National Management Plan For the Genus *Eriocheir* (Mitten Crabs)

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Submitted to the Aquatic Nuisance Species Task Force

Prepared by the
Chinese Mitten Crab Working Group

November 2003

EXECUTIVE SUMMARY

In the short time since its introduction in the late 1980s or early 1990s, the catadromous mitten crab (Genus *Eriocheir*) has become abundant and widely distributed throughout the San Francisco Bay - Sacramento and San Joaquin Delta system (Bay-Delta). In 1998 the downstream migrating density of the Chinese mitten crab, *Eriocheir sinensis*, in the Bay-Delta reached tremendous proportions. This observed increase in population is similar to reports of the German experience with mitten crab in the 1930s and that of other European countries.

The mitten crab has the potential to inflict serious damage on the Bay-Delta ecosystem and the regional economy. The downstream migration of adult mitten crabs has seriously impacted the Central California Valley water diversion fish salvage facilities, which salvage endangered and threatened fish species. In the autumn of 1998 over 775,000 mitten crabs interfered with Federal and State fish salvage facilities in Tracy, California. Bait stealing by mitten crabs threatens a Bay-Delta recreational fishing industry valued at over $2 billion annually. Commercial fisheries, power plants and other water diversion activities have incurred additional costs in years when mitten crabs are abundant. Burrowing and feeding by mitten crabs pose uncertain ecological and economic effects and will continue to do so in the years to come. In addition, consumption of the mitten crab by predators, including humans, may be harmful due to possible accumulation of contaminants and potential transmission of the Asian lung fluke.

The introduction of Chinese mitten crabs to the Bay-Delta, and other diverse regions of the world, indicates that *Eriocheir* are capable of establishing additional populations in habitable U.S. waters. Mitten crabs may be introduced through illegal importation and unintentional release or intentional release to establish a commercial fishery. Crabs may also establish populations through accidental release in vectors such as ballast water. Areas such as the lower Columbia River are at particular risk for invasion by *Eriocheir* due to vectors that could transport mitten crabs to that region.

The Aquatic Nuisance Species Task Force (ANSTF) is an intergovernmental body established by the Nonindigenous Aquatic Nuisance Prevention and Control Act (NANPCA) of 1990. The ANSTF has followed the mitten crab introduction to California since early 1998 and determined that, under the authority of NANPCA, the development of a comprehensive management plan for the genus *Eriocheir* was appropriate and necessary. At the request of the ANSTF, U.S. Fish and Wildlife Service supported a literature review, a public meeting and workshop, and the development of a 1999 report to the ANSTF entitled "The Chinese Mitten Crab Invasion of California: A Draft Management Plan for the Genus *Eriocheir*". In 2001 the ANSTF developed a Mitten Crab Control Committee charged with the task of reviewing and editing that draft plan. The broad and representative membership of the committee has worked cooperatively to complete a management plan that will best meet the needs of this evolving issue.

The goals of this National Management Plan for the Genus *Eriocheir* are to prevent or delay the spread of *Eriocheir* species to new areas and to reduce the negative impacts of existing *Eriocheir* populations in U.S. waters. On the basis of these goals five primary objectives have been developed:

1. To prevent new introductions and spread of mitten crabs in U.S. waters.
2. To develop methods of detecting new populations of mitten crabs in areas where they are not currently present.
3. To monitor existing mitten crab populations.
4. To reduce the negative impacts of existing populations.
5. To develop strategies and methods to control and manage existing populations.

To date significant progress has been made on addressing the goals and objectives of this management plan. Scientific studies have advanced understanding of many aspects of mitten crab ecology in the Bay-Delta System. Health threats to consumers continue to be researched. Control methods have been tested at fish salvage facilities in California's Central Valley. Educational outreach to law enforcement officials, resource managers and the public is ongoing.

While progress has been made, there are many essential tasks of mitten crab management that still must be addressed. These include:

- Develop rapid response plans for high risk regions,
- Develop efficient capture techniques and methods,
- Develop best management practices to prevent the spread of mitten crabs,
- Develop model state regulations that can be used by at risk states,
- Develop educational materials in several languages,
- Develop and implement a mitten crab training program for law enforcement officers, and
- Investigate listing the mitten crab as a plant pest.

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The goals of this "National Management Plan for the Genus *Eriocheir*" are to prevent or delay the spread of *Eriocheir* species to new areas and to reduce the negative impacts of existing *Eriocheir* populations in U.S. waters. The purpose of this management plan is to guide the Aquatic Nuisance Species Task Force (ANSTF) and other interested parties in responding to the introduction of the genus *Eriocheir* into U.S. waters. This plan includes updated material since completion of a draft in 2002. Comments submitted during the public comment period, as well as recent advances in research, have been addressed in this revised version of the plan.

Immediately following this section is a brief description of the history of the genus *Eriocheir* in U.S. waters and impacts of this introduction (section 2). Section 3 describes the problems associated with the population of mitten crabs in the Bay-Delta region. Section 4 reviews options for controlling the spread and the potential consequences of mitten crab populations throughout the U.S. Section 5 details recommendations for population control and management. Section 6 lists the progress-to-date on priorities and recommendations as well as identifying current needs for control and management objectives. Appendices with technical information are at the end of this document.

2. The Genus *Eriocheir*

2.1. Biology of the Genus *Eriocheir*

Identification and Life History

Eriocheir sinensis (Chinese mitten crab) is native to the rivers and estuaries of central Asia, from the west coast of North Korea to south of Shanghai, China (Panning 1939). The Chinese mitten crab is easily identified by the dense patches of setae found on the white-tipped chelae (claws) of larger juveniles and adults; it is these "hairy mittens" that gives this crab its common name. Males and females both exhibit hairy chelae, though the setae are generally fuller and cover a wider area of the chelae in the males (Hoestlandt 1948). Both front claws are approximately equal in size. The carapace is slightly wider than long and has four spines on its anterior lateral margins. The maximum carapace width of adult mitten crabs collected in California is 95 mm, but the majority of adult crabs fall within the 40 to 70 mm size range (Rudnick et al. 2003). The crabs' pigmentation varies from a brownish orange, particularly among juvenile crabs, to a more greenish-brown seen in adult crabs and in newly molted crabs (Zhao 1999). The Chinese mitten crab is a catadromous species; reproduction occurs in water of high salinity and rearing occurs in freshwater and brackish habitats.

After hatching from eggs, mitten crab larvae mature through 5 distinct stages culminating in a megalopae stage. Megalopae settle and migrate upstream to rear, primarily in freshwater streams. It is not yet known how mitten crab megalopae select particular streams to rear in. Adult crabs from 1-5 years of age migrate downstream in the late summer and fall to brackish water, where they spawn. Figure 1 is a schematic representation of the lifecycle of the Chinese mitten crab in the San Francisco estuary. Detailed information about the Chinese mitten crab lifecycle can be found in Appendix A, "Overview of the Life History, Distribution, Abundance and impacts of the Chinese mitten crab (*Eriocheir sinensis*)" and a life history model is currently undergoing revision (Rudnick et al. in preparation).

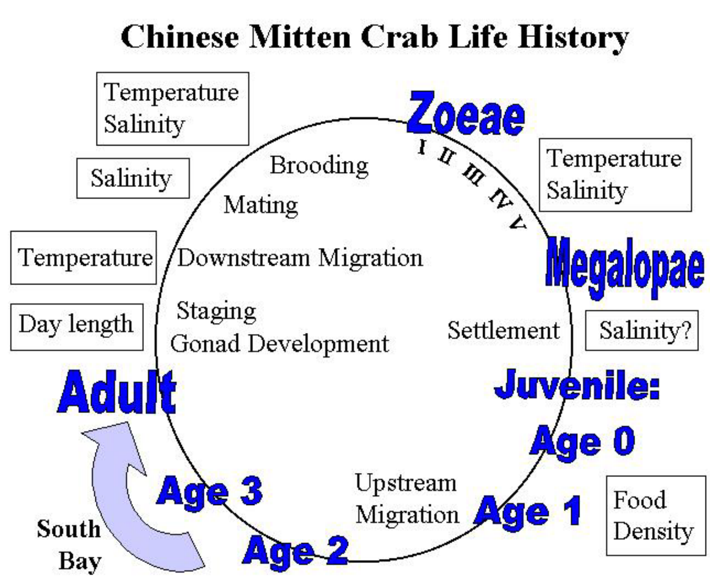


Figure 1. Lifecycle of the San Francisco population of the Chinese mitten crab (*Eriocheir sinensis*). (Provided by Brian Tsukimura, California State, Fresno).

Since its introduction into the Bay – Delta the population of Chinese mitten crabs has fluctuated greatly from year to year. This pattern of fluctuating annual population size is similar to patterns seen with introduced populations of mitten crabs in Europe (Gollasch 1999, Clark et al. 1998). The specific factors that contribute to these population fluctuations are not completely understood. It is likely that mitten crab populations vary with a host of environmental conditions, which can vary seasonally and yearly in the Bay-Delta system. Currently there is insufficient long-term data to be able to predict mitten crab cohort size for a given year (Rudnick et al. 2003). Figure 2 shows the variation in annual mitten crab catch per unit effort by trawl sampling conducted in San Francisco Bay. Figure 3 shows the relative distribution of juveniles and adults found in each year's trawl.

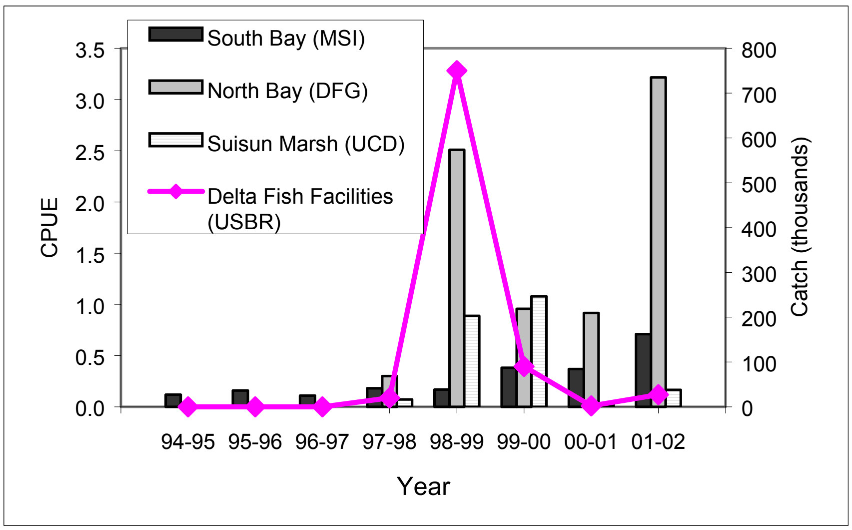


Figure 2. Catch per unit effort for various trawl surveys conducted in the San Francisco Bay. Data from the Marine Science Institute (MSI), CA Department of Fish and Game (CDFG), University of California, Davis and two Fish Salvage Facilities in Tracy, California (Hieb 2002).

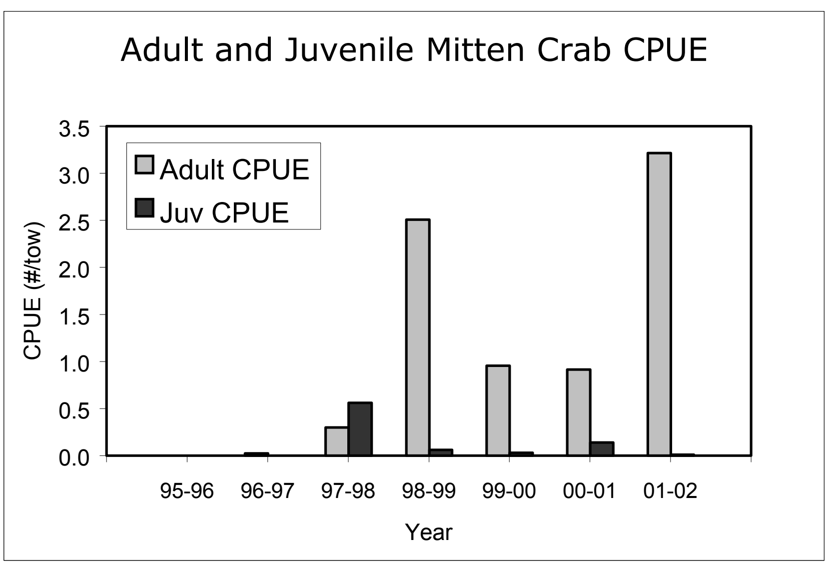


Figure 3. Relative distribution of juvenile and adult mitten crabs found in CDFG otter trawl surveys (Hieb 2002).

Taxonomy and Genetic Variation within the Genus *Eriocheir*

The Chinese mitten crab, *Eriocheir sinensis* H. Milne Edwards (Decapoda: Brachyura: Grapsoidea), is the subject of several taxonomic controversies. The genus *Eriocheir* is currently assigned to the superfamily Grapsoidea, which contains several catadramous and semi-terrestrial crabs. *Eriocheir* is generally considered to be a member of the family Grapsidae, subfamily Varuninae (Schubart et al. 2000).

Eriocheir sinensis is a member of a genus that fluctuates in membership as a result of continued genetic and morphological studies. The *Eriocheir* genus also includes *E. japonica*, a species that has variously been described as closely related to or synonymous with *E. sinensis* (Li et al. 1993), but which many researchers consider a distinct species (Ng. et al. 1999; Cohen and Weinstein 2001; Zhao et al. 2002). *E. japonica* has been described as having two subspecies, *E. japonica hepuensis* and *E. j. japonica* (Dai 1991 as cited in Chan et al. 1995), and some researchers suggest *E.j. hepuensis* should be treated as a unique species, *E. hepuensis* (Guo et al. 1997) while others suggest *E. hepuensis* is not distinguishable from *E. japonica* (Zhao et al. 2002). A recent genetic analysis strongly suggests that *E. japonicus* and *E. sinensis* are closely related and should be considered to be the same species (Tang et al. 2003).

Morphological variation between species in the Genus *Eriocheir* have been described, although whether these differences are a physical expression of population and hybrid differences, or true species-unique characteristics, is debatable. Li et al. (1993) described a mitten crab population with physical traits intermediate to *E. sinensis* and *E. japonicus*, and suggested that the physical characteristics may be caused by variable environmental conditions. Some physical characteristics of mitten crabs are not consistently found on individual crabs. Thus some characteristics, such as the frontal carapace teeth that can change shape with the growth of the carapace, should not be considered to be good identifying characteristics for individual *Eriocheir* species (Li et al. 1993).

Given the physical plasticity and genetic homogeneity of *Eriocheir*, it may be difficult to determine the source of mitten crabs in the Bay-Delta ecosystem. Hanfling et al. (2002) has provided some insights to these questions by conducting a genetic study on several populations of *E. sinensis* throughout the world. The authors found evidence to suggest that the California population of the mitten crab may have resulted from a single invasion event, and also suggest a closer genetic relationship between the California population and European populations of the crab than between the California and Asian populations.

2.2. The Introduction of the Genus *Eriocheir* to U.S. Waters

A Chinese mitten crab (*Eriocheir sinensis*) was first reported in South San Francisco Bay by shrimp trawlers in 1992. In 1996 several dozen of this non-native crab were caught at the U.S. Bureau of Reclamations (USBR) Tracy Fish Collection Facility (TFCF), in California's central valley. The number of migrating crabs in the fall increased to tens of thousands by 1997 and by 1998 to over 775,000 crabs, nearly shutting down TFCF salvage operations (Siegfried 1999). Figure 5 shows the rapid expansion of the Chinese mitten crab through tributaries connected to the San Francisco Bay from 1992 to1998.

The Chinese mitten crab likely arrived in California by one or more of three processes: a natural introduction, such as migration or drift of larvae from native habitat; an unintentional introduction associated with such activities as the importation of cargo or ballast water; or intentional introduction of the crab, for purposes including consumption or aquaculture establishment. Given the wide geographical separation of possible source populations such as China and Europe, combined with the preference of the mitten crab for coastal and freshwater habitats, it is unlikely that the mitten crab arrived in North America from natural causes (Cohen and Carlton 1997). It is likely that the crab became established, unintentionally or intentionally, as a result of human activities.

The prolific population growth of mitten crabs is a serious threat to the Bay-Delta ecosystem. Aspects of mitten crab behavior and physiology make its introduction a potential threat to any ecosystem in which it can survive (Rudnick et al. 2000). Recent studies have demonstrated that the Chinese mitten crab populations in the Bay-Delta system pose several threats to the ecological health and economic vitality of California.

- Mitten crabs are omnivorous throughout their lifecycle and can feed on and directly impact resident flora and fauna (Rogers 2000).
- Bait stealing by mitten crabs interferes with recreational and commercial fishing in the Bay-Delta, particularly from late summer to autumn (USFWS mitten crab database, Rudnick & Resh 2002).
- Fish salvage operations are severely impacted by the downstream migration of large numbers of mitten crabs (Cohen and Weinstein 2001).
- Mitten crabs can block the cooling systems for power plants (Hieb 1998).
- Burrowing by mitten crabs may contribute to bank erosion, which can threaten levee stability or alter the course of streams (Rudnick et al. 2002).
- Agricultural crops may be damaged directly by feeding or indirectly by hydrologic change.
- The potential for bioaccumulation of toxins by this benthic feeder makes it a potentially toxic food source for aquatic predators and humans.
- Mitten crabs can be secondary hosts for the Asian lung fluke (*Paragonimus westermani*), which can cause disease in humans or animals that become infected with the parasite (Yang et al. 2000).

2.3. Potential for Spread in U.S. Waters

In the San Francisco Estuary and its tributaries, the distribution of the Chinese mitten crab rapidly expanded each year between 1992 and 1998 (Figure 4). The mitten crab population increased dramatically in the few short years after the species was first discovered in California. By 2000, mitten crabs were found up to 50 km upstream from the Bay-Delta (Rudnick et al. 2003) and since that time they have continued to spread further upstream (USFWS mitten crab database). This pattern of spread makes it likely that mitten crabs will eventually populate all waterways in California connected to the Bay-Delta. It is possible that the eventual distribution of the mitten crab could include most of the state of California.

California is the only U.S. state with an established Chinese mitten crab population at this time. The potential for spread to other U.S. waters does exist. Records indicate that mitten crabs have been introduced into other regions of North America, but populations did not establish. Mitten crabs have been reported from the Detroit River (1965), Lake Erie (1973) (Nepszy and Leach 1973) and other areas of the Great Lakes region (1973-1994) (Leach, pers. comm. 1994, as cited by Veldhuizen and Stanish 1999), and the Mississippi River Delta (1987) (USFWS 1989).

Most recently mitten crabs have been reported to be present at sites along the West Coast of the U.S. A crab identified as *E. japonica* (Japanese mitten crab), was caught at the mouth of the Columbia River by a sturgeon fisherman in July 1997 (Sytsma, pers. comm. 2003, Jensen, pers. comm. 2003). In addition, there have been several unconfirmed reports in the Columbia River of "hairy crabs" (Pennington 2002). One fisherman reported catching a live mitten crab in Yaquina Bay in central Oregon, but the identification could not be verified. It is still uncertain if any populations of *E. sinensis* or *E. japonica* are established in the Columbia River system or Yaquina Bay. Appendix E describes other regions of the U.S. that are considered high risk for the introduction and establishment of mitten crabs. Educational outreach and monitoring is ongoing throughout high-risk areas of Oregon and Washington in an attempt to detect the possible introduction of mitten crabs into these regions.

A likely vector for dispersal of mitten crabs within the U.S. is the introduction of live crabs by humans. Live mitten crabs have been available for sale in seafood markets of New York City's Chinatown, fetching up to $40/pound (Jung 1998). In the fall of 1999 and again in 2001 illegally imported commercial shipments were intercepted coming into New York via airline transport (Sabia 1999, 2002). The demand for mitten crabs, particularly egg bearing females, provides an economic incentive for individuals to establish new populations of mitten crabs in U.S. waters. The presence of mitten crabs is likely to damage the aggregate economy of affected areas, even though limited individuals could profit from their introduction and harvest.

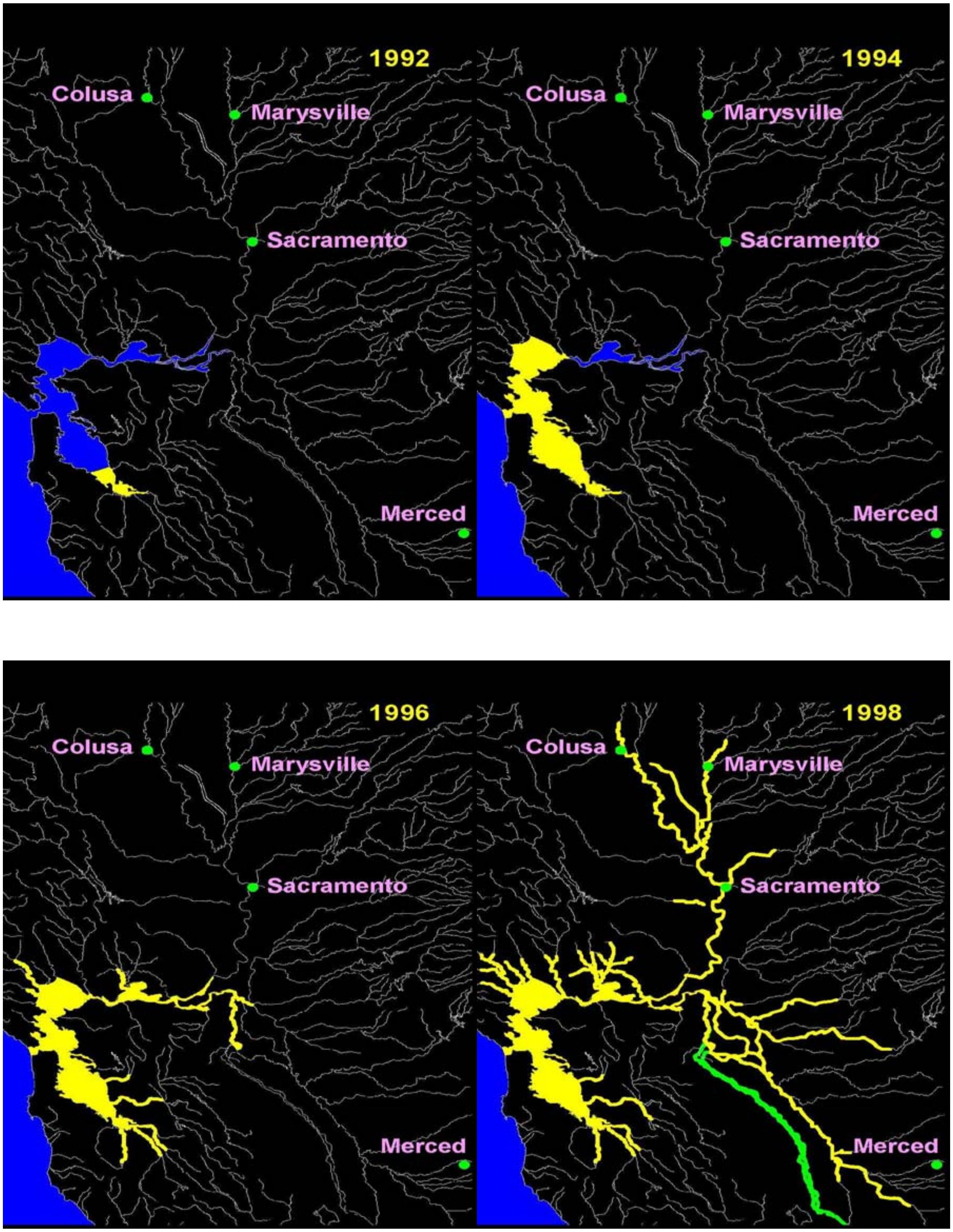


Figure 4. Expansion of the Chinese mitten crab (*Eriocheir sinensis*) population in San Francisco Bay, the Sacramento and San Joaquin Rivers, and the associated watershed from 1992 to 1998. (Diagrams by CDFG).

2.4. History of Mitten Crabs in Other Regions

The wild population of the mitten crabs in their native range have severely decreased because of a combination of water pollution, dams that block migration to rearing areas, and commercial harvesting. Aquaculture of *E. sinensis*, however, is flourishing in China, and aquaculture production of the mitten crab in China is valued at more than U.S. $1 billion (Hymanson et al. 1999).

The historic introduction of *Eriocheir spp.* into Europe demonstrates the potential long-term impacts on U.S. ecosystems. The Chinese mitten crab has become widely established on the European continent and is found, at varying levels of abundance, throughout most of western, central, and northern Europe. The first records of the crab's presence there are from the Aller River, Germany, in 1912, where it was probably introduced by ships' ballast water (Panning 1939). By the late 1930s, the crab became a serious pest in Germany. Mitten crabs caused damage to banks and levees through burrowing activities and to fishing operations through entanglement in nets and injury to netted fish (Panning 1939). *Eriocheir sinensis* has had a "boom and bust" population cycle in Germany, declining during the 1940s but rebounding in the 1950s, 1970s, and early 1980s (Gollasch 1999). The population has been on the rise again since the mid-1990s; in the spring of 1998, 850kg (750,000 individuals) were caught by hand in the river Elbe in just two hours (Gollasch 1999). These oscillations have also occurred in populations of *E. sinensis* in other European countries into which it has spread, including England, the Netherlands, and France (Hoestlandt 1948, Clark et. al 1998, Gollasch 1999).

Large annual population fluctuations of introduced mitten crabs have been observed in England. In the Thames River estuary a large increase in the relative population of mitten crabs, compared to historic levels, has been observed since 1992. Prior to 1992 the population had been relatively constant since the 1970s (Clark et al. 1998). The recent increase is believed by some to be due to improved mitten crab settlement coinciding with several years of drought (Atrill and Thomas 1996).

The Chinese mitten crab has also spread into Denmark, Sweden, Finland, Luxembourg, Poland, Austria, Czechoslovakia, and most recently in Portugal and the Seville area of Spain (Hoestlandt 1948, Haahtela 1963, Anonymous 1972, Ingle 1986, Jażdżewski and Konopacka 1993, Dhur and Massard 1995, Clark et al. 1998, Cabral and Costa 1999). In the Baltic countries, however, the population densities have remained quite low, possibly because the low salinity and/or low temperature of the Baltic Sea inhibit successful reproduction of the Chinese mitten crab (Rassmussen 1987). In all these countries, the most likely mechanisms of introduction have been cited as accidental importation through ballast water or spread to adjacent countries through connected streams or coastal waterways (Cohen and Carlton 1997).

2.5. Regulation of the Genus Eriocheir in U.S. Waters

Actions have been taken by the State of California to control the introduced mitten crab populations. Current California Department of Fish and Game regulations ban the possession and transport of live crabs from the genus *Eriocheir* (Section 671, Title 14). It is considered legal to catch a mitten crab in the inland waters of California with a hook and line if you possess a valid fishing license and immediately kill the crab after capture. There have been many reports that people are catching the crabs for human consumption and for use as bait (USFWS mitten crab database).

