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**Delta Ecological Survey (Phase I):  
Nonindigenous aquatic species in the Sacramento-San Joaquin Delta, a Literature Review**

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## SUMMARY

Introductions of nonindigenous aquatic species (NAS) are a significant threat to estuarine and freshwater systems worldwide. Discharge of ballast water is an important pathway of these invasions, leading to national, international, and state efforts to regulate ballast water discharge and document the current status of NAS and rate of introductions into major port systems such as the Sacramento-San Joaquin Bay-Delta and river system. This project examines the sources, vectors, and extent of invasions into the Delta, the most upstream portion of the San Francisco Estuary system. We reviewed the literature on NAS in the Delta, developed a database format to store, organize and present this information, and analyzed the sources, vectors, and time-sequence of introductions of both estuarine and freshwater NAS currently found in the Delta.

We identified 193 definite or probable introductions into the Delta (69 plants, 89 invertebrates, and 35 vertebrates), and 25 cryptogenic species (17 phytoplankton species, 1 plant, and 7 invertebrates). Invertebrate introductions have increased over time since the 1850s, while introductions of fully aquatic plants and vertebrates show little trend with time, and marsh/riparian plant introductions have declined. Sources of introduced organisms are diverse, with most plants native to Europe or South America, invertebrates largely from either eastern North America or Asia (with Asian sources dominating in recent decades), and most vertebrates native to eastern North America. Pathways of introductions into the Delta are also diverse, and vary considerably among taxa: most plants represent either agricultural weeds or escaped ornamentals, vertebrates have largely been introduced via deliberate stocking (or are unintentional releases associated with stocking), while invertebrates are more likely to have reached the Delta via ship fouling or ballast water releases, along with unintentional releases with fish stocking and individual releases of aquarium, bait or food organisms.

Freshwater and estuarine NAS have distinct introduction histories, with estuarine organisms predominantly reaching the Delta via shipping-related vectors from sources in Europe and Asia, while freshwater organisms are largely from the Americas and Europe and are more likely to be introduced by fish stocking, agriculture, and individual releases. In recent decades, estuarine NAS have become increasingly associated with ballast water and Asian sources, while both the vectors and sources of freshwater NAS are becoming more diverse. Because freshwater NAS are dominant in the Delta, this suggests that ballast water regulation alone will not halt invasions into this system; reducing the rate of freshwater invasions will also require management of numerous diffuse and hard-to-control vectors.

### Summary of Recommendations:

- We recommend more thorough sampling, preferably on an annual basis and at least every 2-3 years, of several habitats and groups that are undersampled by current efforts. In particular, we recommend increased sampling of shallow water habitats, including small channels and sloughs, the margins of larger channels, and temporary pools; of vegetation; and of fouling communities. Improved taxonomic work is needed particularly for species-level identification of larval insects and of phytoplankton and periphyton.
- Continued assessment is needed of the effectiveness of ballast water control in slowing the rate of invasions into the upper estuary.
- We also suggest increased attention be given to other vectors which commonly bring freshwater species to the upper estuary, including aquarium and bait releases, recreational boating and fishing, and garden and ornamental pond escapes.

## **CHAPTER 1: Introduction**

Introductions of nonindigenous aquatic species (NAS) and their social, economic, and ecological effects are increasing. Introductions are considered the second most important threat to biodiversity (after habitat modification) in North America (Wilcove et al. 1998). Coastal marine, estuarine, and tidal freshwater systems are among the most invaded systems worldwide, though the extent of the invasion threat to these systems has been only relatively recently recognized and is still being documented (e.g., Carlton & Geller 1993; Cohen & Carlton 1995; Ruiz et al. 1997, Grosholz 2002). Discharge of ship ballast has been identified as a significant pathway for NAS introductions into these systems (Carlton & Geller 1993, Ruiz et al. 2000). The US Coast Guard implemented a voluntary ballast water exchange program in 1999 under the National Invasive Species Act of 1996. Evaluation of the efficacy of these guidelines in reducing introductions of NAS requires that baseline information be developed on the NAS currently present in estuarine systems.

The biological integrity of the aquatic resources of the Sacramento-San Joaquin River system is essential to the protection of anadromous and estuarine fishery resources of enormous importance to California. This river system drains some 40% of the land area of California, and provides at least a portion of the drinking water to more than 50% of Californians. The rivers and estuary have been dramatically altered in the last 150 years both physically and biologically through urbanization, draining and conversion of wetlands to agriculture, withdrawal and diversion of significant proportions of its annual flow for irrigation and urban water supply, and the introduction of large numbers of NAS which now dominate virtually every habitat sampled in the lower river and estuary (CDFG 1995; Cohen & Carlton 1995). Understanding the sources, extent and effects of invasions into this system, and slowing the rate of future invasions, is an essential component of ongoing efforts to restore the Bay-Delta and river systems.

### **Project Background Information**

This project was initiated in January 2003, and has been managed and carried out by a team of researchers at the University of California, Davis. Ted Grosholz and Peter Moyle were co-principle investigators for the project, responsible for administration of the budget and work plan. Theo Light was hired in February 2003 as a postdoctoral researcher, and has been responsible for carrying out the database development, literature search, data analysis, and report preparation. Our technical advisory committee (TAC) was made up of scientists familiar with the Delta and its native and nonindigenous species, who were consulted for their advice and taxonomic expertise at various stages of the project. The TAC included: Andy Cohen (San Francisco Estuary Institute), Lee Mecum (California Department of Fish and Game), Wayne Fields (Hydrozoology), Lars Anderson (UC Davis), Susan Ellis (California Department of Fish and Game), Kim Webb (US Fish and Wildlife Service), and Erin Williams (US Fish and Wildlife Service).

### **Project Objectives**

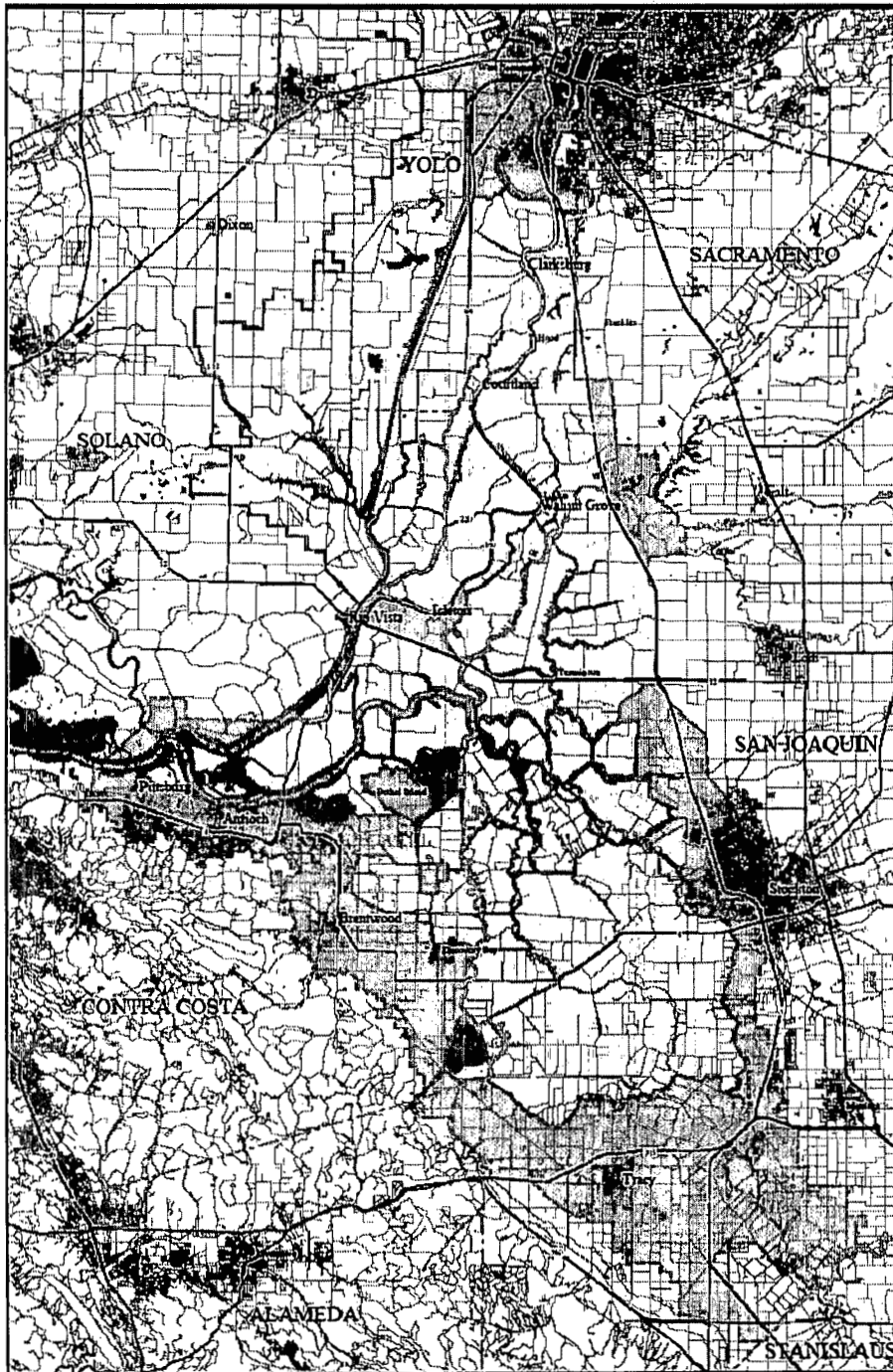
The purpose of this agreement was to survey available information regarding NAS in the Sacramento-San Joaquin Delta and river system (SSJR), in order to characterize the extent, sources, and vectors of invasions and provide a baseline for evaluating the rate of species introductions. The specific project objectives were to:

- Develop a database for NAS (known or suspected) identified through a literature search that includes the timeframe of introductions, native and source regions of introduced species, modes of introduction, geographic distribution, ecological and economic impacts, taxonomy and synonymy, references and other relevant information.
- Review existing literature (published and unpublished) on NAS that have invaded the SSJR to furnish the information relevant to the database.
- Summarize the findings of the literature survey, and provide: (1) an analysis of current diversity patterns, areas of NAS origin, and mechanisms of NAS delivery to the SSJR; (2) recommendations regarding the need for field surveys of taxa and areas poorly represented in the literature; (3) recommendations for a continuous monitoring program to assess future NAS invasions and changes from historical conditions; and (4) an assessment of the effectiveness of ballast water management and other vessel management guidelines issued and regulations promulgated under NISA and the State of California for limiting NAS introductions into the SSJR.

## **CHAPTER 2: Methods**

### **Study Area**

This work reports on NAS present in or adjacent to the Sacramento-San Joaquin Delta, the mostly freshwater upstream portion of the San Francisco Estuary system (CDFG 1995). The Delta is formed at the confluence of the Sacramento and San Joaquin Rivers, and encompasses about 1100 mi<sup>2</sup> of intersecting channels and islands of former tidal marsh, now mainly converted to agriculture. The legal Delta (CDFG 1995) encompasses the area from Chipps Island just downstream of the confluence of the mainstem Sacramento and San Joaquin Rivers upstream to the limits of tidal waters, including the lower reaches of the Sacramento, Cosumnes, Mokelumne, Calaveras and San Joaquin Rivers, as well as innumerable smaller streams, channels, and sloughs (Fig. 1).



**Figure 1:** The Sacramento-San Joaquin Delta. Shaded area is the “legal delta,” the area of our study. (Image from the California Department of Water Resources.)

### Literature review and database

We conducted an extensive review of published and unpublished literature and databases to compile an up-to-date listing, including available ecological information, of known or suspected species introductions into the SSJR. Data for each species were entered into a relational database developed in Microsoft Access. The database was based (in part) on two models: the SERC\_Invasions database of the National Ballast Water Clearinghouse (Smithsonian Ecological Research Center 2004), and the LCRANSdb database of the Lower Columbia River NAS Survey (Waldeck et al. 2003), though it was extensively modified from both of these to fit the goals and limitations of the current project. A complete description of the database structure can be found in Appendix A. Following is a listing of the categories of data included in the database:

**Taxonomy:** Scientific and common names, authority and date, synonyms, hierarchical classification. Taxonomic information generally was obtained from the Integrated Taxonomic Information System ([www.itis.usda.gov](http://www.itis.usda.gov)). Occasionally names and taxonomy follow sources other than ITIS when we considered these sources to be more reliable and/or current than those referenced in ITIS. For species not appearing in ITIS, taxonomic data were derived from the most recent authoritative source available.

