Monitoring for Non-indigenous Organisms

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This memo outlines some of the general needs, opportunities and issues regarding monitoring for non-indigenous species in the San Francisco Bay/Delta Estuary. Research that may be integrated with a monitoring program is briefly discussed, but this memo focusses on the overall considerations relevant to a monitoring program for non-indigenous species. The particular design of such a program should, of course, be tailored to produce the information needed for critical areas of policy and research.

In general, a monitoring program for non-indigenous organisms should address three fundamental objectives:

- To detect new introductions in the ecosystem.
- To track the growth and spread of non-indigenous organisms that are recent arrivals in the ecosystem.
- To identify and assess the mechanisms introducing non-indigenous organisms into the ecosystem.

These objectives and the types of monitoring that may be needed to meet them are discussed in the sections below. An monitoring program for non-indigenous organisms could also support or include research into two broad areas:

- Understanding how non-indigenous organisms affect the ecosystem.
- Understanding how different factors—including characteristics of the environment and characteristics of the introduced organisms—affect the success or failure of introductions.

Research questions in these areas may be addressed through a variety of approaches: by focussing on particular non-indigenous organisms, with species-specific monitoring programs combined with experimental field or laboratory work; by the analysis of data sets developed by monitoring programs that include information on an adequately large number of non-indigenous species, or that include information on non-indigenous 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.

What's Special about Non-indigenous Species?

From time to time the question arises as to whether it is really necessary to separately consider nondigenous species when designing monitoring or research efforts. Won't any good monitoring network automatically gather data on non-indigenous organisms? Won't general research on population dynamics enlighten us about the population dynamics of non-indigenous organisms? Aren't non-indigenous organisms just like other organisms, responding to biotic and abiotic factors as other organisms do, but doing it outside of their native range? While it is true that much may be learned about non-indigenous organisms and biological invasions through general biological monitoring and research, 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 profitable to address them separately.

For example, consider the early phase of invasions, when an introduced organism's population is small and vulnerable to the stochastic perturbations known as Allee effects. A substantial amount of

theoretical and experimental work and data collection has been conducted to explore the genetic and population dynamics of small populations, primarily in order to understand the risks and stresses faced by small, remnant populations of endangered species. 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. Many endangered species are habitat or resource specialists, and many initially had a relatively restricted range. In contrast, some researchers have argued that successful introduced species are typically habitat 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 apparently never doing so—suggest that the study of one type of small population will not fully inform us about the other.

Detecting and Identifying New Introductions in the Ecosystem

There are several potential benefits of a monitoring program providing earlier and more comprehensive detection of new introductions in the Estuary.

- It would provide data on the rate of introduction.
- It would provide data on where and under what conditions new arrivals become established.
- It would enable researchers to study introductions from their earliest stages, providing opportunities for developing a better understanding of the dynamics and impacts of invasions.
- It would provide opportunities to study introductions that fail.
- It would enable resource managers to implement control at an earlier stage in an invasion, before the invading organism has become abundant or widespread, resulting in lower costs, fewer environmental and social side-effects, and greater chances of success.
- Where direct control is not feasible, it would provide an earlier warning of potential impacts from an invasion, which might be avoided or mitigated.

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.

Sampling of appropriate habitats. Simply put, to do a good job of detecting the arrival of non-indigenous species, one had better 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 aren't 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, such habitats have been found to host a relatively high density of non-indigenous

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 non-indigenous species that had previously not been reported from these systems, including several not previously reported from the Pacific Coast (Cohen *et al*. 1998; Cohen and others, unpubl. data). The artificial nature of this habitat may contribute to the abundance of non-indigenous 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.** Some species may be only present or predominantly present in this habitat, which has recently become the focus of sampling efforts due to its importance for juvenile fish. Non-indigenous organisms that are found here and that have been largely or entirely missed by existing sampling programs include the Atlantic periwinkle *Littorina saxatilis* (Carlton & Cohen 1998), the southern hemisphere isopod *Eurylana arcuata* (Cohen unpubl. data), the southern hemisphere amphipod *Orchestia enigmatica* (Bousfield & Carlton 1967) and possibly a mysid shrimp of unknown origin, *Deltamysis holmquistae* (Bowman & Orsi 1992). Carlton (1979) has suggested that non-indigenous species with southerly distributions such as the Indian Ocean barnacle *Balanus amphitrite* may only be able to survive in the warmer waters around the bay margin.

- **Artificial or highly altered lagoons and other small water bodies with limited hydrologic connections to the Estuary.** Species initially collected from such habitats include the southern hemisphere tubeworm *Ficopomatus enigmaticus*, the Atlantic crab *Rhithropanopeus harrisii* and a nudibranch of unknown origin, *Cuthona perca*, in Lake Merritt (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 tributary rivers and sloughs.** In recent years several jellyfish have been initially discovered in the Estuary in such habitats 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, 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. There is no organized effort to sample these habitats, although there may be sporadic 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, CDFG's Delta Outflow sampling program focuses on fish, shrimp and crabs, but collects many other types of invertebrates that generally are not recorded, saved or identified.