Regulations have been passed by other jurisdictions in an attempt to control mitten crabs. The genus *Eriocheir* is listed as an injurious species under the federal Lacey Act, which bans the importation and interstate transport of live crabs (USFWS 1989). The states of Oregon (OAR 635-056-0050, http://arcweb.sos.state.or.us/rules/OARS_600/OAR_635/635_056.html) and Washington (WAC 220-12-090, http://www.leg.wa.gov/WAC/index.cfm?section=220-12-090&fuseaction=section) also prohibit importation and possession of *Eriocheir*. The state of New York banned *Eriocheir sinensis* (Chinese mitten crab) in January 2003 to address the importation of mitten crabs into its jurisdiction (6NYCRR Part 44.8).

3. Scope of Impacts on the San Francisco Bay-Delta System

3.1. The Impacted Area

The Bay-Delta system is an enormous estuary that varies greatly in habitat type and resident species. Much of the historic Bay-Delta habitat has been destroyed or altered since European settlers first arrived in the 1800s. The bays of the system are connected to the Pacific Ocean through the Golden Gate. Shallow and deep bays combine to make up over 254,000 acres of this system, adjacent wetland and agricultural areas influenced directly by the bays total more than 262,000 acres (Monroe and Olofson 1990). The Sacramento - San Joaquin Delta (Delta) covers 738,000 acres drained by hundreds of miles of waterways. Most of the land encompassed by the Delta is below sea level and relies on more than 1,100 miles of levees for protection against flooding (SFEP 2003).

Freshwater streams that flow from the east pour into the bays, through Delta streams, and supply water for residential, commercial and wildlife use along the way. Water flowing through the Delta supplies drinking water to 20 million residents and is used to irrigate 4.5 million acres of farmland and ranches (SFEP 2003). Many migratory fish species also travel through Delta streams seasonally. Disruption of or damage to irrigation systems could have detrimental impacts to water supplies for residential, agricultural, industrial and wildlife use throughout California. The Bay-Delta system is unique, but many of the problems caused by mitten crabs in the Bay-Delta will threaten any estuary in which these non-native crabs establish.

3.2. Ecological Impacts

The established population of the mitten crab could change the structure of the food web and may reduce the abundance and growth rate of various species through competition and predation (Veldhuizen and Stanish 1999). Throughout the world, the mitten crab has broadly been described as an opportunistic omnivore (Panning 1939; Hoestlandt 1948; Vincent 1996). Panning's (1939) statement that mitten crabs "eat whatever they can get" is probably an accurate description of the plasticity of this crab's eating habits. Fishermen in the Bay-Delta have reported that they have experienced substantial bait-stealing by the mitten crab. Crabs will take bait ranging from dead fish and shellfish to worms and even plastic lures (USFWS mitten crab database). Gut content analyses conducted for populations of the crab in Asia, Europe, and the U.S., have shown a predominance of vegetative matter and a variety of benthic macroinvertebrates in the stomachs of mitten crabs (Thiel 1938 as cited in Hoestlandt 1948; Dan et al. 1984; Rogers 2000; Rudnick 2003). Recent analyses of the Bay-Delta population of the crabs has suggested that macroinvertebrates, algae, and detritus are all likely contributors to the mitten crab's diet (Rudnick 2003). Researchers have suggested that the crab shifts toward a more carnivorous diet as it ages, incorporating items such as shrimp and other benthic invertebrates into its diet (Tan et al. 1984; Vincent 1996; Zhao 1999).

The presence of large numbers of mitten crabs can threaten the existence of some species that reside in the Bay-Delta. As the Bay-Delta is home to a variety of endangered and threatened species, any potential ecosystem wide impacts are of great concern. In particular, there is concern about the impacts of the mitten crab on listed populations of Chinook salmon, steelhead trout, freshwater shrimp, clapper rails and frogs in Bay-Delta creeks, as the mitten crabs can constitute a substantial portion of the biomass in many areas inhabited by sensitive species.

Although it is unlikely that mitten crabs prey on healthy, free-swimming fish (Panning 1939; Rudnick 2003), Chinese mitten crabs will readily scavenge dead fish carcasses (Rudnick 2003). In a study of over 3000 crabs from Germany, fish material made up only 2.4% of gut contents analyzed (Thiel 1938 as sited in Panning 1939).

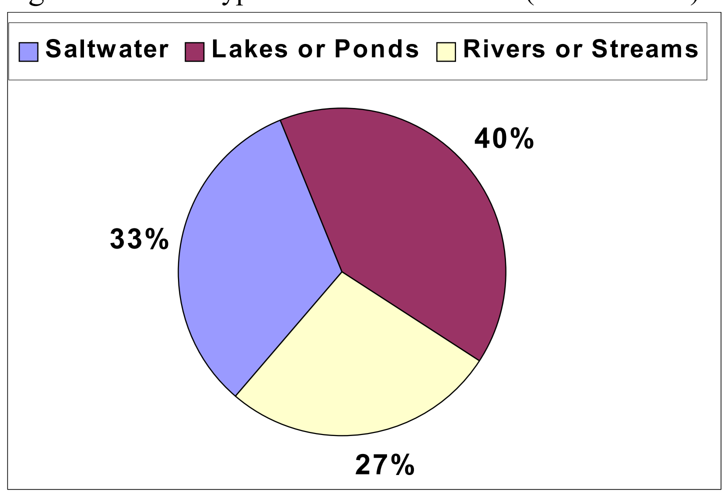
It is possible that mitten crabs prey on the eggs of fish and amphibians; however, their ability to detect and find eggs in the wild is as yet unknown. Crabs are reportedly occupying steelhead-spawning reaches in some Bay-Delta tributaries (Johnson 2001). Direct predation on eggs is a chief concern due to observations of the crabs feeding behavior in gravel streambeds (Johnson 2001).

Anecdotal reports suggest that the Chinese mitten crab has become prey for a wide variety of species in the San Francisco Bay ecosystem, including sturgeon, striped bass, catfish, bullfrogs, loons, raccoons, and egrets (Hoffmann 1999; Veldhuizen and Stanish 1999; Rudnick 2003). No research has been conducted to verify or quantify these reports; however, given the abundance of the crab and the diversity of potential predators, the introduction of the mitten crab may have food web impacts beyond what it itself consumes.

3.3. Fisheries Impacts

Recreational sport fishing is a large industry in California. Over 2.3 million people go fishing every year in California spending over $2 billion annually on fishing related expenses (USDOI et al. 2001). Freshwater fishing accounts for 67% of the total fishing in California (Figure 5). In the Sacramento - San Joaquin Delta region, fishing related jobs account for approximately 2.5% of regional employment (Goldman et al. 1998). The freshwater fishing industry throughout California and the resulting economic benefits are threatened by the presence of mitten crabs.

Figure 5. Water Types Fished in California (USDOI 2001).



The most widely reported impact from mitten crabs in California is the interference with recreational sport fishing through bait stealing (Hieb 1997, USFWS mitten crab database). Anglers often report having extreme difficulty with crabs when attempting to bait fish, especially during the fall and winter months. Many areas have been reported to be “unfishable” during periods of high mitten crab abundance. Fishing interference by mitten crabs results in damage to bait, gear and/or the catch. Many fishermen, in California, report abandoning traditional fishing areas to avoid such interference (Hieb 1998). Similar reports have been presented in the German literature after mitten crabs were introduced (Panning 1938).

The San Francisco Estuary and its tributaries also support large recreational and commercial fisheries for various crayfish and grass shrimp as shown in Table 1. Many commercial bay shrimp and crayfish fishers have reported large numbers of mitten crabs present in their nets and traps. Most mitten crabs are caught by fishing techniques, such as slow moving trawls, that capture benthic animals on the bottom of the water column (Rudnick and Resh 2002). Mitten crabs also feed on the same sources as commercially harvested crayfish, including the red swamp crayfish (*Procambarus clarkii*) and the signal crayfish (*Pacifasticus leniusculus*). Experiments have demonstrated that mitten crabs are superior competitors for shelter when compared to locally occurring crayfish (Rudnick et al. 2000). These findings imply that the mitten crab can significantly impact the shrimp, crayfish and other trawl harvested fisheries in the Bay-Delta and beyond.

Type of Fishery	Targeted Stock	Approximate Annual Retail Value (1998 Dollars)	*Approximate Annual Retail Value (2003 Dollars)
Commercial	San Francisco Crayfish	$750,000	**$847,550**
Commercial	San Francisco Grass shrimp	$1,500,000	**$1,695,090**
*2003 dollars computed based on historic inflation rate (USDOL 2003).			
Figures from CALFED Ecosystem Restoration Program Plan. CALFED Bay-Delta Program. 1998.			

Table 1. Approximate Annual Value of Select Species in the San Francisco Estuary and its Tributaries.

3.4. Fish Salvage Impacts

The most noticeable impacts of mitten crabs occur during their downstream migration in the fall. It is during this time that abundant crab migrations cause the most problems for water diversions, power plants and fisheries. State and Federal facilities pump and divert several million acre-feet of water from the Delta annually. In an effort to protect fisheries and endangered species, the facilities salvage migrating listed and other fish from the system before they reach the facilities turbines and transport them downstream in tanker trucks (Helfrich et al. 2000). Live crabs and their shells can interfere with fish passage, fish salvage and can clog screens, pipes and valves at salvage facilities (Cohen and Weinstein 2001).

In the fall of 1998 high numbers of migrating adult crabs caused severe problems for the fish salvage operations at the State and Federal water facilities in Tracy, California. In 1998 the combined daily crab count for the facilities peaked at 51,292 crabs per day in late September (Veldhuizen et al. 2001). At peak times during the 1998 fall migration period, fish mortality attributed to the crabs at the federal fish salvage facility was 98-99% (Siegfried 1998). Responding to this crab migration required research and development of control methods and increased facility operation costs. The estimated financial impact incurred at the fish salvage facilities that year amounted to over $1 million (White et al. 2000). The number of migrating crabs in 1998 contrasts sharply with the approximately 40-50 crabs collected in 1996 and approximately 16,000 crabs entrained at the federal facility in 1997 (White et al. 2000).

In abundant years migrating mitten crabs can overwhelm the fish salvage facilities, resulting in high fish mortality (White et al. 2000). Several of the anadromous fish species impacted by fish salvage operations are listed as threatened or endangered, under the Endangered Species Act (NOAA 2003). Without the ability to predict annual migrating populations of mitten crabs, salvage facilities are forced to choose between inefficiently expending resources or being unprepared for high mitten crab numbers and abundant fish losses.

3.5. Power Plant Impacts

During the 1997 mitten crab population increase, natural gas power plants in the Delta had intermittent problems with crabs clogging water intakes. Crabs can enter the cooling water intakes during their downstream migration, blocking the plumbing and drastically reducing water flows. Periodic back flushing is then required to prevent overheating of the systems (Hieb 1998). Similar problems will likely be faced by the extensive fish passages and water diversions in the Pacific Northwest, along the Hudson River and in other locations into which the mitten crab may be introduced.

3.6. Burrowing Impacts

As the San Francisco Estuary and tributaries rely heavily on levees for flood protection and water diversion, bank erosion caused by mitten crab burrowing is potentially very damaging (Figure 6). For 2001-2002 alone, California budgeted $23.3 million just to maintain levees (CA 2000). Crab burrows in levee banks and other areas have most likely contributed to bank slumping and erosion (Rudnick et al. 2000).

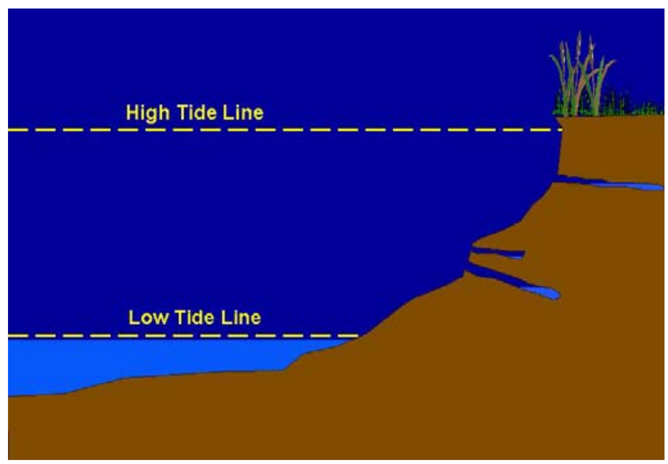


Figure 6. Mitten crab burrows are excavated to retain water during tidal fluctuations. (Diagram by CDFG).

The rate of burrowing and the effects of burrowing vary through the Bay-Delta (Rudnick 2003). Densities of juvenile mitten crabs in the Delta are generally far lower than those found in South San Francisco Bay tributaries (less than 1 burrow/m^2 in most Delta monitoring sites, versus 5 to 30 burrows/m^2 in South San Francisco Bay streams in the same time period) (Rudnick et al. 2003). This difference may arise from two major differences between these areas. A large amount of suitable habitat available to juvenile mitten crabs among the numerous small channels feeding North Bay marshes may lead to juvenile crabs being widely distributed. In addition the greater abundance of aquatic vegetation in shallow, open waters of the North Bay may provide an alternative refuge to burrows (Veldhuizen 2003).

Burrowing may pose the greatest risk in steep banked creeks, such as many creeks in Santa Clara County, California. Observations suggest that high rates of burrowing have been associated with areas of increased erosion and bank collapse in San Francisquito Creek, California (Johnson

2001). The tidal marsh and the mouth of San Francisquito Creek have experienced accelerated erosion in areas where mitten crabs created burrows in marsh sediments. Wave action during high tides subsequently resulted in the formation of sediment pillars. Over time wave action, combined with burrows, resulted in the vertical collapse of the marsh bank in blocks up to 3 m long. Renewed burrowing of the slumped banks, along with wave action, had been observed to result in the continual removal of marsh bank sediments (Phillips 2001).

It appears that damage to levees depends on crab densities, levee structure and bank suitability for burrowing (Veldhuizen and Stanish 1999). Burrowing by mitten crabs into stream and levee banks has been observed in densities up to 39 burrows per m^2 (Rudnick et al. 2003). The highest concentration of burrows has been consistently found in southern San Francisco Bay tributaries (Rudnick et al. 2000). Typically far fewer burrows are found in tributaries surrounding the northern San Francisco Bay, but this may not reflect abundance (Rudnick et al. 2003). Figures 7 and 8 are photos of burrowing and bank slumping in a southern San Francisco Bay tributary.

Figure 7. Burrows in the banks of San Francisquito Creek, California. (Photo provided by Jim Johnson, San Francisquito Watershed Council).

Figure 8. Mitten crab burrows may have accelerated the erosion of this bank on San Francisquito Creek, California. (Photo by Jim Johnson, San Francisquito Watershed Council).

3.7. Potential Agricultural Impacts

Mitten crabs may pose a threat to agriculture in California's Central Valley, since they have been known to feed on agricultural crops in other regions of the world. In China and Korea the crab was reported to damage rice crops by feeding on young rice shoots (Ng 1988). The Sacramento – San Joaquin Delta is located in the Central Valley of California, which is known for productive harvests of a variety of agriculture crops. Among the crops is a large rice industry located near Sacramento, well within the current extent of the mitten crab invasion. The value of this local crop, to the regional economy, is estimated to be $500 million annually (California Rice Commission 2001). There have not been any reports of significant negative impacts to the rice industry in California, but there are also no known investigations of this threat (CDFG 2001).

3.8. Potential Human Health Threats

The Asian Lung Fluke (*Paragonimus westermani*)

In medical literature, the mitten crab is cited as a human health concern as it has been reported to serve as the secondary host for the Asian lung fluke, *Paragonimus westermani* (Yang 2000). Symptoms of Asian lung fluke infection are typically tuberculosis-like. Mammals, including humans, are the final host of the lung fluke, with infection likely through the ingestion of raw or undercooked, infected, crab or transfer of the fluke by utensils contaminated by touching such crabs (USFWS 1989, Marquardt and Demaree 1985). There has been some controversy about the validity of reports that the mitten crab currently present in U.S. waters (*Eriocheir sinensis*) can serve as a host for the Asian lung fluke (Wang and Hess 2002). A study conducted in Seoul, Korea in 1991 positively confirmed the infection of 12% of mitten crabs (*Eriocheir japonicus*), for sale in a market, with the Asian lung fluke (Cho et al. 1991). As indicated previously, there is uncertainty about the validity of classifying *E. sinensis* and *E. japonicus* as distinct species. In other words the populations of mitten crabs present in U.S. waters are capable of serving as the secondary host for the Asian lung fluke.

While evidence suggests that the Chinese mitten crab (*E. sinensis*) can serve as a secondary host for the Asian lung fluke (Yang et al. 2000) no mitten crabs, infected with this parasite have been found in U.S. waters. A recent study by University of California researchers examined approximately 800 mitten crabs from locations throughout the Bay-Delta and its watersheds by 2001 and detected no Asian lung fluke infections (Dugan et al. 2002). The same study confirmed that the primary host for the Asian lung fluke has been found in U.S. waters. One species of snail (*Melanoides tuberculata*) that is a known primary host of the Asian lung fluke and two likely, but unconfirmed, host species have been found in Bay-Delta habitats that overlap with the Chinese mitten crab (Dugan et al. 2002). The potential for infection of humans by Asian lung fluke makes this topic an important concern, even if some controversy exists about the possibility of infection by mitten crabs in the Bay-Delta system.

Until a thorough evaluation can be completed California Department of Health Services (CDHS) recommend ingestion of the crab only if it is fully cooked and that special care be taken during preparation and handling of the crabs to prevent accidental release and ingestion of fluke cysts. They further warn that it is appropriate to assume the fluke is present in California as the vectors of introduction continue to be available (Loscutoff 2001).

<u>Bioaccumulation of Toxic Contaminants</u>

Mitten crabs may bioaccumulate contaminants since they are omnivorous scavengers and have been known to inhabit agricultural ditches and other areas, which may contain elevated contaminant levels (Veldhuizen and Stanish 1999). Preliminary results suggest that the mitten crabs may hyperaccumulate mercury (CDHS unpublished data), but these findings have yet to be evaluated. Research is currently being conducted in a joint effort between U.S. Fish and Wildlife Service, U.S. Geological Survey and University of California, Berkeley to determine if mitten crabs are actually capable of accumulating mercury at levels that would make them a toxic food source for humans or wildlife.

A small pilot study, conducted by the CDHS, found that mitten crabs were able to accumulate some potentially toxic contaminants, Arsenic, Selenium and DDE, in their body tissue but not to dangerous levels considered dangerous for human consumption (Table 2).

Table 2. Draft 1999 Contaminant Analysis Results and Caution and Action Levels.

Average Crab weight (g)	Viscera weight (g)	Vicera wt. / Crab wt.	As (ppm)	Se (mcg)	DDE (ppm)	Date Sampled
189.8	19.3	0.10	0.81	0.0141	2.12	10/26/99
180.4	19.8	0.11	0.69	0.0123	2.26	11/2/99
215.8	22.1	0.10	0.55	0.0146	1.61	11/15/99

ACTION, CONCERN AND RECOMMENDED LEVELS
FOR PARTICULAR CONTAMINANTS

- Arsenic level of concern = 86 ppm (USFDA 1993).
- Selenium recommended daily allowance = 70 mcg per day for an adult (PDARC, et al. 2000).
- USFDA action level (level of contamination at which a food item will be removed from market) for dichloroethenylidene (DDE) in fish = 5 ppm (USFDA 2000).

**Adapted from data provided by California Department of Health Services March, 2001 from a total sample size of 36 crabs.*

4. Developing a Plan to Address the Genus *Eriocheir*

4.1. History of the Management Plan Development

As the Bay-Delta mitten crab population increased, and the potential impacts became widely understood, the need for a comprehensive management plan became obvious. A chronology of the National management plan development follows:

The U.S. Bureau of Reclamation (USBR) hosts a meeting in Tracy, California: An interagency public meeting was held at the Tracy Fish Salvage Facility, in September of 1998. Prior to this meeting, many tours of the fish facilities were given to individuals and groups interested in the operational problems associated with mitten crabs. The media actively reported on the invasion and impacts.

The Interagency Ecological Program (IEP) forms technical teams: The IEP, which supports a broad interagency program of biological research and monitoring of the San Francisco Estuary and Delta, formed a Mitten Crab Project Work Team (PWT) by September of 1998.

- The PWT was divided up into several sub-teams including: Ecology, Levees, Public Health, Agriculture, and Fish Facilities.
- The sub-teams collaborated to produce a mitten crab informational outreach pamphlet.
- Meetings were open to the public and participation was strongly encouraged. All PWT meetings have remained open to the public.

The U.S. Fish and Wildlife Service and California Department of Fish and Game develop a reporting and outreach system: In 1998, USFWS and CDFG developed an educational outreach and reporting system to inform the public and track sightings of mitten crabs. Three components of this program included:

- A website where citizens could report sightings of mitten crabs.
- A message center that citizens could call to report sightings of mitten crabs.
- An online fact sheet of frequently asked mitten crab questions, with answers based on current scientific findings: http://www.delta.dfg.ca.gov/mittencrab/.

Other federal and state organizations address particular aspects of the mitten crab introduction: Several other agencies also took actions to address the ongoing spread of the Chinese mitten crab throughout the Bay-Delta system.

- U.S. Bureau of Reclamation (USBR) developed a website on the Chinese mitten crab, that is no longer functional.
- The USBR and California Department of Water Resources (DWR) developed draft management plans for fish salvage operations in cooperation with endangered species regulators that included; CDFG, U.S. Fish and Wildlife Service (USFWS), and the National Marine Fisheries Service (NMFS).
- USFWS coordinated the September 1998 PWT meeting and a March 1999 Mitten Crab Workshop. USFWS also supported a literature search and report, which was distributed at the Mitten Crab Workshop and is accessible on the ANSTF website http://www.anstaskforce.gov/.

<u>A public workshop is held with stakeholders and technical experts</u>: All of the previous organizational actions culminated in a public workshop co-sponsored by USFWS, the San Francisco Estuary Project, the University of California, Davis Cooperative Extension and the Western Regional Panel on Aquatic Nuisance Species on March 23, 1999 in Sacramento, California. The goals of the workshop were to:

- Provide current information about the mitten crab, management issues and ongoing concerns
- Develop cooperative working relationships
- Identify specific needs
- Make recommendations for action and tasks

Approximately 125 individuals representing diverse organizations and interests including agencies, academia, legislators, environmental groups, exporters, commercial fisherman, regulators, animal rights groups and other stakeholders attended this public workshop. The first part of the day was used to provide current information on the many areas of concern and interest that were necessary to formulate management plan goals and objectives. Technical experts, familiar with the introduction of mitten crabs into Germany (Appendix E), England (Appendix F) and California gave presentations to workshop participants.

The second part of the day was spent in focus groups in an effort to develop detailed information for inclusion in a National Management Plan. The groups were:

- Preventing the spread of mitten crabs.
- Detection and monitoring new and existing populations.
- Reducing environmental and economic impacts.
- Controlling the existing U.S. population of mitten crabs.

These discussions formed the foundation of the cooperative effort to develop the initial 1999 draft National Management Plan. The draft plan highlighted:

- The issues, conclusions and recommendations that came out of the USBR's September 1998 public meeting.
- The information contained in the literature review report.
- The Interagency Ecological Program PWT recommendations and findings from the March 1999 workshop.

An outline of the Workshop Recommendations, along with a list of organizations and individuals represented at the workshop is presented in Appendix B.

The draft management plan was presented to the National Aquatic Nuisance Species Task Force (ANSTF) in August 1999. In the spring of 2001, the ANSTF completed the formation of the Chinese Mitten Crab Control Committee (CMCCC), as provided for under the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (NANPCA). The Committee was formed from a diverse membership that has worked together to review and edit the original draft National Management Plan to better meet the needs of this evolving issue. Appendix C lists the invited CMCCC participants. Due to restructuring of ANSTF committees, the management plan groups are now called "Working Groups", so the official title of the former CMCCC is now the Chinese Mitten Crab Working Group (CMCWG). The NANPCA requires that all National Management Plans be submitted for public review prior to final adoption by the ANSTF. The public comment period for this plan closed on March 31, 2003.

4.2. Management Plan Goals

"To prevent or delay the spread of *Eriocheir* species (mitten crabs) to new areas and to reduce the negative impacts of the existing *Eriocheir* populations in U.S. waters."

These goals will require action in the Bay-Delta region in a complex array of biological, economic and political issues. Complexity will arise from regional activities and characteristics including; the presence of numerous endangered and threatened species; an extensive ecosystem restoration effort headed by the CALFED Program; an increasing human population, and a water diversion system that provides irrigation water for over 4.5 million acres of farm land and drinking water for over 20 million California residents.

The management efforts of stakeholders in the Bay-Delta cannot be directed by any single entity. Actions that successfully realize the management plan's goals will, of necessity, be sensitive to the many restrictions placed on specific actions, and the necessity for inter-organizational collaboration. All management actions should be guided by the unique characteristics of the Bay-Delta system including the needs to: protect endangered species, provide adequate water for human use, protect water quality and to minimize impacts to the environment.

4.3. Management Objectives

The Mitten Crab Working Group derived five primary objectives from the management plan goals. These primary objectives are:

1. To prevent new introductions and spread of mitten crabs in U.S. waters.
2. To develop methods of detecting new populations of mitten crabs in areas where they are not currently present.
3. To monitor existing mitten crab populations.
4. To reduce the negative impacts of existing populations.
5. To develop strategies and methods to control and manage existing populations.

Actions to address the introduction of the genus *Eriocheir* to U.S. waters have been prioritized based on the extent to which actions fulfill the management plan objectives. In some cases action items were assigned a priority status based on special circumstances such as the risk to human health or the time required for implementation. Elements of research, analysis of findings, educational outreach and implementation of management actions should be combined to fulfill each of these objectives.

4.4. Problem Definition Conceptual Model Summary

Problem Definition:
Defining the problems associated with the mitten crab introduction was conducted in a manner consistent with the development of other national management plans. To help define the problem elements, the Ecological Risk Assessment Guidelines (US EPA 1998) and the Generic Nonindigenous Aquatic Organisms Risk Analysis Review (ANSTF 1996) were used to develop the following conceptual model. This model shows how mitten crabs may impact various economic and environmental resources and the ways in which we may detect those impacts (Figure 9).