**Identification:** Image and description (when available), commonly misidentified species.

**Invasion history:** Dates and locations of first collections in the Delta, central California, and western North America; probable invasion date (range); source and native regions; likely introduction vector(s); invasion and residence status; a brief narrative of the invasion history of the species; invasion history in other locations.

**Ecology:** When available, we included basic ecological information regarding body size; general abundance in the Delta; lifespan; fecundity; environmental tolerances (salinity, temperature, dissolved oxygen); trophic status and feeding mode; common prey and predator species; common parasites, commensals, and host species. These data were generally most available for vertebrates, particularly fishes.

**Habitats:** Here we followed the SERC model fairly closely and used (with some modification) their habitat classifications for "horizontal" (e.g., riparian, marsh, vegetation, open water, etc.) and "vertical" (e.g. benthic, littoral, pelagic, etc.) habitat. Separate habitat data can be entered for different life stages (e.g. juvenile and adult fishes), though this was not always done. Based on the center of abundance of the species within the estuary, we categorize species as "freshwater" or "estuarine"; the estuarine category is further subdivided into "regular in the Delta" (those species which are collected nearly annually in the Delta, but which have their center of abundance further downstream) and "rare in the Delta" (those species which have been collected only a few times in the Delta, but which are more abundant downstream).

**Distribution:** We provided a generalized picture of species distribution within the Delta and the lower reaches of its major tributaries.

**Collections:** For some species, we provided detailed information on collection sites, range of dates species were collected, frequency and densities. This was a late addition to the database to facilitate later expansion, and data are currently included for only a selection of benthic species.



**Invasion impacts:** We included a narrative account of known and suspected ecological and economic impacts of each NAS for which this information is available.

**References:** We provided complete citation information for all references, including abstracts (when available electronically) and keywords, with links to all referenced species appearing in the database.

### Sources

Sources for the data reported here fall into three main categories: (1) peer-reviewed published literature, obtained through the UC Davis Library and inter-library loan service, and in some cases online; (2) the "gray" literature, consisting mainly of government reports and some student theses, obtained as above as well as through personal contacts with agency biologists; and (3) online databases, a category of increasing importance both locally and nationally. Preliminary lists of nonindigenous and cryptogenic species compiled from these sources were then submitted to members of the TAC in their respective areas of expertise for corrections and clarification. We were fortunate to follow earlier major efforts to document the NAS and cryptogenic species of the San Francisco Estuary system; Cohen & Carlton's (1995) study was a foundational source of information and references on all taxonomic groups. Additional notable or particularly comprehensive sources for each of the major taxonomic groups include:

**Phytoplankton:** Laws (1988) gives a listing and brief ecological information on 273 diatom species identified from both surface sediments throughout the estuary and late Pleistocene (Sangamon) sediments beneath south San Francisco Bay. Current distribution and abundance of phytoplankton species were obtained from the Interagency Ecological Program's phytoplankton database (IEP 2003).

**Vascular plants:** We assembled a number of plant lists from both published and unpublished sources, including lists for Jepson Prairie (Witham 1996), the Sacramento Regional County Sanitation District bufferlands (SRCSD 2003), the Yolo Bypass Wildlife Area (Babba 1998), Delta Meadows River Park (Bowcutt 1996), and the lower Sacramento River near Collinsville (Willoughby & Davilla 1984). Two major sources of additional site records were the CalFlora plant occurrence database (Calflora 2003) and the UC-Jepson Specimen Management System for California Herbaria ("SMASCH", Jepson Herbarium 2003), both of which are available online. The latter two were particularly important sources for historic collections, allowing us to identify earliest collection dates in California and the Delta for most plant species. Ecology, habitat, and invasion history and impact data were derived mainly from Hickman (1993) and DiTomaso & Healy (2003), wetland indicator status from USFWS (1997), and introduction status elsewhere in the US from the USDA PLANTS online database (USDA 2002).

**Invertebrates:** Beyond what is included in Cohen & Carlton (1995), information on invertebrates in the Delta is relatively dispersed through the published and unpublished literature. The IEP database (benthos and fisheries, which includes many cnidarians and decapods) was the single most important source of distribution and abundance data for benthos and selected other groups (IEP 2003). Although zooplankton and mysids are also sampled under the IEP, these data are not yet available online, and we relied more heavily on published reports, particularly the periodic reports in the IEP Newsletter. Ecological data, when available, came from published papers and reports as well as more generalized sources (i.e., the freshwater invertebrate text of Thorp & Covich 2001).

**Fishes:** Moyle (2002) was our main source for information on life history, ecology, habitat, and invasion impacts; some additional ecological and taxonomic data were derived from FishBase (2003), an online database of fish ecology, taxonomy, and life history. Dill & Cordone (1997) give exhaustive accounts of the introduction histories of most nonindigenous fishes in California. Distribution and abundance within the Delta were obtained from the IEP fisheries database (IEP 2003).

### Criteria for inclusion

**Residence status:** We included in the main table of Delta NAS only aquatic species that are resident to or occasionally (at least once, for lower estuary residents) found within the boundaries of the legal Delta, as described above. We also include species that regularly migrate through the Delta; for most of these, at least one life stage makes extensive use of the Delta. A secondary table gives abbreviated information on NAS present in areas adjacent to the Delta, which could conceivably invade the Delta sometime in the future. For animals, we include only fully aquatic species, here ignoring the many essentially terrestrial reptiles, birds and mammals that can occasionally be found in Delta wetlands (Cohen & Carlton 1995). Plants are limited to species which are usually or always found in wetlands, those rated facW or above in Region 9 on the US Fish and Wildlife Service wetland indicator scale (USFWS 1997). For some analyses we further separate plants into fully aquatic (floating or emergent plants commonly found in standing water) and marsh/riparian species. This distinction was made based on habitat descriptions given in either DiTomaso & Healy (2003) or Hickman (1993).

**Invasion status:** Determining whether a species is native or introduced to a particular region is not always clear-cut, particularly for groups that do not fossilize well or for which regular sampling has begun relatively recently. Criteria for determining native or introduced status have been extensively discussed elsewhere (Chapman & Carlton 1991, 1994; Cohen & Carlton 1995; Ruiz et al. 1997). We followed the determinations of Cohen & Carlton (1995) for most species included in that report; for those not included we applied the criteria of Chapman & Carlton (1991, 1995). We assigned species to one of three categories: (1) **Definite invaders** are species for which most lines of evidence point to their introduced status, and there is broad consensus among experts that they are introduced to the SSJR. Often these are species for which there is a historical record of the introduction and/or the native and introduced ranges of the species are well-defined. (2) **Probable invaders** are those species for which several lines of evidence point to their introduced status, but there is some disagreement among experts regarding their introduced status in the SSJR and the extent of their native range. (3)

**Cryptogenic** species are those that cannot be definitively assigned as native or introduced. In many cases these are species for which the taxonomy is not sufficiently resolved to make a determination. Other species assigned to this category include "cosmopolitan" species in poorly studied groups for which there is some evidence that they may have a long association with mechanisms of human transport (e.g., many oligochaetes; Timm 1980). The listing of cryptogenic species in the current work is conservative rather than exhaustive.

### Vectors

As much as possible, we used the vector names, abbreviations, and categories in the SERC\_Invasions database. We changed the categories for certain vectors to suit the emphases of our analysis; for example, the vector "discarded bait" was moved from the category "Fisheries" to our category "Individual Releases". Vectors we use here which are not found in SERC (2004)

are AQ-aquaculture escapes, BC-biocontrol release, ErC-erosion control, EC-escape from cultivation, RecB-recreational boating/fishing, and RI-released by individual (unofficial plants other than bait or aquarium releases). Vectors in SERC (2004) that do not appear here include AP-aquatic plant shipments, CN-canal, and ND-natural dispersal. (Although some NAS previously introduced to northern California or the West may have reached the Delta by means of "natural dispersal", the original invasion vector was of more interest to our analysis.) Vectors appearing in this report are given in Table 1.

**Table 1:** Names, abbreviations, and categories of vectors bringing NAS to the Delta.

| <b>Vector Category</b>                |                                   |
|---------------------------------------|-----------------------------------|
| <b>Vector abbreviation &amp; name</b> |                                   |
| <b>Agriculture</b>                    |                                   |
| AW                                    | Agricultural Weed                 |
| ErC                                   | Erosion Control                   |
| EC                                    | Escape from cultivation           |
| <b>Biocontrol</b>                     |                                   |
| BC                                    | Biocontrol release                |
| <b>Fisheries</b>                      |                                   |
| AQ                                    | Aquaculture escape                |
| FA                                    | Fisheries Accidental (not Oyster) |
| FI                                    | Fisheries Intentional             |
| OA                                    | Oyster Accidental                 |
| OI                                    | Oyster Intentional                |
| <b>Individual releases</b>            |                                   |
| DiB                                   | Discarded Bait                    |
| GE                                    | Garden Escape                     |
| PR                                    | Pet/Aquarium Release              |
| RecB                                  | Recreational Boating/Fishing      |
| RI                                    | Released by Individual            |
| <b>Shipping</b>                       |                                   |
| BW                                    | Ballast Water                     |
| DrB                                   | Dry Ballast                       |
| FC                                    | Fouling Community                 |
| <b>Research</b>                       |                                   |
| SE                                    | Scientific Escape                 |
| <b>Unknown</b>                        |                                   |
| UnkV                                  | Unknown Vector                    |

### Analysis

We examined patterns in the sources, vectors, and time-sequence of invasions into the SSJR, restricting our analysis to species considered to be definite or probable invaders. Our analysis of invasion sources refers to the original source (native region) of the NAS, even if this was not the immediate source of the invasion. Native regions can usually be documented with more certainty than the immediate invasion source, and this analysis adds to our understanding

of global invasion patterns. Similarly, we focus on the invasion vector bringing the species to central California, even if it subsequently reached the Delta by natural spread.

## CHAPTER 3: Results

### General

We documented a total of 193 definite or probable introductions into the Delta (Appendix B), including 69 plants, 89 invertebrates, and 35 vertebrates (32 fishes, one amphibian, one reptile, and one mammal). Of these, the majority (139 species; 72%) were primarily freshwater species; of the estuarine species, 31 (16%) are regularly encountered in the Delta, while 23 (12%) are occasional visitors, with only one or a few collections in the west Delta.

We listed 25 species as cryptogenic in the Delta (Appendix C), including 17 phytoplankton species, 1 plant, and 7 invertebrates. As noted above, this list is conservative: many more invertebrates, including (as an example) most of the cosmopolitan oligochaetes in the estuary, could arguably be listed as cryptogenic (e.g., CDFG 2003).

### Vascular plants

Nearly all of the 69 species of nonindigenous plants in the Delta have freshwater affinities (67 species; 97%); the two estuarine species are regularly found in the Delta as well as Suisun Marsh and further downstream. Most plants fall into the marsh/riparian category (51 species; 74%), while 18 are fully aquatic.

Most plants introduced to the Delta were native to Eurasia (48 species; 70%), particularly Europe; several of these occur in North Africa as well (Fig. 2). Only 7 plants (10%) were native to eastern or central North America, though many of the European invaders probably reached California from eastern North America populations. Eleven plants (16%) were native to South America, and may have been imported either directly from that continent or from eastern North America (water hyacinth, *Eichhornia crassipes*, for example, was first introduced to the US in New Orleans) (Cohen & Carlton 1995). The remaining plants were native to Africa (2 species) and the south Pacific Islands (1 species).

Agriculture-related vectors (escaped cultivars, agricultural weeds, and plants used for erosion control) account for 36 (52%) of the introduced plants in the Delta (Fig. 3). Another 13 (19%) represent escaped ornamentals, which we grouped with aquarium releases (3 species; 4%) as individual releases for analysis. One species (curly pondweed, *Potamogeton crispus*) was apparently introduced accidentally with stocked fishes. At least one (brassbuttons, *Cotula coronopifolia*) and possibly two others may have been introduced with solid ballast. Fifteen plants could not confidently be assigned to any vector, and were classed as unknown, though possible alternate vectors were posited for some of these.

### Invertebrates

Not quite half of the 89 nonindigenous invertebrates in the Delta are mainly freshwater residents (44 species; 49%). Of the estuarine species, 22 (25%) are regularly found in the Delta while 23 (26%) are only rarely encountered. A diverse group, the invertebrate NAS are dominated by arthropods (43 species; 62%), annelids (17 species; 25%) and molluscs (10 species; 14%) (Appendix B).

