

**Briefing Paper on a Monitoring Plan for
Nonindigenous Organisms
in the San Francisco Bay/Delta Estuary**

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Briefing Paper on a Monitoring Plan for Nonindigenous Organisms

This briefing paper discusses the overall considerations regarding a monitoring program for nonindigenous species in the San Francisco Bay/Delta Estuary. It outlines general needs, opportunities and issues regarding monitoring for nonindigenous species, and briefly discusses types of research that could fruitfully be integrated with a monitoring program. However, the specific design of both monitoring programs and research activities should be tailored to generate the particular information and analyses needed for critical areas of policy and research. For example, this might entail focusing a portion of monitoring and research on a particular nonindigenous species of concern (such as mitten crab, green crab or Asian clam) or on particular habitats of concern (such as tidal wetlands that are the focus of restoration efforts); or a monitoring program could be designed to obtain the data needed to calculate proposed indices of ecosystem condition.

Monitoring and Research Objectives

In general, an overall monitoring program for nonindigenous organisms should address three fundamental objectives:

1. To detect new introductions in the ecosystem.
2. To track the growth and spread of nonindigenous organisms that are recent arrivals in the ecosystem. (In this context, "recent arrivals" means introduced organisms that are thought to be still expanding their range or increasing in abundance.)
3. To identify and assess the mechanisms or pathways that are introducing nonindigenous organisms into the ecosystem.

A monitoring program for nonindigenous organisms could also support or include supplemental research to achieve other objectives or address additional questions. For example, this could include research to:

- Assess the effect of nonindigenous organisms on the ecosystem. This could include investigations of interactions between nonindigenous and native organisms, and impact and risk assessments for ecological or economic impacts.
- Investigate how different factors—including characteristics of the environment, characteristics of the introduced organisms, and characteristics of the transport pathways—affect the success or failure of introductions.
- Assess the effectiveness of various control techniques in controlling the spread and abundance of particular nonindigenous species.

Research questions in these areas may be addressed through a variety of approaches: by focussing on particular nonindigenous organisms, with species-specific monitoring

programs combined with experimental field or laboratory work; by analyzing data sets developed by monitoring programs that include information on a large number of nonindigenous species, or that include information on nonindigenous species in a number of different ecosystems; or by investigations based on mathematical models, such as models of the population dynamics of invading species developed from or tested against monitoring data.

The information and insights derived from these monitoring and research efforts would support the development of strategies and techniques for the prevention, eradication or control of nonindigenous organisms. For example, information on introduction pathways is needed in order to develop effective prevention efforts; the prompt recognition and identification of new introductions is needed for the initiation of eradication efforts; and data on rates and patterns of spread are needed to support control efforts.

The three basic monitoring objectives and the types of monitoring needed to meet them are discussed in the sections below. Possibilities for supplemental research are not discussed further in this paper.

Why Monitor Specifically for Nonindigenous Species?

The question is sometimes raised as to whether it is really necessary to separately think about and plan for nonindigenous species when designing monitoring and research efforts. In other words, it is sometimes argued that a well-designed monitoring program would automatically gather data on all organisms, native and nonindigenous alike, and there is no need to give special attention to nonindigenous species.

While much may be learned about nonindigenous organisms and biological invasions through general biological monitoring and research, the development and implementation of prevention, eradication and control strategies and efforts will require particular types of information about nonindigenous species—different, in many cases, from the types of information sought about native species—as suggested in the preceding section. In addition, the circumstances and characteristics of organisms recently introduced or established in an ecosystem may frequently be distinct enough from the general run of organisms that it will be scientifically profitable to consider them separately. Thus, special data needs and specific monitoring design relative to nonindigenous species may arise from or have value for policy development, management efforts or scientific inquiry.

As one example, consider the early phase of invasions, when an introduced organism's population is small and vulnerable to stochastic perturbations ("Allee effect"). A substantial amount of theoretical and experimental work and data collection has focused on the genetics and population dynamics of small populations, primarily in order to understand the risks and stresses faced by small, remnant populations of endangered species (e. g. Shaffer 1981; Soulé & Simberloff 1986). A similar but separate exploration of small, initial populations of introduced species might appear to be redundant. However, the characteristics of small populations of endangered and introduced organisms may in general be quite different from each other. Many

endangered species are habitat or resource specialists, and many initially had a geographically small range. In contrast, many researchers have argued that successful introduced species are typically habitat and/or resource generalists with wide native ranges. The types of events that produce these two types of small populations, and the types of selection pressures resulting from those events, are also different. The differences in the observed population trajectories—with small introduced populations sometimes phenomenally increasing in abundance and range, and endangered populations rarely doing so—suggest that the study of one type of small population will not fully inform us about the other.

Monitoring Objective 1. Detecting and Identifying New Introductions

There are several advantages that could be realized from a monitoring program that did an effective job of detecting new arrivals in the Estuary. The benefits of earlier and more comprehensive detection of new introductions would include:

Research Benefits:

- Opportunities for researchers to study introductions from their earliest stages, which should help in developing a better understanding of the dynamics and impacts of invasions.
- Opportunities for researchers to study introductions that ultimately fail, as well as introductions that succeed. This could produce insights into what controls the success and failure of introductions.¹
- Better data on where and under what conditions new arrivals become established.
- Better data on the rate of introduction. This information would facilitate comparisons between ecosystems, which may produce insights into the factors that control introductions.

The above types of data and research could, over the longer term, lead to substantial improvements in our ability to manage biological invasions.

Management Benefits:

- Opportunities to implement control at an earlier stage in an invasion, before an invading organism has become abundant or widespread.² Earlier

¹ Simberloff (e. g. 1986, 1989, 1995) among others has pointed out the need for data on both failed and successful invasions in order to analyze invasion patterns and to test hypotheses about the influence of propagule size, invader characteristics, environmental similarity, biotic resistance, disturbance effects, etc.

² An example of this is the recent discovery and rapid eradication in Australia of an exotic mussel that is described as a brackish water counterpart to the zebra mussel, with the potential to cause similar types of impacts (See Appendix 6). Potential methods of eradication were considered after the fortuitous early detection of a

implementation of control programs would reduce the costs of control, produce fewer environmental and social side-effects, and have greater chances of success.

- Earlier warning of potential impacts from an invasion, which would provide greater opportunity to avoid or mitigate impacts, when direct control is not feasible.

There are three necessary elements in a monitoring program designed to detect new arrivals in an ecosystem: (1) sampling of appropriate habitats; (2) recognition of sampled specimens as possible introductions; and (3) identification of those specimens.

(1) Sampling of Appropriate Habitats

Simply put, to do an effective job of detecting the arrival of nonindigenous species, one must sample the habitats where they are likely to be found, or where they are likely to initially become established. Based on either past observations or theory, we can form some judgment about which types of habitats should be the focus of sampling. Some of these are currently sampled on a regular basis; others are not sampled at all.

Some examples of types of habitats in the Bay/Delta Estuary that may commonly harbor NIS and that have not been the focus of existing regional sampling programs include:

- **The surfaces of floating docks and buoys.** At temperate zone sites around the country, the surfaces of floating objects have been found to host a relatively high density of nonindigenous organisms. A series of largely unfunded, volunteer surveys of these habitats in the Bay/Delta Estuary in 1993-97 and in Puget Sound in 1998 produced dozens of records of nonindigenous species that had not previously been reported from these estuarine systems, including several that had not been reported from anywhere on the Pacific Coast of North America (Cohen *et al.* 1998; Cohen and others, unpublished data). The artificial nature of this habitat may contribute to the abundance of nonindigenous organisms, consistent with the theory that disturbed or altered habitat is more easily invaded. There is no ongoing program to sample these habitats.
- **The shallow water margins of the Estuary.** Certain species may be only present or predominantly present in very shallow water habitat near the shores of the Estuary, which has recently become the focus of some sampling efforts due to its importance for juvenile fish. Nonindigenous organisms that are found here and that have been largely or entirely missed by existing sampling programs include the Atlantic periwinkle *Littorina saxatilis*, a benthic organism found on hard substrate only in the high intertidal zone (Carlton & Cohen 1998); the southern hemisphere amphipod *Orchestia enigmatica*, a maritime species found at the water's edge (Bousfield & Carlton 1967); the southern hemisphere isopod *Euryllana arcuata*, a semi-pelagic/ epibenthic organism which appears to be present only in very shallow water containing abundant organic debris (Cohen

non-indigenous periwinkle in San Francisco Bay (Yamauchi 1996; Carlton & Cohen 1998).

unpublished data); and possibly a mysid shrimp of unknown origin, *Deltamysis holmquistae*, which may be restricted to waters in close association with aquatic vegetation and is infrequently collected in plankton tows (Bowman & Orsi 1992). Carlton (1979) has suggested that nonindigenous species with southerly distributions such as the Indian Ocean barnacle *Balanus amphitrite* and the serpulid worm *Ficopomatus enigmaticus* may only be able to survive in the warmer waters around the bay margin. The European green crab *Carcinus maenas* is much commoner in shallow than in deep water, and during the first years after its arrival was not collected by the Interagency Ecological Program's (IEP) otter trawl sampling in the Bay, but was frequently collected by manual sampling along the shore and in near-shore bait traps. IEP conducted ring net sampling for crabs from fishing piers around the Bay, but failed to collect green crabs until the nets were fished in shallow water (K. Hieb, pers. comm.).