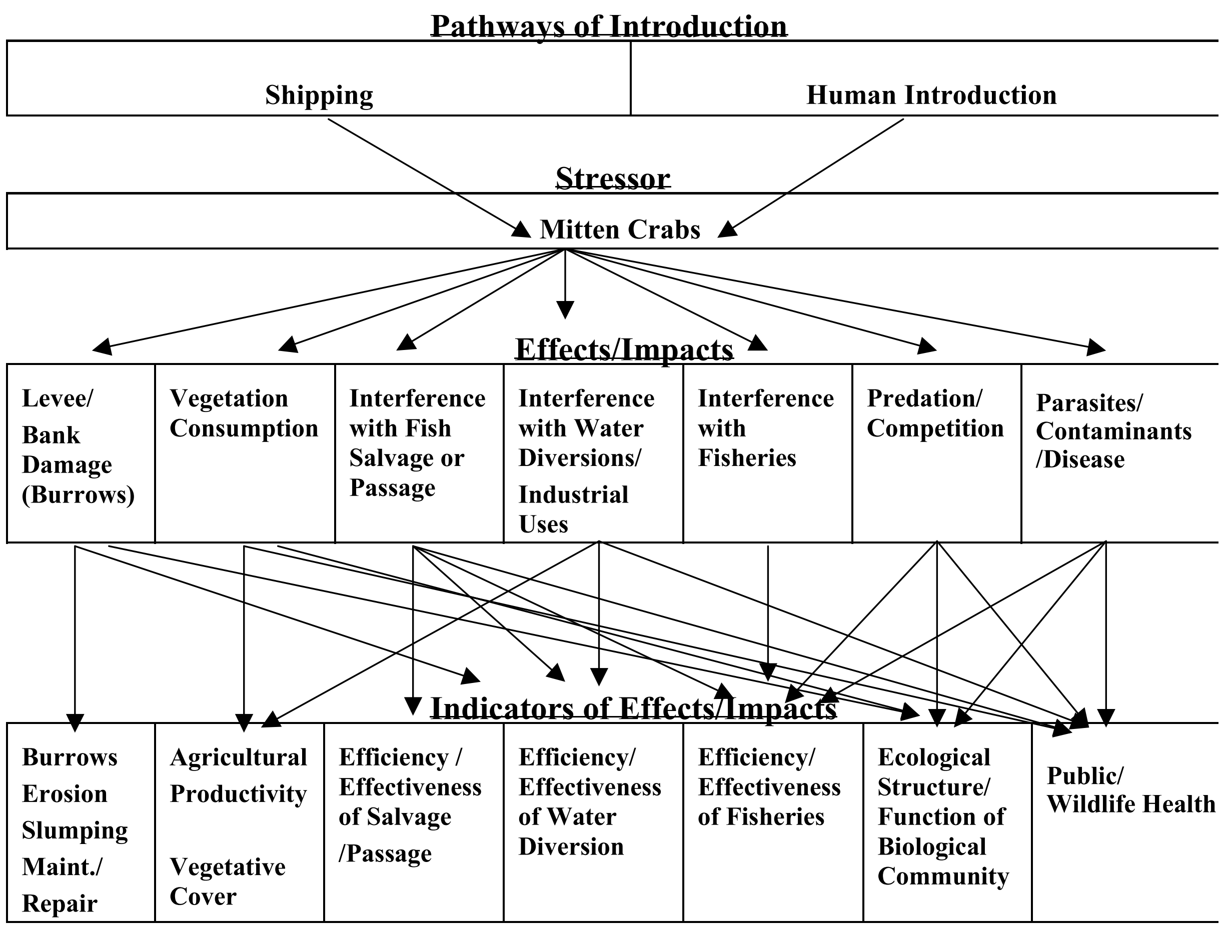


Figure 9. Conceptual model of the causes and results of the introduction of mitten crabs to U.S. waters.

Pathways of Introduction:

Processes associated with shipping and intentional or accidental introduction are a likely source of the mitten crabs populations in the Bay-Delta system. Shipping is believed to be the introduction mechanism of mitten crabs to several other regions as well. Ballast water release is suspected as the primary shipping pathway for crabs introduced to Germany, England, Lake Erie and the Mississippi River (Ingle 1986, Peters and Panning 1933, Panning 1939, Nepszy and Leach 1973 as cited in Veldhuizen and Stanish, 1999) though it is not clear what particular life stages may have been transported. It is also possible that hull fouling may have contributed to mitten crab introductions (Gollasch 1999).

Ballast water release is a possible pathway for the introduction of all life stages of mitten crab. Taking on ballast water is a process that is currently an essential part of normal commercial shipping operations. Ships take up water in order to stabilize the vessel. Depending on variations in ship sizes, routes, and loads, the amount of ballast water taken up may be millions of gallons per ship. In the process of pumping this water into the large tanks of the ship, many living organisms can also be taken into the ballast tanks. These organisms are often capable of surviving long voyages and the subsequent release of the ballast water at a new location. A recent ballast water survey on the U.S. West Coast, by the Smithsonian Environmental Research Center, documented the transport of 13 species of crustaceans in ballast water and live adult crabs in ballast tank sediment (Hines and Ruiz 2000). Clearly ballast water exchange is a potential transport vector for estuaries, particularly for short voyages, along the U.S. West Coast (McDowell 2003).

Figure 10. Customs agents seized these live mitten crabs, in carry –on luggage, at San Francisco International Airport. (Photo provided by Marc Gilkey, USDA.)

Accidental or intentional human introduction is also a likely vector for the establishment of new mitten crab populations. The value of the mitten crab as a food item provides an economic incentive for individuals and commercial entities to establish crab populations that can support a fishery. The mitten crab is a highly valued food item in China and other Asian countries. Peaks in demand for mitten crabs are seasonal with increased activity between October and February when the most sought after crabs, females with ripe ovaries, are available. Mitten crabs have been found in carry-on luggage at Seattle, Los Angeles, and San Francisco airports (figure 10) and have been intercepted as illegal, live imports to markets in Los Angeles, New York and San Francisco (Cohen and Carlton 1997, Jung 1999). There is interest in establishing both commercial fisheries and aquaculture production of the mitten crab to meet the latent demand for this valued food item (CFGC 1999). Due to these financial incentives it is widely hypothesized that intentional releases of crabs into Bay-Delta have occurred in an effort to establish a harvestable population (Cohen and Carlton 1995, Rudnick et al. 2000).

Proactive measures have been implemented to help prevent the introduction of mitten crabs and other non-native invasive species into waters of the U.S. via ballast water transport. Under the NANPCA and the 1996 reauthorization, the Nonindigenous Invasive Species Act (NISA), the U.S. Coast Guard has been charged with developing and implementing restrictions on ballast water releases. Some states, including California, Oregon and Washington, have independently instituted regulatory programs to address this pathway. Research is underway to investigate possible ballast water treatment methods that may afford greater protection than the current best management practice, which is open ocean exchange of ballast water.

Efforts are underway to reduce the risk of human introductions of the mitten crab. For example, in July of 1999, aquaculturalists in some southern states reported being contacted by Chinese businesses that market live mitten crabs. These Chinese businesses attempted to recruit U.S. aquaculturalists to rear Chinese mitten crabs in the U.S. As a result, the ANSTF sent letters to State Directors advising them of the illegal nature of live mitten crab imports under the Lacey Act. As recently as July 2003 the USFWS has been contacted with informational requests regarding aquaculture of mitten crabs in U.S. waters.

In September 1999, information was provided to USFWS port inspectors regarding the possibility of live mitten crab imports during the approaching fall season. USFWS law enforcement officials researched import data to identify import trends and prepared outreach materials describing the mitten crab. These materials were distributed to Food and Drug Administration inspectors and all USFWS designated ports of entry. In October, USFWS law enforcement personnel in New York intercepted five commercial shipments of live mitten crabs (5,570 crabs valued at approximately $111,000.00). These shipments were refused entry into the U.S. and re-exported to their country of origin. USFWS law enforcement personnel continued to monitor imports into New York during the fall months of 2000, but did not intercept any commercial shipment of live mitten crabs. Then, in November 2001, two commercial shipments were intercepted as they came into New York. In July of 2002 a fish importer was arrested in New York and charged with importing a shipment of 1,350 undeclared mitten crabs (DeStefano 2002). The fish importer in this 2002 New York case has been convicted and sentenced to three months in federal prison, three months house arrest and three years probation for illegal the importation of these crabs. The convicted importer has also been fined $3,000. Figure 11 shows the crabs seized in the 2002 New York smuggling case.

Figure 11. Boxes of crabs seized in the 2002 New York mitten crab smuggling case. (Photo by USFWS)

4.5. Measuring the Impacts of the Genus *Eriocheir*

Measuring the impacts of the mitten crab population in the Bay-Delta involves comparison of pre-invasion data with information collected following introduction of the mitten crab. Documentation of post-invasion changes should occur for any potential impacts to ecological, economic, or other resources of concern, and needs to account for other factors that may contribute to those changes. In some cases, a lack of pre-invasion data may require indirect means of measurement. Specific indicators that can help measure environmental and economic impacts include:

1) Quantity, distribution and quality of burrowing (concentration, depth, design, and structure).
2) Changes in the condition of recreational and commercial fisheries.
3) Distribution and abundance of fish and wildlife populations.
4) Annual changes in water diversion efficiency.
5) Changes in flooding, levee failure, bank slumping, and bank maintenance.
6) Changes in survival of fish at salvage and passage operations, due to incidental mitten crab entrainment.
7) Quantity and distribution of damage to agricultural crops and aquatic vegetation.
8) Health indicators for the public, fish and wildlife (incidence of infection by host parasites, evidence of predation, etc.).

5. Implementation

Development and implementation of this National Management Plan must proceed as a cooperative intergovernmental initiative with participation from academia, commercial industries, stakeholders, agencies and other interested parties.

Implementation of actions will occur in phases, with all activities being continually evaluated at each phase to ensure that only actions which have been thoroughly evaluated will be implemented on a broad scale. Actions will initially be implemented as experiments with *a priori* monitoring and planning. Careful monitoring and analysis of the results of experiments will permit ongoing refinement of control methodologies. Successful adaptive management must follow a rational, systematic progression of understanding and management. Figure 11 shows how adaptive management can be applied to control the introduced mitten crab populations.

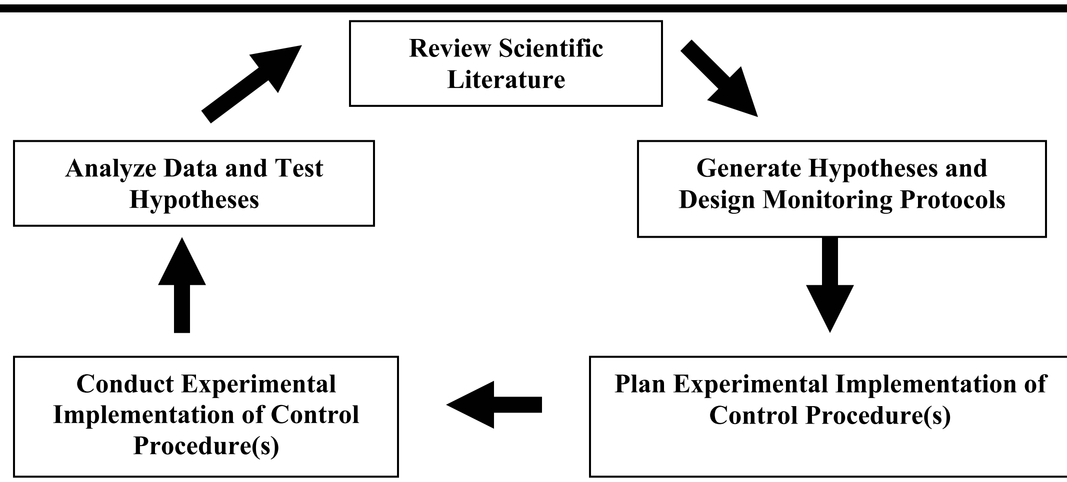


Figure 12. Using strategic adaptive management to control the mitten crab. (Adapted from Ralph and Poole 2002).

Implementation Outline

Actions and tasks have been developed, based on the management plan objectives, and prioritized for implementation in phases. It is anticipated that the timeframe for each phase of the implementation outline will be for an estimated five-year period, depending on the availability of resources, the tasks required and the cumulative, ever increasing understanding.

Specific actions have been classified as primary priorities, secondary priorities or tertiary priorities depending on the urgency for implementation of each action. Matrices, indicating how well each action addresses the management objectives, are followed by detailed summaries of the actions. Procedures to integrate the actions and tasks is further developed and explained in the summaries that follow.

5.1. Primary Priority Actions For Phase I Implementation (years 1-5)

Value in Achieving Management Objective						
	Highest Priority Action Item	Prevent introduction and spread	Detect new populations	Monitor existing population	Reduce negative impacts	Develop methods for population control
Prevention	Develop rapid response plan	high	low	low	high	high
	Develop BMPs for commercial crab industry	high	high	high	high	high
	Educational Outreach to Stakeholders					
	Develop training program for enforcement officers	high	medium	high	high	low
	Support dev. of regulations for high risk states	*high	low	low	high	low
Early Detection	Establish early detection networks	high	high	high	high	low
	Develop & refine detection strategies	high	high	high	high	high
Research	Control strategies	high	medium	medium	high	high
	Crab behavior	high	medium	high	high	high
	Env. tolerance and preferences	high	high	high	medium	high
	Migratory behavior	high	low	high	medium	high
	Recruitment dynamics	high	high	high	low	high
	Reproduction	low	high	high	high	high
	Bounty and harvest programs	low	high	high	high	high
	*Impact on eggs of sensitive fish sp.	low	low	medium	*high	low
	Impact on levees and banks	low	medium	medium	*high	low
	*Public health	low	low	low	*high	low
	#Risk assessment, vulnerability analysis	low	low	low	medium	medium
*Due to the high value of this aspect the item is a high priority.						
#Due to the long implementation time this item is a high priority.						

Table 3. Primary Priority Actions for Phase I of Implementation (years 1-5).

Primary Priority Actions for Phase I Implementation (years 1-5, continued)

Value in Achieving Management Objective							
	Highest Priority Action Item	Prevent introduction and spread	Detect new populations	Monitor existing population	Reduce negative impacts	Develop methods for population control
Providing Information & Education	Identification and early detection materials	high	high	high	high	low
	Identify management partnerships	high	high	high	high	high
	Appoint media contact person	low	low	low	*high	*high
	Distribute health education materials, if crab is found to be a risk	low	medium	medium	*high	low
	Clarify possible APHIS regulation of crab	low	low	low	?	*high
	Hold educational workshop	high	high	high	high	low
*Due to the high value of this aspect the item is a high priority.						

Table 3. Primary Priority Actions for Phase I of Implementation (continued).

<u>Primary Priority Actions to Prevent the Introduction of Mitten Crabs to U.S. Waters</u>

1) Develop Rapid Response Plan to address new introductions.

2) Develop prevention education materials and best management practices (BMPs) for distribution to organizations involved in possessing or transporting live crabs (ie. fishers, restaurants, live markets, shipping firms, etc.)

   a. Investigate details of black market importation, sales and other pathways of introduction

   b. Prevention materials should describe import and interstate transport as illegal, under the Lacey Act and some state regulations, and highlight the risks involved

   c. Materials will be provided in a variety of languages, such as Hmong, Chinese, Korean, Japanese, Vietnamese, Laotian and Cambodian

3) Coordinate outreach to stakeholder organizations to prevent accidental or intentional spread of mitten crabs between U.S. waters.

4) Develop and implement a training and education of law enforcement personnel

   -Develop programs for state and federal law enforcement officers in areas mitten crabs are present or likely to be present in the future.

5) Support development of model regulations for high-risk states to regulate Chinese mitten crab possession and transport.

  -Coordinate and integrate state and federal regulations regarding the interstate transfer of mitten crabs so they are complementary and maximize protection against accidental or intentional transfer.

<u>Primary Priority Actions for Early Detection of New Populations</u>

1) Establish early detection networks to detect new populations, monitor status and detect the spread of existing populations (networks may consist of: fish passage and hydropower facilities, watershed groups, volunteers, residents, anglers, farmers, civil servants, etc.)

  a. High risk and high priority areas should be addressed first (designated based on previous sightings of crabs and the presence of vectors, i.e. Bay-Delta Estuary and other tributaries close to the Bay-Delta, the Columbia River, Yaquina Bay, the Hudson River, the St. Lawrence River and the Mississippi River).

  b. Secondarily, other estuarine waters of the United States that may be capable of supporting mitten crab populations should be monitored.

2) Develop and refine early detection strategies.

<u>Primary Priorities for Research and Development of Management Options</u>

1) Control Strategies, including a foreign literature search
  a) Physical controls
    -Capture methods
    -Traps/Sinks
    -Trawls
    -Barriers; electric, physical and others
  b) Bounty and harvest programs
    -Examine life history characteristics to determine species susceptibility
    -Evaluate feasibility with population modeling
    -Evaluate possibility that these programs will promote translocation
    -Evaluate social, economic and practical feasibility

2) Crab behavior
    -Burrowing behavior
    -Feeding behavior

3) Environmental tolerances and preferences

4) Migratory behavior
    -Cues and timing
    -Substrate preferences
    -Hydrological conditions

5) Recruitment dynamics
    -Cues and timing
    -Survival
    -Locations
    -Hydraulic conditions

6) Reproduction
    -Spawning period and frequency
    -Fecundity
    -Reproductive behavior

7) Impacts by predation on eggs and larvae, especially salmonids, sturgeon, delta smelt and other sensitive species

8) Impacts via levee and bank damage

- -Burrowing: density, morphology, bank collapse, sediment removal rates, bank angle, and variance with sediment type

9) Public health and wildlife health impacts

- -Contaminants
- -Bioaccumulation of toxins
- -Lung fluke
- -Other parasite or disease transfer

10) Risk Assessment and vulnerability analysis

a) Assess and analyze watersheds and facilities around coastal US for susceptibility to mitten crab colonization and the potentially resulting ecological or economic impacts

- -Identify watersheds unlikely to be colonized
- -Rank remaining watersheds as high, medium, or low colonization potential
- -Identify possible transportation vectors
- -List threatened and endangered species most threatened in high risk areas
- -Determine and list facilities that may be impacted

<u>Primary Priorities for Information and Educational Outreach</u>

1) Develop and distribute identification and outreach materials to support detection efforts in areas at high risk for introduction.

2) Develop and identify partnerships for monitoring, outreach, education, primary research and management option development.

3) Appoint media contact person to handle media requests, address incorrect media reports and develop a mitten crab fact sheet.

4) If crab is determined to represent a public health risk, develop/distribute materials in California and other population centers likely to be at risk detailing public health risks and preventive measures.

5) Investigate whether or not the crabs could be listed as a plant pest under APHIS authority (i.e. rice fields, impeding water movement).

6) Hold workshop to share and explore various capture techniques, methods and approaches.

5.2. Secondary Priority Actions For Phase I Implementation

	Value in Achieving Management Objectives					
	Secondary Priority Action Item	Prevent introduction and spread	Detect new populations	Monitor existing population	Reduce negative impacts	Develop methods for population control
Prevention	Encourage at risk areas to evaluate ballasting operations	?	low	low	?	low
Research	Biological controls	medium	low	low	high	high
	*Impact on native biotic community	low	medium	medium	high	high
	*Impacts on agriculture and fisheries	low	medium	medium	high	high
	*Develop monitoring and data collection protocol	high	high	high	low	low
Providing Information & Education	If found to be a public health risk, then develop educational materials	low	medium	medium	high	low
	*Adaptive management, plan implementation, plan revision	high	high	high	high	high
*Dut to implementation time this item is a secondary priority.						

Table 4. Secondary Priority Actions for Phase I of Implementation.

Secondary Priorities Research and Development of Management Options

1) Control strategies, including a foreign literature search
    a) Biological controls - identify potential control agents
        -Predators
        -Pathogens
        -Parasites

2) Negative impacts to:
    a) Native biotic community
        -Prey and dietary shifts with age
        -Competition with other species
        -Parasite and disease transfer
        -Habitat alteration
        -Bioaccumulation of toxins and role in biomagnification
    b) Agriculture, aquaculture, industry and fisheries
        -Damage to crops
        -Disruption of irrigation
        -Impact on commercial Fisheries
        -Impact on recreational Fisheries
        -Disruption of industrial water uses

3) Develop a model monitoring protocol, data collection, and documentation procedures for all mitten crab prevention and control efforts nationwide

Secondary Priorities for Information and Educational Outreach

1) Encourage all areas at risk to evaluate local ballasting operations to determine if hazardous practices occur and to determine if alternative actions may be feasible.
    a) Adaptive Management
        -Form a coordination committee to facilitate implementation of the Control Plan
        -Plan Evaluation and Revision
        -Public workshop to review results of annual work
        -Develop recommendations for Plan adaptations
        -Distribute drafts for review and comment

2) Submit recommended Plan revisions to ANS Task Force

5.3. Tertiary Priority Actions For Phase I Implementation

	Value in Achieving Management Objective					
Tertiary Priority Action Item	Secondary Priority Action Item	Prevent introduction and spread	Detect new populations	Monitor existing population	Reduce negative impacts	Develop methods for population control
Research	*Physiological controls	high	low	low	high	high
Providing Information & Education	#Establish a database for monitoring, education and research	low	high	high	low	low
*Dut to high development cost and uncertainty of results, this item is a tertiary priority.						
#Due to implementation time this item is a tertiary priority.						

Table 5. Tertiary Priority Actions for Phase I of Implementation.

<u>Tertiary Priorities for Research and Development of Management Options</u>
1) Control strategies, including a foreign literature search
   d) Physiological controls
      -Chemical inhibitors
      -Chemical disruptors

<u>Tertiary priorities for Information and Educational Outreach</u>
1) Establish a database for mitten crab monitoring, education and research.

5.4. Actions For Phase II Implementation (years 6-10)

A. Prevent the Spread of Mitten Crabs in U.S. Waters

Conduct educational outreach to prevent the further spread of mitten crabs via suspected vectors.

B. Early Detection

Continue to expand and enhance early detection networks.

C. Research and Development

Implement exclusionary measures by physical control methods (such as traps, sinks, and electrical barriers) as experimental tests.

D. Information and Education

Develop outreach and education program for other areas at risk

E. Evaluate Control Strategies

1) Identify enforcement, compliance and monitoring costs for exclusion program.

2) Implement control programs based on the results of evaluations.

F. Adaptive Management

5.5. Actions For Phase III: Implementation (years 10-15)

A. Prevent the Spread of Mitten Crabs in U.S. Waters

Continue educational outreach with updated information on best practices to prevent the spread of mitten crabs.

B. Early Detection

Continue to enhance early detection networks.

C. Research and Development

Using adaptive management, determine efficiencies of exclusionary program and test other methods.

D. Information and Education

Continue education and outreach programs.

E. Development and Implementation of Control Strategies

Test and implement other methods of control as appropriate.

F. Evaluate Implementation and Results

Use adaptive management to evaluate impacts of the actions implemented on an annual basis. Incorporate lessons learned into future work plan.

5.6. Implementation Summary

Successful implementation of this management plan will entail the coordination and integration of management actions and findings by many stakeholders. In most cases, recommended management actions are directly tied to specific research questions. Successful management of the genus *Eriocheir* will necessitate information sharing and management coordination between organizations as findings from ongoing research become available. This section will provide more detailed summaries of the recommendations for mitten crab management in U.S. waters.

Prevention of Spread

Due to the difficulty of finding and controlling mitten crabs once they are introduced, prevention of new introductions is essential for control. To be successful in preventing new introductions both intentional and accidental introductions must be addressed. The ongoing activities of U.S. Customs agents and state fish and game managers are useful in reducing the threat from intentional introductions of mitten crabs to new estuaries in the U.S. The effectiveness of these programs may be more difficult now since elevated national security concerns have resulted in federal reorganization and creation of the Department of Homeland Security and may shift substantial USDA resources away from focusing on illegal species importation, including mitten crabs.

The potential spread of mitten crabs via ballast water continues to be a priority that has not been adequately addressed. The release of ballast water into U.S. ports could result in further introductions of the genus *Eriocheir* members. Ships arriving from high-risk European waters pose a particular threat for the introduction of Chinese mitten crabs (*E. sinensis*) since the European populations are currently healthier then wild Chinese populations (Veldhuizen 2003a). Ballast water in ships arriving from Japan may also act as vectors for introduction of Japanese mitten crabs (*E. japonica*), which still exist as wild populations (Veldhuizen 2003a). In addition to the transoceanic pathways, the coastal transport of ballast water poses a high risk of dispersal on the West Coast of the U.S., since the only documented population of mitten crabs on the West Coast is located in the Bay-Delta. In addition, shorter travel times for coastwise traffic result in lower mortality of organisms within the ballast tanks.

The transoceanic ballast water vector is currently being addressed by the U.S. Coast Guard (USCG). The USCG published, for public comment, a proposed rule for a Mandatory Ballast Water Management Program on July 30, 2003 (68 FR 44691). This program will require ballast water management practices for all vessels equipped with ballast tanks bound for ports or places within the U.S. (USCG 2003). It is expected that the U.S. Coast Guard will publish a final rule some time in 2004. Mandatory ballast water exchange programs for transoceanic traffic exist in the Great Lakes Region and in the states of California, Oregon, and Washington (McDowell 2003). The U.S. Coast Guard is currently working on developing a verification technique to determine whether a proper open ocean ballast water exchange has been conducted. The final development of an effective verification tool will be to increase the ability for agencies to enforce ballast water exchange regulations. In order for ballasting regulations to be effective, these programs must include a strong inspection, monitoring, and enforcement program (McDowell 2003).

The coastal transport of ballast water has been a more difficult pathway to manage due to the complexity of applying open ocean ballast water exchange (the only approved management tool) to coastal voyages. This poses a particular concern on the U.S. West Coast, where shorter travel times, hence lower mortality within the ballast tanks, can increase the risk of spreading the mitten crab from the Bay-Delta, to other estuaries along the coast. Close coordination between regional organizations will be needed to address the spread of mitten crabs from the Bay-Delta to other West Coast estuaries.

One strategy, to manage West Coast ballast water vector, is to have a mandatory coastal ballast exchange program. The states of Washington and Oregon have already implemented coastal exchange programs, but the programs are new and may not have adequate funding for inspection and monitoring (McDowell 2003). Washington's ballast exchange law currently requires that coastal vessels exchange ballast water 50 miles offshore (Anderson 2003). Washington and Oregon are currently working with California and other organizations to strengthen their programs and to make them consistent along the West Coast (McDowell 2003).

On September 24, 2003, the Marine Invasive Species Act (MISA, Assembly Bill 433) was enacted into California law until January 1, 2010. MISA modified and extended Assembly Bill 703 (AB703), which would sunset on January 1, 2004. MISA reauthorizes many of the provisions in AB703, but also addresses coastal exchange requirements for the Pacific Coast Region for vessels arriving in a California port.

Another potential management strategy is to establish "No Ballast Zones" during times where there are high larval crab abundances in the Bay-Delta. It will likely be difficult to establish, "No Ballast Zones" along the West Coast of North America. A monitoring project would have to be established to determine distribution and timing of high larval crab abundances in the Bay-Delta. Assuring compliance might be difficult since many vessels would have to completely cease operations if they are unable to take on ballast water at the port where they are unloading their cargo. An alternative is to require ships in the "No Ballast Zones" to adequately treat the high-risk water before releasing it into different areas. At this time, however, there are no approved ballast water treatment options currently available. Although experimental treatments might be available in the near future, it will be many years before treatment systems are approved, regulatory programs are implemented, and treatment systems are installed on all vessels (McDowell 2003).