Most invertebrate NAS were natives of either east Asia (33 species; 36%) or eastern North America (33 species; 37%), reflecting dominant patterns of both shipping and oyster stocking (Fig. 2). The remainder are natives of Europe (9 species; 10%), Australia (4), South America (2), Africa (1), or were of unknown origin (7).

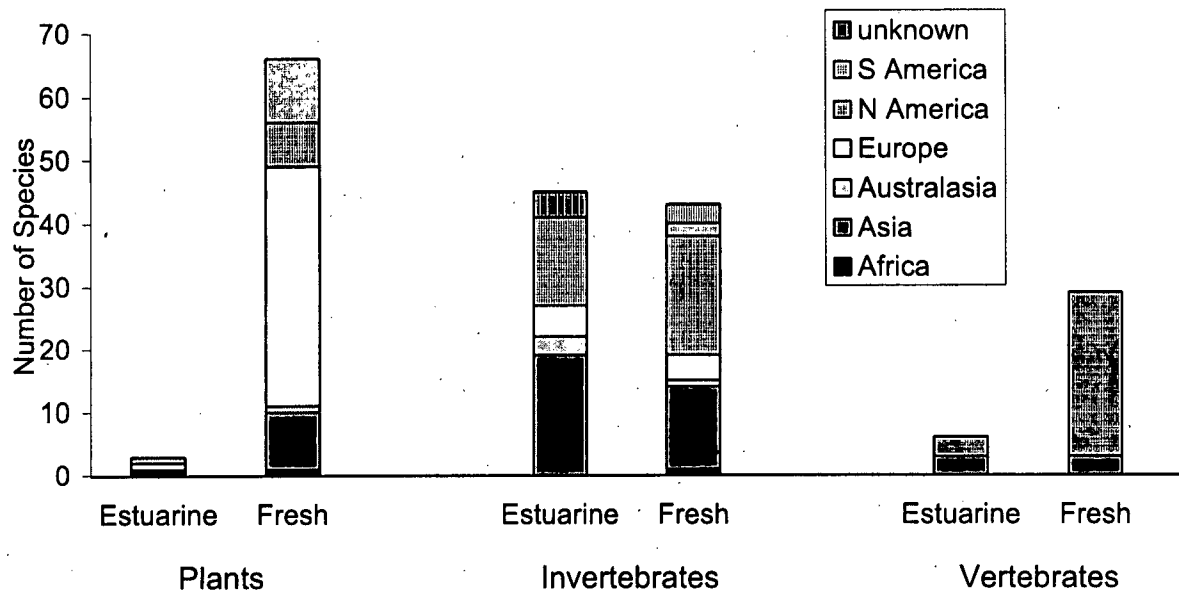
Shipping was the most likely vector for half the invertebrate invaders in the Delta (44 species; 50%), including 38 probable ballast water invaders, 9 species associated with ship fouling, and one with solid ballast (Fig. 3). Thirty-eight invertebrate NAS (42%) were associated with fish or oyster stocking, all but one of these (the deliberately stocked signal crayfish, *Pacifastacus leniusculus*) being non-target, "accidental" species. Remaining vectors include biocontrol releases (2 species), individual releases of food or aquarium species (4), likely hitchhikers on recreational boats or fishing gear (2), scientific escapes (1), and unknown vectors (1).

### Vertebrates

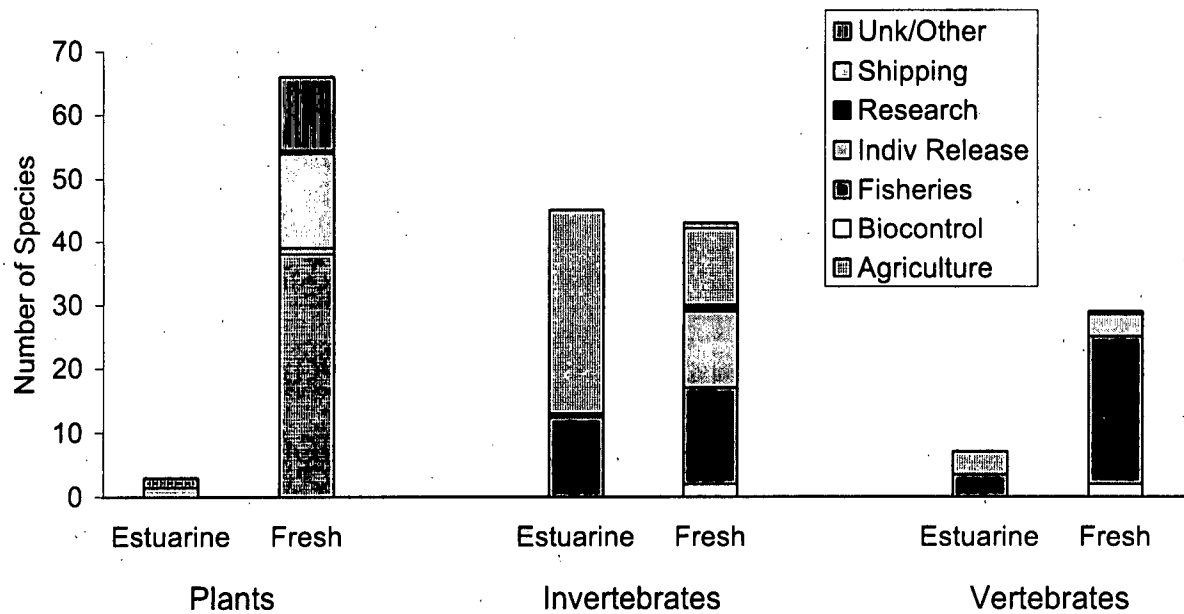
Vertebrate NAS, like plants, were dominated by freshwater species (29 species; 83%). The six estuarine species (all fishes) are regularly found in the Delta; two of these (American shad, *Alosa sapidissima* and striped bass, *Morone saxatilis*) are anadromous species that make extensive use of freshwater for part of their life cycle (Moyle 2002).

Most introduced vertebrates in the estuary are natives of eastern and central North America (29 species; 83%) (Fig. 2). Two (common carp, *Cyprinus carpio* and goldfish) are of Eurasian origin, though the source of introduced populations in the Delta is eastern North America or possibly, in the case of goldfish, Hawaii. The three gobies and one stocked fish (wakasagi, *Hypomesus nipponensis*) are natives of east Asia, and reached the Delta from their native range (Dill & Cordone 1997).

Fisheries-related vectors are responsible for 81% (26 species) of the nonindigenous fishes found in the Delta (Fig. 3). The major single vector of fish introductions was deliberate stocking for sport or forage (22 species; 69%). Two additional species (bigscale logperch, *Percina macrolepida* and rainwater killifish, *Lucania parva*) were probably introduced accidentally along with deliberately stocked fishes or oysters, while red shiner (*Cyprinella lutrensis*) has been stocked elsewhere in California but probably reached the Delta via its use as a baitfish. Blue catfish (*Ictalurus furcatus*) have been stocked in San Diego County, but most likely reached northern California and the Delta as escapes from aquaculture facilities in the Central Valley. Two species (western mosquitofish, *Gambusia affinis* and inland silverside, *Menidia beryllina*) were deliberately released for biocontrol purposes, one (goldfish, *Carassius auratus*) is an aquarium release, and the final three, all estuarine gobies, are believed to have reached the estuary via ballast water or ship fouling (Dill & Cordone 1997; Cohen 1998).



**Figure 2:** Continental origins of the three major groups of Delta NAS, contrasting estuarine and freshwater species.



**Figure 3:** Vectors bringing NAS plants, invertebrates, and vertebrates to the Delta, contrasting estuarine and freshwater species.

The three non-fish vertebrates introduced to the Delta represent a pet release (common slider, *Trachemys scripta*) and two organisms farmed for meat and fur (bullfrog, *Rana catesbeiana* and muskrat, *Ondatra zibethicus*). Bullfrogs have also been imported to California for scientific study and instruction, a possible secondary vector (Cohen & Carlton 1995).

#### Time-frame of introductions

In contrast to the whole-estuary analysis of Cohen & Carlton (1995), overall introductions into the Delta per time period have not increased since the 1880s (Figure 4a). This general result, however, obscures the steady increase in invertebrate introductions and a decline in the rate of plant introductions (Figure 4a). If plants are limited to the fully aquatic species, which have introduction vectors more similar to those of other species in the estuary (i.e., they are less dominated by agriculture-related vectors), then some increase over time in total introductions is evident (Figure 4b). However, this increase is still almost entirely driven by the increasing rate of documented invertebrate introductions. Some of this increase in recent years can probably be attributed to more thorough sampling and more detailed taxonomy, leading to an increasing rate of discovery.

#### Sources & vectors of freshwater and estuarine introductions

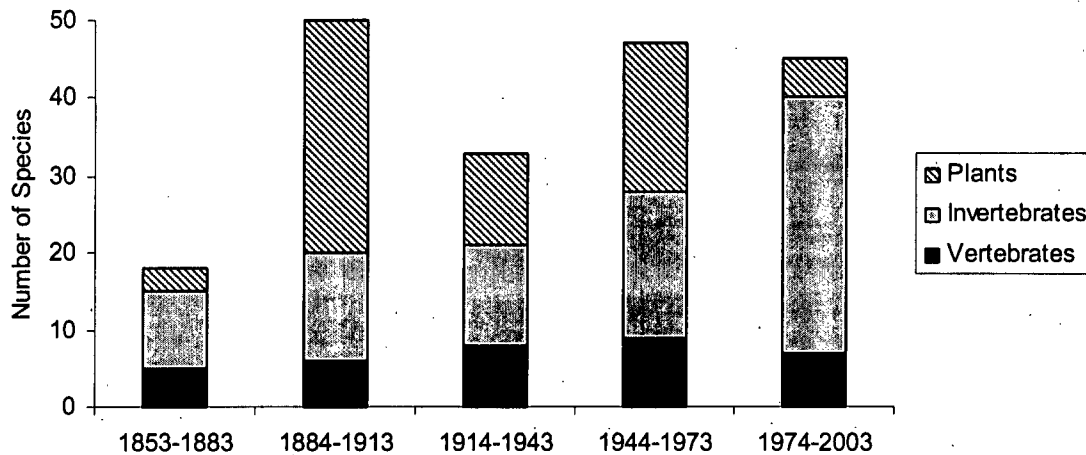
**Sources:** Native regions of Delta NAS differ between estuarine and freshwater species, with estuarine species predominantly from Asia and Europe while freshwater species are mainly from North America and Europe and have more diverse origins overall (all species:  $\chi^2 = 22.2$ ,  $df = 6$ ,  $P = 0.0011$ , Fig. 2; excluding marsh/riparian plants:  $\chi^2 = 16.9$ ,  $df = 6$ ,  $P = 0.0096$ ). This is largely due to the differences among taxonomic groups, since the plants and vertebrates are more associated with freshwater, while half the invertebrates are estuarine. Native regions differ significantly among taxonomic groups, with plants predominantly from Europe, invertebrates from Asia and North America, and vertebrates from North America (all species:  $\chi^2 = 121.3$ ,  $df = 12$ ,  $P < 0.0001$ ; excluding marsh/riparian plants:  $\chi^2 = 62.6$ ,  $df = 12$ ,  $P < 0.0001$ , Fig. 2). For invertebrates, the only taxonomic group with enough estuarine species for comparison, native regions do not differ between estuarine and freshwater species ( $\chi^2 = 7.3$ ,  $df = 6$ ,  $P = 0.29$ , Fig. 2).

Sources of invaders have changed through time, with Asia increasing in importance and Europe and North America decreasing, particularly for estuarine species (all species:  $\chi^2 = 47.6$ ,  $df = 16$ ,  $P < 0.0001$ ; excluding marsh/riparian plants:  $\chi^2 = 39.3$ ,  $df = 16$ ,  $P = 0.001$ ; Africa and Australia excluded to meet assumptions of the Chi-square test; Fig. 5). While Asia emerges as an increasingly important source for estuarine NAS, the sources of freshwater NAS appear to be growing more diverse, though eastern North America remains the most important source overall.