- **Using water diversions as sampling devices.** Several individuals have pointed out 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 non-indigenous organisms. 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).

- **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 course of their activities. Several recent prominent invaders in the Estuary were initially collected and brought to the attention of researchers by such parties: the European green crab *Carcinus maenas* by a baitfish trapper (Cohen *et al*. 1995); the Black Sea jellyfish *Maeotias inexspectata* by a school teacher (Mills & Sommer 1995); the New Zealand seaslug *Philine auriformis* by the Marine Science Institute, an environmental education program in Redwood City (Gosliner 1995)[1]; 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 developed information on the spread of green crab and mitten crab (Cohen *et al*. 1995; Cohen & Carlton 1997).

Recognition of possible introductions. One obstacle to the early detection of new introductions—especially among the invertebrates, algae and protists—is the difficulty of recognizing when a specimen may represent a new introduction in the Estuary. The following discussion is largely based on issues in the recognition and identification of introduced marine invertebrates, the group that I am most familiar with, and which accounts for the largest number of known non-indigenous species in the Estuary. The discussion may also apply to some of the other taxonomic groups.

The confident misidentification of specimens of non-indigenous organisms as native Pacific Coast species commonly arises from the use of regional taxonomic keys without supplemental information. In addition to outright misidentifications, specimens that do not key out readily—which may include non-indigenous species not covered by the key—are often simply left unidentified to species, and eventually shelved and forgotten or discarded. These failures to recognize and to take the steps needed to correctly identify novel species in sampled material could be reduced by providing (1) appropriate informational tools and training to recognize suspected introductions, (2) an efficient process for identifying suspected introductions, and (3) a mandate and funding to perform these tasks. Informational tools and the recognition of suspect introductions are discussed in this section, and identification is discussed in the following section. Since isolating and identifying suspected introductions can be a time-consuming task, and may also require outside expertise, the performance and completion of these tasks will remain haphazard and dependent on individual initiative and interest, unless people are specifically tasked and funded to do them.

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[1] There has recently been some debate on the internet as to whether the recently introduced opisthobranch seaslug in the Estuary is *Philine auriformis* or some other nonindigenous species of *Philine*. In this memo, I will continue to refer to this seaslu as *P. auriformis*.

Regional keys, when well-designed, can effectively distinguish among the organisms known from the region in question. However, in many cases they will not separately distinguish an organism that is not part of the regional biota covered by the key. In other words, a specimen of a new non-indigenous species may key out in a completely proper and satisfactory manner, to be identified confidently and incorrectly as a particular native species, because characteristics that could have distinguished it were not included in the key (because those characteristics were not needed to distinguish among the organisms known from the region that the key was intended to cover).

Nevertheless, taxonomists with substantial experience in the Estuary will often 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 are sometimes stretched to work on types of organisms that they don't know all that well, and sometimes 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 there is no obvious difficulty in keying it out.

Several 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. These include:

- **A comprehensive list of the organisms that have been collected from the Bay/Delta Estuary.** Species lists for parts or all of this ecosystem have routinely 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 the 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 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, illustrations, photographic images, information on known geographic and habitat ranges, references to additional literature, information on dates and sites of collection, and data on the existence and location of preserved specimens exists for most of the organisms in the Estuary. With such information 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 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 lab 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 phonme 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 "things to watch for" might 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 non-indigenous species.

- **A comprehensive and accessible archive of identified 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, or of intertidal invertebates from Maine, could help with the recognition and identification of organisms introduced by ballast water or with the importing of marine baitworms. Such collections would also help with the assessment of mechanisms introducing non-indigenous organisms, discussed further below. Information on the specimens in the collection should be compiled in a database that can be accessed via the internet.

Identification of suspect specimens. Once a taxonomist recognizes that a specimen is probably not an organism previously known from the region, 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 what 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, this may mean sending the specimen to an appropriate specialist elsewhere in the world. This would probably work more efficiently and would get done more often if taxonomists could simply send their suspect material to an individual or laboratory would make an assessment of the material, determine whether it really looks like something new in the region, decide what should be sent off to a specialist and whom to send it to, and then take care of it. While many details would need to be worked out, some system like this, which regional taxonomists are encouraged to make use of, is probably necessary if we really want to recognize and identify new invaders early on.

Tracking the Spread of Non-indigenous Organisms

To some extent, general sampling programs may provide information on the spread within the Estuary of non-indigenous species that belong to the target groups monitored by these programs, such as fish, shrimp, crabs, zooplankton and subtidal benthic infauna. However, it should be noted that 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).

In some cases, these programs could be readily amended to monitor for particular non-indigenous species. For example, some of the regular monitoring programs in the Estuary frequently collected the New Zealand seaslug *Philine auriformis* in the years after its introduction, but did not count or record it as it was not one of their target species. Doing so would have required little additional effort.

In other cases, specific sampling programs may be implemented to monitor particular organisms after their initial detection, as IEP did for green crab and mitten crab. Finally, a public monitoring program, as discussed above, may be useful for monitoring the spread of conspicuous and easily identified organisms.