The development and implementation of a strong ballast water management program for coastal traffic will significantly reduce the risk of mitten crabs spreading along the West Coast. In the short term that will involve further development of coastal exchange regulations, and the incorporation of other management tools such as "No Ballast Zones." In the long term, transoceanic and coastal ballast water vectors will not be adequately addressed until reliable methods are developed to treat ballast water regardless of its origin (McDowell 2003).

Early Detection and Rapid Response

Reports of mitten crab sightings, from several regions of the U.S., highlight the need for early detection of new mitten crab introductions. Early detection of new mitten crab populations in U.S. waters has been designated as a high priority because it affords decision makers the maximum time to address a new introduction. Successful implementation of early detection networks will be enhanced by the development of efficient protocols for sampling and detection of mitten crabs, even at low population levels. Early detection efforts will also hinge upon the dissemination of current information, ongoing educational outreach and coordination between affected organizations.

The early detection component of this management plan began with a pilot program to develop an early detection network on the lower Columbia River. The Columbia River was selected because many biologists believe that this River is a highly likely location for a new mitten crab introduction (Heimowitz et al., appendix E.1). Implementation of the lower Columbia River detection network began in 2000, informed by findings from the Bay-Delta introduction. The Aquatic Nuisance Species Coordinator has administered the lower Columbia River mitten crab program for the Pacific States Marine Fisheries Commission (PSMFC) with coordination provided by Portland State University (PSU).

The lower Columbia River program, with funding support from USFWS and Oregon State University Extension Sea Grant, enables residents and tourists to identify and report any mitten crabs that are present in the lower Columbia River. An educational video titled "You Ought to Tell Somebody – Dealing with Aquatic Invasive Species" was developed by the Pacific Northwest Marine Invasive Species Team (MIST) to educate the public about how to detect and report mitten crabs in the lower Columbia River. A wallet sized identification card developed with support from the Service, PSMFC and Bonneville Power Administration (BPA) serves as another valuable early detection tool. Riverside residents have begun a limited trapping program by deploying artificial substrates and baited crayfish traps.

A rapid response plan (RRP) is needed in the event that a small mitten crab population is detected and it is determined that eradication is feasible. Initial work on a RRP for mitten crabs in the Columbia River has begun at Portland State University. The detection network and RRP, when completed, can serve as models for other areas of the U.S. at high risk for introduction.

The Western Regional Panel of the ANSTF created a "Model Rapid Response Plan for Aquatic Nuisance Species" that includes the following sections (WRPANS 2003):

1) **Define leadership**
2) **Coordination among parties in any response**
3) **Sources of funding and resources**
4) **Quarantine procedures**
5) **Regulatory compliance**
6) **Educational outreach**
7) **Surveys and mapping**
8) **Review of species biology and controls**
9) **Methods for implementation of eradication**
10) **Assessment of treatment**
11) **Monitoring**
12) **Ecological restoration**

The model plan template is available and can be modified for a geographic region or particular species as needed (http://answest.fws.gov/).

Research and Model Development

Understanding of introduced mitten crabs has advanced through research conducted on several general aspects of mitten crab ecology and behavior. These aspects of research and development are listed in the implementation section above. Current research needs include refining the understanding of life history, developing control strategies, quantifying ecological and economic impacts, refining monitoring protocols, and risk assessment.

Initial studies have been completed on many aspects of the U.S. mitten crab population's life history. Other important questions are still being investigated, such as:

- USBR provided support to the CDFG to do a preliminary investigation of crab behavior and movement during migration using telemetry, results are still pending.
- With funding from USFWS, University of California at Santa Barbara (UCSB) investigators conducted a pilot study in 2001 to examine possible locations for assessing larval settlement (Culver and Walter 2002). They found that mitten crabs in South Bay settled in low salinity areas (<5ppt) at the upper reaches of the tidally influenced zone, albeit their numbers were quite low. They also found that settlement was significantly influenced by environmental factors. As has been proposed for mitten crab populations in other regions, strong year classes appear likely to occur in years of low precipitation, while weak year classes will occur in years of high precipitation. Research is ongoing to confirm the annual timing and abundance of mitten crab settlement.
- USFWS is conducting ongoing research into the habitat associations of mitten crabs in tributaries, which drain into the San Francisco Bay.
- Other researchers are conducting a variety of other studies of mitten crabs.

Many of the ecological and economic impacts by mitten crabs have yet to be fully understood. The highest priority should be given to quantifying mitten crab predation on eggs and larvae of listed and protected aquatic species, the impacts that crab burrowing may have on levee and bank stability, impacts on water diversions and potential threats to predators. The USFWS and the IEP Reporting and Monitoring Project are attempting to define overlap between mitten crab rearing areas with steelhead spawning and rearing areas. The same project is also working to bring information to levee districts, Army Corp of Engineers and a U.S. Geological Survey (USGS) sedimentologist to evaluate the burrowing that is occurring in California for possible destructive impacts to levees and banks. A benthic impacts study has support from DWR and CALFED to investigate the ecological impacts of the mitten crab population on the benthic invertebrate community in the Delta. Research related to the ecological and economic impacts of the mitten crab is just beginning and should be supported until an adequate scientific understanding of the salient issues involved.

Other control priorities such as a bounty and harvest programs or biological controls have yet to be extensively investigated. Salvage facility operators have been experimenting with exclusionary devices such as barriers, bars, K-rails and traveling screens since the 1998 invasion (White et al. 2000). Investigation of physical controls has also occurred as part of ongoing projects undertaken by USBR and DWR at the fish salvage facilities (Appendix D compares physical control methods undertaken in 1999 at the State and Federal fish salvage facilities in Tracy, California). The facilities have continued to work within the constraints of their facility and agency resources to find creative ways to address the complications mitten crabs bring to fish salvage operations. Results of their studies have provided valuable data to inform future control efforts.

A reliable method to estimate year class strength would greatly improve the economic efficiency of controlling mitten crabs. Managers of the salvage facilities continually seek to identify a means for estimating the size of the migrating mitten crab population prior to the fall migration so they can get personnel and equipment in place before operations reach a crisis mode. The ability to predict year class strength would also allow facility operators to reduce expenditures during small cohort years.

Researchers have experimented with a variety of physical control methods to reduce the mitten crab population. USBR has provided funding to the San Francisco Estuary Institute to conduct a mitten crab risk analysis of USBR water diversion facilities in the West (Cohen and Weinstein 2001). UCSB, in cooperation with Santa Clara Water District, also implemented a pilot project to evaluate the feasibility of capturing adult crabs via a diversion and pitfall trap during fall downstream migration. Success of this method was very high, with an estimated 11,000 crabs captured on one small creek during a 6-week period, with 85% of the crabs caught in less than 3 weeks. Additional experimentation with various types of traps, artificial substrates, and baits has been conducted (Veldhuizen 2003b, USFWS mitten crab database). Trapping methods have shown variable success, but do not appear to be an effective population control option. Further research on physical controls is needed.

Another priority recommendation is to evaluate case studies of bounty and harvest programs that can be used to develop a similar program for the mitten crab. The financial incentive provided by a bounty and harvest program could have unintended consequences by encouraging the release and establishment of the mitten crab into other regions of the U.S. One appropriate approach to this dilemma is to support a case study of similar bounty and harvest programs that have been implemented in the past as population control measures for nonnative invasive species. Case studies would provide information about the success or risks of such programs. If the results of this work indicate it may be worthwhile to further investigate this approach, a feasibility study may be recommended which would evaluate the unique ramifications and complexities of a mitten crab bounty or harvest program.

The Mitten Crab Working Group has proposed biological controls for further investigation, though at a lower priority level. Biological controls may not yield or maintain host specificity and may impact other resident aquatic species. It is recommended that any proposed biological controls face rigorous study of the possible impacts to non-target organisms prior to any release of biological control agents. Physiological controls are also identified as a research topic area, though at a lower priority level than biological control. Physiological controls would likely require extensive cost for uncertain results.

As a result of the 1999 mitten crab contaminant pilot study (Table 2) the CDHS concluded that more analysis should be done, especially for mercury, arsenic and DDE (Luscutoff 2001). The USFWS in cooperation with U.S. Geological Survey (USGS) and the University of California at Berkeley (UCB) are currently in the process of conducting an analysis of the mercury levels of mitten crabs inhabiting South San Francisco Bay tributaries and the potential risk to wildlife and public health. The results of this mercury study are expected by the end of 2003. The Centers for Disease Control (CDC) also advises an investigation to determine the ability of various freshwater snail species to serve as the primary host for the Oriental lung fluke (*Paragonimus westermani*).

Protocols for evaluating the relative abundance of mitten crab populations still require refinement. Some indirect methods such as artificial habitat traps and burrow density counts have been used to estimate relative abundance, but reliable trapping methods remain elusive. A habitat use study (DWR/IEP) has been under way in the Bay-Delta since 1998 to look at habitats favored by the crabs in the Delta and feasible methods of monitoring and detecting mitten crabs. The results of this study have been shared with the members of the IEP Project Work Team and the Columbia River project, enabling others to build upon initial findings.

Other surveys have also attempted to quantify the relative abundance of mitten crabs throughout the San Francisco Estuary. UCB has been documenting juvenile mitten crab abundance in South San Francisco Bay with surveys in 1995, 1996, 1999, and 2000 to 2003. This study evaluates burrow density with confirmation of crab numbers via limited burrow excavation. A USFWS/IEP project also began in the summer of 2001 to develop a reporting system and monitoring program for crabs sighted in areas upstream of the Bay-Delta. The reporting system has been developed to take advantage of the network of employees, resource professionals, resource users, residents and others to guide monitoring personnel to freshwater rearing areas used by mitten crabs. The monitoring program has worked to document the locations and physical conditions of habitats occupied by crabs, observe crab behavior and experiment with various methods and gears to explore ways to capture mitten crabs. Field observation in the summer of 2001 showed that on average, while crabs over19mm carapace width are attracted to bait, they are unwilling to transverse and enter traps containing bait and they exhibit an aversion to foreign material in general (USFWS mitten crab database). Experimentation with various capture methods will continue through 2003. Simultaneously USFWS is supporting the development of cooperative agriculture and levee monitoring programs to monitor and document potential damage caused by mitten crabs.

Information and Education

Identification and outreach materials have been developed and are being used in the Bay-Delta and the lower Columbia River regions. Portland State University has initiated a program to draft a rapid response plan for the lower Columbia River. Assorted brochures, watch cards, fact sheets, presentations and a video have been developed by CDFG, the Service, DWR, MIST and other organizations. Educational activities, which have been identified as a high priority but are not currently being adequately addressed include:

- Developing partnerships to promote best management practices to prevent the spread of mitten crabs
- Developing educational materials in various languages
- Investigating listing the mitten crab as a plant pest
- Developing model state regulations that can be used by at-risk states

- Developing and implementing a mitten crab training program for law enforcement and inspection officers

Educational outreach to diverse law enforcement organizations must continue in order to maintain adequate deterrence of mitten crab introductions. USDA resources that previously went to airport and cargo port inspections, have now been shifted to the Department of Homeland Security (DHS). Coordination is needed with DHS in order to ensure continued capacity to detect mitten crabs at U.S. ports.

Outreach by USFWS, CDFG and other organizations must continue to educate the public about how to prevent the unintentional spread of mitten crabs into currently unoccupied U.S. waters. Many of the best management practices designed to address the introduction of non-native aquatic species in general will also be effective for the mitten crab, and should be implemented. Whenever possible, BMPs for general invasive species education and outreach should incorporate information about mitten crabs.

Evaluation of Control Strategies and Adaptive Management

Final approval of this management plan will be followed by an interagency and stakeholder meeting. This meeting will summarize the results and findings of the tasks and studies, which have been completed, those that are ongoing and those that still need to be conducted. Cumulative findings will form the basis of the adaptive management and program evaluation process. Ongoing adaptive management (Figure 11) will be used to develop appropriate projects for implementation in each future phase of the management plan.

Phase II Early Detection and Information/Education sections recommend further expansion of these programs to cover additional areas identified as high-risk areas.

An implementation table (Table 6) follows this section that displays projects, related to mitten crab control and management that have been completed, are underway, or recommended with the associated implementing entity and funding organization.

Table 6. Management Actions Completed and In Progress.
*Funding provided by organizations is listed in thousands of dollars.

Management Action	Funded by	Implemented by	1998	1999	2000	2001	2002	2003
Literature search and report	FWS	FWS		$2				
Workshop	FWS, UCD, WRP, SFEP	SFEP		$17				
Monitoring programs; burrowing, life stages, annual distribution	IEP, CALFED, UCB	CDFG	$10	$2	$32	$30	$40	
Detect upstream spread	FWS	FWS				$40	$50	$30
Detect upstream spread	IEP	DWR				$15		
Habitat use study	IEP	DWR	$42	$72	$56	$20		
Interagency coordination	FWS	FWS	$3	$6	$15	$15	$15	$5
Lower Columbia detection and rapid response program	FWS, BPA, PSMFC	PSU			$15	$45	$15	$15
Identification materials	CDFG	CDFG			$5	$5		
Prevention materials	OrSG	OrSG			$20			
Prevention materials	FWS	FWS				$5	$5	$5
Prevention materials	BPA	PSMFC				$7		
Megalopae settling study	FWS	UCSB				$16		
Contaminant - mercury	FWS, USGS	USGS			$63	$60	$45	$2
Lung fluke	NSG, MSI	UCSB			$59	$60		
Salvage facility R & D	USBR	USBR		$150	$200	$350		
Salvage facility R & D	DWR	DWR	$20	$130	$80			
USBR exclusion technology development	USBR	SFEI	$700					
USBR monitoring	USBR	USBR		$40				
USBR facility risk assessment	USBR	USBR		$40				
Benthic impacts	CALFED	DWR			$14	$100	$80	
Migratory cues	USBR	CDFG			$80			
Law enforcement outreach and education	FWS	CDFG					$7	
Evaluation workshop	FWS	FWS					$10	
Salmonid egg predation	FWS	UCSB						$14
Environmental factors influencing abundance	FWS	FWS						$15
Breeding migration	SCVWD	UCSB				$4		$20

USFWS fiscal year 2004 funding is anticipated to be the same or less as 2003 ($86,000).

Table 7. Acronyms for Organizations Listed in Table 6

Acronym	Organization	Type of Organization
BPA	Bonneville Power Administration	Corporate
CALFED	California Bay-Delta Authority	Inter-agency
CDFG	California Department of Fish and Game	CA State
DWR	Department of Water Resources	CA State
FWS	U.S. Fish and Wildlife Service	Federal
IEP	Interagency Ecological Program	Inter-agency
MSI	Marine Science Institute	Non-profit
NSG	National Sea Grant	Federal
OrSG	Oregon SeaGrant	Inter-agency
PSMFC	Pacific States Marine Fisheries Commission	Inter-state commission
SCVWD	Santa Clara Valley Water District	Special District
SFEP	San Francisco Estuary Project	Non-profit
UCB	University of California at Berkeley	CA State
UCD	University of California at Davis	CA State
UCSB	University of California at San Barbara	CA State
USBR	U.S. Bureau of Reclamation	Federal
USGS	U.S. Geological Survey	Federal
WRP	Western Regional Panel on Invasive Species	Inter-agency

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APPENDICES

Appendix A. Overview of the Life History, Distribution, Abundance, and Impacts of the Chinese mitten crab, *Eriocheir sinensis*

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Funding provided by the United States Fish and Wildlife Service

Printed by the California Department of Water Resources, Environmental Services Office

March 1999

STATUS

The Chinese mitten crab, *Eriocheir sinensis* (H. Milne-Edwards 1854), is a recently introduced species to the San Francisco Estuary and associated watershed. The most probable mechanisms of introduction to the estuary were deliberate release to establish a fishery and accidental release via ballast water (Cohen and Carlton 1997). This species is native to coastal rivers and estuaries of Korea and China along the Yellow Sea (Panning 1939). The Chinese mitten crab is presently well-established throughout the San Francisco Bay, the Sacramento-San Joaquin Delta, and the mainstems of the major rivers and tributaries that flow into the estuary. Both the distribution and population size of this species continue to rapidly increase.

The establishment of this species in North America is of concern, because the crab is considered a pest in northern Europe. The crab was accidentally introduced to Germany in the early 1900s, proliferated and spread to many northern European rivers and estuaries, where it impacted local fisheries and levee integrity. The California Department of Fish and Game (CDFG) added the genus *Eriocheir* to its List of Prohibited Species (Section 671, Title 14) in 1986 (USFWS 1989). United States Fish and Wildlife Service (USFWS) added the genus to its injurious wildlife list under the Lacey Act in 1989 (USFWS 1989).

LIFE HISTORY

The Chinese mitten crab belongs to the Order Decapoda and Family Grapsidae. This species is native to China where it is commonly called the river crab or Shanghai crab (Tan et al. 1984). The Chinese mitten crab, like other species in the genus *Eriocheir*, is characterized by the brown setae densely covering the front claws, producing the appearance of "hairy" claws. However, very small juveniles (< 25 mm carapace width (cw)) rarely have setae on their claws. (See Ingle (1980) for detailed identification characteristics). The Chinese mitten crab is a catadromous species; adults reproduce in brackish or salt water areas while offspring migrate upstream to fresh or brackish water areas to rear.

Lifecycle

Larvae

Eggs are carried by the female under the abdominal flap until hatching. For proper egg development and adherence, salinity near 25‰ is required (Vincent 1996). Females carrying eggs were collected from the San Francisco Estuary in areas with a salinity of about 10‰, but it is unknown if these eggs successfully developed (CDFG unpublished data). Hatching occurs during the spring and early summer months in brackish water areas of estuaries (Anger 1991) (Table 1).

The larvae are planktonic for approximately one to two months and pass through a series of development stages: a prezoea stage (a brief, non-feeding stage), five zoeal stages, and a megalopa stage (Anger 1991, Kim and Hwang 1995). Optimal water temperatures for all larval stages range from 15 to 18 °C (Anger 1991). The prezoea and zoea I stage occur in lower estuaries at salinities between 10‰ to 25‰ (Anger 1991). Larvae in the zoea I stage are very euryhaline, tolerating a wide range of salinities, especially compared to the later zoeal stages (Anger 1991). This characteristic allows them to survive the variable salinity conditions of lower estuaries (Anger 1991). Early zoeal stages mainly occur at the surface of the water column and are transported by surface currents toward the mouth of or out of the estuary. The subsequent zoeal stages tend to occur in nearshore marine waters or in lower estuaries and have a reduced tolerance for low salinities. Stages IV and V are stenohaline with maximum survival at salinities of 32‰ (Anger 1991). The megalopae occur lower in the water column and have an increased tolerance to low salinities. Carried by onshore-directed near-bottom counter currents toward the coast and inner estuaries, the megalopae eventually settle to the floor from late spring to mid-summer and develop into benthic juvenile crabs (Anger 1991). If gradually acclimated to brackish water, metamorphosis from megalopa to juvenile crab can occur in salinities as low as 5‰, although 15‰ to 25‰ is optimal (Anger 1991). Thus, metamorphosis from megalopa to first juvenile instar can occur in both seawater and freshwater (Anger 1991). This finding is supported by field collections and laboratory observations (Peters and Panning 1933; Panning 1939, and Hinrichs and Grell 1937, as cited in Anger 1991; Anger 1991).

Under unfavorable conditions of low salinity (≤15‰) and temperature (≤15 °C), an additional zoeal stage and megalopa stage have occasionally been observed (Anger 1991). These additional stages are likely adaptations to a highly variable environment (Sandifer and Smith 1979, as cited in Anger 1991). Refer to the Factors Affecting Potential Distribution section below for additional information on Chinese mitten crab salinity and temperature tolerances.

Table 1. Timing of life stages of the Chinese mitten crab in various regions.

	Hatching	Settlement	Upstream Migration	Downstream Migration	Spawning Season
China-Korea	?	?	February-May	fall	?-May
Europe	?-July	?	March-July, peak variable between years	August-November peak: September	October-January?
San Francisco Estuary	January?-May?	?	year-round, with peak in spring	August-January peak: September-October	November-January?

Juveniles

Juvenile mitten crabs rear in brackish and fresh water areas. In tidal areas, they may burrow in banks and levees between the high and low tide marks in which they retreat during low tide and during the day for protection from predators and desiccation, or they may remain in the subtidal zone (Panning 1939, Kaestner 1970, Ingle 1986, Veldhuizen and Hieb 1998a). Burrows are typically found in vertical river banks but have also been found in firm marsh bottoms in areas that are dewatered during low tide and upstream of tidal areas (Panning 1939, Halat 1996, Veldhuizen 1997, Veldhuizen and Hieb 1998a, K. Hieb, CDFG, unpublished data). Mitten crab burrows angle slightly downward and are elipitical in shape (Panning 1939). However, crabs do not always construct their own burrows. In the San Francisco Estuary (Suisun Marsh), mitten crabs were observed utilizing burrows made by the introduced Harris mud crab (*Rhithropanopeus harrisii*) (Veldhuizen and Hieb 1998a). Mitten crabs may also utilize dense moist vegetation, root wads, debris, and shallow ponded water as cover during lowtide (Veldhuizen and Hieb 1998a). They apparently do not burrow as extensively in non-tidal areas, probably because they are not subject to desiccation (Veldhuizen and Hieb 1998a).

Results of a monitoring survey conducted in the San Francisco Estuary (Suisun Marsh and Sacramento-San Joaquin Delta) indicated burrowing crabs were most abundant in tidally influenced areas of low salinity (Veldhuizen 1997, Holmes and Osmondson 1998). Most burrowing crabs were found below the root profile of vegetation lining steep, clay banks (Veldhuizen and Hieb 1998a). Crabs in these areas were typically less than 25 mm cw.

A portion of the juvenile population remains in the subtidal zone during lowtide. Juvenile crabs in freshwater frequent areas with hard bottoms and submerged vegetation (Pape 1939, as cited in Nepszy and Leach 1973). In tidal, freshwater areas of the Sacramento-San Joaquin Delta, juvenile crabs were collected more frequently in shallow areas with dense submerged vegetation (especially *Egeria*) than in shallow, unvegetated areas (L. Grimaldo, California Department of Water Resources (CDWR), unpublished data). They also inhabit channel bottoms (CDFG, unpublished data).

During late winter through spring, large numbers of juvenile crabs migrate upstream (see Table 1). In China, juveniles migrate upstream from February to early May, and the onset of migration follows an increase in temperature (Tan et al. 1984, X. Fu, pers. comm. 1999). In Europe, they began migrating in March and continued through July, with the peak migration period varying between years (Peters 1938). The crabs were mainly observed travelling in the main channels but also entered smaller channels with slow moving water. The crabs traveled upstream at a rate of 1 to 3 km per day, depending on size, and were most active at night (Panning 1939, Kaestner 1970, Tan et al. 1994, Vincent 1996). Increasing water temperatures, high population densities, and food competition were hypothesized as migratory cues in Germany (Panning 1939, Ingle 1986).

In California during February and March of 1998, CDFG received several reports of large numbers of migrating juvenile mitten crabs. The United States Bureau of Reclamation's (USBR) Tracy Fish Collection Facility, which entrains and salvages fish from water diversions in the Sacramento-San Joaquin Delta, collected large numbers of juvenile mitten crabs in late January through February. In other areas of the watershed, the crabs were most noticeable in small creeks or when concentrated at the base of weirs or other migratory barriers. Mitten crabs were reported climbing over weirs in the Sutter and Yolo bypasses, such as the Sacramento Weir, in February and March 1998. Thousands of mitten crabs migrated up Mormon Slough and Littlejohns Creek, east of Stockton, California, during these same months. In most cases, the juvenile crabs migrated upstream. However, those entrained at the USBR fish collection facility were travelling with the current.

The migrating juvenile crabs ranged in size from 25 to 40 mm cw (1 to 1.5 inches), and at least 75% of the crabs observed were males (CDFG, unpublished data). The crabs probably reared in the delta during the previous year. Based on their size, these crabs were estimated to be nearly 1 year old (having hatched the previous spring) and would probably reach maturity by the subsequent fall (K. Hieb, pers. comm.).

Adults

Crabs reach maturity at 1 to 5 years of age, depending upon environmental conditions (Panning 1939, Cohen and Carlton 1995) (Table 2). During late summer to early fall, the mitten crabs undergo a puberty molt and migrate downstream, at a rate of 8 to 12 km per day, to salt water to reproduce (Panning 1939, Kaestner 1970, Anger 1991) (see Table 1). The gonads develop during the migration (Panning 1939). Mating and fertilization occur during late fall through winter. Ovigerous females are present winter through spring in Europe and have been collected at depths of 10 to 15 m in the outer Elbe Estuary in the North Sea (Anger 1991). In Korea, ovigerous females were collected as late as May in the lower estuary and tidal mudflats (Kim and Hwang 1995). In the San Francisco Estuary, ovigerous females have been collected

November through May and are found mainly in South Bay, San Pablo Bay, and Suisun Bay (Veldhuizen and Hieb 1998a, CDFG unpublished data).

Spawning occurs in lower estuaries where the average salinity is 20‰ (Anger 1991), although Ingle (1986) and Vincent (1996) report that salinity above 25‰ is required for proper egg development and adherence. Females produce 250,000 to 1 million eggs and carry the eggs until hatching (Panning 1939, Cohen and Carlton 1995). Both sexes die within several months after reproducing (Kaestner 1970). According to Wolff and Sandee (1971), post-spawning crabs are collected in the lower estuarine regions of Holland until June-July; shortly thereafter only dead crabs are found. Panning (1938) reported that a small portion of the spawning population migrates back upstream after mating, but it is unclear whether these crabs survived just for several more months or to the next spawning season.

Growth and Maturation

The growth rate of the crab is inversely related to its size. According to Panning (1938), small crabs increase in size 24% between molts while large crabs ($\geq$ 70 mm) increase only 11%. In Germany, crabs molt 6 to 8 times the first year, 4 to 5 times the second year, 2 to 3 times the third year, and 1 time per year thereafter (Panning 1939) (Panning defined a year as running from July to July, as hatching is complete by July). The frequency of molting is dependent on temperature and nutrient availability. Molting probably occurs more frequently in China and California as the water temperature is warmer than in Germany. This is suggested by the variation in age of maturity. Crabs mature at 3 to 5 years in Europe (Panning 1939), but in 1 to 2 years in China (Cohen and Carlton 1995) and an estimated 2 to 3 years in California (Table 2).

Table 2. Lifespan and size of the Chinese mitten crab in various regions.

	Lifespan	Average Adult Size (cw)	Maximum Size (cw)
China-Korea	1-2 yrs	?	?
Europe	3-5 yrs	56 mm	+70 mm
San Francisco Estuary	2-3 yrs	40-60 mm	86 mm

Hoestlandt (1948) examined the gonadal development of male and female crabs. As female crabs mature, the abdomen increases in width, the setae under the abdomen increase in length, and the setae on the claws and legs increase in length. Mature females (having undergone a puberty molt) are characterized by an abdomen nearly equal in width to the thoracic plate and abdominal setae equal to the width of the abdomen (Hoestlandt 1948). The ovaries begin to develop as early as July. As they develop, their color changes from being transparent or pinkish when immature to pink to orange to purple or brownish when fully mature (Hoestlandt 1948).