- **Artificial or highly altered lagoons and other small water bodies with limited hydrologic connections to the Estuary.** Species initially collected from lagoon-type habitats around the Estuary include the southern hemisphere tubeworm *Ficopomatus enigmaticus*, the Atlantic crab *Rhithropanopeus harrisi* and a nudibranch of unknown origin, *Cuthona perca*, all initially collected in Lake Merritt, a brackish water body connected to the Bay by a narrow tidal channel (Carlton 1979); the Japanese jellyfish *Aurelia "aurita"* in Foster City Lagoon (Greenberg 1996); and the European green crab *Carcinus maenas* in Redwood Shores Lagoon (Cohen *et al.* 1995). Cohen *et al.* (1995) suggest that these lagoons may act as "invasion incubators," in part because of their ability to retain planktonic larvae in small areas and thereby increase the probability of their finding mates when mature. There is no program to sample these habitats.
- **Small brackish tributary rivers and sloughs.** In recent years several jellyfish have been initially discovered in the Estuary in the Petaluma and Napa rivers and Suisun Marsh sloughs (Mills & Sommer 1995; J. Rees, pers. comm.). There has been long-term sampling of fish in Suisun Marsh sloughs (e. g. see Moyle *et al.* 1986, Meng *et al.* 1994), but otherwise rather limited sampling of these habitats.
- **Areas near shipping facilities.** It has been suggested that new introductions arriving via ships' ballast water or as fouling on ships' hulls might be found in greater abundance and earlier in their expansion in the vicinity of ports and ship terminals, drydocks, etc. This has been observed, for example, for nonindigenous copepods in the Pacific Northwest (J. Cordell, pers. comm.). There is no organized effort to sample these habitats in the Estuary, although there may be occasional short-term sampling efforts in conjunction with environmental assessments of port-related projects or in response to chemical spills, or longer-term sampling at particular contaminated sites.

Beyond targeting some currently undersampled and potentially interesting habitats, a program seeking to detect invasions at an early stage should cast a wide net, and make creative use of existing activities to gather records and specimens of unfamiliar organisms observed in the Estuary. Some possibilities include:

- **Amending existing sampling efforts.** Some existing programs targeting particular species or groups of organisms may incidentally collect other types of organisms but not retain them for identification. For example, the Interagency Ecological Program's Delta Outflow sampling program focuses on fish, crabs and shrimp, but typically collects many types of invertebrates that are not recorded, saved or identified. Appendix 1 summarizes the major long-term programs that currently sample biota in the Estuary, and additional information is provided in two monitoring inventories on the San Francisco Estuary Institute website.³
- **Using water diversions as sampling devices.** It has been noted that the fish screen and bypass facilities at the state and federal pumps are highly effective sampling devices for introduced fish, mitten crabs and other nonindigenous organisms (e. g. Liston *et al.* 1996; Siegfried 1999). Water diversions throughout the Bay/Delta system could be incorporated into a monitoring program to, among other things, watch for new introductions. For example, monitoring of cooling water intake filter screens at five power plants in the Estuary in 1978-79 produced the first records of the isopod *Eurylana arcuata* on the Pacific Coast of North America (Bowman *et al.* 1981). Similarly, monitoring at power plants documented the invasion, spread and abundance of mitten crabs *Eriocheir sinensis* in England (Anon. 1935; Ingle & Andrews 1976; Andrews *et al.* 1982; Attrill & Thomas 1996a,b). Fish populations in the Estuary have also been monitored at power plant intakes (e. g. Herald and Simpson 1955). Some information on the major water diversions from the Estuary is provided in Appendix 2.

As a sampling device, a water diversion is analogous to an extremely large pump sampler. Sampling at diversion screens has some advantages and some disadvantages. Large volumes of water may be sampled over relatively long times, at relatively low cost. For example, Bowman *et al.* (1981) collected samples of 24-hour duration from power plant filter screens at five sites in San Francisco Bay, taken each week for a year. On the other hand, the capture efficiency of these devices may vary in an unknown fashion with varying flow rates, and the consistency of operation of the device and the continuity of sampling opportunity is not under the control of the researcher. For example, since the mid-1970s fish and mobile invertebrate populations were monitored in the Thames River by means of regular collections at the intake screens of the West Thurrock Power Station, east of London. Among other data, these collections indicated rising numbers of mitten crabs in the late 1980s and early 1990s, but this monitoring came to an abrupt end in 1993 with the closure of the power station (Attrill & Thomas 1996a).

- **Developing a public monitoring program.** It may be possible to systematically enlist environmental education programs, commercial crayfish harvesters, shrimpers and baitfish trappers, baitshops, anglers or others as additional eyes on the Bay/Delta ecosystem, to look for, collect and report on unfamiliar organisms or on known, newly-arrived invaders that they encounter in the

³ The CMARP Monitoring Program Inventory (<http://www.sfei.org/cmarpinv>), and the California Coastal Water Quality Monitoring Inventory (<http://www.sfei.org/camp/index.html>).

course of their activities. Several recently-arrived nonindigenous organisms in the Estuary were initially collected and brought to the attention of researchers by such individuals: the European green crab *Carcinus maenas* by a baitfish trapper (Cohen *et al.* 1995); the Black Sea jellyfish *Maeotias inexpectata* by a school teacher (Mills & Sommer 1995); the New Zealand seaslug *Philine auriformis*⁴ by the Marine Science Institute, an environmental education program in Redwood City (Gosliner 1995); the Chinese mitten crab *Eriocheir sinensis* by a shrimper and the Marine Science Institute (Cohen & Carlton 1997); and the Asian clam *Potamocorbula amurensis* by a Diablo Valley College biology class (Carlton *et al.* 1990). In the 1990s, informal networks using shrimpers, bait trappers and anglers provided information on the spread of green crabs and mitten crabs (Cohen *et al.* 1995; Cohen & Carlton 1997). Posters used to solicit reports of observations on these crabs are reproduced in Appendix 5. The California Department of Fish and Game has also gathered substantial information on the distribution of mitten crabs from members of the general public. Appendices 3 and 4 provide information on the Estuary's commercial fisheries and on sampling conducted in the Estuary by environmental education programs, relevant to their potential use in a public monitoring program.

(2) Recognition of Possible Introductions

One obstacle to the early detection of new introductions—especially among small or taxonomically obscure organisms, which includes many types of invertebrates, protozoans, microalgae and macroalgae—is the difficulty of recognizing when a specimen may represent a new organism for the Estuary. The following discussion is largely based on issues relating to the recognition and identification of introduced marine invertebrates, the group that I am most familiar with (and the group which accounts for the largest number of known nonindigenous species in the Estuary). The general thrust of the discussion should also apply to these other taxonomic categories.

Nonindigenous marine organisms in the Estuary have often been misidentified initially as native Pacific Coast species.⁵ This error commonly arises from using regional taxonomic keys without making use of supplemental information. In addition to outright misidentifications, specimens that do not key out readily—which may include nonindigenous species not covered by the key, as well as damaged or poorly preserved specimens, and specimens of the wrong gender or in the wrong stage of development for the key—are often simply left unidentified to species, and eventually either shelved and forgotten or discarded.

