

CHAPTER 2. METHODS

(A) DEFINITIONS

1. STUDY ZONE

The study zone for this report is defined as the estuarine and aquatic habitats that are within the normal range of tidal influence in San Francisco Bay, the Sacramento-San Joaquin Delta and tributaries, and referred to herein as the San Francisco Estuary or the Estuary (Fig. 1). The primary data set (Chapter 3 and Table 1) contains all demonstrably nonindigenous organisms that are characteristically found in estuarine or aquatic habitats (including marshes, mudflats, etc.), and for which there is significant evidence supporting their establishment within the study zone.

2. PRIMARY DATA SET: INTRODUCED SPECIES IN THE SAN FRANCISCO ESTUARY

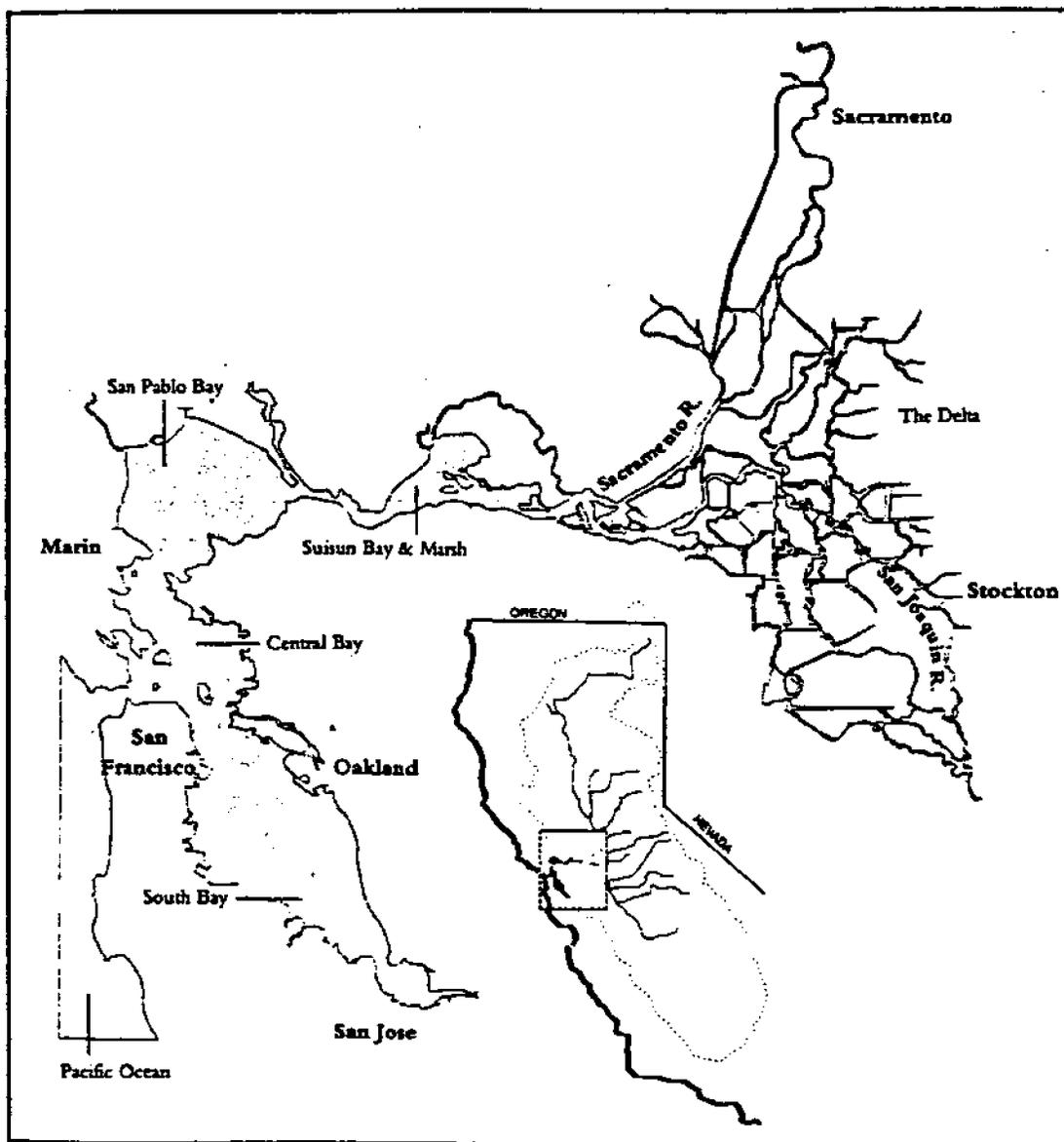
Inclusion in the primary data set thus requires evidence demonstrating that the organism in question is (1) not native to the Estuary, and (2) currently established in the Estuary.

We define native organisms as those organisms present aboriginally, which for the Bay-Delta region means prior to 1769 when the first European explorers entered the area. The types of evidence that we utilized to determine the native versus introduced status of aquatic and estuarine organisms, as discussed by Carlton (1979a) and Chapman & Carlton (1991, 1994), include:

- global systematic evidence (involving taxonomic information from both morphology and molecular genetics) and biogeographic evidence, including the global distribution of closely related species;
- the existence of identifiable mechanisms of human-mediated transport;
- historical evidence of presence or absence;
- archaeological evidence of presence or absence;
- paleontological evidence of presence or absence;
- the extent to which distribution can be explained by natural dispersal mechanisms;
- rapid or sudden changes in abundance or distribution;
- highly restricted or anomalously disjunct distributions (in comparison to distributions of known native organisms);
- occurrence in assemblages with other known introduced species; and
- for parasites or commensals, occurrence on introduced organisms.