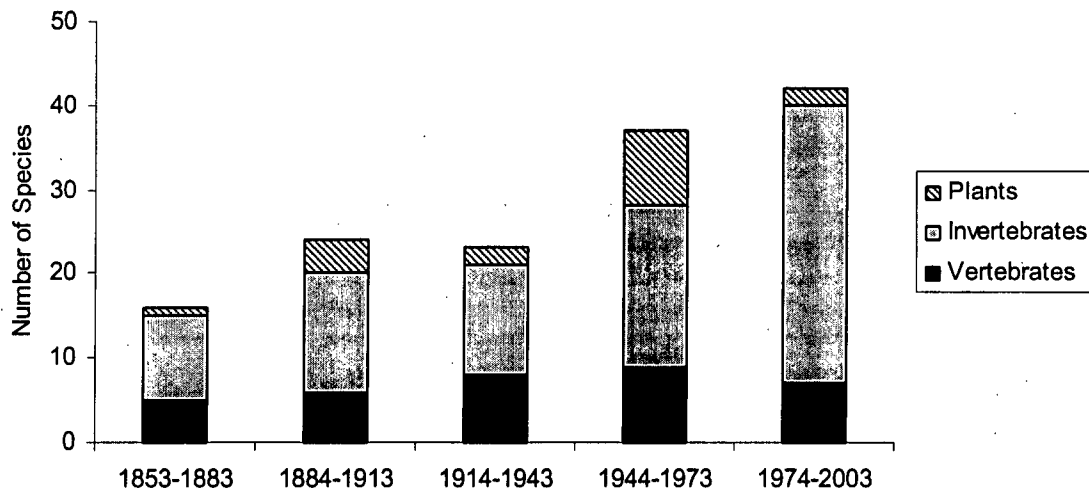
**Vectors:** Vectors also differ between estuarine and freshwater NAS, with estuarine species much more likely to arrive via shipping, while freshwater species are more associated with agriculture, fisheries, or individual releases (all species:  $\chi^2 = 83.7$ ,  $df = 6$ ,  $P < 0.0001$ ; excluding marsh/riparian plants:  $\chi^2 = 53.2$ ,  $df = 6$ ,  $P < 0.0001$ ; Fig. 3). This is partly, but not entirely, due to the differences in dominant vectors among taxonomic groups. Considering invertebrates separately, estuarine species are still significantly more likely to arrive via shipping, while sources of freshwater species are quite diverse ( $\chi^2 = 19.5$ ,  $df = 5$ ,  $P = 0.0015$ ; Fig. 3).

Vectors bringing NAS to the Delta have changed through time, with shipping increasing in importance and fisheries decreasing for both freshwater and estuarine species, while individual releases have increased and agriculture-related vectors have decreased for freshwater species (all species:  $\chi^2 = 91.3$ ,  $df = 24$ ,  $P < 0.0001$ ; excluding marsh/riparian plants:  $\chi^2 = 73.7$ ,  $df = 24$ ,  $P < 0.0001$ ; Fig. 6). While shipping has become nearly the exclusive vector bringing estuarine NAS to the Delta, the vectors, like sources, of freshwater NAS have grown increasingly diverse, particularly in the last three decades (Fig. 6).

a.

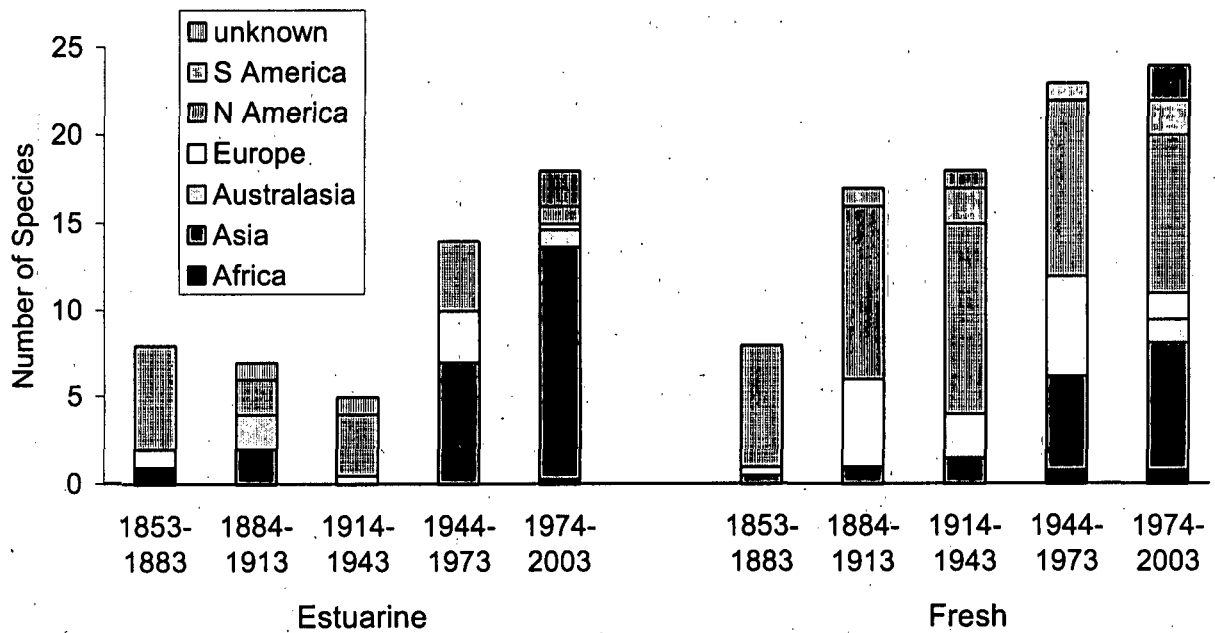


b.

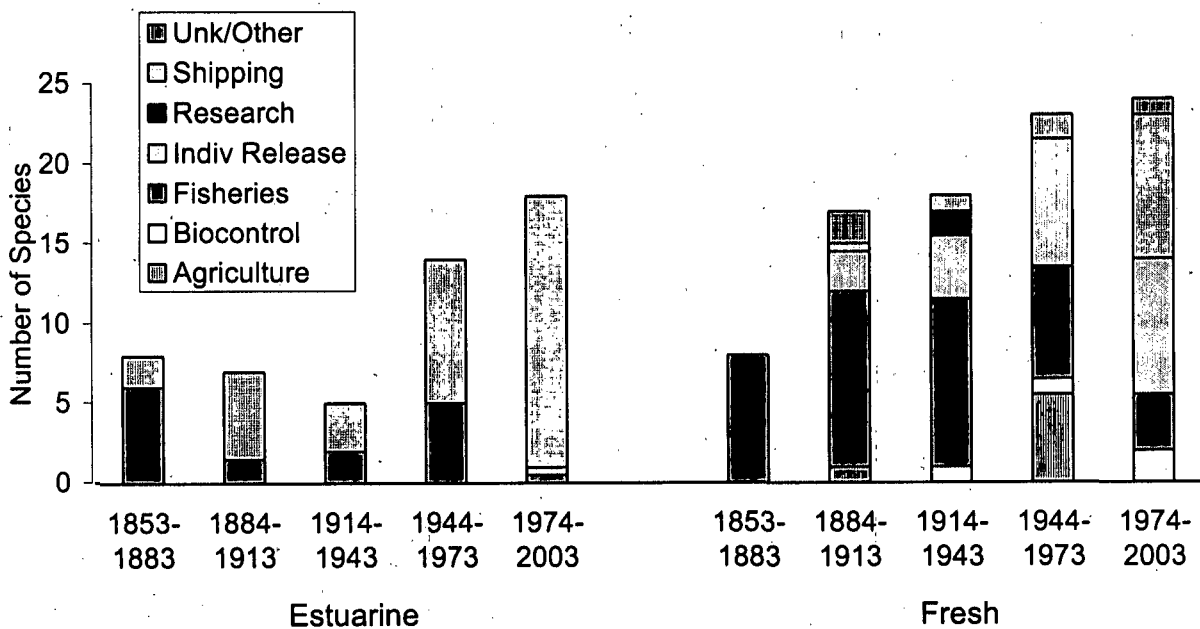


**Figure 4:** Changes over time in the rate of introductions of the major taxonomic groups of Delta NAS. (a) All species; (b) excluding marsh and riparian plants.





**Figure 5:** Changes over time in the native origins of estuarine and freshwater NAS in the Delta (this figure includes fully aquatic plants only).



**Figure 6:** Changes over time in the vectors bringing estuarine and freshwater NAS to the Delta (this figure includes fully aquatic plants only).

## CHAPTER 4: Conclusions

The Sacramento-San Joaquin Delta, like the lower estuary, is a highly invaded system. In addition to the high diversity of nonindigenous species, most sampled communities are dominated in both numbers and biomass by NAS. For example, the 2002 and 2003 summer townet surveys of juvenile fishes in upper estuary, 90% of fishes captured in 2002, and 88% in 2003, were nonindigenous to the Delta (Bryant 2003). Eight years (1992-99) of sampling a wide variety of habitats in the south Delta revealed a fish community consisting of fewer than 5% native individuals (Feyrer & Healy 2003). In benthic sampling throughout the Delta, typically 95% or more of the biomass consists of NAS, largely *Corbicula* (W. Fields, pers. comm.). The most abundant copepod and mysid species in the Delta in most seasons are also nonindigenous (IEP 2003).

The introduction histories of estuarine and freshwater NAS in the Delta are clearly divergent. For example, most fishes have freshwater affinities and were deliberately introduced in the late 1800's and early 1900's, mainly from eastern North America (Dill & Cordone 1997). Along with these introductions came a number of unintended species, including fishes, invertebrates, and aquatic plants. In contrast, many of the estuarine invertebrate and fish invaders reached the Delta in ballast water, solid ballast, and attached to vessel hulls (Cohen & Carlton 1995). In the most recent three decades, estuarine NAS have become increasingly associated with ballast water and Asian sources, while both the vectors and sources of freshwater NAS are becoming more diverse. Individual releases, shipping, and biological control have increased in importance for freshwater NAS.

### Effectiveness of ballast water regulation

Much management attention continues to be focused on minimizing ballast water as a source of introductions into estuaries. The National Invasive Species Act of 1996 established voluntary guidelines for ballast water exchange and management, effective in 1999 for all vessels entering US waters from beyond the exclusive economic zone (EEZ). As of January 2004, the California Marine Invasive Species Act has required mid-ocean ballast water exchange prior to entering California ports.

Shipping-related vectors, particularly ballast water, are presently the most important category of vectors bringing NAS to the Delta. In the last 30 years, about half (18 of 37 species) the new NAS regularly encountered in the Delta (freshwater and regularly resident estuarine species) were probably introduced via ballast water. This invasion vector has also seen the greatest increase in recent years. Assuming the above-cited regulations are relatively effective, we should expect significant declines in the rate of new invasions into the Delta in the future.

For primarily freshwater species, however, the diverse category of individual releases is about coequal with shipping as a vector of new invasions into the Delta. This vector has increased in importance over the last 60 years, and can be expected to continue to increase in the future, partially canceling expected gains from ballast water regulation. Human population increases in central California, as well as growing popularity of recreational boating and fishing, aquariums and backyard water gardens, and the ease of importation of exotic species via the web (Padilla & Williams 2004) can be expected to drive this increase. This suggests that protecting the Delta from further freshwater invasions will require ongoing management of numerous diffuse and hard-to-control vectors.

## CHAPTER 5: Recommendations

### A. Sampling recommendations

#### *Introduction*

The Sacramento-San Joaquin Delta is, in many respects, a very intensively sampled system. The Interagency Ecological Program's Environmental Monitoring Program (IEP EMP) has regularly monitored the upper estuary since 1971 for zooplankton (currently 19 sites, 8 in the Delta), phytoplankton (11 sites, 7 in the Delta) and benthic invertebrates (10 sites, 6 in the Delta) (Mueller-Solger 2001). At least six separate sampling programs of the California Department of Fish and Game (DFG), Department of Water Resources (DWR), US Fish and Wildlife Service (FWS), and the University of California, Davis (UCD) sample fishes and selected invertebrates in and around the Delta and Suisun Bay. The earliest of these, DFG's Summer Townet Survey, was initiated in 1959, and the most recent, DWR's Yolo Bypass Study, began in 1998. All six are ongoing (IEP 2004).

Most of these sampling programs, however, have some shared limitations. Because most programs seek mainly to quantify population trends in relatively abundant species, they primarily focus on habitats and sampling regimes that can be sampled easily, quantitatively, and repeatably. Routine benthic, fisheries, and plankton sampling is largely carried out in midchannel habitats and over unstructured, unvegetated habitats. However, the highest diversity and abundance of species is often found in shoreline habitats or associated with aquatic vegetation or other cover, such as rip-rap (Chotkowski 1999; W. Fields, pers. comm.; R. Schroeder, pers. comm.). Other undersampled habitats and groups include fouling communities, temporary water bodies and small sloughs. We therefore recommend that sampling for NAS in the Delta be focused on these undersampled habitats and groups associated with them.