⁴ There has recently been some debate among researchers (some of which is reported on the internet at <http://www.austmus.gov.au/science/division/invert/mal/forum/philcali.htm> and at <http://www.austmus.gov.au/science/division/invert/mal/forum/philauri.htm>) as to whether the recently introduced opisthobranch seaslug in San Francisco Bay is *Philine auriformis*, or some other non-indigenous species of *Philine*. In this paper, I will continue to refer to the *Philine* in the Bay as *Philine auriformis*.

⁵ See, for example, Table 2, "Examples of introduced species initially introduced as native taxa" in Carlton 1979, p. 24.

The frequency of failures to recognize novel species in sampled material and to take the steps needed to correctly identify them could be reduced by providing:

1. Appropriate informational tools and training to recognize suspected introductions.
2. An efficient process for identifying suspected introductions.
3. A mandate and funding to perform these tasks.

The first issue, informational tools and the recognition of suspect introductions, is discussed in the following paragraphs. The second issue, a process for identifying these organisms, is discussed in the next section; however, unless such a process is readily available there will be little incentive for most working taxonomists to look for and separate out possible introductions. Regarding the third issue, the need for a mandate and funding, since isolating and identifying suspected introductions can be a time-consuming task and may also require outside expertise, the performance and completion of this task will remain haphazard and dependent on the vagaries individual initiative and interest, unless the individuals engaged in taxonomic work in the Estuary are specifically tasked and funded to do them.

Regional keys, when properly designed, are based on a selected set of morphological characteristics (occasionally supplemented by behavioral characteristics) that are sufficient to distinguish among the organisms known from the region in question. However, such keys may be of little help in distinguishing, and typically of no help in identifying, organisms that have not been previously recognized in the region and are therefore not covered by the key. Thus, a specimen of a novel nonindigenous species may key out in a completely proper and satisfactory manner in such a key, to be identified confidently and incorrectly as a particular native species, simply because characteristics that could have distinguished it were not included in the key—as they were not necessary or useful for distinguishing among the organisms known from the region that the key was intended to cover.

Nevertheless, taxonomists with long experience in the Estuary will generally recognize when something new comes before them, at least in the taxonomic groups that they are most familiar with. However, because there are many highly-diverse and speciose invertebrate groups and few invertebrate taxonomists, taxonomists sometimes end up working on groups of organisms that they don't know all that well, and on occasion taxonomists are employed who lack substantial experience in the Estuary. In either of these cases the taxonomist may not recognize when a specimen represents a new species in the ecosystem, if no obvious difficulty arises in keying it out. Certain types of informational tools could be developed that would substitute, to some extent, for the expert knowledge that comes from long familiarity with a regional biota, or that would supplement that knowledge.

One noteworthy and illustrative attempt to deal with this problem within the context of an invertebrate key is William J. Light's volume on the Spionidae (a family of polychaete worms) of San Francisco Bay (Light 1978). This volume was the first in the California Academy of Science's ambitious but never-completed series on the

Invertebrates of the San Francisco Bay Estuary System.⁶ These volumes were to consist of detailed, annotated keys plus supplemental information and references, each volume to cover "a group of convenient size, ranging from family to phylum," with the series ultimately covering all of the invertebrates recorded in the Estuary (Lindberg 1981, p. 1).

The Spionidae volume included keys in three distinct formats (pictorial dichotomous keys, verbal dichotomous keys, and tabular keys) at both the genus and species level, and which included all genera recorded from California; descriptions of every species recorded from the Bay along with the synonymy for each species; world distribution records; comments on and figures of morphological variations; notes on ecology; notes on preparation, dissection and handling of specimens; and a complete, illustrated glossary of terms. It described the taxonomic problem relative to the potential occurrence of nonindigenous species, and the approach it took to address this problem, as follows:

"All species known to occur in San Francisco Bay are included in these keys. In addition, those species not yet recorded from the Bay, but which are likely to occur there and which might be confused with species already known from the Bay, are likewise included...In the event that a species is encountered which almost, but not quite, fits one of those presented in the keys, the user should turn to the remarks section under the account for that species in the systematic section. There he will find detailed comments on every known species in the world which could possibly be confused with the taxon in question...In most cases, these remarks will, in fact, treat every single described species within that genus. In the case of extremely large groups,...species-groups and complexes have been delineated. When a member of such a species complex occurs in San Francisco Bay, it is distinguished from all other known species of that complex...These keys and descriptions have been compiled with the concept of the world fauna constantly in mind" (Light 1978, p. 1-4).

The volume notes that the inclusion of such detailed differential diagnoses "is necessary because many species from various parts of the world have already been introduced into San Francisco Bay, and the likelihood is high that more such exotic species will be discovered" (Light 1978, p. 2). The contents and organization of this volume provide a good example of the type of information which, if it were made readily available to taxonomists working in the Estuary for all invertebrate and other obscure or difficult taxonomic groups, would significantly facilitate the recognition (and at least the initial steps in the identification) of possible specimens of nonindigenous species.

Thus, the completion and the timely, periodic revision of a series of taxonomic volumes on the organisms in the Estuary constructed along the lines of Light's Spionidae volume would be one approach to providing needed information tools to taxonomists to address the recognition of nonindigenous species. A somewhat less ambitious, but still

⁶ A volume on the Acmaeidae, a family of gastropod molluscs, was the only other volume published in the series (Lindberg 1981).

useful approach, would be to develop a set of tools and supporting services such as the following:

- **A comprehensive list of the organisms that have been collected from the Bay/Delta Estuary.** Comprehensive species lists for parts or for all of this ecosystem have often been compiled for birds, mammals, fish and plants, but there are few if any such lists for invertebrates. If such a list were available, taxonomists could check invertebrate identifications determined from regional keys (such as the commonly-used keys for invertebrates of the central California coast) against the list. If the species as determined from the key was not on the list of species previously recorded from the Estuary, this would warn the taxonomist that the identification might not be correct, and that additional information should be sought beyond that provided in the key.
- **Ready access to supplemental information on organisms known from the Estuary.** Supplemental information such as detailed taxonomic descriptions, scientific illustrations, photographic images, information on known geographic and habitat ranges, information on morphological variations, information on other species that the species in question may be confused with, notes on ecology, references to additional literature, information on dates and sites of collection, and data on the existence and location of preserved specimens exists for many of the organisms in the Estuary. With such information at hand a taxonomist often can quickly determine whether an identification made from a key makes sense, and where to look for help if further work is needed. However, finding that information can be difficult and time-consuming.

Some, perhaps most, of this information could be made available over the internet, compiled on software that was made available to the taxonomists working in the Estuary, or compiled in a central archive that was organized to provide support (via telephone or email) to the region's taxonomists. (A good deal of this sort of information has already been collected at various institutions in the region. Every taxonomic laboratory compiles at least some of the most commonly used information.) It would be a boon to both the recognition of suspect introductions and to other taxonomic work in the Estuary if a taxonomist confronted by a difficult specimen could quickly access such information electronically, or could contact a central archive and have the necessary illustration or species description faxed back.

- **Rapid dissemination among regional taxonomists of information on new introductions to the Pacific Coast and other parts of the world, and on suspected introductions in the Estuary.** The dissemination of information on "organisms to watch for" would be facilitated by setting up a communication network and/or newsletter for regional taxonomists (as has been done for southern California by organizing the Southern California Association of Marine Invertebrate Taxonomists (SCAMIT)), and by organizing an annual meeting of regional taxonomists to share information, demonstrate techniques, and discuss the identity of problematical specimens. This would benefit all aspects of taxonomic work, including the recognition and identification of nonindigenous species.

- **A comprehensive and accessible archive of preserved specimens.** At a minimum this should include all known Pacific Coast estuarine organisms. It could also usefully include a collection of invasive estuarine organisms from other parts of the world; and collections of certain taxonomic groups from source areas that have been frequent contributors to the Estuary's biota. For example a collection of zooplankton from the estuaries of Japan, Korea and China would help with the recognition and identification of organisms introduced through ballast water discharges, and a collection of intertidal invertebrates from Maine would be useful for monitoring the arrival of organisms inadvertently imported with marine baitworms. Such collections would also help with the assessment of mechanisms introducing nonindigenous organisms, discussed further below. Information on the specimens in the collection should be compiled in a database that can be accessed through the internet.

