduces marketability.

Research Gaps: The effect of quarantine treatments on fruit quality is often inconsistent due to poor understanding of the biochemical basis of an observed quarantine-induced injury and a lack of complete information regarding the influence of pre-harvest factors on the injury. These are long-standing problems that cause failures of treatments already in place or hinder the development of new treatments. There is limited and unreliable data available on crop tolerances to quarantine treatments, particularly for irradiation.

Actions: ARS will:

- Determine tolerance thresholds and compositional quality for tropical and temperate crops subjected to quarantine treatments.
- Utilize genomic, proteomic and metabolomic techniques to answer basic questions regarding the influence of quarantine treatment-induced stresses (e.g., high or low temperature) on fresh commodity physiology.
- Enhance understanding of the influence of maturity on fresh commodity quality following quarantine treatment.
- Increase understanding of the influence of pre-harvest factors, such as growing temperature and other environmental influences, on fresh commodity quality following specific treatment protocols.
- Develop novel methods to alleviate damage caused by quarantine treatments.

***Anticipated Products*:**

- New or improved quarantine treatments or approaches that allow safe import or export of fresh commodities.
- Increased knowledge of pest biology, ecology, behavior, genetics, and biological control agents, and of plant traits conferring pest resistance.

- Discovery, characterization, and synthesis of insect attractants, repellents and confusants.
- New biological control agents.
- Increased knowledge of the genomics and basic biology and ecology of biological control agents.
- Information on endosymbionts associated with subtropical and tropical insect pests.
- Identification of plant traits that might be used to develop pest-resistant plants.
- Development of plants with pest resistance.
- Novel methods of reducing the impact of anthropod pests of fruit, vegetable and ornamental plants.
- Improved pest sampling and detection methods.
- Improved mating disruption technology.
- New or improved quarantine treatments or approaches that allow safe import or export of fresh commodities.

***Potential Benefits (Outcomes)*:**

- Exclusion of exotic pest from the United States.
- New or expanded markets for U.S. fresh commodities using improved quarantine procedures.
- Increased income for U.S. producers through increased trade.
- Increased availability of fresh commodities for the consumer.
- Increased availability of suitable quarantine treatments for fruits and vegetables that meet organic labeling requirements.
- Reduced impact of integrated pest management tactics and postharvest quarantine treatments on the environment.
- Strategies for improved integrated pest management of temperate, subtropical and tropical insect pests.
- Reductions in crop losses due to insect pests and plant diseases.
- Reductions in expenditures to manage insect and disease pests.
- Reduction in the use of methyl bromide and organophosphate pesticides.

USDA ARS Resources:

- Euroean Biocontrol Laboratory, Montpelier, France
- Fruit and Vegetable Research Unit, Wapato, Washington
- Insect Behavior and Biocontrol Research Unit, Gainesville, Florida

- Post-Harvest Tropical Commodities Research Unit, Hilo, Hawaii
- Subtropical Insects Research Unit, Fort Pierce, Florida
- Tropical Plant Pest Research Unit, Honolulu, Hawaii

Component IV: Protection of Post-harvest Commodities and Quarantine

4b. Durable Commodities (U.S. Value 2007: $68 billion)

Problem Statement**:** Stored grains (mainly corn, wheat, and rice) are damaged during storage and processing by the following insect pests:

- Stored Corn: Maize Weevils, Flat and Rusty Grain Beetles, Red Flour Beetles, Sawtoothed Grain Beetles, and Almond Moths, Angoumois Grain Moths, and Indianmeal Moths
- Stored Wheat: Lesser Grain Borers, Rice Weevils, Red Flour Beetles, Rusty Grain Beetles, and Sawtoothed Grain Beetles
- Stored Rice: Lesser Grain Borers, Angoumois Grain Moths, Maize and Rice Weevils, Red Flour Beetles, Rusty Grain Beetles, and Sawtoothed Grain Beetles
- Grain-based Products: Red and Confused Flour Beetles, Cigarette Beetles, Indianmeal Moths, Sawtoothed Grain Beetles, Warehouse and other Trogodermid Beetles, Flies and Incidental Night-Flying Moths
- Dried Fruits and Nuts: Research is Conducted in Parlier, California, under National Program 308, Methyl Bromide Alternatives

Research Needs**:**

1. **Insect Pests of Stored Grain (corn, wheat, and rice)**

   Importance: Insects damage an estimated five to ten percent of the grain stored in the United States each year. They also can make grain more susceptible to development of mycotoxins. Insecticides used for their control incur additional costs and many insecticides historically used for insect control in stored grain are being lost because of resistance or regulatory changes. Information on the biology or control of psocids and other recently discovered pests of stored grains is limited. Furthermore, new pests are being introduced into the United States in grain imported from other countries, such as from organic grains from China.

   Research Gaps: Detection methods with food attractants and pheromones need to be improved or developed. In addition, interpretation of trap catches needs to be clarified in order to expedite pest management decisions. New and improved automated methods are needed for monitoring insect pests at grain depths below one meter in commercial grain elevators and for monitoring outdoor pest insect populations to predict grain elevator pests. Preventative and remedial control methods, as well as new combinations of control methods are also needed for insects in conventional and organic stored grains. This includes characterizing the biology of new target pests, as well as identifying new physiological targets and approaches for pest control through long-term research on genomics and proteomics.