As male crabs mature, the setae on the claws and legs increase in length. The claw size and setae length of mature males is greater than that of females. Male crabs undergo a puberty molt between July and August (Hoestlandt 1948). The gonads begin developing after this molt (Hoestlandt 1948). Rapid development occurs August and September and full maturity is reached by October or November (Hoestlandt 1948). The crabs ranged in size from 35 to 66 mm cw (Hoestlandt 1948). All crabs over 55 mm reached maturity (Hoestlandt 1948). However, some crabs ranging in size from 35 to 45 mm cw did not mature (Hoestlandt 1948). In addition, Hoestlandt examined one male (46mm cw) collected in October in the spawning area. It had immature secondary sexual characteristics (did not go through a puberty molt) but had fully developed gonads. This suggests that the puberty molt is not always directly related to the development stage of the gonads (Hoestlandt 1948).

Diet

Mitten crabs are omnivores, with juveniles eating mostly vegetation, but preying upon animals, especially small invertebrates, as they grow (Tan et al. 1984). According to Kaestner (1970), the crab feeds by running backward and stirring up mud. Mitten crabs also glean food off the bottom's surface and consume submerged vegetation (pers. obs.). Thiel (1938) concluded from his examination of 3,000 mitten crab stomachs that vegetation accounted for two-thirds of the diet and animal matter accounted for the rest. The vegetation types found included filamentous algae, *Potomogeton*, *Elodea,* and *Lemna*. Types of animal material found in the stomachs included *Tubifex*, molluscs, *Daphnia*, *Gammarus*, *Corophium*, *Crangon*, and chironomids (Thiel 1938, Hoestlandt 1948). Thiel (1938) found no trace of amphibians, and fish were found in only 2.4% of the stomachs. Using specimens collected from the species native range, Tan et al. (1984) also found the crabs consumed mainly vegetation and detritus, but also found they consumed shrimp, fish, and aquatic insects. Hoestlandt (1948) found the crab fed mainly from spring to autumn, but some adult stomachs collected in winter were found to be one-third full.

German fishermen in the 1930s claimed the crabs caught and consumed fish and greatly impacted population levels. Panning (1939) and the results of Thiel's diet analysis discount this claim. The crabs are too slow to harm or capture most adult fish, as evidence by crabs and fish occupying the same aquarium for many months (Panning 1939). Hoestlandt (1948) suggested the crab was a serious competitor for food, but not a direct predator. However, Kaestner (1970) reported that fish are attacked at weirs.

Predators

Relatively little is known about the predators of the mitten crab. Predatory fishes, waterfowl, and aquatic birds were noted as predators of the mitten crab in Germany (Panning 1939). White sturgeon, striped bass, black bass, catfish, bullfrogs, loons, and egrets have been reported to prey upon the crabs in the San Francisco Estuary (Veldhuizen and Hieb 1998a, CDFG unpublished data). Other predatory fishes, river otters, raccoons, and other wading birds most likely consume mitten crabs.

DISTRIBUTION AND ABUNDANCE

Asia

The Chinese mitten crab is native to coastal rivers and estuaries of Korea and China along the Yellow Sea (Panning 1939). It inhabits the Changjiang River valley and northern China (Li et al. 1993). The mitten crab has been reported to migrate 1400 km (800 miles) up the Yangtze River from the Yellow Sea (Panning 1939). Although the crab is found far inland, it prefers low-lying regions near the coast (Panning 1939). In Korea, the crab is common in rice fields near the coast, but only occupies riverine habitats when inland (Panning 1939).

In an effort to increase the commercial fishery in the Guangdong Province, "seed" crabs from the Changjiang estuary were released in the Zhujiang River drainage and Yantian River (Li et al. 1993). Crabs were planted in the Zhujiang estuary from 1973 to 1981 and from 1987 to at least 1993 (Li et al. 1993). Within a few years, the crab population was abundant enough to support a fishery (Li et al. 1993). Introductions to the Yantian River occurred in 1983 and 1984 (Li et al. 1993). Thus, the current distribution of *E. sinensis* extends south of its natural range.

Europe

The Chinese mitten crab was accidentally introduced to and became established in northern Europe, where the population exploded and rapidly expanded in distribution (Panning 1939). The crab was probably introduced to Germany in the early 1900s, coinciding with a period of increased maritime traffic between Europe and eastern Asia (Ingle 1986, Panning 1939). The first report of a Chinese mitten crab was from the Aller River near Rethem, Germany, Weser River system, in 1912 (Panning 1939). The crabs were caught as by-catch in flounder nets at the mouth of the Elbe beginning around 1915 (Panning 1939). The first reports of the mitten crab present in nontidal reaches of rivers were made from above Hamburg, Germany in 1926 (Panning 1939). By 1927, large masses of crabs were reported in the same area (Panning 1939). During the late 1920s-early 1930s, the mitten crab invaded the Ems, Weser, Elbe, Havel, Oder, and Rhine rivers and the Midland Canal, spreading to the neighboring countries of Denmark, southeastern Sweden, southern Finland, Poland (then East Prussia), Czechoslovakia, the Netherlands, Belgium, northern France, and England (Ingle 1986, Peters and Panning 1933, Peters 1938, Panning 1939, Wolff and Sandee 1971). Juvenile crabs were reported as far inland as Prague, Czechoslovakia, which is 700 km (580 miles) up the Elbe River from the North Sea (Peters and Panning 1933, Panning 1939).

The artificial connection between the North and Baltic seas facilitated the spread of the crab to the Baltic coast countries, either through ballast water or ocean current transport of larvae (Panning 1939, Jazdzewski and Konopacka 1993). The crab reached the French mediterranean through the interconnecting canal system (Hoestlandt 1959, as cited in Cohen and Carlton 1995).

By 1930, population control measures were required in Germany. The total catch of crabs in Germany was estimated at 262,600 kg in 1936 and 190,400 kg in 1937. In some locations, over 100,000 crabs were trapped per day (Panning 1939). In 1938, the most densely populated areas were the Elbe River from the mouth up to Prague, Czechoslovakia, and the coastal regions of Germany and Holland from the Elbe to the Rhine rivers (Panning 1939). The mitten crab population in other countries was reported as sparse (Panning 1939).

Only intermittent collections of the mitten crab have been reported in many countries since the proliferation of the 1930s. After the population declined in the 1940s, only a few crabs are annually collected along the Baltic Sea coast and in freshwater areas (Jazdzewski and Konopacka 1993). In the Seine estuary of France, few crabs were collected. During the 52 years of sampling, from the 1940s to the 1990s, only 60 individuals were reported (Vincent 1996). During the winter of 1963, France experienced a cold spell. Following that winter, no crabs were captured in the Seine estuary until 1975. Although adult crabs can tolerate 0 °C temperatures for up to seven days, the severe weather conditions were probably fatal for the juvenile crabs residing in freshwater (Vincent 1996).

In other areas, such as the Netherlands, periodic localized population explosions occurred (Ingle 1986, J. Mares, Strandwerkgroep, email comm. to K. Webb, USFWS, November 1998). From the mid-1930s to the mid-1950s, the mitten crab was very abundant along the Belgian coast and in coastal streams (Strandwerkgroep 1998). The population declined substantially for unknown reasons and only a few crabs were sighted every year.

Mitten crab abundance is currently increasing in portions of southern Holland, Belgium, England, and Germany, coinciding with an improvement in water quality. In Holland and Belgium, the population increased during the 1990s, with hundreds of crab sightings each year (Strandwerkgroep 1998). During the summer and fall of 1996, eel fisherman reportedly caught more crabs than eels (Strandwerkgroep 1998, J. Mares, Strandwerkgroep, email comm. to K. Webb, USFWS, November 1998).

Since first detected in England, the majority of sightings, although sporadic, were in the River Thames. Long-term fish and macroinvertebrate abundance data has been collected at an intake pump located near the mouth of the River Thames (Attrill and Thomas 1996). According to the data, mitten crab occurrences became more frequent after 1988 (Attrill and Thomas 1996). Crab abundance increased in late 1991 and increased significantly in November 1992 with 32 crabs per 500 million Liters (Attrill and Thomas 1996). During October 1992, hundreds of crabs were captured in the intake tanks of a power station located 45 km upstream of West Thurrock in the River Thames (Attrill and Thomas 1996). The population increase in southeast England estuaries from 1989 to 1992 coincided with a decrease in outflow and an increase in salinity (Attrill and Thomas 1996).

North America

Although only established in California, the mitten crab has been collected in other parts of North America. An adult male was collected in the Detroit River at Windsor, Ontario, in October 1965, and a female and two male adults were collected in Lake Erie in April and May of 1973 (Nepszy and Leach 1973). Another six to seven crabs were collected in the Great Lakes region between 1973 and 1994 (J. Leach, pers. comm. 1994, as cited in Cohen and Carlton 1997). Because the Great Lakes are too fresh for successful egg develop (Cohen and Carlton 1997), mitten crabs were probably transported in ballast water as larvae or introduced as adults. In Louisiana in 1987, an adult was collected in the Mississippi River Delta (D. Felder, pers. comm. 1995, as cited in USFWS 1989).

San Francisco Estuary

The Chinese mitten crab was first collected in south San Francisco Bay by commercial shrimp trawlers in 1992 and was collected in San Pablo Bay in fall 1994 (Hieb 1997). In 1996, a total of 45 mitten crabs were collected from the Sacramento-San Joaquin Delta, Suisun Bay, and Suisun Marsh (Hieb 1997, Veldhuizen 1997). In 1997, an estimated 16,000 to 20,000 mitten crabs were captured in the estuary (USBR unpublished data). In 1998, over one million mitten crabs were collected in the estuary (USBR unpublished data).

As of January 1999, the known distribution of the Chinese mitten crab in California extends north of Delevan National Wildlife Refuge in the Sacramento River drainage, north of Marysville in the Feather River drainage, east of Roseville in the American River drainage, in Littlejohns Creek and Mormon Slough to eastern San Joaquin County near Calaveras County, south in the San Joaquin River drainage near San Luis National Wildlife Refuge, and south in the California Aqueduct near Kettleman City and Taft (Veldhuizen and Hieb 1998b, K. Hieb, CDFG, unpublished data). In addition, the mitten crab is present throughout most tributaries to San Pablo, Suisun, and South bays (Veldhuizen and Hieb 1998b). The mitten crab's potential distribution in the San Francisco Estuary watershed extends throughout all waterways up to any migration barrier, such as large dams.

Other Regions

A Chinese mitten crab was found in Hawaii in the 1950s (Edmondson 1959, as cited in Gollash 1997).

POTENTIAL DISPERSAL MECHANISMS

The Chinese mitten crab may potentially expand its range along the West Coast of North America. The most probable dispersal mechanisms are ocean currents, ballast water transport, and human transport. Planktonic larval mitten crabs may be carried out of the San Francisco Bay to the Pacific Ocean, especially during periods of high outflow, where they potentially could be disbursed by ocean currents to coastal streams and estuaries to the north and south of San Francisco Bay, following a similar disbursement pattern as the European green crab, *Carcinus maenas* (Grosholz and Ruiz 1995). The mitten crab may have been dispersed by ocean currents along the coast of northern Europe (Vincent 1996).

The transport of foreign species in ballast water and their subsequent release to new waters is very common. Ballast water transport is thought to be the introduction mechanism of the mitten crab to Germany, England, the Mississippi River delta, and Lake Erie (Ingle 1986, Peters and Panning 1933, Panning 1939, Nepszy and Leach 1973). It is one of the more probable modes of introduction of the mitten crab to the San Francisco Estuary (Cohen and Carlton 1997). Ships travelling to and from West Coast ports may transport the mitten crab from the San Francisco Estuary to new locations.

Expansion of the crab's range may also be facilitated through human activity, such as deliberate release to establish a local fishery. The developing gonads and meat of the Chinese mitten crab are considered a delicacy. The developing, orange ovaries of the maturing female are prized for their flavor. In China, the mitten crab supports a fishery with an annual catch of over 10,000 tons (Li et al. 1993). The mitten crab has been found in passengers' carry-on luggage at Seattle, San Francisco and Los Angeles international airports and imported live to markets in Los Angeles and San Francisco in California and to cities in New York (Cohen and Carlton 1997, K. Hieb, pers. comm. 1999). In 1986, markets in San Francisco and Los Angeles were selling live crabs for US$27.50 to $32.00 per kg (Cohen and Carlton 1997). In Singapore, the 1996 retail price was $80 to $110 per kg with a total regional demand estimated at $340 million annually (unknown if these price estimates are in US currency) (Synergy 1996). In Bangkok, the going rate was about US$1 per kg several years ago (Andre Cattrijsse, University of Gent, Belgium, email to Ted Frink, CDWR, 1998).

FACTORS EFFECTING ESTABLISHMENT

Although the Chinese mitten crab may be transported to new watersheds, establishment may not occur. The appropriate habitat conditions must be present. However, determining the species' ultimate range on the West Coast of North America is problemmatic due to the lack of information on specific physiological requirements and tolerances for all life stages. Below are the findings of one study conducted on larval crabs and other anecdotal information on physiological tolerances.

In a series of laboratory experiments, Anger (1991) determined the salinity and temperature tolerances of each larval stage of *E. sinensis*. For all combinations of constant temperature (6, 9, 12, 15, and 18 °C) and salinity (10‰, 15‰, 20‰, 25‰, and 32‰), Anger found:

- Salinity tolerance ranges: zoeal stage I, 10‰ to 32‰; zoeal stage II, 10‰ to 32‰; zoeal stage III, 10‰ to 32‰; zoeal stage IV, 15‰ to 32‰; zoeal stage V, 15‰ to 32‰; megalopa, $\leq$5‰ to 32‰. (Note: actual salinity tolerance range is dependent upon temperature.)

- Above 12 °C, successful development from hatching through metamorphosis occurred at most salinities.

- At 6 and 9 °C and at any salinity, all larvae died during the first zoeal stage.

- At 15‰ and 15 °C, high mortality and developmental abnormalities occurred.

- At 10‰, no larvae survived beyond stage I at 15 °C and no lavae survived beyond stage III at 18 °C.

- Zoeal stage I and megalopa suffered high mortality in a combination of 32‰ and temperature $\leq$15 °C.

- Complete development did not occur in constant salinities of 15‰ and 10‰.

- Survival (lifespan) increased at higher temperatures for all salinities.

- Range of salinity tolerance increased with increasing temperature.

- In general, development time and mortality increased at relatively low and high salinities.

Thus, successful development of larval mitten crabs requires temperatures above 9 °C and access to a range of salinities.

Based on the species current distribution, the Chinese mitten crab can become established in areas with temperature regimes between 10 and 25 °C. Temperatures in the Yellow Sea range from 15 to 25 °C, and the average yearly surface temperature of the North and Baltic seas range from 10 to 15 °C (Williams et al. 1960, as cited in USFWS 1989). In addition, adult mitten crabs can tolerate extremely low temperatures. They can survive in water temp of 0 °C for up to seven days and resume normal activity if placed in warmer water (Vincent 1996). Higher temperatures of 27 to 29 °C is reported as suitable for mitten crab culture in Singapore (Synergy 1996). In tributaries to south San Francisco Bay, juvenile crabs occupied areas with water temperatures of 20 to 31 °C (Halat 1996). Temperature regimes similar to those of the Yellow Sea off the coast of China and Korea and of the North and Baltic seas off the coast of Northern Europe and Scandinavia exist along the coast of North America (Williams et al. 1960, as cited in USFWS 1989). Suitable temperatures occur on the west coast from British Colombia's Queen Charlotte Island to the Baja Peninsula and on the east coast from Nova Scotia to Florida (Williams et al. 1960, as cited in USFWS 1989).

Juvenile and adult Chinese mitten crabs can also survive long periods out of water. Crabs can survive up to 38 days in a wet meadow (Nepszy and Leach 1973) and at least 10 days in a burrow in a dessicating field (CDFG and CDWR unpublished data). Air temperature in the burrow was significantly lower than the ambient air temperature. Thus, the Chinese mitten crab can survive in areas with fluctuating water levels.

IMPACTS OF THE CHINESE MITTEN CRAB IN CALIFORNIA

Based on the impacts of the mitten crab in its native range and in Europe, a large mitten crab population poses several threats to California. These impacts have both ecological and economic consequences. The impacts of the increasing crab population are already evident.

Impacts on Levees

In Germany, the numerous burrows constructed by mitten crabs accelerated bank erosion rates and caused reduced levee stability (Peters and Panning 1933, Panning 1939). In some locations, burrows were reported to be up to 50 cm (20 inches) deep (Peters and Panning 1933). In south San Francisco Bay creeks, mitten crab burrow densities of nearly 30 burrows/m^2 (3 burrows/ft^2) have been reported with most burrows no more than 20 to 30 cm (8 to 12 inches) deep (Halat 1996). Densities in the Sacramento-San Joaquin Delta and Suisun Marsh are currently much lower ($\leq$ 5 crabs/m^2) (Veldhuizen 1997, Holmes and Osmondson 1998), but are expected to increase to levels comparable to south San Francisco Bay creeks within several years.

Based on currently available data, any damage to banks or levees in the estuary should be confined to tidally influenced areas and will be dependent on crab density, levee structure, and suitability of the bank for burrowing. Due to the extensive levee system protecting agricultural fields and communities in the delta, deterioration of levees due to mitten crab burrows is of great concern.

Impacts on Fisheries

The most widely reported economic impact of mitten crabs in Europe was damage to commercial fishing nets and the catch when high numbers of crabs were caught (Panning 1939). The crabs ate the abdomens of the fish and caused increased wear on the nets. Crabs also filled eel-basket pots and hoop nets, preventing eels from entering the traps, thus reducing catch (Panning 1939). In 1981, the mitten crab population in the Netherlands increased substantially, resulting in serious damage to fishing nets (Ingle 1986). However, with the currently low population level in most areas of Europe and a demand for crabs by Chinese restaurants, mitten crabs are no longer a problematic by-catch (C. Schubart, email comm. with K. Hieb, November 17, 1997).

In the San Francisco Estuary, the crab has been a nuisance to commercial bay shrimp trawlers and sport anglers for several years. In south San Francisco Bay, commercial shrimp trawlers find it time consuming to remove crabs from their nets (one fisherman twice caught over 200 crabs in a single tow during fall 1996). They are also concerned that a large catch of mitten crabs will damage their nets and the shrimp. Damaged shrimp are unsuitable for the bait market. Currently, shrimp trawlers are able to move to other areas in south San Francisco Bay with fewer crabs, but this option will diminish as the mitten crab population grows.

A commercial fishery for the introduced signal crayfish (*Pacifastacus leniusculus*) is located in the Sacramento-San Joaquin Delta. During fall 1998, when large numbers of adult mitten crabs migrated downstream, mitten crabs were caught in crayfish traps. If the mitten crab population continues to increase, the crab will become a serious pest by filling the traps and, thus, reducing the crayfish catch. In addition, the mitten crab overlaps in dietary and habitat preferences with the signal crayfish which may reduce crayfish abundance and growth rate.

The sport fishery in the Sacramento-San Joaquin Delta is also impacted by the increasing mitten crab population through loss of bait. The majority of complaints received by CDFG concerning the mitten crab are from recreational anglers.

Water Diversion Impacts

Currently, the most conspicuous impact of the crab in California is on the fish salvage operations at the Federal and State water pumping plants and fish collection facilities in the south delta. These facilities pump and divert several million acre-feet of water from the Sacramento-San Joaquin Delta annually. The fish collection facilities screen all water heading toward the pumping plants and salvage millions of fish.

At the fish facilities, out-migrating adult crabs are entrained along with fish. Only 25 crabs were counted at both the federal Tracy Fish Collection Facility (TFCF) and the State Skinner Fish Facility (SFF) in 1996. In 1997, an estimated 16,000 to 20,000 crabs were captured in the holding tanks at TFCF (USBR unpublished data). In 1998, nearly 1 million crabs were entrained into the federal facility alone (USBR unpublished data). The fish salvage operations at TFCF and SFF were severely hindered by the large numbers of mitten crabs in the holding tanks and fish transport trucks. Initially, crabs were entrained seasonally, mainly during the fall downstream migration period. In 1998, due to the large population size, mitten crabs were entrained year-round with approximately 100 crabs captured per week during the non-migratory periods and 5,000 to 40,000 crabs captured per day during the peak fall migratory period (USBR unpublished data).

In Europe, reports were made of crabs entering water intake pipes or trapped on the screens (Ingle 1986, Attrill and Thomas 1996, Vincent 1996, J. Mares, Strandwerkgroep, email comm. to K. Webb, USFWS, November 1998). In California, Pacific Gas and Electric Company (PG&E) reported the Pittsburg Power Plant, located on the southern shore of Suisun Bay, was affected by high numbers of adults in fall 1997 and 1998, and the Contra Costa Plant, located near Antioch, was affected in fall 1998 (K. Hieb, CDFG, pers. comm. 1998). Workers noticed reduced flows in the cooling water system. Upon back-flushing, they found the internal piping system had been partially blocked by hundreds of crabs.

Agricultural Impacts and Concerns

In its native range in China and Korea, juvenile mitten crabs were reported to damage rice crops by consuming the young rice shoots and burrowing in the rice field levees (Ng 1988, as cited in Halat 1996). Rice fields in tidally influenced areas apparently are most subject to damage. However, no control measures have been reported. In some rice fields, the crab is even cultured with fish. Apparently, the mitten crab is stocked at a rate that does not damage the rice crop.

Ecological Concerns

The ecological impact of a large mitten crab population is the least understood of all the potential impacts. A large population of mitten crabs could change the structure of the estuary's fresh and brackish water benthic invertebrate communities through direct predation and effect the abundance and growth rates of other species through competition. In tributaries to south San Francisco Bay, the mitten crab and the introduced red swamp crayfish (*Procambarus clarkii*) co-occur, overlapping in dietary and habitat preferences. A 1996 survey found no negative correlation between the presence of the mitten crab and presence of the red swamp crayfish in tributaries to south San Francisco Bay; the crayfish was always present in areas with the mitten crab (Halat 1996). However, at almost all sites mitten crabs were visually more abundant, active, and aggressive than crayfish (Halat 1996). If competition does occur, the mitten crab may reduce abundance and growth rates of the red swamp crayfish and the introduced signal crayfish (*Pacifasticus leniusculus*), which supports a commercial fishery in the Sacramento-San Joaquin Delta.

Fish species which produce demersal or adhesive eggs may also be impacted. Chinese mitten crabs may prey on the eggs of nest building species, such as centrarchids. Some fish species spawn in submergent vegetation, a known habitat of mitten crabs, and thus expose their eggs to mitten crab predation. Mitten crabs have the ability to reach salmonid spawning grounds. However, with the cold water temperatures in these areas supressing the crabs' metabolic activity, the predation rate may be low.

Public Health Concerns

The presence of the mitten crab is also a human health concern, as it is a secondary host to the Oriental lung fluke (*Paragonimus westermani*), with mammals, including humans, as the final host. The fluke causes tuberculosis-like or influenza-like symptoms in humans. Humans risk infestation through the consumption of raw or partially cooked infected mitten crabs or the transfer of the crab's bodily fluids through nonsterile cooking practices (USFWS 1989, Marquardt and Demaree 1985, as cited in Halat 1996). Neither the lung fluke nor any of the freshwater snail species that serve as the primary intermediate host for the fluke in Asia have been found in the estuary. It has been noted that several species of freshwater snails currently present in the watershed could possibly serve as an intermediate host or that the correct snail species is present but yet undetected (USFWS 1989).

Mitten crabs are known to inhabitat agricultural ditches and other areas that may contain high levels of contaminants. The crabs potentially could bioaccumulate contaminants, which then would be transferred to predators, such as sturgeon, and to humans.

POPULATION CONTROL MEASURES

In Germany, extensive efforts were undertaken by the government in the 1920s and the 1930s to control mitten crab populations in some rivers (Panning 1939). Control measures often took advantage of the mitten crab's migratory behavior. When the crabs reached a barrier, such as a weir or small dam, their upstream migration slowed and they congregrated in large numbers below the obstruction. The crabs attempted to bypass the obstruction by climbing over the barrier or climbing up the banks. A variety of trapping methods were used to capture the crabs as they attempted to circumvent the structure (see Peters and Hoppe 1938 and Panning 1939). In some locations, traps were placed on the upstream side of dams and captured juvenile crabs as they migrated upstream, climbed over the dam, and fell into the traps. In other locations, troughs where constructed at the top of the levee and the crabs were funneled toward them. The crabs fell into the troughs and could not escape; the troughs were tiled to prevent the crabs from climbing out. Barrels, wrapped with wire netting or canvas, were also placed below dams amongst the congregrating crabs. The crabs would climb up the barrels and fall inside. At one trapping site, over 113,000 crabs were captured in a single day (Panning 1939). Electrical screens were also installed on the river bottom. Frequencies of 30 to 40 pulses per minute were found to disable and then kill the crabs (Halsband 1968, as cited in USFWS 1989).

It is unknown whether these control efforts were successful at controlling the population, as literature is very scarce. The population did decline in the late 1940s, coinciding with increasing water pollution. One hypothesis for the decline of mitten crabs is the increasing water pollution reduced prey abundance (Gollash 1999). Increasing water pollution is attributed to the decline of the mitten crab in other locations, also (Vincent 1996).

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Appendix B. Summary of the 1999 Mitten Crab Workshop Recommendations

The Mitten Crab Workshop held on March 23, 1999 in Sacramento, California provided a forum to learn about the crab and develop recommendations for the draft National Management Plan. Break-out groups explored the four subject areas of Preventing Spread; Detection and Monitoring; Reducing Impacts; and Controlling Populations. Participants developed outlines of their discussions and facilitators presented the results to the gathering. The following is a summary of the break-out groups outlines.

Objective A. **Prevent Spread**

Strategy 1. Identify natural and human-assisted pathways of spread
- a) Ballast water/hull fouling
- b) Human transport/releases
- c) Ocean currents
- d) Dredging
- e) Recreational/commercial boat equipment

Strategy 2. Reduce risk of human-assisted spread
- a) Enhance enforcement of possession and transportation prohibitions
- b) Develop/implement education and outreach program to provide information about regulations, enforcement efforts, penalties and negative impacts.
- c) Encourage development of comparable/compatible regulations, enforcement and education programs for states, provinces, and drainage basins at risk
- d) Support efforts to restrict the transfer of crabs via ballast water releases
- e) Identify areas of large populations and support ban of ballast water uptake in these areas
- f) Develop larval identification techniques

Objective B. **Promptly Detect New Populations and Monitor Status and Impacts of Known Populations.**

Strategy 1. Monitor status and impacts of known populations
- a) Develop standard sampling methods and protocols
  - *Considerations: bycatch, impacts to other species, nocturnal behavior. Suggested methods: traps, trawls, seines, snorkel surveys, settling plates
- b) Develop and implement a cooperative monitoring program for the San Francisco Estuary and Central Valley which includes state and federal facilities data, commercial fisherman, volunteers, and existing monitoring programs.