(3) Identification of Suspect Specimens

Once a taxonomist recognizes that a specimen is possibly not a native organism, the next step is to figure out what it is and where it's from. This requires a different set of informational tools and a different type of effort from that which is needed to identify organisms belonging to the known biota of a region. Identifying a new arrival may require global knowledge of the various species in the particular taxonomic group that the organism belongs to, as well as access to the world literature on that group. In some cases, it may be necessary to send the specimen to an appropriate specialist elsewhere in the world, or to obtain specimens for comparison from other parts of the world. This would probably work more efficiently and would get done more often if taxonomists had the option of simply sending their suspect material to an individual or laboratory that would make an assessment of the material, determine whether it really appears to be something new in the region, decide what should be sent off to specialists and whom to send it to, and then take care of these tasks. While many details would need to be worked out, some system like this, which regional taxonomists would be encouraged to make use of, is probably necessary if we really want to recognize and systematically identify new invaders early on.

Monitoring Objective 2. Tracking the Spread of Nonindigenous Organisms

General sampling programs will provide some information on the spread within the Estuary of nonindigenous species that belong to the target groups monitored by these programs, such as fish, shrimp, crabs, zooplankton or subtidal benthic infauna. Even so, several prominent introductions in these target groups have not been effectively tracked by the existing monitoring programs, such as green crab, mitten crab and probably gobies. Species that do not belong to these target groups are much less likely to be tracked. Effective tracking of particular invasive organisms of concern may require either some modification of existing sampling programs, or the implementation of sampling efforts specifically designed for those organisms.

In some cases, existing sampling and monitoring programs may be easily amended to monitor for particular nonindigenous species. For example, in the years after its introduction some of the regular monitoring programs in the Estuary frequently

collected the New Zealand sea slug *Philine auriformis* but did not record or quantify its presence in their samples, as it did not belong to any of the targeted groups of species. Adding the sea slug to the target species and recording its presence and abundance would have entailed little additional effort, while providing a much more complete picture of the distribution and spread of this organism in the Estuary.

In other cases, specific sampling programs may be implemented that are intended to monitor particular organisms after their initial detection. For example, the Interagency Ecological Program has implemented sampling efforts specifically designed to monitor the distribution and spread of green crab and mitten crab in the Estuary (Hieb 1997; Holmes & Osmondson 1999). In addition, a public monitoring program, as discussed above, may be useful for monitoring the spread of conspicuous and easily identified organisms.

Monitoring Objective 3. Assessing the Mechanisms Introducing Nonindigenous Organisms

A third component of nonindigenous species monitoring is monitoring of the mechanisms that transport and release nonindigenous organisms into the Estuary. Such monitoring is fundamental to the development and implementation of programs to reduce or prevent the introduction of additional nonindigenous species. Data on patterns, rates and trends in the transport and release of nonindigenous species are needed to make and support appropriate policy decisions about the necessity of managing or regulating these mechanisms; to design effective management or regulatory approaches; and to assess the effectiveness of such approaches when implemented. Such monitoring may also assist the detection and identification of new introductions in the Estuary, by providing information on which species to watch for.

Several mechanisms that transport or release organisms are obvious candidates for such monitoring:

- Ship's ballast water is generally thought to be the most important mechanism transporting freshwater and marine organisms around the world today. In several parts of the world, ballast water and the sediments associated with it have been sampled by various techniques which have collected a wide variety of living organisms including fish, invertebrates, phytoplankton, protozoans, bacteria and viruses, sometimes in considerable abundance (studies and results summarized in Cohen 1998). Ballast water discharges have also been responsible for some of the most spectacular and damaging recent invasions in the Estuary and elsewhere; and there has been considerable and increasing public and regulatory attention to this mechanism. However, there is as yet no program implemented or planned to sample the ballast water arriving in the Bay/Delta region in order to characterize and monitor the organisms being released into the Estuary .
- Seaweed is used to pack marine baitworms that are imported from the east coast of North America, and this seaweed is frequently discarded into the Estuary by anglers (Lau 1995). The seaweed typically contains a substantial number of nonindigenous organisms (Lau 1995; Cohen, unpublished data), and is probably responsible for

introducing several species that are now established on the Pacific Coast (Carlton & Cohen 1998; Cohen, unpublished data). This mechanism which routinely releases Atlantic intertidal organisms into the Estuary remains entirely unmanaged and unregulated. Nonindigenous organisms may also be transported in the seaweed used to pack lobsters and perhaps other seafood products, and possibly discarded into the Estuary from shoreside restaurants (Miller 1968).

- Other pathways by which nonindigenous organisms can be released into the Estuary, and which may warrant monitoring, include:
 - > Baitfish or other live aquatic bait organisms (worms, shrimp, etc.) imported into the region and the organisms associated with them (including parasites of the bait organism and organisms in the water or other medium used to transport the bait organism).
 - > Fish or other aquatic organisms imported into aquaculture facilities, or into other holding or rearing facilities for live aquatic organisms, and the organisms associated with them (including parasites and organisms in the transport water or transport medium).
 - > Aquatic organisms imported into the region for live sale as food or pets or as ornamental plants, and the organisms associated with them (including parasites and organisms in the transport water or transport medium).
 - > Organisms in the water in ships' seachests and other components of a ships' seawater system.
 - > Organisms attached as fouling to the hulls of ships, or attached to ships' anchor chains or carried in sediment or water in chain lockers;
 - > Organisms attached to the hulls or trailers of recreational boats entering the region, or carried in the water in bait tanks, engines, etc.

Monitoring programs for a few of these introduction pathways are in place, such as monitoring of trailered boats for zebra mussels (*Dreissena polymorpha*) at California highway border stations by the California Department of Food and Agriculture (Janik 1997). These efforts may benefit from review and possible modification or augmentation. For other pathways, there currently is no monitoring conducted.

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Appendix 1.

Biological Monitoring Programs in the San Francisco Bay/Delta Estuary

(For further information on these and other monitoring programs in the Estuary, see the CMARP Monitoring Program Inventory at <http://www.sfei.org/cmarpinv>)

(A) On-Going/Long-Term Programs

PHYTOPLANKTON

San Pablo Bay to Delta

Program: Phytoplankton chlorophyll and species composition

Agency: Department of Water Resources

Start Date: 1970

Purpose: To track changes in chlorophyll concentrations and phytoplankton community composition.

Study Area and Sampling Schedule: 15 stations, ranging west to San Pablo Bay, north to Georgiana Slough, and south to Manteca. Monthly or semi-monthly sampling.

Sampling Methods: Van Dorn bottle

Taxonomic Work: Phytoplankton cells and colonies are counted and identified to genus, or to species for common forms. Unfamiliar species identified to lowest possible taxonomic level.

Taxonomist is George Webber

Species Lists/Records: Comprehensive lists are kept at DWR. Annotated lists are published in IEP annual reports and newsletters.

Contact: Peggy Lehman, Kitty Tripoli (DWR)

Sources of Information: Lehman, 1996; P. Lehman, K. Tripoli, pers. comm.

ZOOPLANKTON

Suisun Bay to Delta

Program: *Neomysis* /Zooplankton Study

Agency: California Department of Fish and Game/Interagency Ecological Program

Start Date: 1968 (*Neomysis*); 1972 (zooplankton)

Purpose: To determine how the distribution and abundance of *Neomysis* and zooplankton, as important fish food, are affected by phytoplankton concentrations, gravitational circulation and other factors.

Study Area and Sampling Schedule: 35 locations in Suisun Bay and the Delta until 1994; reduced to 16 locations ranging from western Suisun Bay north to Threemile Slough on the Sacramento River and east to Rough and Ready Island on the Sacramento River. Depending on flows and year, sampling has ranged downstream as far as San Pablo Bay and upstream to Hood and Stockton. Sampled once a month from November through March and twice a month April through October.

Sampling Methods: *Neomysis* net (since 1968) and Clarke-Bumpus net (since 1972) towed bottom to surface in stepwise oblique tow. Microzooplankton sampled by pump as hose is raised from bottom to surface, and collected on 43 μm mesh. Samples preserved in 10% formalin and stained with Rose Bengal dye.

Taxonomic Work: All abundant copepods and all mysids are identified to species; other copepods such as *Diaptomus* may be identified to genus and others such as harpacticoids to order. Of the rotifers only *Synchaeta bicornis* is identified to species. Three genera of cladocerans are identified: *Daphnia*, *Bosmina* and *Diaptomus*; the rest are lumped as "other." Two genera of

amphipods are identified: *Corophium* and *Gammarus*. Taxonomists include James Orsi (CDFG), Sally Skelton, and Wim Kimmerer (Romberg-Tiburon Center).