Furthermore, the spatial scale over which species assemblages of small benthic invertebrates vary is much smaller than that of either fishes or zoo/phytoplankton. With benthic invertebrates, you may see dramatic changes in which species are present (not just numbers) over scales of meters. IEP sampling for benthic invertebrates noted above (10 sites, 6 in the Delta) is similar in spatial extent to that for fishes and plankton, which vary over much larger scales. This limited spatial sampling has likely hugely underestimated benthic diversity. Since the scale of variation is 10 to 100 times smaller than for fishes and plankton, we recommend *at least* a ten fold increase in the number of sampling sites for benthic invertebrates, with a target of at least 100 sites around the Delta distributed among the habitats discussed below. Agency sampling has chosen convenient sites and species to examine changes in the system over time or to have an index of response to human activities. For the purposes of the current project, species lists do not need to be replicated frequently in time. An annual survey would be more than adequate and a survey every 2-3 years (if really thorough) would be acceptable.

#### *Adequately sampled groups and habitats:*

1. Fishes are probably adequately sampled in the estuary. The existing sampling programs are quite extensive and have successfully detected all of the recent fish introductions (shimofuri goby, shokihaze goby) in the upper estuary. Even though shallow-water, vegetated habitats are relatively undersampled for fishes (Chotkowski 1999), this has

probably resulted more in a mischaracterization of overall abundances than in missing species completely.

2. Zooplankton are probably adequately sampled in the estuary, with the exception of zooplankton associated with temporary water bodies and small sloughs as discussed below. While existing sampling programs do not sample shallow vegetated habitats, this again probably results mostly in mischaracterization of relative abundances, with vegetation-associated species appearing to be less common than they are.

*Undersampled groups and habitats:*

3. **Benthic infauna of shallow water habitats, including larval insects.** Since most benthic sampling has been done mid-channel, shallow, shoreline habitats should be sampled for benthic infauna. Mid-channel sampling misses most insect species, which tend to be associated with shallow water and/or vegetation. The taxonomic resources for insects will be a limitation, since it is difficult to determine what is native and what is not.
4. **Vegetation-associated invertebrates, including larval insects.** Because of sampling difficulties, vegetated areas are generally avoided in routine invertebrate sampling in the Delta and estuary. In a study of the invertebrate associations of native and introduced aquatic plants, Toft and others (1999, 2002) found three previously undetected nonindigenous invertebrates in the Delta (the amphipod *Crangonyx floridanus* and isopods *Caecidotea racovitzai* and *Asellus hilgendorffii*). This suggests that a comprehensive survey of invertebrates associated with both floating and emergent aquatic vegetation, particularly nonindigenous plant species, may turn up some additional nonindigenous invertebrates.
5. **Fouling communities.** There is no regular sampling program for fouling organisms in the Delta. Several non-indigenous freshwater fouling organisms (*Cordylophora caspia*, *Urnatella gracilis*, *Balanus improvisus*) are known mainly from studies of the Delta-Mendota Canal (Eng 1975), and are rarely, if ever, collected in routine benthic or other sampling (IEP 2004). Rapid assessment of nonindigenous species in estuaries typically focuses on fouling organisms because the habitat is easily sampled and often contains a significant component of nonindigenous organisms (Cohen et al 1998, 2001). Non-indigenous organisms are frequently associated with artificial substrates such as docks, pilings, floats, and buoys (Chapman & Carlton 1991). We recommend a thorough assessment of fouling communities in the Delta, particularly in and around the ports of Stockton and Sacramento and in heavily used recreational boating areas.
6. **Temporary (particularly fishless) habitats.** "Tidepools" in upper marshes, nearby vernal pools, and floodplain habitats are undersampled in the estuary; such habitats should be sampled for both zooplankton and benthos. Fishless habitats, in particular, may contain very different species than nearby permanent waters. Such habitats are inherently seasonal, and hence will need to be sampled in winter or spring as conditions warrant. Although repeated sampling of these habitats would be ideal to capture seasonal variations, even a single annual sampling could capture some otherwise unsampled species.
7. **Small channels and sloughs.** Many of these have overhanging vegetation and hence could be considered an extension of the shallow water/vegetated habitats mentioned

above. Small sloughs should be sampled for both zooplankton and benthos. Possible sites include Beaver Slough, Hog Slough, Sycamore Slough, Seventeen Mile Slough, Jackson Slough, Georgiana Slough, White Slough and the San Joaquin River south of Hwy 4 (Lee Mecum, pers. comm.).

8. **Phytoplankton and periphyton.** Phytoplankton have been relatively well sampled in the Delta (IEP 2004), but the taxonomy and biogeographic history of most groups are poorly known. While numerous species have been identified as cryptogenic, none have conclusively been determined to be nonindigenous (Cohen & Carlton 1995). This group merits more attention, though further sampling is probably not as important as consultation with taxonomic experts. Benthic algae and periphyton are not routinely sampled in the Delta, and should be assessed in any comprehensive survey, perhaps in conjunction with surveys of fouling invertebrates. Diatoms (with silicate structures) and other unicellular taxa such as foraminifera that fossilize well should be a priority, because there is the possibility of looking at core samples and inferring what was here in the past (this has already been done to some extent with forams). These could be sampled by benthic coring on a one-time basis with routine phytoplankton sampling carried out through IEP providing follow-up.
9. **Parasites and commensals.** Many species of parasites and commensals, many of them introduced, are no doubt associated with each of the free-living NAS in the Delta. These groups have been only sporadically investigated (e.g., Edwards & Nahhas 1968; Hensley & Nahhas 1975). While a thorough assessment of symbionts would no doubt add many species to the overall NAS list for the Delta, it would add little to our understanding of vectors and sources of invaders. Furthermore, the taxonomic resources for many of these groups are limited and scattered throughout the literature. Since there is little or no baseline for most parasites (even macroparasites, with a few exceptions such as fish monogenes), it would be difficult to label anything as exotic. We therefore feel that this group should be given low priority at present.

#### B. Other recommendations

The increasing importance of aquarium releases, recreational boating and fishing, and similar vectors bringing freshwater species to the Delta has received relatively little management attention, particularly compared to that addressed to ballast water. Some of the most expensive and troublesome invaders in the Delta, the aquatic plants, have been almost exclusively released by individual aquarists and backyard pond hobbyists. The most recently documented Delta invader, the New Zealand mud snail, was an apparent hitchhiker on recreational fishing gear; this species has attracted considerable management concern due to its high abundances and negative impacts in other invaded systems. If zebra mussels, perhaps our most-feared potential invader, ever reach the Delta, they will probably arrive as hitchhikers as well. These examples, along with the overall trend, suggest a need for increased attention to this category of introduction vectors. Education of aquarium hobbyists, gardeners, fishers and boaters, as well as development of appropriate, cost-effective regulation of trade in exotic species (Padilla & Williams 2004) will be required to address this increasingly important vector of invasions into the SSJR.

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## APPENDIX A: Database description

### General information

The relational database (DeltaInvasions) was developed in Microsoft ACCESS 2000 (version 9.0.2719). It was based (in part) on two models: the SERC\_Invasions database of the National Ballast Water Clearinghouse (Smithsonian Ecological Research Center 2003), and the LCRANSdb database of the Lower Columbia River NAS Survey (Draheim Waldeck et al. 2003). At the time of development, we had access to the table structure only of the SERC\_Invasions database. While we have attempted to make our database compatible with SERC's, particularly by using common codes and ecological terms, we used a simplified table structure more suited to our objectives for the current project.

Currently, the database contains information on all known or suspected NAS identified from the literature search as occurring in the Sacramento-San Joaquin Delta (as described in the Introduction to this report). It could relatively easily be extended to include species from the lower San Francisco Estuary as well, and to include native as well as nonindigenous and cryptogenic species.

### Accessing and entering data using the main DeltaSpecies form

The simplest way to view data on individual species, and to enter new species information, is by using the form DeltaSpecies. This form has been set to open automatically when the database is launched. Taxonomic fields, including scientific and common names, can be searched with the "find" function. **To enter new data:** click ►\* at the bottom of the form to begin a new record. Note that the ScientificName field updates the table DeltaTaxonomy. Attempting to add a species already in this table (which includes some lower estuary invaders and nearby invaders) will result in an error message. If you get this message, add the species to the DeltaSpecies table first. **Sorting:** The form is currently set to sort taxonomically by major group, then alphabetically by species; certain modifications may cause it to default to sorting by SpeciesID number (approximately alphabetically). To re-establish the taxonomic sort, choose Records: Apply Filter/Sort. If this doesn't work, you need to re-load the desired sort order. Choose Records: Filter: Advanced Filter/Sort, then right-click anywhere on the page and choose "Load from Query". Choose "qryDeltaSpeciesSort", then right-click again and choose "Apply Filter/Sort".

### Other forms

**DeltaReferences:** Use this form to enter new references or view full reference information, including abstract, cited species, etc. **Note:** References must be entered here (or directly into the DeltaReferences table) before citation information can be entered in the DeltaSpecies form.

**Subforms:** Typically these will be accessed via one of the main forms. Access them directly only if modifications to the structure of the subform are needed.

### Tables

**DeltaCollections** contains collection information for certain benthic species. This table was a late addition to the database to facilitate future expansion, and therefore is not complete. Included information is from the IEP benthic database (IEP 2003). Further information from this database is needed, as well as collection information from the more dispersed literature.

Collection site information (at least a station code) must first be entered in the DeltaStations table. (All current and historic IEP benthos, zooplankton, and phytoplankton stations should be in this table already.) Collections information can then be entered directly into the table or into the subform located on the "Collections" tab of the DeltaSpecies form.

**DeltaHabitats** contains habitat information for each NAS species and some cryptogenic species. Multiple records may be entered for each species if different life stages occupy different habitats. Data can be entered via the subform located on the "Habitats" tab of the DeltaSpecies form.

**DeltaNearbyInvaders** contains abbreviated information on NAS found in areas adjacent to the Delta, which may be expected in the Delta in the future (or may have been overlooked there). To add new species to this list, add them to the table DeltaTaxonomy first.

**DeltaOtherRegions** contains information and citations relating to other locations where each species has been introduced. This table is not comprehensive—records were entered as they were encountered, but for most species no extensive effort was made to track down introduction records, particularly for sites outside the United States.

**DeltaReferences** contains full information on all references cited in other tables. All species referred to appear in the subdatasheet (and species information can be added here). References can be entered most easily using the DeltaReferences form.

**DeltaSpecies** contains the majority of the species-level information on NAS found in the Sacramento-San Joaquin Delta, including basic taxonomic information, population status, invasion history, ecology, impacts, and general distribution. Citations to references for each species appear in the subdatasheet accessible by clicking the "+" on the far left of the record. Data can be entered into this table most easily using the DeltaSpecies form.

**DeltaSpecies-referenceLinks** is a junction table linking references to cited species in both the DeltaSpecies and DeltaNearbyInvaders tables.

**DeltaStations** contains site information, including verbal descriptions and latitude/longitude, for collection sites referenced in tblDeltaCollections. Currently this table contains information only for IEP Environmental Monitoring Program sites. Site information (at least a site code) must be added to this table before collection information is entered into the DeltaCollections table or subform.

**DeltaTaxonomicGroups** contains common names for the major taxonomic groups of Delta NAS. When adding new groups, maintain taxonomic sort order by assigning an appropriate group code (may be decimal if necessary to insert between existing groups).

**DeltaTaxonomy** is the central location for all species names (including some lower estuary invaders and nearby invaders), and contains full taxonomic information for NAS and cryptogenic species found in the Delta. Update species names, spelling and taxonomic information in this table. (This can also be done via the DeltaSpecies form for Delta NAS.)

