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