Species Lists/Records: Records at CDFG and on STORET.

Specimens: Preserved collection goes back many years and is stored at CDFG in Stockton.

Contact: James Orsi (CDFG)

Sources of Information: Davis, 1988; SFEI, 1990; Hansen, 1993; Kimmerer 1996; CMARP Monitoring Program Inventory; J. Orsi, pers. comm.

BENTHIC INVERTEBRATES

San Pablo Bay to Delta

Program: D-1485 compliance monitoring

Agency: California Department of Water Resources

Start Date: 1975

Purpose: Baseline monitoring of benthic fauna to determine compliance with D-1485 standards, to track long-term trends, and to detect changes in community composition.

Study Area and Sampling Schedule: Monthly sampling at 5-8 sampling stations in 1975-1995 and 10 stations in 1996-1997, ranging from San Pablo Bay to the Delta.

Sampling Methods: Ponar dredge, seived through 1 mm and 0.5 mm seive.

Taxonomic Work: Specimens identified to lowest possible taxonomic level. Taxonomist is Wayne Fields (Hydrozoology, Inc.)

Species Lists/Records: Results are published in annual "Bulletin 132" and species lists are on the DWR Environmental Services website.

Specimens: Samples stored at Hydrozoology. Unfamiliar species are kept in 75% alcohol.

Contact: Heather Peterson (DWR)

Sources of Information: SFEI 1990; Hansen 1993; Thompson *et al.* 1997; H. Peterson, pers. comm.

Other Comments: Occasional extended sampling of the entire Estuary (i. e. for *Potamocorbula amurensis*).

BENTHIC INVERTEBRATES

South Bay to Delta

Program: Regional Monitoring Program Benthic Pilot Study

Agency: Combined program of San Francisco Estuary Institute/Regional Monitoring Program, California Department of Water Resources, and Bay Area Dischargers Association/Local Effects Monitoring Program

Start Date: 1994

Purpose: To evaluate the effects of contamination on resident biota, community structure and function.

Study Area and Sampling Schedule: 19 sites in South Bay, San Pablo Bay, Suisun Bay, and Delta, sampled monthly.

Sampling Methods: 0.05 square meter Ponar grab, seived through 1 mm and 0.5 mm seive.

Taxonomic Work: All organisms identified to lowest possible taxonomic level, including unfamiliar species. Primary taxonomists are Brian Fak, Patricia McGregor, and Sonja Foree. Outside specialists from SCAMIT and the California Academy of Sciences are consulted as needed.

Species Lists/Records: In Regional Monitoring Program annual reports, and available from SFEI.

Specimens: Preserved in 75% ethanol.

Sources of Information: Thompson *et al.* 1996, 1997; B. Thompson, pers. comm.

BENTHIC INVERTEBRATES**Suisun Bay**

Program: Benthic monitoring in the North Bay

Agency: U. S. Geological Survey

Start Date: 1989

Purpose: To track the species composition of shallow water benthos in the North Bay and to complement DWR's D-1485 program. In future, the data may be used to compare species composition with ambient contaminant levels.

Study Area and Sampling Schedule: Seven sampling stations in Suisun Bay near Martinez, Concord, Chipps Island, and Suisun cutoff. Samples are taken monthly.

Sampling Methods: 0.05 square meter Van Veen grab; screened at 0.5 mm and fixed in 10% formalin. After sorting the samples are preserved in ethanol.

Taxonomic Work: Crustaceans are sorted to family or lower, and annelids to polychaetes and oligochaetes. Funding is inadequate for identification to lowest possible taxonomic level. Work has begun on identification of stored samples, which will be published as an open-file report on benthic community composition at these sites from 1989-1997.

Species Lists/Records: Available from USGS.

Specimens: Stored at USGS.

Contact: Jan Thompson (USGS)

Sources of Information: J. Thompson, pers. comm.

FISH, CRABS AND SHRIMP**South Bay to Delta**

Program: Delta Outflow / San Francisco Bay Study

Agency: California Department of Fish and Game/Interagency Ecological Program

Start Date: 1980

Purpose: To study the association of delta freshwater outflow with distribution and abundance of fish, shrimp, and crabs in the Estuary; to calculate abundance indices for fish, crabs and shrimp.

Study Area and Sampling Schedule: Monthly sampling at 52 stations in the Bay and Delta ranging south to the Dumbarton Bridge, to just west of Alcatraz Island, north to the confluence of the Sacramento River and Steamboat/Cache sloughs, and east to Old River Flats on the San Joaquin River. Historically 70-80 stations were sampled.

Sampling Methods: Midwater trawl, otter trawl and plankton net. Beach seine and baited ring nets (for crabs) used at selected stations. Fish, crabs and shrimp are identified, other organisms are returned to the water.

Taxonomic Work: Familiar species of fish and crabs are identified and processed at the sampling location and then returned to the water. A sample of shrimp and unfamiliar fish and crabs are preserved in 10% formalin and processed in the laboratory. Taxonomists used include Bob Lea (marine fish), Greg Jensen (University of Washington—shrimp and crabs), Mary Wicksten (Texas A&M—shrimp), William Eschmeyer (California Academy of Sciences—fish).

Species Lists/Records: Available from CDFG and on STORET.

Specimens: Archived samples going back to 1985 are stored at CDFG.

Contact: Kathy Hieb (CDFG)

Sources of Information: Davis 1988; SFEI 1990; Hansen 1993; CMARP Monitoring Program Inventory; K. Hieb, pers. comm.

FISH AND SHRIMP**San Pablo Bay to Delta and Rivers**

Program: Striped Bass Fall Midwater Trawl Survey

Agency: California Department of Fish and Game/Interagency Ecological Program

Start Date: 1967 (no sampling in 1974 and 1979)

Purpose: To monitor trends in striped bass abundance, growth and mortality and identify factors underlying population changes.

Study Area and Sampling Schedule: Monthly sampling at about 90-100 stations from San Pablo Bay to Rio Vista and Stockton, during September to December. Earlier in the program sampling continued to March and stations through Central and South bay were included; historically, a total of about 165 stations were sampled.

Sampling Methods: Midwater trawl on a diagonal tow.

Taxonomic Work: Fish identified to species and shrimp to genus at the sampling location.

Species Lists/Records: On STORET.

Contact: Donald E. Stevens (CDFG)

Sources of Information: Davis 1988; SFEI 1990; Hansen 1993; CMARP Monitoring Program Inventory.

FISH AND ZOOPLANKTON

San Pablo Bay to Delta

Program: Striped Bass Egg and Larvae Survey

Agency: California Department of Fish and Game/Interagency Ecological Program

Start Date: 1968; not conducted in some years.

Purpose: To monitor trends in striped bass abundance, growth and mortality and identify factors underlying population changes.

Study Area and Sampling Schedule: About 35-60 stations sampled each year ranging from Benicia to Colusa, generally from mid-April to mid-July. Historically a total of about 80 stations have been sampled.

Sampling Methods: Ichthyoplankton sampled with 505 μm mesh net, and zooplankton with 154 μm mesh Clarke-Bumpus net, towed above the bottom. Samples preserved in 5% formalin or in 95% ethanol (for otoliths).

Species Lists/Records: On STORET.

Contact: Donald E. Stevens (CDFG)

Sources of Information: Davis 1988; SFEI 1990; Hansen 1993; CMARP Monitoring Program Inventory.

FISH

San Pablo Bay to Delta and Rivers

Program: Striped Bass Summer Towntnet Survey

Agency: California Department of Fish and Game/Interagency Ecological Program

Start Date: 1959 (no sampling in 1966 and 1983; surveys have been conducted since 1953, but procedures were inconsistent prior to 1959)

Purpose: To monitor trends in striped bass abundance, growth and mortality and identify factors underlying population changes.

Study Area and Sampling Schedule: About 30-35 stations from San Pablo Bay to Rio Vista and Stockton sampled every 2 weeks in the summer. Historically, a total of about 50 sites have been sampled.

Sampling Methods: Three 10-minute tows against the current.

Taxonomic Work: Fish identified to species at the sampling location.

Species Lists/Records: On STORET.

Contact: Donald E. Stevens (CDFG)

Sources of Information: Davis 1988; SFEI 1990; Hansen 1993; CMARP Monitoring Program Inventory.