**APPENDIX B: Delta NAS**

Following is the list of species determined to be definite or probable invaders in the Sacramento-San Joaquin Delta, giving general salinity habitat, dates first recorded in the Delta and in central California, native region (if known) and probable invasion vector(s). The full names for vector abbreviations are given at the end of the table.

| Scientific Name                             | Common Name              | Salinity habitat           | Date first recorded: |            |                          | Vector        |
|---------------------------------------------|--------------------------|----------------------------|----------------------|------------|--------------------------|---------------|
|                                             |                          |                            | Delta                | Central CA | Native Region            |               |
| Plants (dicots)                             |                          |                            |                      |            |                          |               |
| Apium graveolens                            | wild celery              | Fresh                      | 1892                 | 1882       | Eurasia                  | EC            |
| Bacopa rotundifolia                         | disc waterhyssop         | Fresh                      | 1998*                | 1949*      | North America            | AW            |
| Bidens vulgata                              | big devils beggartick    | Fresh                      | 1893                 | 1893       | e N America              | UnkV          |
| Boehmeria cylindrica                        | smallspike false nettle  | Fresh                      | 2000                 | 2000       | e and c N America        | UnkV          |
| Cabomba caroliniana                         | Carolina fanwort         | Fresh                      | 1980                 | 1980       | e N America              | PR            |
| Chenopodium macrospermum<br>var. halophilum | saltloving goosefoot     | Estuarine-regular in Delta | 1923                 | 1923       | South America            | UnkV          |
| Conium maculatum                            | poison hemlock           | Fresh                      | 1979                 | 1892       | Europe                   | GE            |
| Cotula coronopifolia                        | brassbuttons             | Estuarine-regular in Delta | 1979*                | 1878       | s Africa                 | DrB           |
| Elatine ambigua                             | Asian waterwort          | Fresh                      | 1979-8               | 1946       | e & s Asia               | AW            |
| Hypericum mutilum                           | dwarf St. John's wort    | Fresh                      | 1957*                | 1957       | e N America              | GE      AW    |
| Lepidium latifolium                         | perennial pepperweed     | Fresh                      | 1941                 | 1936       | Eurasia                  | AW            |
| Limosella australis                         | Welsh mudwort            | Fresh                      | 1957                 | 1957       | e N America              | UnkV      DrB |
| Ludwigia peploides ssp.<br>montevidensis    | floating primrose-willow | Fresh                      | 1949                 | 1916       | s S America              | GE            |
| Lythrum hyssopifolia                        | hyssop loosestrife       | Fresh                      | 1890                 | 1879       | Eurasia                  | GE      AW    |
| Lythrum tribracteatum                       | threebract loosestrife   | Fresh                      | 1930                 | 1930       | s Europe                 | GE      AW    |
| Mentha piperita                             | peppermint               | Fresh                      | 1979*                | 1892       | Europe                   | EC            |
| Mentha aquatica                             | water mint               | Fresh                      | 1984*                | 1957       | Europe                   | EC            |
| Mentha pulegium                             | pennyroyal               | Fresh                      | 1888                 | 1887       | Europe                   | EC            |
| Mentha spicata                              | spearmint                | Fresh                      | 1991*                | 1891       | Europe                   | EC            |
| Myriophyllum aquaticum                      | parrotfeather            | Fresh                      | 1979*                | 1957*      | S America                | EC      PR    |
| Myriophyllum spicatum                       | Eurasian water-milfoil   | Fresh                      | 1979                 | 1976       | Eurasia                  | PR            |
| Phyla nodiflora                             | turkey tangle fogfruit   | Fresh                      | 1934*                | 1864       | S America                | ErC           |
| Plantago major                              | common plantain          | Fresh                      | 1891                 | 1891       | Europe                   | AW      EC    |
| Polygonum hydropiper                        | marshpepper              | Fresh                      | 1891                 | 1891       | Europe                   | EC            |
| Polygonum patulum                           | Bellard's smartweed      | Fresh                      | 1893                 | 1893       | e Europe                 | UnkV      EC  |
| Polygonum persicaria                        | lady's-thumb             | Fresh                      | 1934                 | 1888       | Europe                   | GE            |
| Pseudognaphalium luteoalbum                 | Jersey cudweed           | Fresh                      | 1991                 | 1928       | Europe                   | AW      EC    |
| Ranunculus muricatus                        | spinyfruit buttercup     | Fresh                      | 1979-8               | 1882       | Europe (Mediterranean to | GE      AW    |
| Rorippa nasturtium-aquaticum                | watercress               | Fresh                      | 1890                 | 1885       | Europe                   | EC            |

| Scientific Name             | Common Name               | Salinity habitat           | Date first recorded: |            | Native Region                  | Vector |            |               |
|-----------------------------|---------------------------|----------------------------|----------------------|------------|--------------------------------|--------|------------|---------------|
|                             |                           |                            | Delta                | Central CA |                                | Delta  | Central CA | Native Region |
| Plants (dicots)             |                           |                            |                      |            |                                |        |            |               |
| Rubus discolor              | Himalayan blackberry      | Fresh                      | 1979-8               | 1919       | Armenia                        | EC     |            |               |
| Rumex conglomeratus         | clustered dock            | Fresh                      | 1890                 | 1890       | Europe                         | AW     | EC         |               |
| Rumex crispus               | curly dock                | Fresh                      | 1895                 | 1887       | Eurasia                        | AW     | EC         |               |
| Rumex dentatus              | toothed dock              | Fresh                      | 1893                 | 1893       | Eurasia                        | AW     |            |               |
| Rumex obtusifolius          | bitter dock               | Fresh                      | 1989*                | 1907       | w Europe                       | AW     | EC         |               |
| Rumex stenophyllus          | narrowleaf dock           | Fresh                      | 1990                 | 1948       | Eurasia                        | AW     | EC         |               |
| Salix babylonica            | weeping willow            | Fresh                      | 1980                 | 1905       | Asia                           | GE     |            |               |
| Sesbania punicea            | scarlet wisteria tree     | Fresh                      | 1999                 | 1994       | S America                      | GE     |            |               |
| Spergularia maritima        | media sandspurry          | Estuarine-regular in Delta | 1979                 | 1951       | Europe                         | UnkV   | DrB        |               |
| Tamarix ssp.                | tamarisk                  | Fresh                      | 1928                 | 1895       | Eurasia                        | EC     | GE         | ErC           |
| Verbena bonariensis         | purpletop vervain         | Fresh                      | 1996                 | 1938       | S America                      | GE     |            |               |
| Veronica anagallis-aquatica | water speedwell           | Fresh                      | 1971*                | 1881       | Europe                         | UnkV   | GE         |               |
| Plants (monocots)           |                           |                            |                      |            |                                |        |            |               |
| Agrostis avenacea           | Pacific bentgrass         | Fresh                      | 1946                 | 1935       | s Pacific Islands              | UnkV   | EC         |               |
| Agrostis gigantea           | redtop                    | Fresh                      | 1996*                | 1970*      | Europe                         | EC     |            |               |
| Agrostis stolonifera        | creeping bentgrass        | Fresh                      | 1996*                | 1896       | Europe and North Africa        | EC     |            |               |
| Agrostis tandilensis        | Kennedy's bentgrass       | Fresh                      | 1979-8               | 1958       | Argentina                      | UnkV   | EC         |               |
| Alisma lanceolatum          | lanceleaf water plantain  | Fresh                      | 1985*                | 1946       | Eurasia, N Africa              | GE     |            |               |
| Arundo donax                | giant reed                | Fresh                      | 1980                 | 1949       | India                          | ErC    | EC         |               |
| Crypsis alopecuroides       | pricklegrass              | Fresh                      | 2002-0               | 2001       | Europe                         | AW     |            |               |
| Crypsis schoenoides         | swamp prickle grass       | Fresh                      | 1940                 | 1940       | Europe                         | UnkV   | EC         |               |
| Crypsis vaginiflora         | African pricklegrass      | Fresh                      | 1907                 | 1898       | Mediterranean                  | UnkV   | AW         |               |
| Cyperus difformis           | variable flatsedge        | Fresh                      | 1998*                | 1921       | Asia and Africa                | AW     |            |               |
| Echinochloa crus-galli      | barnyard grass            | Fresh                      | 1930                 | 1891       | Eurasia and Africa             | AW     |            |               |
| Echinochloa crus-pavonis    | gulf cockspur grass       | Fresh                      | 1893                 | 1893       | Eurasia and Africa             | AW     |            |               |
| Echinochloa oryzoides       | early water grass         | Fresh                      | 1953                 | 1953       | Eurasia                        | AW     |            |               |
| Egeria densa                | Brazilian waterweed       | Fresh                      | 1946                 | 1938       | Argentina, Brazil, and Uruguay | PR     |            |               |
| Eichhornia crassipes        | water hyacinth            | Fresh                      | 1904                 | 1904       | Amazon River basin             | GE     |            |               |
| Hainardia cylindrica        | barbgrass                 | Fresh                      | 1979-8               | 1896       | Europe                         | UnkV   |            |               |
| Iris pseudacorus            | yellow iris               | Fresh                      | 1969                 | 1957       | Europe                         | GE     |            |               |
| Panicum rigidulum var.      | redtop panicgrass         | Fresh                      | 1972*                | 1950       | e N America                    | UnkV   |            |               |
| Polypogon elongatus         | streambank rabbitsfoot    | Fresh                      | 1897                 | 1897       | S America                      | AW     |            |               |
| Polypogon interruptus       | ditch rabbitsfoot grass   | Fresh                      | 1992-9               | 1885       | S America                      | AW     |            |               |
| Polypogon maritimus         | Mediterranean beard grass | Fresh                      | 1979-8               | 1892       | Mediterranean Europe and       | AW     |            |               |
| Polypogon monspeliensis     | annual rabbitsfoot grass  | Fresh                      | 1904                 | 1882       | Europe                         | AW     |            |               |

| Scientific Name               | Common Name             | Salinity habitat           | Date first recorded: |            |                              | Vector |     |    |
|-------------------------------|-------------------------|----------------------------|----------------------|------------|------------------------------|--------|-----|----|
|                               |                         |                            | Delta                | Central CA | Native Region                |        |     |    |
| Plants (monocots)             |                         |                            |                      |            |                              |        |     |    |
| Polypogon viridis             | water bent              | Fresh                      | 1928                 | 1896       | Europe                       | AW     |     |    |
| Potamogeton crispus           | curly pondweed          | Fresh                      | 1946                 | 1946       | Europe                       | FA     |     |    |
| Schoenoplectus glaucus        | tuberous bulrush        | Fresh                      | 2003*                | 1948       | Europe                       | EC     | AW  |    |
| Schoenoplectus mucronatus     | ricefield bulrush       | Fresh                      | 2003*                | 1946       | Eurasia                      | AW     |     |    |
| Setaria sphacelata            | African bristlegrass    | Fresh                      | 1979-8               | 1904       | Africa                       | UnkV   |     |    |
| Typha angustifolia            | narrow-leafed cattail   | Fresh                      | 1909                 | 1909       | Europe                       | UnkV   |     |    |
| Invertebrates                 |                         |                            |                      |            |                              |        |     |    |
| Annelida                      |                         |                            |                      |            |                              |        |     |    |
| Branchiobdellida              |                         |                            |                      |            |                              |        |     |    |
| Cambarincola sp.              | crayfish worm           | Fresh                      | 1979                 | 1979       | e N America or Pacific NW    | FA     |     |    |
| Hirudinea                     |                         |                            |                      |            |                              |        |     |    |
| Myzobdella lugubris           | ectoparasite of catfish | Fresh                      | 1975*                | 1975*      | e N America                  | FA     |     |    |
| Oligochaeta                   |                         |                            |                      |            |                              |        |     |    |
| Branchiura sowerbyi           |                         | Fresh                      | 1950                 | 1950       | India, Manmar, Java, China,  | BW     | DrB | AP |
| Paranais frici                |                         | Fresh                      | 1973                 | 1961       | Europe                       | BW     | DrB | AP |
| Potamothenrix bavaricus       |                         | Fresh                      | 1991                 | 1965       | Europe                       | BW     | DiB | AP |
| Potamothenrix sp. A           |                         | Fresh                      | 1998                 | 1998       | Europe?                      | BW     | DiB | AP |
| Tubificoides brownae          |                         | Estuarine-rare in Delta    | 1992                 | 1961       | n Atlantic                   | DrB    | BW  | OA |
| Varichaetadrilus angustipenis |                         | Fresh                      | 1975*                | 1975       | e N America                  | BW     | AP  |    |
| Polychaeta                    |                         |                            |                      |            |                              |        |     |    |
| Amaeana sp.                   |                         | Estuarine-rare in Delta    | 2001                 | 1999       | unknown                      | BW     |     |    |
| Boccardiella ligierica        |                         | Estuarine-regular in Delta | 1977                 | 1954       | w Europe                     | BW     |     |    |
| Heteromastus filiformis       |                         | Estuarine-rare in Delta    | 1936                 | 1936       | e N America                  | OA     | BW  |    |
| Laonome sp.                   |                         | Fresh                      | 1989                 | 1989       | unknown                      | BW     |     |    |
| Manayunkia speciosa           |                         | Fresh                      | 1963*                | 1963*      | e N America                  | FA     | BW  |    |
| Marenzelleria viridis         |                         | Fresh                      | 1991                 | 1991       | e N America                  | BW     |     |    |
| Neanthes succinea             | pile worm               | Estuarine-rare in Delta    | 1896                 | 1896       | e N America                  | OA     | FC  | BW |
| Streblospio benedicti         |                         | Estuarine-rare in Delta    | 1986                 | 1932       | western and eastern Atlantic | BW     | OA  | FC |
| Typosyllis sp.                |                         | Estuarine-rare in Delta    | 1998                 | 1997       | Japan                        | BW     |     |    |