Actions: ARS will:

Detection

- Develop methods for acoustic or electromagnetic detection of insects inside grain kernels.

Monitoring

- Develop and improve attractants for stored-product insects.
- Improve methods for interpretation of trap catches to aid in pest management decision making.
- Develop automated methods for monitoring insect pests at grain depths below one meter in commercial grain elevators.
- Determine whether outdoor populations of insects are an important source of infestation, and, if so, develop methods to use monitoring information from these populations to develop predictive tools.

Biology, Control, Organic

- Evaluate efficacy of registered organic insecticides as they become available.
- Improve efficacy of registered microbial agents through synergism.
- Evaluate efficacy of new microbial agents.
- Improve the ability of naturally occurring parasitoid wasps to suppress stored grain pests.
- Improve efficacy of aeration.

Control, Conventional

- Evaluate efficacy of registered insecticides as they become available.
- Optimize control technologies.
- Develop simulation models and expert systems to aid in decision making for pest management and for optimizing control technologies.
- Characterize biology of stored-product insects and their natural enemies.

Biology, Emerging Pests

- Characterize biology of emerging pests.
- Develop control technologies for emerging pests.

Control, New Physiological Targets

- Conduct genomic/proteomic studies on stored-product insects to identify potential physiological targets in the insect that can be exploited for insect control.

2. Insect Pests in Grain-processing Facilities and Stored Processed Commodities

Importance: Insect control costs and processed commodities losses have not been quantified for proprietary reasons, but probably greatly exceed the cost of losses to grain stored in the United States each year. Insects in processed commodities damage the reputations of food processors, no matter where in the marketing channel the insect infests the product. These insects also may cause allergy and other health-related problems. Many insecticides historically used for insect control in processing facilities and stored processed commodities are being lost because of insect resistance and regulatory changes. Information on the biology or control of psocids and other recently discovered pests of grain-processing facilities and stored processed commodities is limited.

Research Gaps: Detection methods before the grain is purchased for storage and processing need to be developed or improved and interpretation of the trap catches need to be clarified in order to expedite pest management decisions. New and improved automated methods are needed for monitoring insect pests that are continually being moved within facilities, as well as in and out of facilities, or are contained within difficult to sample shrink wrapped packages of processed commodities stacked on pallets. Monitoring techniques are also needed for outdoor populations that may serve as a source of pest populations and for pest refugia in flour mills that may allow pests to avoid control treatments. An understanding of the role of survivorship in refugia will help clarify the impacts of refugia on pest population dynamics and may be an important predictive tool. Preventative, remedial, and new combinations of control methods such as repellants, aerosols, and insect growth regulators must be developed and optimized for insects in conventional and organic stored grains. This includes characterizing the biology of new target pests and identifying totally new physiological targets and approaches for pest control through long-term research on genomics and proteomics. Improved insect-resistant packaging is also mandatory for protecting processed commodities from insect infestation.

Actions: ARS will:

Detection

- Develop methods for acoustic or electromagnetic detection of insects inside stored products.

Monitoring

- Develop and improve attractants for stored-product insects.
- Improve methods for implementation and interpretation of trap catches to aid in pest management decision making.

- Determine whether outdoor populations of insects are an important source of infestation, and, if so, develop methods to use monitoring information from these populations to develop predictive tools.
- Determine locations of refugia in flour mills that may allow pests to avoid control treatments, and determine how survivorship in refugia impacts pest population dynamics.

Biology, Control, Organic

- Evaluate efficacy of registered organic insecticides as they become available.

Control, Conventional

- Evaluate efficacy of registered insecticides as they become available.

Control, Optimize Technologies

- Develop simulation models and expert systems to aid in decision making for pest management and for optimizing control technologies.
- Characterize biology of stored-product insects.

Biology, Emerging Pests

- Characterize biology of emerging pests.
- Develop control technologies for emerging pests.

Control, New Physiological Targets

- Conduct genomic/proteomic studies on stored-product insects to identify potential physiological targets in the insect that can be exploited for insect control.

<u>Anticipated Products</u>:

- Improved pest detection methods in grain.
- New and improved traps and attractants for stored-product insect pests, and improved methods for implementation of monitoring programs and for interpreting results of trap catches.
- Optimization of use of registered conventional and organic insecticides.
- Development of computer-based pest management decision-making programs
- Increased knowledge of pest biology, ecology, behavior, genetics, and biological control agents.
- Development of knowledge of biology and control of emerging pests.
- Identification of novel physiological targets in insects for pest control through genomic and proteomic studies.

Potential Benefits (Outcomes):

- Strategies for improved Integrated Pest Management (IPM) of stored-product insect pests.
- Reductions in losses to stored grains and processed commodities caused by insect pests.
- Reductions in expenditures to manage insect pests.
- IPM tactics that are ecologically sound.
- Development of novel pest control technologies.

USDA ARS Resources:

- Biological Research Unit, Manhattan, Kansas
- Crop Bioprotection Research Unit, Peoria, Illinois
- Insect Behavior and Biocontrol Research Unit, Gainesville, Florida