FISH

Delta

Program: Clifton Court Forebay Entrainment-Predation Loss Study

Agency: California Department of Fish and Game/Interagency Ecological Program

Start Date: 1991

Purpose: To assess the loss of fish from entrainment or predation related to water project operations.

Study Area and Sampling Schedule: Six stations in the forebay. Weekly during the day, biweekly at night.

Sampling Methods: Gill net and hook-and-line.

Taxonomic Work: All fish identified to species at the sampling site.

Contact: Bob Fujimura (CDFG)

Sources of Information: CMARP Monitoring Program Inventory.

FISH

Delta

Program: Delta Fish Facilities Salvage Monitoring Program–Tracy Fish Collection Facility

Agency: U. S. Bureau of Reclamation

Start Date: 1957 (data incomplete prior to 1979)

Purpose: To monitor the entrainment of fish species of concern as a result of state and federal water project operations.

Sampling Methods: Year-round sampling four times a day, or every 2 hours when pumps are operating.

Taxonomic Work: All fish species keyed out. Unfamiliar fish sent to Johnson Wang (if larval) or to Kathy Hieb (if post-larval).

Species Lists/Records: Kept at the facility.

Specimens: Voucher collection kept for day-to-day taxonomy but no long-term collection maintained.

Contact: Scott Siegfried (USBR)

Sources of Information: Barrow 1996; Arnold 1999.

Other Comments: Mitten crabs are also counted, and samples sent to Kathy Hieb (CDFG).

FISH

Delta

Program: Delta Fish Facilities Salvage Monitoring Program–Skinner Fish Facility

Agency: Department of Water Resources, California Department of Fish and Game

Start Date: 1968 (data incomplete prior to 1979)

Purpose: To estimate juvenile fish losses in the forebay and identify the causes.

Sampling Methods: Similar to Tracy.

Taxonomic Work: Similar to Tracy.

Sources of Information: Barrow 1996; Arnold 1999.

Other Comments: Mitten crab are counted.

FISH**Delta**

Program: South Delta Temporary Barriers Monitoring Program

Agency: California Department of Fish and Game

Start Date: 1991

Purpose: To assess the status of fish communities near the barriers.

Sampling Methods: Hoop nets and electrofishing at 15-18 stations.

Contact: Jennifer Bull (CDFG)

Sources of Information: Hansen 1993.

FISH**Delta**

Program: North Bay Aqueduct Monitoring Program

Agency: California Department of Fish and Game

Start Date: 1986

Purpose: To measure the impact of North Bay Aqueduct diversions on the composition and abundance of fish populations.

Study Area and Sampling Schedule: 2 stations in Barker Slough. Biweekly during February, June, and October.

Sampling Methods: Otter trawl, gillnet.

Contact: Jennifer Bull (CDFG)

Sources of Information: Hansen 1993.

FISH**Suisun Marsh**

Program: Suisun Marsh Fish Study

Agency: UC Davis (Peter Moyle), under contract to Department of Water Resources

Purpose: To monitor trends in fish species composition and abundance.

Start Date: 1979.

Study Area and Sampling Schedule: Three locations in each of 5 sloughs within Suisun Marsh. Monthly sampling.

Sampling Methods: Otter trawl at 21 stations every month; beach seine at 2 stations every month.

Taxonomic Work: All fish are identified. Unfamiliar fish or crabs are preserved and sent to CDFG (Kathy Hieb) for identification.

Species Lists/Records: On DWR's ACCESS database and filed at UC Davis.

Contact: Scott Matern (UC Davis)

Sources of Information: Moyle *et al.* 1986; Meng *et al.* 1994; Matern 1997; S. Matern, pers. comm.

FISH**Suisun Bay**

Program: Montezuma Slough Control Structure Monitoring Program

Agency: California Department of Fish and Game

Start Date: 1987

Purpose: To monitor abundance of predator fish and migration of adult salmon.

Study Area and Sampling Schedule: 6-8 stations in Montezuma Slough.

Sources of Information: Hansen 1993.

FISH

Suisun Bay to Sacramento River

Program: Salmon Program elements: smolt abundance, smolt survival, and distribution and abundance of juvenile salmonids

Agency: U. S. Fish and Wildlife Service

Start Date: 1978

Purpose: To monitor the abundance and distribution of four populations of chinook salmon and to track the magnitude and pattern of mortality resulting from water project operations.

Study Area and Sampling Schedule: Over 150 sites from Benicia to Princeton. Sampling is weekly or biweekly every month of the year.

Sampling Methods: Midwater trawl, beach seine, rotary screw trap, fyke net.

Taxonomic Work: Fish are identified to species level to the abilities of field staff. Unfamiliar species are sent to Johnson Wang and others.

Species Lists/Records: Available from USFWS Stockton office.

Contact: Mark Pierce (USFWS)

Sources of Information: Hansen 1993; M. Pierce. pers. comm.

FISH

San Pablo Bay to Sacramento River

Program: Delta Smelt Monitoring Program

Agency: California Department of Fish and Game

Start Date: 1991

Purpose: To monitor annual population levels and identify causes of decline.

Study Area and Sampling Schedule: Over 200 sites from San Pablo Bay to Knights Landing on the Sacramento River to Tracy and Byron on the San Joaquin River.

Sampling Methods: Midwater trawl, fall beach seine, substrate for eggs, larval purse seine, and egg and larvae net.

Taxonomic Work: All fish identified and fork lengths recorded. Unfamiliar fish may or may not be kept for identification.

Species Lists/Records: Delta smelt data are available from CDFG.

Contact: Dale Sweetnam (CDFG)

Sources of Information: Hansen 1993; D. Sweetnam, pers. comm.

(B) Other Programs**ZOOPLANKTON****South Bay to San Pablo Bay**

Program: Pilot Study of Zooplankton in the Lower Estuary

Agency: Interagency Ecological Program/Romberg Tiburon Center

Start Date: 1997

Purpose: To assess changes in zooplankton since the 1978-81 USGS survey; to develop a sampling design for long-term monitoring; to identify numerically important species

Study Area and Sampling Schedule: Monthly sampling at 30 stations in South, Central, and San Pablo Bays; plus supplementary sampling.

Sampling Methods: Surface tows and vertical tows with 150 μm net.

Taxonomic Work: All zooplankton are identified to lowest possible level. Wim Kimmerer does the first round of identification; unfamiliar specimens are sent to other taxonomists including Tony Chess at NMFS, Jeff Cordell at University of Washington and Sally Davis at CDFG.

Species Lists/Records: Available from Wim Kimmerer.

Specimens: Samples are preserved in ethanol at the Romberg-Tiburon Center.

Contact: Wim Kimmerer (Romberg-Tiburon Center)

Sources of Information: Kimmerer 1997, 1998; Kimmerer *et al.* 1999; J. Orsi, pers. comm.

Other Comments: Additional sampling is being conducted by Steve Bollens on the monthly USGS cruises on *R/V Polaris*, consisting of vertical tows with an 80 μm mesh net.

ZOOPLANKTON**Central Bay to Suisun Bay**

Program: Sampling for zooplankton in the middle Estuary

Agency: National Marine Fisheries Service

Start Date: 1997; program expected to run about 5 years.

Purpose: To assess zooplankton density and composition for comparison with the diet of young salmonids.

Study Area and Sampling Schedule: Eight stations in the Central Bay; from San Pablo through Chippis Island. Sampling 3 times a year in winter, spring, and fall.

Sampling Methods: 300 μm Tucker Trawl, captures top subsurface layer and bottom layer; 250 μm Manta Trawl, skims surface of water.

Taxonomic Work: Identified to lowest possible taxa; unfamiliar species are not kept. Taxonomists are Tony Chess and Beth Norton (NMFS).

Species Lists/Records: Available from Tony Chess or Beth Norton.

Specimens: Voucher samples are preserved in 10% formalin and stored at NMFS in Tiburon.

Contact: Beth Norton (NMFS).

INVERTEBRATES**South Bay to western Delta**

Program: Fouling Community/Rapid Assessment Survey

Agency: San Francisco Estuary Institute

Start Date: 1993

Purpose: To develop a baseline description of the fouling community; to detect new introductions; to track changes in community composition.

Study Area and Sampling Schedule: 19 marina stations from the South Bay to Bethel Island. Sampled about once a year. Specimens fixed in formalin; most transferred to 75% ethanol.