| Scientific Name                    | Common Name              | Salinity habitat           | Date first recorded: |            | Native Region               | Vector |
|------------------------------------|--------------------------|----------------------------|----------------------|------------|-----------------------------|--------|
|                                    |                          |                            | Delta                | Central CA |                             |        |
| <b>Mollusca</b>                    |                          |                            |                      |            |                             |        |
| <b>Gastropoda</b>                  |                          |                            |                      |            |                             |        |
| Cipangopaludina chinensis malleata | Chinese mysterysnail     | Fresh                      | 1938                 | 1892       | China, Japan                | RI     |
| Melanoides tuberculata             | red-rim melania          | Fresh                      | 1988                 | 1988       | Africa to east Indies       | PR     |
| Philine auriformis                 | tortellini snail         | Estuarine-rare in Delta    | 2001                 | 1992       | New Zealand                 | BW     |
| Potamopyrgus antipodarum           | New Zealand mud snail    | Fresh                      | 2003                 | 2003       | New Zealand                 | RecB   |
| <b>Bivalvia</b>                    |                          |                            |                      |            |                             |        |
| Corbicula fluminea                 | Asian clam               | Fresh                      | 1945                 | 1945       | China, Korea, Japan         | RI     |
| Macoma petalum                     | Baltic clam              | Estuarine-rare in Delta    | 1988                 | ~1869      | nw Atlantic                 | OA DrB |
| Musculista senhousia               | Japanese mussel          | Estuarine-rare in Delta    | 1946                 | 1941       | Japan, China                | OA     |
| Mya arenaria                       | soft-shell clam          | Estuarine-rare in Delta    | 1874                 | 1874       | e N America                 | OA     |
| Potamocorbula amurensis            | Amur river corbula       | Estuarine-regular in Delta | 1986                 | 1986       | s China to s Siberia, Japan | BW     |
| Venerupis philippinarum            | Japanese littleneck clam | Estuarine-rare in Delta    | 1946                 | 1930       | w Pacific                   | OA     |
| <b>Arthropoda</b>                  |                          |                            |                      |            |                             |        |
| <b>Ostracoda</b>                   |                          |                            |                      |            |                             |        |
| Eusarsiella zostericola            |                          | Estuarine-rare in Delta    | 1994*                | 1953*      | nw Atlantic                 | OA     |
| <b>Cladocera</b>                   |                          |                            |                      |            |                             |        |
| Daphnia lumholtzi                  | daphnia                  | Fresh                      | 1999                 | 1999       | Africa, Asia, Australia     | RecB   |
| <b>Copepoda</b>                    |                          |                            |                      |            |                             |        |
| Acartiella sinensis                |                          | Estuarine-regular in Delta | 1993                 | 1993       | China                       | BW     |
| Eurytemora affinis                 |                          | Estuarine-regular in Delta | 1912                 | 1912       | e N America                 | FA     |
| Lernaea cyprinacea                 | Lernaea                  | Fresh                      | 1975*                | 1975*      | Asia                        | FA PR  |
| Limnoithona sinensis               |                          | Fresh                      | 1979                 | 1979       | Yangtze River, China        | BW     |
| Limnoithona tetraspina             |                          | Estuarine-regular in Delta | 1993                 | 1993       | Yangtze River, China        | BW     |
| Oithona davisae                    |                          | Estuarine-rare in Delta    | 1979                 | 1979       | Japan                       | BW     |
| Pseudodiaptomus forbesi            |                          | Fresh                      | 1987                 | 1987       | Yangtze River, China        | BW     |
| Pseudodiaptomus marinus            |                          | Estuarine-rare in Delta    | 1986                 | 1986       | China, Japan                | BW OA  |
| Sinocalanus doerrii                |                          | Fresh                      | 1978                 | 1978       | Chinese rivers              | BW     |
| Tortanus dextrilobatus             |                          | Estuarine-regular in Delta | 1993                 | 1993       | Korea, China                | BW     |
| <b>Cirripedia</b>                  |                          |                            |                      |            |                             |        |
| Balanus improvisus                 | bay barnacle             | Estuarine-regular in Delta | 1853                 | 1853       | e N America                 | FC OI  |

| Scientific Name                  | Common Name             | Salinity habitat           | Date first recorded: |            | Native Region                | Vector |    |     |
|----------------------------------|-------------------------|----------------------------|----------------------|------------|------------------------------|--------|----|-----|
|                                  |                         |                            | Delta                | Central CA |                              |        |    |     |
| <b>Mysidacea</b>                 |                         |                            |                      |            |                              |        |    |     |
| <i>Acanthomysis aspera</i>       |                         | Estuarine-rare in Delta    | 1992                 | 1992       | Japan                        | BW     |    |     |
| <i>Acanthomysis bowmani</i>      |                         | Estuarine-regular in Delta | 1993                 | 1993       | e Asia                       | BW     |    |     |
| <i>Acanthomysis hwanhaiensis</i> |                         | Estuarine-rare in Delta    | 1997                 | 1997       | Korea                        | BW     |    |     |
| <i>Deltamysis holmquistae</i>    |                         | Estuarine-rare in Delta    | 1977                 | 1977       | unknown                      | BW     |    |     |
| <b>Cumacea</b>                   |                         |                            |                      |            |                              |        |    |     |
| <i>Nippoleucon hinumensis</i>    |                         | Estuarine-regular in Delta | 1986                 | 1986       | Japan                        | BW     |    |     |
| <b>Isopoda</b>                   |                         |                            |                      |            |                              |        |    |     |
| <i>Asellus hilgendorffii</i>     |                         | Fresh                      | 1978                 | 1978       | China, Japan, Siberia        | BW     |    |     |
| <i>Caecidotea racovitzai</i>     |                         | Fresh                      | 1999                 | 1999       | ne N America                 | BW     | AP |     |
| <i>Iais californica</i>          |                         | Estuarine-rare in Delta    | 1904*                | 1904*      | Australia, New Zealand       | FC     |    |     |
| <i>Munna</i> sp. A               |                         | Fresh                      | 1989                 | 1989       | unknown                      | UnkV   |    |     |
| <i>Sphaeroma quoyanum</i>        |                         | Estuarine-rare in Delta    | 1893                 | 1893       | Australia, New Zealand,      | FC     |    |     |
| <i>Synidotea laevidorsalis</i>   |                         | Estuarine-regular in Delta | 1897                 | 1897       | e Asia                       | FC     |    |     |
| <b>Tanaidacea</b>                |                         |                            |                      |            |                              |        |    |     |
| <i>Sinelobus stanfordi</i>       |                         | Estuarine-regular in Delta | 1943                 | 1943       | unknown                      | FC     | BW |     |
| <b>Amphipoda</b>                 |                         |                            |                      |            |                              |        |    |     |
| <i>Ampelisca abdita</i>          |                         | Estuarine-rare in Delta    | 1954                 | 1954       | nw Atlantic                  | BW     | OA |     |
| <i>Corophium alienense</i>       |                         | Estuarine-regular in Delta | 1973                 | 1973       | Southeast Asia?              | BW     |    |     |
| <i>Crangonyx floridanus</i>      |                         | Fresh                      | 1998                 | 1998       | e & e-c N America            | BW     | AP |     |
| <i>Gammarus daiberi</i>          |                         | Estuarine-regular in Delta | 1983                 | 1983       | e N Atlantic                 | BW     | AP | FC  |
| <i>Grandidierella japonica</i>   |                         | Estuarine-regular in Delta | 1976                 | 1966       | Japan                        | OA     | BW | FC  |
| <i>Melita nitida</i>             |                         | Estuarine-regular in Delta | 1938                 | 1938       | e N America                  | FC     | OA | DrB |
| <i>Monocorophium acherusicum</i> |                         | Estuarine-regular in Delta | 1912                 | 1912       | uncertain                    | OA     | FC |     |
| <i>Monocorophium insidiosum</i>  |                         | Estuarine-rare in Delta    | 1931                 | 1931       | n Atlantic                   | FC     | OA |     |
| <i>Parapleustes derzhavini</i>   |                         | Estuarine-rare in Delta    | 1977                 | 1904       | e Asia                       | FC     |    |     |
| <b>Decapoda</b>                  |                         |                            |                      |            |                              |        |    |     |
| <i>Exopalaemon modestus</i>      | Asian freshwater shrimp | Fresh                      | 2001                 | 2001       | Russia, Korea, China, Taiwan | BW     |    |     |
| <i>Palaemon macrodactylus</i>    | oriental shrimp         | Estuarine-regular in Delta | 1957                 | 1957       | Korea, Japan, N China        | BW     | FC |     |
| <i>Orconectes virilis</i>        | virile crayfish         | Fresh                      | 1959                 | 1940       | mw N America                 | SE     |    |     |
| <i>Pacifastacus leniusculus</i>  | signal crayfish         | Fresh                      | 1959                 | 1912       | nw N America                 | FI     |    |     |
| <i>Procambarus clarkii</i>       | red swamp crayfish      | Fresh                      | 1959*                | 1959*      | se US                        | RI     |    |     |
| <i>Eriocheir sinensis</i>        | Chinese mitten crab     | Estuarine-regular in Delta | 1996                 | 1992       | China, Korea                 | RI     | BW |     |
| <i>Rhithropanopeus harrisi</i>   | Harris mud crab         | Estuarine-regular in Delta | 1975                 | 1937       | e N America                  | OA     | FC | BW  |

| Scientific Name              | Common Name                     | Salinity habitat           | Date first recorded: |            | Native Region           | Vector |    |
|------------------------------|---------------------------------|----------------------------|----------------------|------------|-------------------------|--------|----|
|                              |                                 |                            | Delta                | Central CA |                         |        |    |
| <b>Insecta</b>               |                                 |                            |                      |            |                         |        |    |
| Neochetina bruchi            | chevroned water hyacinth weevil | Fresh                      | 1982                 | 1982       | Argentina               | BC     |    |
| Neochetina eichhorniae       | mottled water hyacinth weevil   | Fresh                      | 1982                 | 1982       | Argentina               | BC     |    |
| <b>Miscellaneous Phyla</b>   |                                 |                            |                      |            |                         |        |    |
| <b>Myxozoa</b>               |                                 |                            |                      |            |                         |        |    |
| Myxobolus koi                | parasite of carp                | Fresh                      | 1975*                | 1975*      | Japan                   | FA     |    |
| <b>Cnidaria</b>              |                                 |                            |                      |            |                         |        |    |
| Blackfordia virginica        |                                 | Estuarine-regular in Delta | 2001                 | 1970       | Black Sea, Europe       | BW     | FC |
| Cordylophora caspia          | freshwater hydroid              | Fresh                      | 1950*                | 1950*      | Black and Caspian Seas  | FC     | BW |
| Craspedacusta sowerbii       | freshwater jellyfish            | Fresh                      | 1953                 | 1953       | China                   | AP     | PR |
| Maeotias marginata           | Black Sea jellyfish             | Estuarine-regular in Delta | 1981*                | 1981*      | Black and Caspian Seas  | BW     | FC |
| Moerisia sp.                 |                                 | Estuarine-rare in Delta    | 1997                 | 1993       | Eurasia or North Africa | BW     | FC |
| <b>Platyhelminthes</b>       |                                 |                            |                      |            |                         |        |    |
| Alloglossidium corti         | trematode parasite of catfishes | Fresh                      | 1968*                | 1968*      | e N America             | FA     |    |
| Atractolytocestus huronensis | cestode parasite of cyprinids   | Fresh                      | 1975*                | 1975*      | unknown                 | FA     |    |
| Bothriocephalus claviceps    | cestode parasite of sunfishes   | Fresh                      | 1968*                | 1968*      | e N America             | FA     |    |
| Corallobothrium fimbriatum   | cestode parasite of catfishes   | Fresh                      | 1968                 | 1968*      | e N America             | FA     |    |
| Dactylogyrus extensus        | trematode parasite of carp      | Fresh                      | 1975*                | 1975*      | Eurasia                 | FA     |    |
| Khawia iowensis              | cestode parasite of carp        | Fresh                      | 1975*                | 1975*      | unknown                 | FA     |    |
| Ligictaluridus pricei        | trematode parasite of catfishes | Fresh                      | 1975*                | 1975*      | e N America             | FA     |    |
| Megathylacoides giganteum    | cestode parasite of catfishes   | Fresh                      | 1968*                | 1968*      | e N America             | FA     |    |
| Pisciamphistoma stunkardi    | trematode parasite of sunfishes | Fresh                      | 1968*                | 1968*      | e N America             | FA     |    |
| <b>Nematoda</b>              |                                 |                            |                      |            |                         |        |    |
| Capillaria catenata          | nematode parasite of fishes     | Fresh                      | 1975*                | 1975*      | e N America             | FA     |    |
| Hysterothylacium brachyurum  | nematode parasite of fishes     | Estuarine-regular in Delta | 1975*                | 1975*      | e N America             | FA     |    |
| Philometroides sanguinea     | nematode parasite of goldfish   | Fresh                      | 1975*                | 1975*      | Japan                   | FA     |    |
| <b>Entoprocta</b>            |                                 |                            |                      |            |                         |        |    |
| Urnatella gracilis           | freshwater entoproct            | Fresh                      | 1982                 | 1972       | e & mw N America        | AP     | PR |