Strategy 2. Establish detection and monitoring programs for other areas at risk
- a) Use standard methods and protocols developed for the Bay-Delta to initiate a detection and monitoring program for West Coast (WA, OR, BC, Columbia River basin), Mississippi River, New York and other areas at risk.

Objective C. **Reduce negative impacts**

Strategy 1. Develop understanding of negative impacts on ecology, levees and agriculture

a) Improve understanding of biology, life history, environmental tolerances, critical habitats of mitten crabs, and species at risk from mitten crabs
b) Monitor/evaluate impacts to agriculture (education and outreach to farmers)
c) Monitor/evaluate impacts to levees (education/outreach to levee districts)
d) Evaluate current and potential impacts to recovery and restoration efforts (e.g., ESA listed species)

Strategy 2. If warranted, develop methods to reduce impacts
a) Assess exclusionary measures such as traps and barriers
b) Assess preferred slopes, soil types, etc.
c) Assess reducing local populations through environment modifications

Strategy 3. Develop program to manage populations at state, federal and NGO fish facilities to reduce impacts on fish salvage, fish passage and water diversion operations.
a) Identify and evaluate measures to keep crabs out of facilities and industry
b) Identify and evaluate measures to remove crabs from inside facilities and plants
c) Identify water management constraints
d) Identify value of modifications of South Delta barriers

Strategy 4. Evaluate potential beneficial uses for crab
a) Evaluate value for Human consumption, Feed, Fertilizer, Bait
b) Identify public health concerns
1) Investigate presence of lung fluke hosts
2) Investigate contaminant loads and potential risks

Objective D. **Develop strategies for Population Control**

Strategy 1. Evaluate potential control methods that take advantage of biology and life history and possible impacts (by-catch, listed species, recreation, etc)
a) Improve understanding of biology and life history, migratory behavior, recruitment dynamics, reproductive biology, feeding ecology.
b) Evaluate value, risks and impacts of trapping, fishing, etc.
c) Evaluate the value, risks, options and impacts of a commercial harvest
d) Evaluate the value, risks, options and impacts of a contract fishery
e) Evaluate the value, risks, options and impacts of sport fishery

Strategy 2. Evaluate control methods that utilize other technologies
a) Chemical
b) Biological- Genetic parasitic castrator, viruses, pheromones, sterilization

1999 Mitten Crab Workshop participants included representatives from:

Action for Animals
AEB
California Department of Water Resources
California Department of Fish and Game
California Department of Public Health
California Department of Food and Agriculture
California Environmental Protection Agency
California Fish and Game Commission
California, Oregon and Washington Sea Grants
California Rice Promotion Board
California Rice Research Board
California State Water Resources Control Board
California State University, Hayward, Fresno and Sacramento
Cargill Salt
County Agriculture Departments of Glenn, Sutter and Colusa counties
Delta Protection Commission
Glenn County Department of Agriculture
H & N Fish Company
IEC America
Institute for Marine Sciences, Germany
Kjeldsen, Sinnock, & Neudeck
Law Offices of Jung & Jung
Levine-Fricke
London Museum of Natural History
Marine Science Institute of Redwood City
National Marine Fisheries Service
Pacific Coast Federation of Fisherman
Pacific Fisheries Legislative Task Force
Portland State University
Queen Mary & Westfield College
Reclamation Districts 800, 2035
Sacramento and Stone Lakes National Wildlife Refuges
Sacramento County Flood Control
San Francisco Estuary Institute
San Francisco Estuary Project
San Francisco Regional Water Quality Control Board
Santa Clara Valley Water District
Smithsonian Environmental Research Center
State Parole Board
Strategic Environmental
Sutter County Department of Agriculture
Tulalip Tribes Fisheries Department
University of California, Davis, Berkeley and Santa Barbara
University of Washington

University of London
U. S. Bureau of Reclamation
U.S. Environmental Protection Agency
U.S. Fish and Wildlife Service
U.S. Geological Survey
Washington Department of Fish and Wildlife
West Basin Research Association

Appendix C. Aquatic Nuisance Species Task Force Mitten Crab Control Committee and Working Group Invited Members

The following are gratefully acknowledged for coordinating the creation of this National Management Plan for the Genus *Eriocheir*:

Kim Webb	U.S. Fish and Wildlife Service
Erin Williams	U.S. Fish and Wildlife Service
David Bergendorf	U.S. Fish and Wildlife Service
Ray VonFlue	U.S. Fish and Wildlife Service

Invited Members of the Mitten Crab Control Committee and Working Group

Dave Bolland	Association of California Water Agencies
Karen McDowell	California Sea Grant
Susan Ellis	California Department of Fish and Game
Les Harder	California Department of Water Resources
Jeff Janik	California Department of Water Resources
Pat Akers	California Department of Food and Agriculture
Blaine Parker	Columbia River Inter-Tribal Fish Commission
Jim Crenshaw	California Sportfish Protection Alliance
Bill Jennings	DeltaKeeper
Kerstin Wasson	Elkhorn Slough Reserve
David Jung	Law Offices of Jung and Jung
Diane Windham	National Marine Fisheries Service
Andrew DeVogelaere	National Oceanic and Atmospheric Administration
Tim Sinnott	New York Department of Environmental Conservation
John Kahabka	New York Power Authority
Chuck O'Neill	New York Sea Grant, SUNY College
Paul Heimowitz	Oregon Sea Grant
Stephen Phillips	Pacific States Marine Fisheries Commission
Mark Sytsma	Portland State University
Marilyn Leland	Prince William Sound Regional Citizens Advisory Council
Kevin Anderson	Puget Sound Water Quality Action Team
Dana Dickey	Rice Research Board
Thomas Ryan	Santa Clara County Water District
Marcia Brockbank	San Francisco Estuary Project
Ted Grosholz	University of California, Davis
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Henry Lee	U.S. Environmental Protection Agency
Jim Athearn	U.S. Army Corp of Engineers
Lynn O'Leary	U.S. Army Corp of Engineers
Tim McNary	U.S. Department of Agriculture
Krista Doebbler	U.S. Bureau of Reclamation
Scott Smith	Washington Department of Fish and Wildlife

Special acknowledgement for their contributions:

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Cindy Messer	California Department of Water Resources
Stacy Stanish	California Department of Water Resources
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Jim Johnson	San Francisquito Creek Watershed Council
Roni Robbins	School of Biological Sciences, University of London
Greg Ruiz	Smithsonian Environmental Research Center
Brent Bridges	U.S. Bureau of Reclamation
Lloyd Hess	U.S. Bureau of Reclamation
Scott Siegfried	U.S. Bureau of Reclamation
Marc Gilkey	U.S. Department of Agriculture
Larry Phillips	U.S. Geological Survey
Debbie Rudnick	University of California, Berkeley

and the Interagency Ecological Program Mitten Crab Project Work Team

Appendix D. 1999 Response to Chinese Mitten Crab at the California State and Federal Fish Salvage Facilities

STATE WATER PROJECT PLAN FOR MITTEN CRAB EXCLUSION AND CONTROL AT THE SKINNER FISH FACILITY
JUNE 14, 1999

Over the past several months staff from Delta Field Division, Operations and Environmental Services Qffice met to develop a plan for controlling and excluding the Chinese Mitten crab from the Skinner Fish Facility.

OBJECTIVE

Exclude mitten crabs from the State Water Project and Skinner Fish Facility in numbers adequate to eliminate any curtailment of fish salvage or project export operations.

BACKGROUND

The Chinese mitten crab invades the State and Federal Water Projects pumping plants during its annual spawning migration in the months of September through November. In 1998, the spawning migration resulted in millions of crabs impacting fish salvage and project export operations at both the state and federal Delta facilities. At the Skinner Fish Facility crabs hindered fish salvage operations and resulted in curtailed SWP pumping operations.

PROPOSED PLAN

Physical modifications

DWR proposes to install a mitten crab barrier upstream of the Skinner Fish Facility trash racks in the intake channel. The proposed barrier would be about a four foot high "k" rail-similar to a concrete highway barrier. It would be coated with a slick paint to minimize crabs attachment to it. It would be placed in sections at a diagonal across the intake channel (see Attachment). Since crabs move along the river bottom and do not swim in the water column, the barrier would divert crab movement away from the fish facility and along the upstream side of the barrier to a trap or collection point located on land or at the water edge. Delta Field Division would install the barrier by August 1, 1999. Captured crabs would be hauled off site for rendering as fertilizer or killed and buried on-site. Divers have inspected the intake channel and determined that it is suitable for placement of the barrier. Current restrictions on project export due to Delta smelt concerns have delayed efforts to measure intake channel velocity profiles. These measurements will take place prior to installation of the barrier once current restrictions are lifted.

DWR also proposes to install a screen at the Clifton Court radial gates. Each of the 5 radial gates would be fitted with a "Grizzly" metal screen 4 to 6 feet high with 1-inch openings. The screen would be constructed of vertical metal bars welded to a frame and fit into existing channels used to secure the stop logs. The gate screen will rest on the bottom substrate and provide a barrier to mitten crab movement but allow water passage when the radial gates are lifted.

DWR does not plan to install a travelling screen in the Skinner Fish Facility for crab removal. The proactive approaches proposed here focus on preventing mitten from entering the Skinner Fish Facility. In addition, two travelling screens sould be required at Skinner for each of the secondaries. Since USBR will be evaluating travelling screens at their Tracy facility, the DWR plan provides other options to control mitten crabs.

Operational Options

Operation of the Clifton Court Forebay Gates will be adjusted to reduce intake during hours of any potential peak crab migration periods identified in further research. This adjusted operation will occur within the requirements set forth in Standard Operating Order 200.7-A to protect south Delta water levels.

Shifting fish salvage operations between the primary and secondary holding tanks will allow one system to be cleaned of crabs while the other is in use. These shifts will be coordinated with operations scheduling to minimize disruptions to Banks Pumping Plant schedule.

Joint Point of Diversion between the export facilities will be pursued as a fishery protection measure and provide flexibility for operations in the event measures to control mitten crabs are inadequate. Staff are actively working with the USBR, SDWA and DWR Office of State Water Project Planning to develop a response plan in accordance with WR 98-9 to allow SWP operations to be shifted from Banks to Tracy Pumping Plant. The response plan will address south Delta water level concerns. In addition, coordination with fishery agencies will be pursued to identify the benefits to fishery salvage operations.

ACTION ITEMS

Delta Field Division will design and install the barrier in the intake channel. The 700 lineal feet of 'k'-rail has been delivered to the site. In addition, the field division will design, fabricate, and install the Clifton Court gate screens.

Operations and Maintenance will provide funding for barrier tests and will evaluate different flow and pumping conditions on the ability to trap crabs against the barrier when sufficient water is available to pump at Banks Pumping Plant.

JOC staff will coordinate with fishery agencies regarding operating guidelines and the potential for shifting operations between secondary channels to provide an opportunity for cleaning out mitten crabs without affecting export operations and endangered species take limits. JOC staff are also working on Joint Point of Diversion.

JOC staff will investigate forecasted tide and gate operations at CCF to determine if conditions will allow shifting of day/night intake operations. Staff will coordinate with operations scheduling and evaluate flexibility to operate intake gates during periods of low mitten crab activity.

ESO staff will also collect and evaluate data on temperature affects of mitten crab movement. This data will be used to determine if any potential benefits may result from adjusting CCF gate operations.

ESO and Department of Fish and Game staff will discuss procedures to improve counting and reporting of mitten crabs collected at the Skinner fish facility.

ESO and JOC staff will coordinate with Planning that the autumn Old River at Head barrier could have some benefits on reducing or delaying mitten crabs arrival at both state and federal facilities.

PARTICIPANTS

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Environmental Services Office---John Andrew and Ted Frink

Operations and Maintenance---Dan Peterson, Jeff Janik, and Victor Pacheco

STATE OF CALIFORNIA --THE RESOURCES AGENCY GRAY DAVIS. Governor
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Chinese Mitten Crab Experimental Exclusion Barrier "Grizzly" Bar Rack
Research Project. August -November 1999

The Department of Water Resources is planning to conduct a pilot study of a Chinese mitten crab exclusion grizzly bar rack at the radial intake gates at Clifton Court Forebay between August and November 1999. As the lead agency for CEQA compliance on the project, we concluded that there are no significant environmental impacts associated with the pilot study and that the project is categorically exempt under CEQA Guidelines Article 19, subsections No.15301 and No.15306. We filed a Notice of Exemption (NOE) on June 22, 1999, with the State Clearinghouse, Office of Planning and Research. For your information, I have enclosed a copy of the NOE with the project description as well as DWR's mitten crab control plan for 1999.

DWR has presented the project proposal to agency staff of the IEP Fish Facilities Mitten Crab Project Work Team and made a formal presentation on June 15, 1999, to the CALFED Ops Group. As part of the program implementation, I request your agency's review of the proposed plan and would like to receive comments or concurrence in writing as soon as possible, so that we may address or implement changes if necessary.

Management Alternatives for the Tracy Office (Bureau of Reclamation), in Anticipation of Further Detrimental Impacts by Chinese Mitten Crabs Upon Fish Salvage Operations at the Tracy Fish Collection Facility (TFCF)

May 20, 1999

Executive Summary

Starting in September, 1998, Chinese mitten crabs began to migrate to the TFCF in such high numbers that they clogged many of the fish salvage features. This resulted in the deaths of thousands of fish that would have been salvaged under normal operations. To successfully salvage fish, it became imperative to separate them from crabs. Mechanical crab removal or separation efforts were undertaken in the secondary channel and holding tanks and included trapping, dipping, and screening. Captured crabs were buried and killed off-site.

The 1998 migration of crabs through TFCF was a learning experience (Figures 1-6). Because we monitored crabs as bycatch in bi-hourly fish counts and evaluated our attempts crab removal, we estimated that at least 750,000 were likely to have come through the TFCF in September to November of 1998, most moved in at night, and more were males than females. Furthernore, our attempts at removing crabs, while not successful at first, indicated that crabs move along the bottom and sides of channels and are poor swimmers.

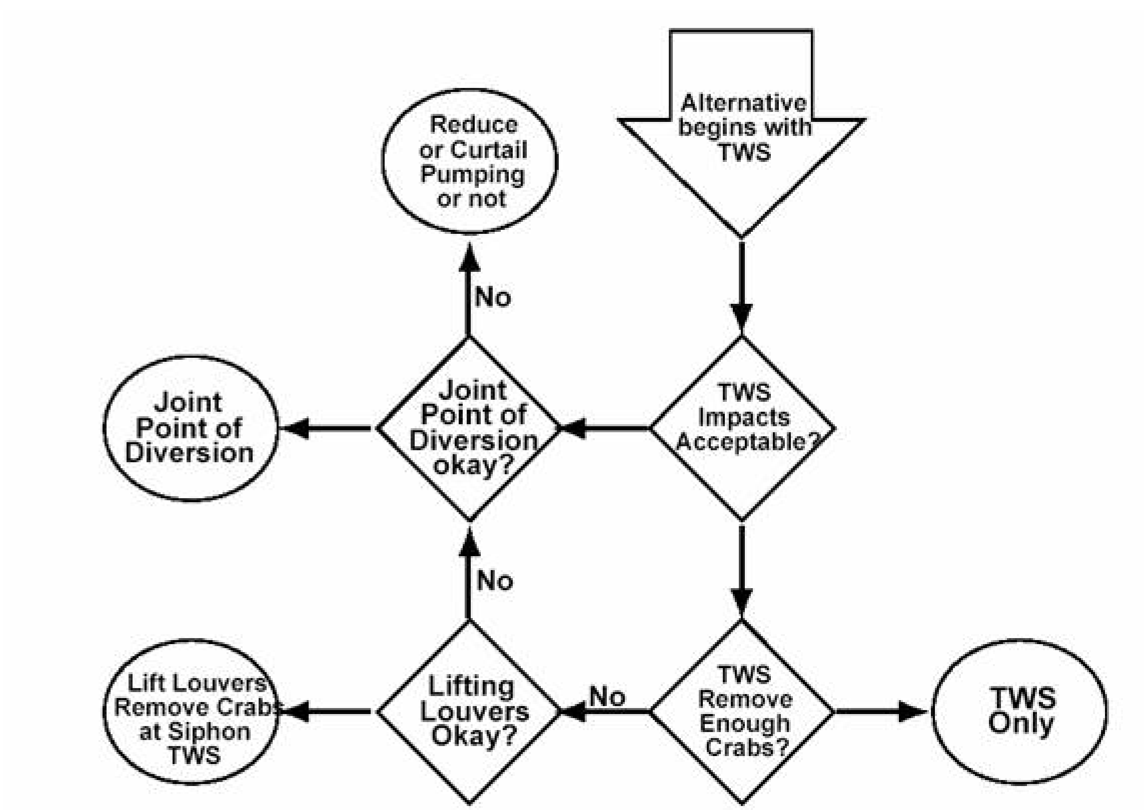
Crab removal efforts were mainly reactionary, and in some cases, experimental. The method that showed the most promise was a scaled down version of a travelling water screen (TWS), which removed over 80% of crabs from the water column in the secondaries. Laboratory testing of appropriately scaled models at Reclamation's Technical Services Center (TSC) in Denver have removed an even higher percentage.

After developing and discussing a number of alternatives, as outlined in the Mitten Crab Management Plan (attached), Reclamation has decided to select as its preferred alternative a "combination" alternative, which entails the TWS as its centerpiece. Other actions produced 16 alternatives, often in various combinations, and included joint point of diversion, lifting of louvers to let crabs pass the TFCF, removal of crabs outside of the TFCF, crab removal by fish friendly pumps to above ground pools, and restricted pumping.

Comments from specialists from all but one of the appropriate regulatory agencies have been gathered and incorporated into the main body of the recent draft of the crab management plan. We realize that if the TWS does not work effectively, then immediate coordination and consultation will take place with the other resource agencies, stakeholders, and within Reclamation to determine alternative courses of action (contingency plans, in attached flow chart). It is our hope that these contingency actions and their criteria for activation will be sanctioned well in advance of their being needed. Since informal review is near completion, we would like to take the next step of gaining official approval, in writing. This may entail entering into an "Agreement", or MOU.

If the TWS is found to exert unacceptable impacts upon the fish (as determined by Tracy Office Management as well as by regulatory agencies), then we will pursue joint point of diversion with SWP. If this is not possible, we will have to either stop pumping or continue, facing the consequences. If the TWS exerts acceptable impacts upon the fish and works well, it will be the sole chosen method of crab control. If the impacts are acceptable, but the TWS is not keeping pace with an overabundance of crabs, then the option of also lifting louvers will be considered. If this is an option, then crabs will be removed from the DMC at the Byron Road siphon. If this is not an option, we will consider joint point of diversion. If joint point is not an option, we will either stop pumping or continue, facing the consequences. Comments from appropriate regulatory agency specialists have been gathered and incorporated into the main body of the recent draft of the crab management plan.

In summary, there are at least five possible actions: 1) Sole TWS implementation; 2) joint point of diversion; 3) lift louvers and use TWS; 4) cease pumping; or 5) continue pumping, with consequences (management will have to help me determine what we think the consequences will be). It may be possible that at any time any combination of these actions may be chosen as we feel appropriate. Aggressive monitoring and mitigation programs will be assured as complications with endangered or other special status species are possible.



Decision-making flow chart for TWS contingencies.

Management Alternatives for the Tracy Office (Bureau of Reclamation), in Anticipation of Further Detrimental Impacts by Chinese Mitten Crabs Upon Fish Salvage Operations at the Tracy Fish Collection Facility (TFCF)

Introduction

Mitten Crab Overabundance

There has been an exponential increase in Chinese mitten crabs entrained through the Tracy Fish Collection Facility (TFCF) since they were first collected there in September, 1996. These catadramous crabs have expanded their range from the San Francisco Bay into the Delta. They are drawn on their annual seaward breeding migration to CVP export flows pumped through the TFCF. Their numbers entrained at the TFCF increased from mere dozens in 1996 to over 30 000 in 1997, to over 775,000 in 1998, a 25 fold increase over the last two years. Of the crabs entrained through the TFCF in 1998, over 500,000 were extrapolated from ten-minute fish counts (subsampling) and over 275,000 were estimated to have been removed by trapping. Over 90% were collected in September and October (Figure 1). The start of peaks in 1997 and 1998 coincided closely with the onset of cooler water temperatures (Figures 2 and 3).

As the numbers and range of mitten crabs has increased, so has the length of time over which they are collected. Now they are captured nearly year-round. The majority entrained have been males (Figure 4), travelling at night (Figure 5). Trapping efforts at TFCF indicate that they primarily move along the bottom of the channel. If the crabs continue to increase at the present rate and south Delta barriers are not in place, as many as 20 million may migrate to the TFCF in September and October, 1999.

Crab Removal Efforts

Starting in September, 1998, the mitten crabs began to migrate to the TFCF in such high numbers that they clogged many of the fish salvage features. This resulted in the deaths of thousands of fish that would have been salvaged under normal operations. To successfully salvage fish, it became imperative to separate them from crabs. Mechanical crab removal or separation efforts were undertaken in the secondary channel and holding tanks and included trapping, dipping, and screening. Captured crabs were buried and killed off-site.

A crab trap with numerous additional modifications was constructed and placed in the secondary channel. Modifications included adding baffles and a funnel, adding a pump, and finally adding a deflector (Figure 6). Each was periodically subjected to lifting currents which lowered the traps' efficiency, and revealed the crabs' habit of moving along the bottom of the channel. The crab trap's removal efficiency was near 60% when it rested on the bottom but near zero percent when currents lifted it off the bottom *(Appendix A).* When the trap was modified, its efficiency was similar but ranged widely as it was still subjected to lifting currents. Traps were only efficient when maintained properly, which required extensive effort.

The effects of crab trapping on fish salvage were not well quantified but numerous qualitative observations were made. White catfish, yellowfin gobies, and other bottom dwelling fish species were captured in traps (direct loss) while few or none of the midwater or pelagic fish species were captured *(Appendix B).* Indirect loss due to the traps' interference with salvage "criteria" flows could not be determined from the limited testing.

Fish salvage operations in the collect tanks were modified concurrent with trap testing in the secondary channel in order to salvage as many fish as possible. Changes included drawing down the water in the collect tanks at a different rate and lowering the collect tank screen in order to separate crabs from fish. The fish were then loaded into the fish haul trucks for release back into the Delta and the crabs into a dump truck for disposal in the spoils area. This procedure proved effective but lengthened the salvage effort *and still killed and/or missed an undetermined and possibly significant number of fish.*

Another method of separating crabs from fish, called "dipping", was implemented into the modified salvage procedure. This entailed dipnetting fish fr0m 500 gallon buckets used to load fish in transport trucks. This apparently worked quite well for separating pelagic and midwater fish from crabs. The procedure's effect on bottom dwelling fish was detrimental as these fish were killed along with whatever crabs made it this far. Further testing of trapping and dipping efforts was abandoned when they were deemed inefficient.

Another effort involved using a travelling screen originally designed for removing debris in the secondary channel lab model located at Reclamation's Denver Technical Research Center (TSC) was tried and tested for filtering mitten crabs from salvage operations. This modular unit fit within the 8 ft wide channel but did not occupy its entire height. The screen was operated for 6 days, showing it was at least 80% efficient under most conditions *(Appendix* C). TSC engineers believe that with improvements to better fit the TFCF secondaries, it could remove over 90% of the crabs. Plans are under way to have a full-sized unit built and installed to the TFCF secondaries before the mitten crab migration in 1999.

<u>Alternatives</u>

Alternative Development

Reclamation is concerned that next year's mitten crab invasion will overpower the salvage operations at the TFCF and has charged the Tracy Office with formulating management alternatives for dealing with the anticipated invasion. Dealing with the mitten crab invasion will be exascerbated by the potential removal of south Delta barriers on October 1, 1999, and subsequent onslaught of debris. The Tracy Office's Fish Facility Branch is drawing upon their experience with the biological, mechanical, and operational aspects of mitten crab control to develop alternatives for dealing with them. The following is a discussion of the considerations used by the Fish Facility Branch for developing the alternatives.

Note: Alternatives take into account that Chinese mitten crabs will most likely arrive in the vicinity of TFCF sometime in September or October 1999, at around the time that temperatures in the Delta begin to drop noticeably. Most mitten crabs move at night and primarily along the bottom and sides of waterways. Close coordination with the Interagency Ecological Program (IEP) is needed in order to track the crabs and water temperatures in order to best be prepared for their arrival.

General Explanation of Alternatives and Comparisons Between Them

Fourteen alternatives were developed at a brainstorming session involving Fish Facility Branch personnel. The alternatives included a No Action alternative (i.e. no change from existing operations), utilization of the travelling water screen, lifting the louvers, crab removals from the intake channel or at south Delta barriers or within the TFCF, re-operation or reductions in pumping through the TFCF, nonstructural barriers, trashrack alteration, or a combination thereof.

Since the last draft of this document, we have added options for joint point of diversion as negotiated between Reclamation and DWR. DFG comments (Appendix D) indicate that such an arrangement "would allow the SWP/DWR to possibly do make-up pumping at the same time the CVP is curtailing for mitten crabs, thereby negating any net reduction in CVP diversions. This may be possible throughout much of the mitten crab season at the TFCF... ". ThIs is possible because the SWP has not experienced the same impacts at the same time as the CVP, and may not do so in 1999, either. Joint Point of Diversion is an option which applies to all alternatives that include reduced pumping. Another additional option is the testing of the fish friendly pumps to above ground tanks as a system for pumping and separating crabs from salvage. This would only be initiated on an evaluative basis.

Criteria for analyzing alternatives were: 1) financial cost; 2) additional manpower required; 3) risk to fish salvage; 4) risk to water supply (exports); 5) whether or not the alternative can be implemented in time for the 1999 crab migration; 6) public relations value; 7) crab elimination efficiency; 8) required permits and environmental documentation; and 9) whether or not it is anticipated that stakeholders will buyoff on the alternative. Analyzing alternatives was completed through comparisons and is outlined in *Appendix E.* The assumptions underlying all alternatives are: 1) that in 1999 more crabs will be entrained through the TFCF than in 1998; 2) south Delta barriers will remain in place until October 1 (Reclamation is in the process of reviewing the possibility of leaving south Delta barriers in place until the crabs have migrated out of the Delta); and 3) crabs will be removed from Tracy Office property and handled by contractors as specified under contract.

Alternative 1. No Action.

If mitten crab numbers continue to increase exponentially, they will exceed the TFCF's ability to handle them, especially if south Delta barriers are removed at the same time. As of late Spring 1999, the barriers had not been placed, so debris will still be a problem, but not in uncontrollable amounts. The impacts will be much like in 1998, when barriers were not in place. While debris will not be released all at once, crabs will be allowed to migrate to the TFCF. If they arrive in far greater numbers than in 1998, continuous cleaning may be necessary. Extensive cleaning will be required on primary and secondary louvers as well. If they pass through the secondaries, they will again clog the holding tanks, 500 gallon loadout buckets, release pipes in the trucks, and pipes at release sites. In 1998, when thousands of crabs were allowed into some truckloads, most fish died in hauls to release sites. The situation would likely happen again in 1999 under the "No Action " alternative.