Sampling Methods: Fouling community sampled by hand; benthos sampled with Ponar grab.

Taxonomic Work: To lowest possible taxa.

Species Lists/Records: Being compiled at SFEI.
Specimens: At San Francisco Estuary Institute.
Contact: Andrew Cohen (SFEI)

GREEN CRABS, MITTEN CRABS

South Bay to San Pablo Bay

Program: Green Crab and Mitten Crab Surveys
Agency: California Department of Fish and Game
Start Date: 1995

Purpose: To track the spread of green and mitten crabs in the Estuary.

Study Area and Sampling Schedule: Eight sites in South, Central, and San Pablo Bays for green crabs; 4 sites in Alviso Slough, Guadalupe Creek, and Alameda Creek for mitten crabs.

Sampling Methods: Baited traps.

Contact: Kathy Hieb (CDFG)

Sources of Information: Hieb 1997.

MITTEN CRABS

Suisun Marsh and Delta

Program: Juvenile Mitten Crab Survey
Agency: California Department of Fish and Game/ Interagency Ecological Program
Start Date: 1997

Purpose: To track changes in abundance of mitten crabs.

Study Area and Sampling Schedule: Eight stations in Suisun Marsh, 14 stations in the Delta; sampled once or twice during the summer.

Sampling Methods: Visual survey along a transect

Sources of Information: Holmes and Osmondson 1999.

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Appendix 2.

Water Diversions in the San Francisco Bay/Delta Estuary

(A) The State & Federal Water Projects

Diversions began at the Central Valley Project's (CVP) Tracy Pumping Plant in 1951 and at the State Water Project's (SWP) Harvey O. Banks Delta Pumping Plant in 1968. Fish screens and fish salvage facilities have been constructed at both sites (the Tracy Fish Collection Facility at the CVP pumps and the John E. Skinner Delta Fish Protective Facility at the SWP pumps) to reduce entrainment losses of fish. Both facilities are required to monitor for incidental take of winter-run chinook salmon and delta smelt, and salvage and loss data is available on a daily basis. Fish salvage sampling began in 1957 at the CVP facility and in 1968 at the SWP facility. Bi-hourly sampling takes place 24 hours a day, seven days a week. Liston *et al* (1996) analyzed fish salvage data at the CVP facility to assess the relative abundance of native and non-native fish. Other focused sampling programs, including sampling for invertebrates, have been conducted at these facilities from time to time (S. Siegfried, pers. comm.). Currently, these facilities are used to sample and monitor mitten crabs (Siegfried 1999).

(B) Municipal Water Diversions

There are seventeen municipal water diversions within the Estuary: six on the San Joaquin River, two on the Sacramento River, and one each on the Calaveras River, Barker Slough, Smith Canal, Old River, Little Potato Slough, Turner Cut, Rock Slough and in Suisun Bay (Table 1). The intake pipe diameters range from 3 to 33 inches. Intake screens and filters include trashracks and slotted filters with various opening sizes, perforated plates (typically 5/32"), wedgewire filters (typically 3/32") and gravel filters (CDFG 1998).

(C) Industrial and Agricultural Water Diversions

There are eighteen large industrial or agricultural water diversions in the Delta: three on the Sacramento River, five on the San Joaquin River, two on Bishop Cut, five on Sugar Cut, two on New York Slough and one on the Calaveras River (Table 2). Intake diameters range from 4 to 8 inches. These diversions are reportedly unscreened except for a few with trashracks (CDFG 1998). There are about another 1,800 small water diversions in the Delta, primarily agricultural. None of these are screened (Monroe & Kelly 1992).

(D) Power Plant Cooling Water Intakes

There are four power plants in operation that draw cooling water from the Bay/Delta Estuary, at Potrero and Hunters Point in San Francisco, at Pittsburg, and the Contra Costa Plant in Antioch (Table 3). Former plants at Oleum, Martinez, Avon & Rancho Seco have been removed from service (M. Jones, M. Krone, R. Kino, pers. comm.).

On various occasions, power plant intakes and screens have been used for sampling the Estuary's biota. In the 1950s, sampling at Potrero power plant in San Francisco provided information on the composition of the Bay's fish community (Herald & Simpson 1955). From May 1978 to April 1979, filter screens at five power plants (Potrero, Hunters Point, Oleum, Pittsburg and Contra Costa) were sampled for invertebrates, with 24-hour samples gathered weekly. An exotic isopod *Euryllana arcuata*, which is probably native to New Zealand, was repeatedly collected from the screens at the Oleum plant, its first reported occurrence in North America (Bowman *et al.* 1981).

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Table 1. Municipal Water Diversions in the Bay/Delta Estuary					
Data from CDFG 1998					
Site	Operator/User	Diversion Type	Flow Rate	Intake Diameter	Screen Type
Mallard Slough	CCWD	vertical pump	<40 cfs	33"	none
Smith Canal	?	floodgate	?	24"	none
Barker Slough	N. Bay Aqueduct	vertical pump	?	24"	wedgewire
Little Potato Slough	Terminus Tract	siphon	?	16"	none
San Joaquin River	Antioch	vertical pump	?	16"	wedgewire
Turner Cut	McDonald Island	siphon	?	10"	slotted
San Joaquin River	Stockton	vertical pump	?	10"	none
San Joaquin River	Boggs Tract	slant pipe	?	9"	none
Calaveras River	?	vertical pump	?	8"	trash rack
Sacramento River	Walnut Grove	pipe	?	7"	none
San Joaquin River	?	centrifugal pump	?	6"	none
San Joaquin River	?	centrifugal pump	?	6"	none
Suisun Bay	?	pump	?	6"	none
San Joaquin River	?	centrifugal pump	?	3"	none
Old River	CCWD–Los Vaqueros	?	250 cfs	?	3/32" wedgewire
Rock Slough	CCWD	centrifugal pump	50-250 cfs	?	3/32" wedgewire to be installed
Sacramento River	Calif. Dept. of General Services	underflow	?	?	gravel filter

Table 2. Large Industrial and Agricultural Water Diversions in the Delta					
Data from CDFG 1998					
Site	Operator/User	Diversion Type	Flow Rate	Intake Diameter	Screen Type
San Joaquin River	?	vertical pump	?	3 @ 18"	none
Sugar Cut	El Pescadero	vertical pump	?	16"	trash rack
Sugar Cut	El Pescadero	centrifugal pump	?	16"	trash rack
Sacramento River	Delta Sugar	vertical pump	?	2 @ 15"	none
Calaveras River	?	vertical pump	?	12"	trash rack
Sugar Cut	El Pescadero	vertical pump	?	2 @ 9"	trash rack
Sugar Cut	El Pescadero	centrifugal pump	?	9"	none
Bishop Cut	King Island	centrifugal pump	?	6"	none
Bishop Cut	Bishop Tract	pump	?	6"	none
San Joaquin River	?	slant pump	?	6"	none
San Joaquin River	?	centrifugal pump	?	4"	none
Sacramento River	Delta Sugar	vertical pump	?	?	none
New York Slough	?	vertical pump	?	?	trash rack
New York Slough	?	vertical pump	?	?	?

Table 3. Power Plant Cooling Water Diversions in the Bay/Delta Estuary				
Data from M. Jones, M. Krone, R. Kino; CDFG 1998				
Site	Owner	Intake	Flow Rate	Screens
Potrero	Southern California Energy	56 square foot cross-section	2 pumps @ 175 cfs each	3/8" mesh travelling screens
Hunters Point Units 2-3	PG&E	2 intake channels	187 cfs ?	6 travelling screens
Hunters Point Unit 4	PG&E	2 intake channels	225 cfs ?	2 travelling screens
Pittsburg Units 1-4	Southern California Energy	120 square foot cross-section	8 pumps @ 110 cfs each	3/8" mesh travelling screens
Pittsburg Units 5-6	Southern California Energy	81 square foot cross-section	4 pumps @ 179 cfs each	3/8" mesh travelling screens
Pittsburg Unit 7	Southern California Energy		uses cooling towers	
Contra Costa (Antioch) Units 1-5	Southern California Energy		not in operation	
Contra Costa (Antioch) Units 6-7	Southern California Energy	120 square foot cross-section	4 pumps @ 170 cfs each	3/8" mesh travelling screens

Appendix 3.