Assessing the Mechanisms Introducing Non-indigenous Organisms

A third component of monitoring for non-indigenous species, essential to developing and implementing programs to reduce or prevent the introduction of additional non-indigenous species, is monitoring the organisms transported and released into the Estuary by various mechanisms. Information on the transport and release of non-indigenous species is 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 help with the detection and identification of non-indigenous species within the Estuary, by providing information on what to expect.

Several mechanisms are obvious candidates for such monitoring:

- Ship's ballast water is generally thought to be the most important mechanism transporting freshwater and estuarine 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 (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. However, as far as I am aware, not a single gallon of ballast water arriving in the Estuary has yet been sampled for its biota.

- Seaweed used to pack marine baitworms imported from the east coast of North America, and often discarded into the Estuary by anglers, frequently contains a substantial number of non-indigenous organisms (Cohen and others, unpubl. data), and has probably introduced some species that are now established on the Pacific Coast (Carlton & Cohen 1998; Cohen, unpubl. data). This mechanism of introduction remains unmanaged and unregulated. Non-indigenous 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 sources of non-indigenous organisms that may be released into the Estuary and that may merit monitoring include: organisms in the water used to transport baitfish or fish imported to fish farms from out-of-state; organisms in the water in ships' seachests and other components of a ships' seawater system; organisms attached as fouling to the hulls of ships, and organisms attached to ships' anchor chains or carried in sediment or water in chain lockers.

Literature Cited

Bousfield, E. L. and J. T. Carlton. 1967. New records of Talitridae (Crustacea: Amphipoda) from the central California coast. *Bull. S. Calif. Acad. Sci.* 66(4):277-284.

Bowman, T. E., Bruce, N. L. and J. D. Standing. 1981. Recent introduction of the cirolanid isopod crustacean *Cirolana arcuata* into San Francisco Bay. *J. Crust. Biol.* 1(4):545-557.

Bowman, T. E. and J. J. Orsi. 1992. *Deltamysis holmquistae*, a new genus and species of Mysidacea from the Sacramento-San Joaquin Estuary of California (Mysidae: Mysinae: Heteromysini). *Proc. Biol. Soc. Wash.* 105(4): 733-742.

Carlton, J. T. 1979. History, Biogeography, and Ecology of the Introduced Marine and Estuarine Invertebrates of the Pacific Coast of North America. Ph. D. thesis, Univ. California, Davis, 904 pp.

Carlton, J. T. and A. N. Cohen. 1998. Periwinkle's progress: the Atlantic snail *Littorina saxatilis* (Mollusca: Gastropoda) establishes a colony on a Pacific shore. *Veliger* 41(4): 333-338.

Cohen, A. N. 1998. *Ships' Ballast Water and the Introduction of Exotic Organisms into the San Francisco Estuary: Current Status of the Problem and Options for Management*. A report for CALFED and the California Urban Water Agencies. San Francisco Estuary Institute, Richmond CA.

Cohen, A. N. and J. T. Carlton. 1997. Transoceanic transport mechanisms: The introduction of the Chinese mitten crab *Eriocheir sinensis* to California. *Pac. Sci.* 51(1): 1-11.

Cohen, A. N., J. T. Carlton and M. C. Fountain. 1995. Introduction, dispersal and potential impacts of the green crab *Carcinus maenas* in San Francisco Bay, California,.*Mar. Biol.* 122: 225-237.

Cohen, A. N., C. E. Mills, H. Berry, M. J. Wonham, B. Bingham, B. Bookheim, J. T. Carlton, J. W. Chapman, J. R. Cordell, L. H. Harris, T. Klinger, A. Kohn, C. C. Lambert, G. Lambert, K. Li, D. Secord and J. Toft. 1998. *Report of the Puget Sound Expedition, September 8-16, 1998; A Rapid Assessment Survey of Non-indigenous Species in the Shallow Waters of Puget Sound*. Washington State Department of Natural Resources, Olympia WA and United States Fish and Wildlife Service, Olympia WA.

Gosliner, T. 1995. The introduction and spread of *Philine auriformis* (Gastropoda: Opisthobranchia) from New Zealand to San Francisco Bay and Bodega Harbor. *Mar. Biol.* 122: 249-255.

Greenberg, N., R. L. Garthwaithe and D. C. Potts. 1996. Allozyme and morphological evidence for a newly introduced species of *Aurelia* in San Francisco Bay, California. *Mar. Biol.* 125: 401-410.

Miller, R. L. 1969. *Ascophyllum nodosum*: A source of exotic invertebrates introduced into west coast near-shore marine waters. *Veliger* 12(2): 230-231.

Mills, C. E. and F. Sommer. 1995. Invertebrate introductions in marine habitats: two species of hydromedusae (Cnidaria) native to the Black Sea, *Maeotias inexspectata* and *Blackfordia virginica*, invade San Francisco Bay. *Mar. Biol.* 122: 279-288.