| Scientific Name          | Common Name          | Salinity habitat           | Date first recorded: |            | Native Region                 | Vector |       |
|--------------------------|----------------------|----------------------------|----------------------|------------|-------------------------------|--------|-------|
|                          |                      |                            | Delta                | Central CA |                               |        |       |
| Vertebrates              |                      |                            |                      |            |                               |        |       |
| Fishes                   |                      |                            |                      |            |                               |        |       |
| Acanthogobius flavimanus | yellowfin goby       | Estuarine-regular in Delta | 1963                 | 1963       | Japan, Korea, China           | BW     | FC    |
| Alosa sapidissima        | American shad        | Estuarine-regular in Delta | 1871                 | 1871       | e N America                   | FI     |       |
| Ameiurus catus           | white catfish        | Fresh                      | 1874                 | 1874       | e N America                   | FI     |       |
| Ameiurus melas           | black bullhead       | Fresh                      | 1952*                | 1931       | e N America                   | FI     |       |
| Ameiurus nebulosus       | brown bullhead       | Fresh                      | 1874                 | 1874       | c N America                   | FI     |       |
| Carassius auratus        | goldfish             | Fresh                      | 1963*                | 1863       | Asia                          | PR     |       |
| Cyprinella lutrensis     | red shiner           | Fresh                      | 1994                 | 1954       | c N America                   | DiB    | FI    |
| Cyprinus carpio          | common carp          | Fresh                      | 1883                 | 1972       | Eurasia                       | FI     |       |
| Dorosoma petenense       | threadfin shad       | Fresh                      | 1961                 | 1959       | c and se N America, C America | FI     |       |
| Gambusia affinis         | western mosquitofish | Fresh                      | 1924-1               | 1922       | c and se N America            | BC     |       |
| Hypomesus nipponensis    | wakasagi             | Fresh                      | 1990*                | 1959       | Japan                         | FI     |       |
| Ictalurus furcatus       | blue catfish         | Fresh                      | 1978                 | 1978       | c and se N America            | AQ     | FI    |
| Ictalurus punctatus      | channel catfish      | Fresh                      | 1943                 | 1942       | c N America                   | FI     |       |
| Lepomis cyanellus        | green sunfish        | Fresh                      | 1896                 | 1896       | Mississippi drainage          | FI     | FA    |
| Lepomis gibbosus         | pumpkinseed          | Fresh                      | 1980                 | 1983       | e N America                   | FI     |       |
| Lepomis gulosus          | warmouth             | Fresh                      | 1941*                | 1891       | c and se N America            | FI     |       |
| Lepomis macrochirus      | bluegill             | Fresh                      | 1909-1               | 1908       | c and se N America            | FI     |       |
| Lepomis microlophus      | redear sunfish       | Fresh                      | 1956                 | 1956       | c and se N America            | FI     |       |
| Lucania parva            | rainwater killifish  | Estuarine-regular in Delta | 1958                 | 1958       | e and s N America             | OA     | BW FA |
| Menidia beryllina        | inland silverside    | Fresh                      | 1971                 | 1967       | se N America                  | BC     |       |
| Micropterus coosae       | redeye bass          | Fresh                      | 1999*                | 1962       | se N America                  | FI     |       |
| Micropterus dolomieu     | smallmouth bass      | Fresh                      | 1898-9               | 1874       | c N America                   | FI     |       |
| Micropterus punctulatus  | spotted bass         | Fresh                      | 2002                 | 1937       | c and se N America            | FI     |       |
| Micropterus salmoides    | largemouth bass      | Fresh                      | 1909                 | 1891       | c N America                   | FI     |       |
| Morone saxatilis         | striped bass         | Estuarine-regular in Delta | 1879                 | 1879       | e N America                   | FI     |       |
| Notemigonus crysoleucas  | golden shiner        | Fresh                      | 1940*                | 1891       | e and c N America             | FI     |       |
| Percina macrolepida      | bigscale logperch    | Fresh                      | 1970                 | 1953       | sw N America                  | FA     |       |
| Pimephales promelas      | fathead minnow       | Fresh                      | 1953                 | 1953       | c N America                   | FI     |       |
| Pomoxis annularis        | white crappie        | Fresh                      | 1963-6               | 1951       | c and se N Amer               | FI     |       |
| Pomoxis nigromaculatus   | black crappie        | Fresh                      | 1931                 | 1908       | c and se N America            | FI     |       |
| Tridentiger barbatus     | shokihaze goby       | Estuarine-regular in Delta | 1997                 | 1997       | Japan, Korea, China           | BW     |       |
| Tridentiger bifasciatus  | shimofuri goby       | Estuarine-regular in Delta | 1985                 | 1985       | e Asia                        | BW     |       |

| Scientific Name    | Common Name   | Salinity habitat | Date first recorded: |            |               | Vector |
|--------------------|---------------|------------------|----------------------|------------|---------------|--------|
|                    |               |                  | Delta                | Central CA | Native Region |        |
| Amphibians         |               |                  |                      |            |               |        |
| Rana catesbeiana   | bullfrog      | Fresh            | 1933                 | 1896       | e N America   | AQ SE  |
| Reptiles           |               |                  |                      |            |               |        |
| Trachemys scripta  | common slider | Fresh            | 1989*                | 1976*      | se US         | PR     |
| Mammals            |               |                  |                      |            |               |        |
| Ondatra zibethicus | muskrat       | Fresh            | 1943                 | 1930s      | e N America   | AQ     |

**Vectors:** AQ-Aquaculture escape, AW-Agricultural Weed, BC-Biocontrol release, BW-Ballast Water, DiB-Discarded Bait, DrB-Dry Ballast, EC-Escape from cultivation, ErC-Erosion Control, FA-Fisheries Accidental (not Oyster), FC-Fouling Community, FI-Fisheries Intentional, GE-Garden Escape, OA-Oyster Accidental, OI-Oyster Intentional, PR-Pet/Aquarium Release, RecB-Recreational Boating/Fishing, RI-Released by Individual, SE-Scientific Escape, UnkV-Unknown.

\*indicates dates which probably differ by 10 or more years from the actual invasion date.

**APPENDIX C: Cryptogenic Species in the Delta**

The following table lists species determined to cryptogenic in the Sacramento-San Joaquin Delta.

| <b>ScientificName</b>        | <b>CommonName</b>      |
|------------------------------|------------------------|
| <b>Microalgae</b>            |                        |
| Anabaena sp.                 | blue-green alga        |
| Oscillatoria sp.             | blue-green alga        |
| Nitzschia sp.                | diatom                 |
| Aulacoseira spp.             | diatom                 |
| Chaetoceros spp.             | diatom                 |
| Coscinodiscus spp.           | diatom                 |
| Cyclotella spp.              | diatom                 |
| Asterionella sp.             | diatom                 |
| Achnanthes sp.               | diatom                 |
| Biddulphia spp.              | diatom                 |
| Navicula spp.                | diatom                 |
| Pleurosigma sp.              | diatom                 |
| Rhizosolenia sp.             | diatom                 |
| Skeletonema sp.              | diatom                 |
| Thalassiosira sp.            | diatom                 |
| Gymnodinium sp.              | dinoflagellate         |
| Scenedesmus sp.              | chlorophyceae          |
| <b>Vascular plants</b>       |                        |
| Phalaris arundinacea         | reed canarygrass       |
| <b>Invertebrates</b>         |                        |
| Prostoma graecense           | freshwater ribbon worm |
| Synchaeta bicornis           | rotifer                |
| Aulodrilus limnobius         | oligochaete            |
| Bothrioneurum vej dovskyanum | oligochaete            |
| Limnodrilus udekemianus      | oligochaete            |
| Limnodrilus hoffmeisteri     | oligochaete            |
| Grandifoxus grandis          | amphipod               |

**APPENDIX D: Nearby Invaders**

The following table lists NAS found in areas adjacent to the Sacramento-San Joaquin Delta.

| ScientificName              | CommonName                                     | Date | SourceRegion              | Vector                  |
|-----------------------------|------------------------------------------------|------|---------------------------|-------------------------|
| <b>Dicots</b>               |                                                |      |                           |                         |
| Callitriche stagnalis       | pond water-starwort                            |      |                           |                         |
| Polygonum pensylvanicum     | pinkweed, Pennsylvania smartweed               |      | e N America               | Escape from cultivation |
| Nymphaea odorata            | fragrant waterlily, American white waterlily   |      | e N America               | Garden Escape           |
| Nymphaea mexicana           | yellow waterlily, banana waterlily             |      | se N America, Mexico      | Garden Escape           |
| Lythrum salicaria           | purple loosestrife                             | 1968 | Europe                    | Dry Ballast             |
| Rotala indica               | Indian toothcup                                |      |                           |                         |
| <b>Monocots</b>             |                                                |      |                           |                         |
| Najas gracillima            | thread-leaved water nymph, slender water nymph |      | e N America               | Agricultural Weed       |
| Aponogeton distachyos       | Cape pondweed                                  |      | s Africa                  | Pet/Aquarium Release    |
| Eleocharis pachycarpa       | black sand spikerush                           |      | Chile                     |                         |
| Fimbristylis miliacea       | grasslike fimbry                               | 1866 | Eurasia                   | Agricultural Weed       |
| Heteranthera limosa         | blue mudplantain, ducksalad                    |      | e & c N America           | Agricultural Weed       |
| Hydrilla verticillata       | hydrilla, waterhyme, Florida elodea            | 1976 | Eurasia & central Africa  | Pet/Aquarium Release    |
| Monochoria vaginalis        | heartshape false pickerelweed                  |      |                           | Agricultural Weed       |
| Najas graminea              | rice-field water-nymph                         |      | Asia                      | Agricultural Weed       |
| Ottelia alismoides          | ducklettuce                                    |      | Africa, India, sw Pacific | Agricultural Weed       |
| Peltandra virginica         | tuckahoe, green arrow arum                     |      | e N America               |                         |
| <b>Gastropods</b>           |                                                |      |                           |                         |
| Planorbella duryi           | seminole rams-horn                             |      | Florida                   | Pet/Aquarium Release    |
| Pseudosuccinea columella    | mimic limnaea                                  | 1921 | e N America               |                         |
| Radix auricularia           | big-eared radix                                | 1922 | Europe                    | Pet/Aquarium Release    |
| <b>Fishes</b>               |                                                |      |                           |                         |
| Esox lucius                 | northern pike                                  | 1994 | e N America               | Released by Individual  |
| Morone chrysops             | white bass                                     | 1987 | e N America               | Released by Individual  |
| <b>Reptiles</b>             |                                                |      |                           |                         |
| Apalone spinifera           | spiny softshell turtle                         | 1998 | e N America               | Pet/Aquarium Release    |
| Nerodia fasciata fasciata   | southern water snake                           | 1992 | e N America               | Pet/Aquarium Release    |
| Graptemys pseudogeographica | false map turtle                               | 1994 | e N America               | Pet/Aquarium Release    |
| Pseudemys spp.              | cooter                                         | 1994 | e N America               | Pet/Aquarium Release    |
| Chrysemys picta             | painted turtle                                 | 1997 | e & c N America           | Pet/Aquarium Release    |
| Chelydra serpentina         | snapping turtle                                | 1976 | e N America               | Pet/Aquarium Release    |