Commercial Fisheries in the San Francisco Bay/Delta Estuary

Crayfish

Crayfish (*Pacifastacus leniusculus*) are taken commercially in baited traps in the Sacramento River, mainly from the mouth of the Feather River downstream to around Rio Vista. Typical traps are about 1 foot in diameter and 2.5 feet long, with half-centimeter mesh. The season runs from April through September/October with a lull in August while the crayfish are molting.

Bay Shrimp

Bay shrimp (primarily *Crangon franciscorum*) are harvested from San Francisco Bay for fishing bait. The shrimp are caught in bottom trawl nets with 1/8 to 1/4 inch mesh. There are normally about 20-30 permit holders each year, with about 15 actively fishing. Most fishing effort is concentrated south of the San Mateo Bridge; a few boats fish the North Bay. Shrimp fishing is not permitted east of the mothball fleet in western Suisun Bay. The catch is typically smaller in dry years, when many of the shrimp are concentrated east of this point. In the 1950s, data on the fish caught in shrimp nets at the northern end of the South Bay was used to characterize the Bay fish community (Herald & Simpson 1955).

Brine Shrimp

Brine shrimp (*Artemia salina*) are collected from San Francisco Bay salt ponds for use as fish food. The brine shrimp are collected in a wire-mesh net towed through the water.

Baitfish

Yellowfin gobies (*Acanthogobius flavimanus*), long-jawed mudsuckers (*Gillichthys mirabilis*) and staghorn sculpin (*Leptocottus armatus*) are harvested from San Francisco Bay for fishing bait. The fish are caught in wire-mesh bottom traps which are typically around the Bay margins, often tossed in from shore or floating docks. There are about 10-20 permit holders each year.

Herring

Pacific herring (*Clupea harengus pallasii*) are harvested in San Francisco Bay for their roe, most of which is salted and exported to Asia. There are currently about 400 permit holders in the fishery, including about 10 roe-on-kelp permits. Fish are caught with gill nets with 2-1/8 inch mesh. Herring are fished from Paradise Cay to Redwood City, with most of the effort concentrated around San Francisco and Sausalito. There is a small amount of fishing outside of the Golden Gate. The season is December through March.

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Appendix 4.

Examples of Sampling by Environmental Education Programs in the San Francisco Bay/Delta Estuary

Marine Science Institute (MSI), Redwood City

Sampling by otter trawl, plankton net and Petersen grab on about 300 trips per year in the South Bay, with 3 of each type of tow and grab per trip. Data from sampling are recorded by interns on about a third of the trips. Beach seines are done in Redwood Creek at the Institute about 100 times/year.

MSI brought two recent invasions to the attention of the Bay Area scientific community. In the summer of 1993, MSI staff began collecting in otter trawls a sea slug that was previously unknown to them. Staff member K. Bowman brought the organism to T. Gosliner at the California Academy of Science's Invertebrate Zoology department (CASIZ), who identified it as *Philine auriformis* from New Zealand (Gosliner 1995). In the fall of 1994, MSI staff brought to CASIZ an unfamiliar crab that had been brought to MSI by a South Bay shrimp trawler; R. Van Syoc identified the crab as *Eriocheir sinensis*, the Chinese mitten crab (Cohen & Carlton 1997).

Shorebird Nature Center, Berkeley

Sampling by otter trawl, plankton net and Petersen grab is conducted from a boat in the Central Bay, 11-12 times/year from March to July. Vertical plankton tows are taken from the Berkeley Pier from January to May, with a plankton sample sent about once a month to the Berkeley Department of Public Health to check for dinoflagellates. The intertidal community in a cobble and mudflat area and the dock fouling community in the Berkeley Marina are visually examined about 2-3 times/week from March to June.

East Bay Regional Park District–Crab Cove Visitor Center, Alameda

Sampling by seine net in the eelgrass beds at Crown Beach in Alameda about 1-2 per month during the school year. The intertidal cobble and mudflat area in Crab Cove are examined for a "resource inventory" about 1-2 per year.

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Appendix 5.

Posters and Pamphlets Designed to Solicit Information from the Public on European Green Crab and Chinese Mitten Crab

See attachments.

Appendix 6.

Monitoring, Early Detection and Rapid Response in Australia: Invasion by the Brackish-Water Fouling Mussel *Mytilopsis*

The tropical mussel *Mytilopsis* cf. *sallei* was found in Darwin Harbor in Northern Australia on March 27, 1999 by a survey team from the CSIRO Center for Research on Introduced Marine Pests (CRIMP). CRIMP conducts a monitoring program for nonindigenous marine species in Australia which includes regular harbor surveys. The mussel had not been found in Darwin Harbor during a survey there six months earlier, nor had it ever been found in Australia before.

The mussel is native either to the Caribbean or (as argued by Marelli & Gray 1985, who believe the mussel is *Mytilopsis adamsi*) to the eastern tropical Pacific. It has also been reported, apparently as an introduction, in Fiji, Japan, Hong Kong, Taiwan and India (Morton 1980; Marelli & Gray 1983, 1985). It tolerates a wide range of salinities, temperature and oxygen levels (Morton 1981; Rao *et al.* 1988) and has been collected from coastal lakes and streams (Marelli & Berrend 1978; Marelli & Gray 1983). It is tolerant of pollution and is resistant, both in larval and adult stages, to chlorine at normal disinfecting doses (Rao *et al.* 1988). In harbors in India it is reported at nuisance-level abundances, fouling boat hulls and clogging seawater intake pipes and reducing populations of pre-existing mussels and oysters (Morton 1981; Rao *et al.* 1989). It belongs to the same family as the zebra mussel *Dreissena polymorpha*, and its behavior in Indian waters marks it as a brackish-water pest analogous to the freshwater zebra mussel.

In Australia the mussel was found heavily infesting the Cullen Bay Marina, which is connected to Darwin Harbor through a lock. Four days later a lighter infestation was found in a nearby locked marina, and over the week the mussel was found on a few boats in a third marina and adjoining waters around Darwin Harbor. In most or all cases the infested boats had recently been in Cullen Bay Marina.

The mussel was first found on Saturday, March 27, the weekend before the Easter holiday when there is typically a lot of boating activity. On Monday, March 29, the Northern Territory government declared a national disaster emergency, closing the marinas to boat traffic in or out. On Wednesday, March 31 the government began adding chlorine to Cullen Bay Marina. It would take some time, however, to gather enough chlorine to deliver the desired dose to the marina, which held about 150 boats. Meanwhile, a host of other activities got underway, including research into different chemical treatments, a search by the police for the whereabouts of all boats that been in Cullen Bay Marina anytime during the preceding six months, a search for the owners of all the boats currently in the marinas, the setting up of an information hotline and a website, and the development of informational brochures and fact sheets.

The major dosing of Cullen Bay Marina began on April 4. The government tried to maintain chlorine concentrations for several days with additional doses while directing boat owners to turn on their engines for 30 minutes each day, run their showers and flush their toilets in order to run chlorinated water through their water systems and kill any mussels that had settled there. This effort was hampered by non-compliance by some boat owners, absentee boat owners who could not be located, and heavy rains on the night of April 7 that diluted the concentration of chlorine.

Meanwhile the second marina was treated with copper sulphate starting on April 3, which seemed to work better than chlorine. Copper sulphate was then applied to Cullen Bay Marina and the third marina. Only partial figures have been obtained, but it appears that well over 120 metric tons of chlorine and over 6 metric tons of copper sulphate were applied to the marinas.

On April 10, ten days after treatments began, mussels were found infesting the storm drains at Cullen Bay, which were then treated.

By April 12 the mussels in all three marinas were judged to be dead, and boats that had been treated internally as well as externally were cleared to depart the marinas. Departures were restricted to high tide, when the water level was higher outside than inside the marinas, and so that the transfer of water through the locks was into the marinas.

On April 16 a few mussels were found on the hull of a boat that had left Cullen Bay Marina, and the marinas were again quarantined. On April 19 a small number of mussels were found alive on a piling in Cullen Bay Marina.

Between April 20 and 23 the quarantine was ended and all three marinas were opened to full access. It's unclear whether all the boats that had been in Cullen Bay Marina were ever tracked down; however, the mussel has not been found again in Australia.

This chronology of events has been summarized from the CRIMP web site (http://www.nt.gov.au/news/cullen_bay.shtml) and other sources.

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