The No Action alternative would: 1) be low cost until we are forced into another alternative, ultimately at a higher cost; 2) require at least 2 additional people to handle crab separation operations at the TFCF; 3) have maximum risk to fish salvage as crabs would clog TFCF fish salvage features and most fish would die; 4) have high risk to water supply as pumping may be halted until effective fish salvage can be assured; 5) be implementable by the time the crabs arrive; 6) have minimal public relations value as it would show neither the creativity nor preparation expected of us by other agencies, the public, or our stakeholders; 7) have a minimal crab elimination efficiency as many would still be released back to the Delta; 8) would not require permits or environmental documentation; and 9) *would not be expected to obtain buyoff from our stakeholders.

**NMFS comments on the No Action alternative indicate that the mitten crab's adverse impacts on fish collection and handling have the potential to require cessation of pumping should listed species be present. We do not anticipate any NMFS-regulated species being present. We do, however, expect splittail to be present in the vicinity of the TFCF and do not expect to get buyoff from USFWS for the same reasons that NMFS voiced their concerns above (high mortality in salvage attempts).*

**San Luis: Delta-Mendota Water Authority (Authority) comment that they do not find the No Action to be a viable alternative (Appendix F).*

<u>Alternative 2. The Travelling Water Screen (TWS) with minor operational changes.</u>

The TWS showed the most promise last year as far as removing crabs from the TFCF bypass system. TSC engineers believe they can provide a model which could remove over 90% of crabs. Presently, they are working on researching the model' s effects on fish salvage at their Denver laboratory. Plans are also under way to have a full-sized unit built and installed to the TFCF secondary channel by August, 1999 for full testing. This alternative would have the screen left in the secondary portion of the bypass system for the duration of the crab migration.

Alternative 2 would: 1) be low cost in terms of additional funds, as money is already being set aside for the screen's construction, operational testing, and research of its efficiency in collecting crabs and minimizing impacts on fish salvage; 2) require 1-2 additional people to maintain it; 3) *have relatively low fish salvage risk and; 4) *have low water supply risk; 5) can be installed prior to the next crab migration; 6) be good for public relations as it shows that we have been working on a TWS solution since September, 1998; 7) have a high crab elimination efficiency; 8) require a study design and report, and alteration of our 1992/1998 salvage Agreement with DFG; and 9) * * *be expected to receive buyoff from all stakeholders.*

*Note: This alternatives assumes the TWS will operate proficiently without complications or shutdown. Since a TWS of this size has not been tried over an extended period of time within the secondary channel then it can't be stated with any reason of certainty, other than limited testing at the TSC lab and at the TFCF, whether or not complications will arise. In the event that complications do arise resulting in ineffective or non-use of the TWS, then other arrangements will need to be made in order to handle the mitten crabs. These other arrangements could result in increased risk factors towards fish salvage and water supply operations.

***Note regarding alternatives* 3,6, *6a,* 7, *and 7a, all of which incorporate use of the TWS: According to DFG comments (Appendix D), more intensive, and quantified studies (both before and after installation and implementation) of the TWS, investigating its impacts upon salvage efficiency and hydraulics, would need to be carried out. Results of these studies would be used to quantify salvage, loss and take under T &E Species Biological Opinions, especially if splittail and some Spring-run chinook salmon are present. If Reclamation cannot quantify these effects, there is a chance that NMFS and USFWS might derive more conservative ways of estimating a take penalty to be imposed on top of salvage estimates made during the time period of TWS operation.*

***NMFS comments (Appendix E) state that if fish are present and the TWS does not work, they will not have much discretion to stand by and watch substantial "takings" of fishes they are charged with protecting under ESA, which may include proposed listings for Central Valley fall and late-fall chinook scheduled for decisions in September of* 1999. *Any take level, depending on its severity, has the potential to halt pumping.*

***NMFS has voiced no objections to trying the TWS, deferring critical evaluation until it has been tried and debugged, and its effects, both good and bad, evaluated by NMFS. They want it removed when no longer needed. USFWS has not yet responded and is being pursued as a participant in this process.*

***Authority finds this, and all others with TWS and without lifting of louvers or pumping reductions, to be viable alternatives and will assist in the maintenance and installation, as a partner to Reclamation, which is funding it (Appendix F).*

<u>Alternative 3. Travelling Water Screen (TWS) with Reduced Pumping.</u>

Actions under Alternative 3 would be the same as Alternative 2, except that it would also entail reductions in pumping to aid the TWS and other TFCF operations. Reduced pumping would entrain fewer crabs into the TFCF and require less manpower to handle them. The TWS and other operations could then better able to keep pace with the fewer crabs showing up. However, reduced pumping means less water being pumped during this time of the year and the lost water would probably have to be made up some how. We don't expect this to be a popular alternative within our agency or amongst the water user community.

Alternative 4. Lifting the Louvers (only) to allow crabs to pass through the TFCF.

This management alternative proposes to alter salvage operations by lifting the primary louvers high enough to let the crabs pass along the bottom (6 inches), allow most topwater and midwater fish to enter into the bypass system, and allow much of the debris and bottom dwelling fish to flow on down to the Tracy Pumping Plant (TPP). Reclamation would probably be required to mitigate for fish lost from the Delta to the DMC. One big negative impact from this alternative would be the influx of crabs and debris showing up at the TPP and subsequently into the Delta Mendota Canal (DMC).

Actions under Alternative 4 would: 1) be mid-range in cost, as operational costs would be negligible, but costs for mitigating the loss of bottomfish could be incurred; 2) no additional people would need to be hired, but an increase in incidental assistance would be required of existing personnel; 3) fish salvage risk would be quite high for bottom fish, as they would be lost under lifted louvers; 4)* high risk to water supply, as the potential for conflict exists between resource agencies' directives for fish salvage in violation of existing agreements; 5) be implementable by the time crabs arrive at the TFCF; 6) have low public relations value. Although we would demonstrate an effective way to separate crabs from our salvage, we would be losing many fish to the DMC, which would be unpopular with much of the public and with resource agencies. ; 7) crab elimination efficiency would be mid-range as it would be high for the TFCF but low for the TPP & DMC; 8) require NEPA documentation and a rewriting of the existing 1992/1998 Agreement for operations of the TFCF to allow for operational changes and mitigation for lost fish; and 9)** not be expected to obtain stakeholder buyoff from the environmental community or resource agencies because of fish lost under louvers. Furthermore, it is expected that water users' would be concerned that the additional crabs conveyed into the DMC would threaten the integrity of the pumps, turnouts, and other structures, and that mitten crabs could eat their crops and burrow into levees and banks.

*Authority believes there is too much risk to the water districts if louvers are lifted and crabs end up pumped into the DMC (Appendix F).
**Alternatives which entail the lifting of louvers (4,5,6,7, 7a) have DFG and NMFS concerned. The former's concerns center on their not agreeing to our assumption that predominantly bottom fish would be lost and that lifting the louvers alters our salvage estimation process by removing much of the louvering process itself. DFG was not aware that we are only suggesting a six inch lifting. NMFS (comments, Appendix E) neither accepted nor rejected louver lifting, but stated that if it were employed, they might re-evaluate Reclamation's allowed incidental take to account for additional unscreened area. Reclamation believes they can allow 99% of crabs under the louvers, and keep 99% of splittail, salmon, steelhead, and smelt from doing the same. The only special status species they anticipate impacting is the white sturgeon, and those occur in very low numbers. They will monitor the event if it takes place and might do preliminary tests by lifting the secondaries 6 inches and testing crab and special status fish species entrainment there. Reclamation will mitigate any impacts that they determine to exert.

Alternative 5. Lift Louvers to allow crabs to pass through and remove crabs from the intake channel before they reach TPP and points downstream in the DMC.

This alternative would be basically the same as Alternative 4 except that crabs would be removed from the intake channel prior to reaching the TPP. Either Reclamation or a contractor service could perform the removal procedure. If a contractor performed the procedure, then the removal method would have to be approved by Reclamation and within IEP guidelines. Methods could include nets or traps set in the intake channel or at the outflow of the Byron Road siphon. Either location would allow for room to operate without impacting watercraft travel, as none is permitted within the DMC, and would only require land use permission from Reclamation. If contracted out, the contracting process could be extensive, complicated, and time-consuming, as much of the technology will be new and untested. The quality and quantity of potential contractors could improve in the future if crabs are approved for harvesting and marketing.

Actions under Alternative 5 would: 1) be higher cost than just lifting the primary louvers by themselves. (Cost of removing crabs from the intake channel is unknown at this time.); 2) require at least one additional person to monitor and assist in the crab removal contract; 3) risk fish salvage the same as with lifting louvers by themselves but be a greater risk than alternatives utilizing the TWS; 4)*risk water supply less than Alternative 4 because crabs would be removed from TPP and points downstream in the DMC, but be greater than alternatives 2 and 3 because it is less acceptable than the TWS concept to resource agencies; 5) be doubtful that a contract could be let in time for the crab migration in 1999; 6) be much better for public relations than Alternative 4 as crabs would not only be removed from the TFCF, but would entail collecting crabs prior to reaching the TPP; however, it would not be as good for public relations as TWS alternatives 2 and 3 because bottomfish would most likely be lost; 7) have a crab elimination efficiency higher than alternative 4, but less than TWS alternatives 2 and 3 because crabs will still enter the TFCF bypass system anyway; 8) require NEPA, complex contracting, and rewriting of the existing 1992/1998 Agreement for TFCF operations because of operational changes and mitigation for lost fish; and 9) probably not obtain stakeholder buyoff from the environmental community or resource agencies because of fish lost under louvers unless they are mitigated for or covered in incidental take.

**Authority believes this alternative would require more testing and trial methods to ensure that crabs are removed prior to the intake of the pumps, but may be an option for next year. Otherwise, there is too much risk to the water districts if crabs are pumped into the DMC (Appendix F).*

Alternative 5a. Lift Louvers to allow crabs to pass through. Remove crabs from the intake channel before the reach TPP and points downstream in the DMC and Reductions in Pumping.

This alternative would be basically the same as Alternative 5 except that pumping would be reduced to reduce the number of crabs entrained through the TFCF. This would allow TFCF operators to keep pace with the increased workload volume and complexity.

Alternative 5a would: I) cost slightly more than alternatives 4 and 5, in terms of lost water, unless the lost water is made up elsewhere, and also considerably more than TWS alternatives 2 and 3 which will remove most crabs at minimal cost; 2) require fewer than the one additional manpower in 5 and the one or more in TWS alternatives 2 and 3; 3) be less fish salvage risk than 5 as reduced pumping will be better for fish salvage and more than 2 and 3 which do not involve louver lifting and subsequent loss of bottomfish; 4)* have slightly lower water supply risk than 5, although reduced pumping is already part of this alternative. The reduction is a concession that will please resource agencies to the point that further reductions should not be requested, and higher than alternatives 8-10 because they entail creative harvesting; 5) quite possibly not be implementable this year because of contract complexity; 6) have an even lower PR rating than alternative 5 because of the reduction in pumping, and basically be the same as the lifting louvers only alternative because gains made in removing crabs are cancelled out by fish losses and reductions in pumping; 7) have a crab elimination efficiency higher than alternatives 4 and 5 because of reduced pumping bringing in fewer crabs, but lower than TWS alternatives 2 and 3; 8) require NEPA, contracts, and rewriting of the existing 1992/1998 Agreement for *TFCF* operations because of operational changes and mitigation for lost fish; and 9) probably not obtain stakeholder buyoff from water users because of reduced pumping, or the environmental community or resource agencies because of fish lost under louvers.

**Authority would not accept this alternative as it requires a reduction in pumping (Appendix F).*

<u>Alternative 6. Lift Louvers to allow crabs to pass through and Travelling Water Screen.</u>

Alternative 6 was developed to combine the two very effective methods of eliminating crabs from salvage operations. Unfortunately, they are mutually exclusive. There is little value in doing one when doing the other. If the majority of the crabs are leaving the TFCF under the louvers, then a TWS would not be necessary. If the TWS works well, there is no reason to take the risks associated with lifting the louvers.

Alternative 6 would: 1)* be less costly than the alternatives which include intake crab removal (5, 5a, 7, 7a), but more costly than Alternatives 2-4 which do not; 2) require 1-2 additional people to assist in operating the TWS; 3) have a lower fish salvage risk than alternatives 4 and 5 which do not include the TWS, the same as alternative 7, slightly higher than alternative 5a which includes reduced pumping, and significantly higher than alternatives 2 and 3 which do not .require lifting of louvers; 4) has a slightly lower water supply risk than Alternative 1 which has great uncertainty, higher than all but alternative 4 because they either include the TWS or intake channel crab removal or alternatives 8-13 because they entail creative harvesting, and the same moderately high level as Alternative 4 because neither includes intake crab removal; 5) is implementable in time for the crab migration in 1999; 6) has a mid-range PR value, higher than those with reduced pumping (3 ,5a, 7a) or lifting louvers only (4) and lower than those which mainly entail crab trapping or the TWS (2,5,7,8-13); 7) have a crab elimination efficiency less than those which employ even more methods of control (7 -13) and those which only include the TWS (2) and greater than the No Action alternative and those without the TWS; 8) require NEPA, contracts, and rewriting of the existing 1992/1998 Agreement for TFCF operations because of operational changes and mitigation for lost fish, and effectiveness monitoring report on the TWS; and 9) not be expected to obtain stakeholder buyoff from the environmental community or resource agencies because of fish lost beneath the louvers.

**Authority believes this method is not cost effective as it is redundant (TWS and lifting louvers doing the same thing)(Appendix F).*

<u>Alternative 7. Lift louvers to allow crabs to pass through. Travelling Water Screen. And Remove crabs from the intake channel before they reach TPP Tracy Pumping Plant and points downstream in the DMC.</u>

Alternative 7 was developed by combining the two very effective methods of eliminating crabs from salvage operations. Unfortunately, they are once again mutually exclusive. There is little value in doing one when doing the other; if the majority of the crabs are leaving the TFCF under the louvers, then the TWS would not be necessary. If the TWS works well, there is no reason to take the risks associated with lifting the louvers.

Alternative 7 would: 1) be moderate to high cost due to the cost of the contract to remove crabs from the DMC and mitigate lost fish but less than alternatives 5a and 7a which are similar but also require reduced pumping; 2) require 1-2 additional people (or more) to assist in operating the TWS and oversee the crab removal contract, which is more than any other alternative except the No Action alternative and #8 which require at least 2 people for assistance; 3) have a lower fish salvage risk than alternatives 4 and 5 which do not include the TWS, the same as #6, slightly higher than #5a which has reduced pumping, and much higher than #2 and #3 which do not require lifting of louvers; 4)* has a much lower water supply risk than #1 which has great uncertainty , and #4 and #6 which do not include trapping, higher than #2 and #3 because they include a TWS and 8-13 because they entail creative harvesting, and similar to 5, 5a, and 7a because they too include trapping; 5) quite possibly not be implementable in time for the crab migration in 1999 due to the complexity of contracts, etc.; 6) have moderate PR value, higher than those with reduced pumping (3, 5a, 7a) or lifting of louvers (4, 5, 5a, 6, 7), because it employs the TWS, but is less than #3 with TWS only and #s 8-13 because they avoid lifting the louvers and involve active removal of crabs; 7) have a crab elimination efficiency less than those which employ even more methods of control (#s 7, 7a) and those which only include the TWS (#s 2 and 3) and greater than the No Action alternative and those without the TWS; 8) require NEPA, contracts, rewriting of the existing 1992/1998 Agreement for TFCF operations because of operational changes and mitigation for lost fish, and effectiveness monitoring; and 9) not be expected to obtain stakeholder buyoff from the environmental community or resource agencies because of fish lost under the louvers.

**Authority believes this alternative would require more testing and trial methods to ensure that crabs are removed prior to the intake of the pumps, but may be an option for next year. Otherwise, there is too much risk to the water districts if crabs are pumped into the DMC (Appendix F).*

<u>Alternative 7a. Lift Louvers to allow crabs to pass through. Travelling Water Screen. Remove crabs from the intake channel before they reach TPP (Tracv Pumping Plant).and points downstream in the DMC. and Reductions in Pumping.</u>

Alternative 7a was developed to combine several very effective methods of eliminating crabs from salvage operations. Unfortunately, they also may be mutually exclusive. There is little value in doing one when doing the other; if the majority of the crabs are leaving the TFCF under the louvers, then the TWS would not be necessary. If the TWS works well, there is no reason to take the risks associated with lifting the louvers. If the TWS does not work well because of overloading, then reduced pumping might be necessary.

Alternative 7a would: 1) be high cost due to the cost of additional manpower for the TWS and the contract to remove crabs from the DMC, the cost of the contract to mitigate lost fish, and cost to make up pumping; 2) require 1-2 additional people to assist in operating the TWS and oversee the crab removal contract, which is more than any other alternative except the No Action alternative and alternative 8 which require at least 2 people for assistance; 3) have a lower fish salvage risk than alternatives 4 and 5 which do not include the TWS, and the risky No Action, slightly less than those which are similar but do not reduce pumping, the same as 5a which does not have the TWS or reduced pumping, higher than those with the TWS (2 and 3) or creative harvesting (8-13) slightly higher than 5a which has reduced pumping and much higher than 2 and 3 which do not require lifting of louvers; 4)* has a much lower water supply risk than 1which has great uncertainty , and 4 and 6 which do not include trapping, higher than 2 and 3 because they include the TWS and 8-13 because they entail creative harvesting, and similar to 5, 5a, and 7 because they too include trapping; 5) quite possibly not be implementable in time for the crab migration in 1999 due to the complexity of contracts, etc.; 6) have a PR value as low as or lower than all but the No Action alternative because of reduced pumping and lifting of louvers; 7) have a high crab elimination efficiency because many methods of control have been confined with reduced pumping, less than the TWS alternative with reduced pumping (3) and trashrack alteration (9); 8) require NEPA, contracts, rewriting of the existing 1992/1998 Agreement for TFCF operations because of operational changes and mitigation for lost fish, and effectiveness monitoring; and 9) not be expected to obtain stakeholder buyoff from the environmental community or resource agencies because of fish lost under louvers, or the water user community due to reductions in pumping.

**Authority believes this alternative would require more testing and trial methods to ensure that crabs are removed prior to the intake of the pumps, but may be an option for next year. Otherwise, there is too much risk to the water districts if crabs are pumped into the DMC (Appendix F).*

<u>Alternative 8. Harvest Crabs from in Front of TFCF by Reclamation</u>

The best place to remove crabs would be in front of the trashrack structure. Harvesting behind the trashrack structure would also be highly beneficial, but the lack of room to operate would be an issue, plus crabs would still pile up onto the trashrack structure itself. If the crabs could be collected in front of the TFCF it would prevent crabs from entering the TFCF and allow for efficient fish salvage operations. There are advantages to Reclamation performing the work: knowledge of the facility , liability is already established, and the work would be better coordinated with along with the normal workload. Unfortunately, Reclamation may not have the time or resources to develop a method for harvesting the crabs in front of the TFCF.

Alternative 8 would: 1) be medium to high cost, assuming that the project would be expensive but that Reclamation could implement the alternative for less cost than a contract; 2) require at least 2 additional people, likely even more, to carry out the work. More than any other alternative; 3) have lower fish salvage risk than all but the TWS (2 and 3) and re-operation (10) alternatives; 4) have lower water supply risk than all but TWS only (2), harvesting in front of TFCF by contract (8a), and nonstructural barriers (9); 5)** quite possibly not be implementable in time for the crab migration in 1999 due to the complexity of designing a method for harvesting crabs and getting it installed and operational; 6) have higher PR value than all except alternatives 8a and 13 which likewise remove crabs before they can impact the TFCF, and slightly higher than nonstructural barriers (9) which divert crabs from the TFCF but do not remove them from the Delta; 7) have a unknown crab elimination efficiency because removal methods have not been determined as of yet; 8) require NEPA documents in order to operate in front of the TFCF, which would likely be a negative declaration; 9) *be expected to obtain buyoff from all stakeholders.

**NMFS withholds full acceptance of this alternative, depending on techniques.*
***Authority believes this would be an acceptable option if they had enough time to determine the method of removal and time to test its effectiveness (Appendix F).*

<u>Alternative 8a. Harvest crabs from in front of TFCF by contract.</u>

This alternative was developed under the assumption that Reclamation would neither have the interest nor the resources available necessary to design, plan, and implement a crab harvest program for in front of the TFCF. Doing so under contract will require contract development and occasional coordination with TFCF operations staff. Actual methods have not even been determined, making the possibility of this happening this year a major uncertainty.

Alternative 8a would: 1) be high cost, assuming that the effort by contract would be more expensive than if done by Reclamation; 2) require fewer than one additional person to assist in overseeing the work; 3) have lower fish salvage risk than all but the TWS (2 and 3) and re-operation (10) alternatives; 4) have lower water supply risk than all but TWS only (2), harvesting in front of TFCF by Reclamation (8), and nonstructural barriers (9); 5)** not be implementable this year, require NEPA documents, contracts, rewriting of the existing 1992/1998 Agreement for TFCF operations because of operational changes and mitigation for lost fish, and effectiveness monitoring; 6) higher PR value than all except alternatives 8 and 13 which likewise remove crabs before they can impact the TFCF, and slightly higher than the nonstructural barriers (9) alternative which diverts crabs from the TFCF but do not remove them from the Delta; 7) have an unknown crab elimination efficiency because removal methods have not been determined as of yet; 8) require NEPA documents in order to operate in front of the TFCF, which would likely be a negative declaration, and require a somewhat complicated contract; 9) *be expected to obtain buyoff from all stakeholders.

**NMFS withholds full acceptance of this alternative, depending on techniques.*

***Authority believes this would be an acceptable option if they had enough time to determine the method of removal and time to test its effectiveness (Appendix F).*

Alternative 9. Nonstructural barriers

Biological controls, including crabicides, sound; light deterrents; electricity, sterilization, etc. are outside of the scope of the Tracy Office's research capabilities for the upcoming crab migration season. However, these alternatives were discussed as reasonable and prudent alternatives because one of them might prove to be quite effective in the future. None have been tried at the TFCF and each would probably require more time than is available to be set up. In the meantime, electricity, and possibly, strobe lights, will be tested in the near future on crabs in the experimental fish screen in Denver at the TSC lab. There are too many questions at this time to be able to compare to the other alternatives.

*NMFS would like to see details of what we propose in order to comment.

***This alternative is acceptable to Authority, but with insufficient time to prove efficiency (Appendix F).*

Alternative 10. Re-Qperation

The 1998 TFCF fish salvage operational modifications were crudely effective and marginally acceptable by DFG. This re-operation alternative was included in our discussions in order to explore further changes to last year's operations in the unlikely event that we will need to resort to last year's operations scenario. The major component of this particular alternative is to operate the TFCF during the day only, as most crabs are entrained at night, and assumes that those crabs that would have been entrained at night will not be entrained at all. This assumption may very well be flawed as it is not known for sure whether those crabs not being entrained at night won't simply be entrained during the next day's operations. This may well be the case as crabs were still entrained in experiments when TFCF pumps were turned on for several minutes at a time, weeks after pumping had ceased. This alternative carries an high degree of uncertainty. There is also valid concern over the loss of export water, unless it can compensated for. Other methods could include increased frequency of haulouts with fewer crabs and fish, increased manpower and labor-intensive manual crab removal throughout the TFCF, increasing the lift height of the lift screen in the holding tanks, and increasing the diameter both of the outlet pipe on the fish haul truck outlets on loadout buckets (as per DFG comments, Appendix D). Such changes would salvage more fish but allow for easier transport of crabs, as well.

Alternative 10 would: 1) incur potentially high costs to make up lost water; 2) require no additional manpower; 3) incur low fish salvage risk (assuming it works in theory); 4)* high water supply risk; 5) be implementable in time for the crab migration; 6) have moderate PR value as reductions in pumping would make it unpopular with water users but somewhat popular with the environmental community and resource agencies; 7) possibly not eliminate crabs, but simply delay them, yielding a low crab elimination efficiency; 8) not require environmental documentation as reduced pumping is already considered to be part of standard operating procedures under the existing 1992/1998 Agreement for TFCF operations; 9) not expected to obtain buyoff from water users.

Authority finds this alternative unacceptable in that there is no opportunity to make up the lost pumping conveyance, too much risk to pumping losses (Appendix F).

<u>Alternative 11. Harvest crabs from within TFCF (by contract)</u>

This alternative was developed to explore the possibility of removing crabs from within the TFCF compound. There may be some advantages to doing this: 1) much of the necessary equipment could stay on-site, near operators who could monitor crab removal effectiveness; 2) contractors could remove all crabs, including those found in fish salvage and fish counts, taking them off Reclamation's hands; 3) save Reclamation the effort and time that they would expend themselves, in harvesting crabs. Major disadvantages include: I) Fish Facility operators' time will likely be needed to assist when procedures do not go well; 2) space constraints at the TFCF may preclude the presence of an operation of the size needed to capture and process crabs; 3) untested interference with "criteria" flows required to efficiently salvage fish brought on by structures placed within the TFCF.

This alternative would: 1) be low direct cost to Reclamation, but high cost for a contract: overall moderate; 2) require less than one additional person; 3) have moderate to high fish salvage risk as effects of the harvest would be unknown until the work begins, and because there is a chance it could interfere with standard operating procedures; 4) have moderate to high water supply risk related to the uncertainty of the work's impacts on criteria flows, which, if appreciable, might prompt resource agencies to request a halt in pumping; 5)**quite possibly not be implementable in time for the crab migration in 1999 due to the complexity of contracts and designing effective crab harvest procedures; 6) have moderate PR value, but resource agencies might not support untested harvest methods; 7) effectively remove the crabs from the facility; 8) require NEPA documents, contracts, rewriting of the existing 1992/1998 Agreement for TFCF operations because of operational changes and mitigation for lost fish, and effectiveness monitoring; 9)*not be expected to obtain stakeholder buyoff due to the uncertainty of the entire operation.

**NMFS withholds full acceptance of this alternative, depending on techniques.*

***Authority finds this alternative unacceptable in that there does not appear to them to be enough time to define an acceptable method of harvesting crabs without possibly interfering with the fish salvage (Appendix F).*

<u>Alternative 12. TrashRack Alteration</u>

Because most crabs can penetrate the trashrack structure, but not the louvers *(shell dimensions do not allow it, sievenet observations behind the secondaries bear this out),* it would be possible to prevent most crabs from entering the TFCF if the trashrack spacing was narrowed to the same size, or smaller, than that of the louvers. Reclamation would hire a contractor to build and install a new trash rack. Although this would likely prevent crabs from entering the TFCF, the rack would continuously foul up with debris and crabs, thereby not filtering fish the way it was originally designed. There would also be increased risk of differential head forming between the front and back of the trashrack, thus lowering the downstream water elevation and potentially overloading the structure. This alternative does not appear favorable as water agencies would not support a new structure that violates the salvage Agreement nor would water users support an alternative which would threaten their exports if it doesn't work.

Alternative 12 would: 1) be high cost to build the structure and possible shutdown of pumping if/when it does not work; 2) at least one additional person, maybe even two, would be needed to continuously clean the rack; 3) high fish salvage risk; 4)*high water supply risk; 5) not be implementable in time for the crab migration in 1999; 6) have potential for high PR value if the rack can be kept clean and agreement could be reached on altering the design of the facility; 7) have a very high crab elimination efficiency; 8) require NEPA, contracts, rewriting of the existing 1992/1998 Agreement for TFCF operations because of operational changes and mitigation for lost fish, and effectiveness monitoring; 9)* not be expected to gain stakeholder buyoff as water users will be concerned that the trashrack will not be able to hold up to the onslaught of debris and crabs and could threaten water exports.

**Authority believes that there are no data to support the trash rack's ability to handle increased loads and that its loss could be catastrophic to the operation of the TPP and DMC (Appendix F).*

***NMFS cautiously thinks this alternative might work with modern, automated design (Appendix E).*

<u>Alternative 13. Collect crabs at barriers</u>

This alternative would require that south Delta barriers be left in place through the end of October and entails collection of crabs at barrier culverts by personnel from other resource agencies. This alternative has since become quite unlikely as the water year began wet and barriers were not placed.

This alternative would: 1) be low cost to Reclamation, as other agencies would be responsible for cooperating; 2) require no additional manpower (within Reclamation); 3) have the potential for low fish salvage risk and; 4) water supply risk; 5) quite possibly be implementable this year (1999); 6) have maximum PR value as crabs would be dealt with by an interagency effort and removed before they reach the TFCF & TPP; 7) have high crab elimination efficiency because should remove most of the crabs prior to reaching the TFCF; 8) require NEPA documents, contracts, rewriting of the existing 1992/1998 Agreement for TFCF operations because of operational changes and mitigation for lost fish, and effectiveness monitoring; and 9) may or may not be expected to receive full support from all stakeholders as it represents an interagency approach to dealing with the mitten crab problem. The complication here is the potential for effects of barrier removal upon the possibly "soon to be listed Stanislaus/San Joaquin fall-run chinook salmon adult immigration. It may also affect delta smelt if their center of concentration is in this part of the Delta in specific water year types" (DFG comments, Appendix D). NMFS believes this may be a good idea, and less expensive than trying to do the same thing at the TFCF.

The Authority would make this alternative their first choice as it removes the crabs farthest from the pumping plant, and would combine this alternative with #2.

Recommendations

This Year (1999), an Adaptive Management Process

The flow chart below details the decision process that the Tracy Office of the Bureau of Reclamation will follow. For the upcoming mitten crab migration, the Tracy Office recommends pursuing construction and installation of a travelling water screen (TWS) device and installing it in the secondary channel of the fish facility as an effective means of separating crabs from the fish and with minimal impact to fish salvage operations. Additional manpower will be on-duty to assist with operation of the TWS and on-call in the event that problems arise related to use of the TWS. Removal of the crabs from the facility will be pursued through contract. If for some reason a contract can't be set up, Reclamation will consult with DFG regarding alternative removal efforts.

In the event that the TWS alternative by itself does not work effectively, then immediate coordination and consultation will take place with the other resource agencies, stakeholders, and within Reclamation to determine alternative courses of action *(contingency plans*). If, for instance, the TWS is found to exert unacceptable impacts upon the fish (as determined by Tracy Office Management as well as by regulatory agencies), then we will pursue joint point of diversion with SWP. If this is not possible, we will have to either stop pumping or continue, facing the consequences. If the TWS exerts acceptable impacts upon the fish and works well, it will be the sole chosen method of crab control. If the impacts are acceptable, but the TWS is not keeping pace with an overabundance of crabs, then the option of also lifting louvers will be considered. If this is an option, then crabs will be removed from the DMC at the Byron Road siphon (Lloyd does not like this one). If this is not an option, we will consider joint point of diversion. If joint point is not an option, we will either stop pumping or continue, facing the consequences. In summary, there are at least five possible actions: 1) Sole TWS implementation; 2) joint point of diversion, 3) lift louvers and use TWS; 4) and cease pumping; or 5) continue pumping, with consequences (management will have to help me determine what we think the consequences will be). It may be possible that at any time any combination of these actions may be chosen as we feel appropriate.

If no other alternatives are immediately available, the Tracy Office will resort to last year's operations modifications until directed otherwise *(as discussed in paragraphs* 2 *and* 3 *on page* 2 *of this document).*

The Tracy Office also recommends that serious consideration be given towards collection of the crabs at the south Delta barrier sites. This has the potential for providing tremendous benefits to fish facility and pumping plant operations and if moved on could quite possibly be implemented this year.

Monitoring

The Tracy Office, through involvement with Denver TSC, and coordination with IEP, has been evaluating the TWS model in their Denver laboratory, through effectiveness (removal of crabs) and evaluative (impacts upon fish salvage) studies. Continuous effectiveness (as a crab removal method) and evaluation (of impacts upon salvage) monitoring will continue after the full sized unit is placed in the TFCF secondaries. Studies will also be undertaken using the fish friendly pumps to above ground holding tanks as a method of systematically separating crabs from fish. Any other new methods of crab control employed (impacts of louver lifting upon splittail, crab collection at siphon outlet, for example) will be subject to investigation, as well. These studies will be overseen by accredited fisheries scientists {professors) and follow a monitoring plan that is still in production.

Possible Mitigation

Mitigation requirements will be determined through evaluation of impacts upon salvage and loss, most noticeably to special status and endangered species. Mitigation will be partly a function of incidental take as calculated by regulatory agencies in response to results from research and monitoring efforts Reclamation undertakes in conjunction with crab management activities. Mitigation can be direct financial recompensation, or the stocking of salmon, striped bass, or sturgeon (will eat mitten crabs as well as replace fish lost to DMC) habitat restoration, or other means.

Coordination

Recent developments pertaining to TFCF operations have indicated that the mitten crab management plan is, essentially, re-operation, and may be covered under other agreements which can be re-written to provide for more flexibility and interagency coooperation. One case in point is the 1992 *Agreement between Reclamation and Fish and Game to Reduce and Offset Direct Fish Losses at the Tracy Fish Collection Facility, which is being re-written with consideration of anticipated operational changes, which could include mitten crab management. Another case in point is the SWP's mitten crab control plan, which is quite similar to ours. They intend to follow many of Reclamation's leads, as well as to diverge where they wish to act differently. Their alternatives for controlling crabs at their facility are likely to be more structural, and between their methods and Reclamation's, the best future means of crab control can be determined.*

Future Years

Much of what will be implemented in future years depends on what does and what does not work this year. Between Reclamation and DWR, a full range of methods will be tested. For future years, the Tracy Office not only recommends continued thought be given towards collecting crabs at the south Delta barriers, but that other means of harvesting crabs throughout the Delta be seriously considered, especially in front of the TFCF. Alternative means of diverting crabs away from the confluence of the TFCF and TPP should also continue to be studied for viability.

Alternative	Cost	Additional Manpower	Fish Salvage Risk	Water Supply Risk	This Year ?	PR	Crab Elimination Efficiency	Permits And Env. Docs	Stake Holder Buyoff ?
1. No Action	Lo/Hi	2	10	8	Y	1	1	No	No
2. Travelling Water Screen	Lo	1-2	3	2	Y	4	8	Report, Design, Agreement	Yes
3. Travelling Water Screen + Reduced Pumping	Lo + H2O	1	2	*3	Y	2.5	9	Report. Agreement	No
4. Lift Louvers	Lo +mit$	<1	7+	7+	Y	2	5-	NEPA	No
5. Lift Louvers +intake crab removal	M-Hi +mit$	<1	7+	3+	?	3	5+	NEPA, contracts	No
5a. Lift Louvers +intake crab removal +reduced pumping	M-H +mit$ +H2O	<1	6	3+	?	2	6+	NEPA, Contracts, Agreement	No
6. Lift Louvers +Travelling Water Screen	Lo +mit$	1-2	6+	7+	Y	2.5	6+	NEPA, Report, Agreement	No
7. Lift Louvers +Travelling Water Screen +intake crab removal	M-H +mit$	1-2+	6+	3+	?	3	7+	NEPA, Contracts, Agreement, Report	Yes
7a. Lift Louvers, +Travelling Water Screen, intake crab removal, +reduced pumping	M-H +mit$ +H2O	1-2	6	3+	?	2	8+	NEPA, Contracts, Agreement, Report	No
8. Harvest in front of TFCF by BOR	M-H	2+	3	2	N	4	5?	Agreement	Yes
8a. Harvest in front (contract)	Lo	0	3	2	?	4	5?	contract	Yes
9. Nonstructural barriers	M-H	0	?	2	N	4	5?	Report	Yes
10. Re-operation	Lo +H2O	0	2+	2+	Y	3-	3?	Agreement, Report	No
11. Harvest crabs from within TFCF (contract)	Lo	<1	5+	5+	Y	3	5	Agreement, Report	Yes
12. Trash Rack Alteration	Hi	1+	8	8	N	3.5	9	Agreement, Report	No
13. Collect crabs at Barriers	Lo	0	N/A	N/A	Y	4	8+	Report	Yes

May 20,1999

Appendix E. Summaries of the "High Risk" Areas: Columbia River, Hudson River, Mississippi River, St. Lawrence River

E.1. Mitten Crabs in the Columbia River Basin and Other Estuaries of the Pacific Northwest

Abundant estuarine and freshwater habitat, temperate climate, proximity to California, and significant shipping and live seafood traffic put Oregon and Washington at relatively high risk of invasion by the Chinese mitten crab. The Columbia River basin has been identified as particularly vulnerable given its exposure through several major ports, population centers in Portland and Vancouver, and extensive network of rivers and streams. In fact, a single male mitten crab (identified as the Japanese species, *Eriocheir japonica*) was collected in 1997 by a sturgeon angler near the mouth of the Columbia River in Astoria, Oregon. Although no other specimens have been collected and verified, there have been several other unconfirmed reports of mitten crab caught in the lower Columbia River as recently as the summer of 2001. A small-scale trapping program is underway in response to these reports. If mitten crabs could successfully travel past Bonneville Dam and the other major Army Corps of Engineer projects in the basin (which may prove difficult because of the massive nature of these projects), their migratory range suggests they could extend upstream to northeastern Washington as well as into Idaho via the Snake River system. Mitten crabs could also occupy the heavily populated Willamette River watershed if able to navigate past the natural barrier of Willamette Falls at river mile 26. Such an invasion might bring major impacts similar to those seen in California and Europe. The Clackamas River enters below the Williamette and would also be exposed to the risk of negative impacts from the crabs. The federal listing of a number of salmonid species under the Endangered Species Act in Oregon and Washington heightens the potential severity of their ecological impacts in the region. Mitten crabs could wreak havoc at the numerous fish ladders, fish traps, tide gates, and other structures critical to fish and water management.

Although the Columbia River basin offers immense potential for freshwater rearing grounds, mitten crab populations could be limited by the relatively small amount of estuarine habitat suitable for egg and larval development. The Columbia River salt wedge extends 40-50 miles into the estuary but only a small portion offers salinities above the 25 parts per thousand associated with proper egg development and adherence (Vincent, 1996). It is unknown how the Columbia River plume would affect survival of zoeal larvae in nearshore waters particularly the later stages that require higher salinity environments (Anger, 1991).

From the perspective of saltwater habitat, other estuaries in the Pacific Northwest may be equally vulnerable to invasion. Coos Bay, an active port on the southern Oregon coast, contains approximately 13,000 acres of estuarine habitat. Although the Coos River watershed offers relatively low levels of freshwater rearing habitat, it could serve as a stepping stone for mitten crab invasion into the Northwest. Other Oregon estuaries that may provide adequate habitat abundance and pathway links include Yaquina Bay on the central coast and Tillamook Bay on the north coast. In Washington, Puget Sound and adjacent straits represent another significant risk of mitten crab introduction, both in terms of vulnerability to invasion and the magnitude of potential economic and ecological impacts. The Puget Sound basin includes over one thousand square miles of marine waters fed by12 major rivers and as well as many smaller drainages. On the Washington coast, Grays Harbor and Willapa Bay contain hundreds of thousands of acres of suitable estuarine habitat. Willapa Bay hosts a number of invasive species, many of which are associated with the area's prominent aquaculture operations. Grays Harbor is fed by a more extensive river system and is also more exposed to risk from ballast water discharges than Willapa Bay.

Summary cooperatively developed by:
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Stephen Phillips, Pacific States Marine Fisheries Commission
Mark Sytsma, Portland State University
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E.2. Susceptibility of the Hudson River Basin to *Eriocheir* Species

The Hudson River is the source of potable water for six municipalities and for New York City during drought emergencies. It is also the cooling water source for six electric generating stations, the largest of which is the Indian Point Nuclear Generating Station. There is no major diversion of water for agricultural uses in the Hudson River watershed and the water storage reservoirs used to regulate flows during the summer lie above the Troy Dam at Troy, New York, which forms the upper limit of the tidal section of this estuary. The impact of mitten crabs on the water intakes in the tidal section of the estuary is the issue of greatest concern to the municipal and industrial users of water from the Hudson River. The proximity to air cargo imports, live seafood markets and the exposure to large population centers in New York elevates the risk for mitten crab introduction into the Hudson River.

The Hudson River is essentially a drowned valley with environmental conditions within the reported tolerance levels for Chinese mitten crabs. There are no dikes along the tidal stretch of this estuary. There are railroad embankments along the length of the river between New York City and Albany. Suitable habitat exists along the length of the river, in various forms and locations. The Hudson River also has over fifty tributaries that also may have suitable habitat. The interconnectivity of the inland waters of New York highlights the special risks involved to this state. In particular, if the crab enters the Erie Canal through the Mohawk River, levees could be threatened. The dominant vegetation in the shallow water areas in the freshwater section of the estuary is an exotic nuisance species, the water chestnut (*Trapa natans*). Thus, the potential impact of mitten crabs on the submerged plant community is not a major issue. Except for a gill net fishery for American shad during the spring, there are no commercial fisheries within this estuary. However, the recreational fisheries for striped bass, blue crab, and freshwater game species are very large and the potential impact of mitten crabs on these fisheries is a major concern.

The lower portion of the Hudson River estuary has a detritus-based food web and the major fish species depend upon epibenthic invertebrate populations. The benthic and epibenthic invertebrates are probably the organisms most likely to be affected directly by mitten crabs and the food web in the lower portion of the Hudson River may be especially susceptible to disruption by this nuisance species. The presence of a major food resource, zebra mussels, in the upper portion of the Hudson River estuary increases the concern about an irruption of mitten crabs and a change in the food web in the lower portion of the estuary. As a practical aside, a large number of mitten crabs could be collected at the cooling water intakes at the electric generating stations if this species became abundant in the Hudson River estuary. Crab disposal could also be a problem.

Biological and Geographic Information provided by:
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E.3. Suitability of Mississippi River Habitat to Support Chinese Mitten Crab Populations

The Mississippi River is one of the world's major river systems in size, habitat diversity, and biological productivity. It is the largest river in North America, stretching 2,358 miles from the headwaters at Lake Itasca, Minnesota to the Gulf of Mexico in southeastern Louisiana. The Mississippi river, third longest river in the world and the seventh greatest in terms of discharge, is managed primarily as a flood control outlet and commercial waterway. The river's watershed includes approximately 1.2 million square miles, or about 41% of the continental US and a small portion of Canada. Most of the river and its ecosystem have been extensively modified for commercial navigation and other human developments. Much of the watershed is intensively cultivated, and many tributaries deliver substantial amounts of sediment, nutrients, and pesticides into the river. Pollutants also enter the river from both metropolitan areas and industrial sites (Status and Trends of the Nation's Biological Resources, Volume I).

The Mississippi River can be divided into two distinct hydrogeomorphic regimes: The Upper Mississippi River (UMR), flowing 1,462 kilometers from St. Anthony Falls in Minneapolis, Minnesota to the mouth of the Ohio River at Cairo, Illinois, and the Lower Mississippi River (LMR) Alluvial Plain, from Cairo to the Gulf of Mexico (Lew, 1995; Derby et al., 1995). The Mississippi River is characterized by many oxbow lakes and sloughs, natural and man made channels, with major tributaries and many meandering streams. Human development has greatly altered the Upper and Lower Mississippi River and its floodplain. Intensive channelization to facilitate navigation and extensive modification with levees to accommodate agriculture and protect human development from flooding, also has contributed to the significant alteration of the river (Grubaugh and Anderson 1988; Interagency Floodplain Management Review Committee 1994). Erosion caused by human activities, such as agriculture and construction within the watershed, has increased the rate of sediment delivery to the receiving waters. Runoff has also increased because water storage in the watershed has been reduced by drainage of wetlands, urbanization, and other factors (Interagency Floodplain Management Review Committee 1994).

Water quality problems occur throughout the length of the Mississippi, though the type of problems and their seriousness vary greatly. Point source pollution is a particularly serious problem in the LMR where the states from Arkansas to Louisiana are home to some of the country's most polluting industries. The most severe water quality problems attributed to nonpoint runoff in the UMR are excessive loadings of suspended solids, nutrients and sediment, and contamination from toxic materials, including pesticides and heavy metals. These problems are associated with rapid accumulation of silt and sediment in the backwaters of the River, increased rates of eutrophication from elevated nutrient levels, and increased levels of ammonia and pathogens from animal wastes (Robinson and Marks 1994).

The LMR channel is wide and generally shallow in the northern part of its alluvial valley, with course bed material delivered by tributaries. In the southern part of the valley the channel is comprised mainly of silt and clay (Autin et al., 1991). The two major distributary channels extend outward from the main-stem near Baton Rouge, Louisiana, and extend southward into the Gulf of Mexico, with associated natural levee ridges, forested swamps, and coastal marshes. Aquatic macrohabitats of the LMR channel environment are characterized by the main river channel, secondary channels, sandbars, gyres below bars, tributary mouths, natural banks, and areas associated with dike systems and revetted banks (Cobb and Clark 1981). The Missouri River is the principle supplier of sediment to the Mississippi. According to Keown et al., 1986, presently, about one-fourth of the suspended sediment load of the Mississippi River is diverted to the Atchafalaya River (a major distributary channel). The LMR and Atchafalaya River estuarine environments are important production areas for many fishes and invertebrates. With 41% of the U.S. coastal wetlands and 25% of all U.S. wetlands, Louisiana is home to one of the Earth's largest and richest estuarine areas (Johnston et. al., 1995). In the LMR, saltwater from the Gulf of Mexico generally intrudes some distance upstream from the mouth of Southwest Pass, Louisiana. The extent of intrusion depends primarily on river discharge; however, flow duration, wind velocity and direction, tides, and riverbed configuration all influence the movement of saltwater in the Mississippi River (Lupachev, 1976). Salinity levels (measured as chloride concentrations) in the Mississippi generally range from approximately 25 mg/L (upstream surface levels) to approximately 20,000 mg/L, (associated with intrusion at the lower depths of a saltwater wedge in the Delta region; (Rodney Mach, pers. comm.).

Numerous species of animals and plants have been introduced into the LMR. Many of these (e.g. zebra mussels) are extremely detrimental to industrial and other infrastructure, and can threaten native species. Zebra mussels entered the UMR via the Illinois River. Zebra mussel populations expanded rapidly, and by mid-1993, they were found throughout most of the Upper and Lower Mississippi River (Sparks et al. 1994; Benson and Boydstun 1995). Other aquatic nuisance species that occur in the LMR include water hyacinth, hydrilla, purple loosestrife, nutria, and several species of carp. The Chinese mitten crab (*Eriocheir sinensis*), is a catadromous species, i.e. reproduction occurs in water of higher salinities. Juveniles of this species then migrate upstream in the spring to freshwater areas to develop. Adult crabs from 1-5 years of age then migrate back downstream to brackish water where they mature and reproduce. Within the United States, the mitten crab is known to be established only in the San Francisco Bay Delta, although they have been reported in other areas of the country, including a specimen collected from the Mississippi River Delta (1987) (D.Felder, pers. comm.). However, since the initial observation, monitoring efforts conducted by the University of Louisiana at Lafayette for the presence of this species have been unsuccessful (Marilyn Barrett O'Leary, pers. comm.). The coastal wetlands and estuarine habitat of the LMR would likely provide suitable habitat to support Chinese mitten crab populations.

Beckett et al. 1983, Beckett and Pennington, 1986, indicate that, in addition to other variables, the distribution of benthic invertebrates in the LMR is strongly influenced by current velocity and substrate composition. Channel habitat is characterized by deep water, a swift current (1-5 meters per second), and constantly shifting coarse-sand or gravel substrates (Fremling et al. 1989; Baker et al. 1991). The shifting, course sand and gravel substrates of the main and secondary channel habitats in the LMR support few macroinvertebrates (Wright, 1982; Beckett et al.1983; Beckett and Pennington, 1986) . Abandoned channels characterized by slack currents and silty substrates, support high densities of invertebrates, including phantom midges, segmented worms, and fingernail clams (Mathis et al., 1981; Beckett et al., 1983; Beckett and Pennington 1986). The hard substrates provided by revetments, stone dikes, and articulated concrete mattresses (used to control bank erosion) support significant numbers of invertebrates in the LMR (Mathis et al. 1982, Beckett and Pennington 1986, and Way et al. 1995). Rocky substrates associated with dike structures have been shown to support higher total densities of aquatic invertebrates than abandoned channels, natural river banks, dike field, temporary and secondary channels, sandbars, revetted banks, main channel, and permanent secondary channels (Mathis et al., 1981, 1982; Wright 1982). Therefore, substrates associated with abandoned channels and dike structures would likely provide suitable habitat for mitten crabs. Mitten crabs might also inhabit areas near the banks (possibly in muddy or sandy substrates) and the channel bottom, where the current is slower. In addition, the coastal wetlands of the Atchafalaya and the Mississippi River delta could provide adequate nursery and estuarine habitat to support the critical reproductive phase of the mitten crab's life cycle before migrating to the upper portions of the river.

The UMR also supports a diversity of benthic invertebrates. Much of the UMR is characterized by sand and gravel substrates, in addition to significant sediment deposits. Elstad (1986), who studied habitat on Lake Onalaska, found at least 144 taxa of benthic invertebrates; eight major groups, including segmented worms, leeches, flies, isopods, amphipods, snails, and bivalve mollusks, including pearly mussels. Between 1975 and 1990, the species composition of the benthic invertebrate communities surveyed in the UMR near La Crosse, Wisconsin, showed 19% occurring in open-water habitat, 44% in bays, 50% in side channels, and 62% in marshes. The riverine habitat of the UMR, with its negligible salinity levels, ample supply of benthic invertebrate prey species, and varying substrate composition, could provide adequate habitat conditions to support mitten crab populations during the juvenile and non-reproducing adult phases of the species' life cycle.

The Chinese mitten crab was reported to have proliferated and spread so successfully in Germany as to negatively impact levees (through burrowing) and fisheries (through interfering with the catch and damaging nets) (Panning 1939). It appears that damage to levees or banks depends on crab densities, levee structure and bank suitability (Veldhuizen and Stanish 1999). If established in the Mississippi River or it's tributaries, mitten crabs could adversely impact coastal and riverine ecosystems, presenting a serious threat to levees, agriculture, other water diversion systems and possibly interfere with local fisheries. Like the San Francisco Estuary, the Mississippi River and its watersheds rely heavily on levees for flood protection and water diversion and would likely experience similar adverse impacts if faced with established mitten crab populations.

Summary provided by:
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E.4. Suitability of St. Lawrence River Basin Habitats for Mitten Crab Establishment

The St. Lawrence River is one of the largest and most uniformly flowing rivers in North America. An international waterway whose waters are shared with Canada, the river originates as the outflow of Lake Ontario and continues for 114 miles. Ninety nine percent of the flow above the power plants and diversion structures is from Lake Ontario. The drainage area of the St. Lawrence and its tributaries is a mixture of agricultural lands, municipalities and industries. This includes a broad range of intakes (agricultural, industrial and municipal) as well as point source and industrial discharges. Most of the St. Lawrence drainage is in New York. The lower half of the river includes Lake St. Lawrence, which includes shallow/littoral shoal waters, islands and deep constricted navigation channels. This results in upwellings, backwaters, and eddy currents. The banks of the river and the islands in Lake St. Louis and downstream tend to be highly erodable and would likely suffer significantly from mitten crab burrowing.

Temperatures generally peak about 22-23 C in August and decline to a minimum of about .5 C in Mid-January. In shallow waters, highs may reach 27 C. During the winter, the St. Lawrence experiences ice usually from early February. It forms and grows rapidly at first, then slowly expands for an average 5-week period. Very rapid erosion usually lasts 2 weeks only. Dissolved oxygen is reported to be adequate and relatively stable. Conductivity is locally variable, with some seasonal trends detected. pH values indicate that the system is well buffered, alkaline and hardwater. Lower pHs are typically found at the mouths of major New York tributaries. The system generally has high clarity with low turbidity values. Zebra mussels (Dreissena polymorpha) have been contributing to increasing water clarity by filtering large amounts of plankton and particulate matter from the water column since their introduction into the system in 1989. The river experiences some instances of nutrient loading, which can result in algal blooms, and excessive plant growth. Several localized areas have been identified as impaired for beneficial uses because of contamination and/or sedimentation issues. Sources may be high nutrient levels and pathogens from failing septic systems as evidenced by excessive alga growth. There is also a health advisory limiting consumption of selected fish species due to contaminants of priority organics such as PCBs, mirex, and dioxin. Source is suspected to be contaminated sediments assumed to be transported from Lake Ontario. PCBs are also input via local industry. Mercury is a contaminant of concern on the St. Lawrence. Toxic reduction projects are reducing the incidence of this metal in the system (Duke Engineering & Services, 1999).

In general, the St. Lawrence River seems to fall within the range of environmental conditions tolerable for mitten crab establishment (as discussed in Veldhuizen and Stanish, 1999). However, the winter ice period may be detrimental and an impediment to crab reproduction and survival, unless areas of 10C or warmer are accessible. The proximity to large population centers in New York, Quebec and Montreal highlight the risk of introduction of Chinese mitten crabs into this system through live seafood imports and releases. In 1999 and 2001, several commercial shipments of live Chinese mitten crabs were intercepted by U.S. Fish and Wildlife Service law enforcement officials, as they were being imported into New York via air freight (Sabia, pers. comm., 2000, 2002). The extensive shipping industry use of the St. Lawrence River also represents an especially elevated risk of introduction through the release of mitten crabs in ballast water. Approximately ten Chinese mitten crabs are known to have been collected from various areas of the Great Lakes, probably transported in ballast water (Veldhuizen and Stanish, 1999).

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Appendix F. Contact List for Organizations Managing the Genus *Eriocheir*

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