We define established organisms as those organisms present and reproducing "in the wild" whose numbers, distribution and persistence over time suggest that, barring unforeseen catastrophic events or successful eradication efforts, they will continue to be present in the future. "In the wild" implies reproduction and persistence of the population without direct human intervention or assistance (such

Figure 1. The San Francisco Estuary



as reproductive assistance via hatcheries or periodic renewal of the population through the importation of spat), but may include dependence on human-altered or created habitats, such as water bodies warmed by the cooling-water effluent from power plants, pilings, floating docks, and salt ponds or other manipulated, semi-enclosed lagoons. The types of evidence that we used to assess establishment include:

- population size;
- persistence of the population over time;
- distribution (broad or restricted) of the population, and trends in distribution;
- for species dependent on sexual reproduction, the presence of both males and females, and the presence of ovigerous females; and
- the age structure of the population as an indicator of successful reproduction.

3. OTHER DATA SETS

Beyond the primary data set, we considered and compiled information on several additional categories of organisms, including:

- cryptogenic organisms, that is, organisms in the Estuary that are neither demonstrably native nor introduced (Table 2);
- nonindigenous organisms that have been reported from or were intentionally introduced to the Estuary, but which did not become established or for which there is inadequate evidence regarding their establishment (Table 8 and Appendix 2);
- nonindigenous organisms which are established in aquatic environments tributary to or adjacent to the Estuary, and which may in the future extend their range into the Estuary (Table 9);
- nonindigenous organisms which are not characteristically found in estuarine or aquatic habitats but which have been occasionally reported from or may make occasional use of the Estuary (Appendix 1).

Probably the largest and most difficult "gray zone" between the primary data set and organisms in these additional categories involves those nonindigenous plants reported from coastal or freshwater wetlands for which specific information on occurrence within the tidal boundaries of the Estuary is not available. Although previous regional studies of aquatic invasions (Mills et al., 1993, 1995) have included many such gray-zone plants, we limited inclusion in our primary data set to those that both: (a) have habitat descriptions indicating that they are primarily marsh plants, and not primarily terrestrial or moist ground plants occasionally found in or near marshes; and (b) have been reported specifically from the Delta, and not just from the Central Valley or the Bay Area generally. Similar questions arose, though less commonly, with other types of organisms, to which we applied similar logic.

Those candidate organisms which are not listed in Table 1 because of criterion (a), are instead listed in Appendix 1. Adding the plants in Appendix 1 to the organisms in Table 1 would produce a list of nonindigenous organisms for the Estuary comparable those produced for the Great Lakes (Mills et al., 1993) and the Hudson River (Mills et al., 1995), as discussed further in Chapter 5. Candidate

organisms which failed to meet criterion (b) are listed in Table 9. Even following these restrictive criteria, we may have included in Table 1 some plants that are found in the Delta region in marshes or diked ponds, but not in tidal waters.

(B) DATA SOURCES AND PRESENTATION

Initial lists of taxa in the above-described categories were compiled from the prior studies discussed in the introduction and from a review of the regional biological and systematic literature including regional monographic studies, keys, field guides and checklists; from published (mainly in the gray literature) and unpublished species lists generated by public agencies and private consultants; and from discussions with taxonomists, field biologists, refuge managers and consultants familiar with the region.

Further information on the species thus identified was developed through a review of the pertinent current and historical biological literature, museum records and specimen collections, and interviews with biologists. We also undertook limited field work in order to check the presence or distribution of certain species, and to check for the presence of previously unreported species in some rarely sampled habitats. This information was used to develop the following species lists:

- Table 1, listing introduced species in the Estuary;
- Table 2, listing cryptogenic species in the Estuary;
- Table 8, listing species recently recorded from the Estuary but whose establishment is uncertain;
- Table 9 and Appendix 3, listing introduced species in adjacent aquatic habitats;
- Appendix 1, listing terrestrial species that may occasionally be found in the Estuary;
- Appendix 2, listing older inoculations of nonindigenous species that did not become established; and
- Appendix 4, listing introduced species in the northeastern Pacific known only from the Estuary.

For each species listed in Table 1 we determined where possible:

- the date of first collection or observation or planting in the Estuary, in California and in northeastern Pacific waters or coastal states or provinces; and where this was unavailable, the date of the first written account of the organism in the area;
- the native range of the species;
- the immediate geographic source of the introduction;
- the transport mechanism;
- the organism's current taxonomic status, most frequently utilized synonyms, and common names; and
- its current spatial distribution and abundance in the Estuary.

We included common names from Turgeon et al. (1988) and Carlton (1992) for mollusks, Cairns et al. (1991) for coelenterates, Williams et al. (1989) for

decapods, Gosner (1978) for other invertebrates, Robins et al. (1991) for fish and Hickman (1983) for higher plants.

The data are presented in the species descriptions in Chapter 3 and summarized (in large part) in Table 1. Some of these data are also provided for the species listed in Tables 8 and 9 and the appendices. We also reviewed the available information on the ecological roles and economic impacts of individual introduced species and of introduced species assemblages. This information is summarized in the species descriptions in Chapter 3 and discussed in Chapter 6.

(C) ANALYSIS

The primary data set in Chapter 3 and Table 1 was quantitatively analyzed with regard to taxonomic groups, native regions, timing and transport mechanisms. The results are presented in Chapter 5.

1. TAXONOMY

The numbers of species per taxonomic group were tabulated at two levels of aggregation. A first tabulation was done at the taxonomic levels of order (for vertebrates), phylum (for invertebrates), subkingdom (for plants) and kingdom (for protozoans). A second, more highly-aggregated, tabulation was done at the levels of class (vertebrates), a traditional, non-phyletic grouping (invertebrates), and kingdom (plants and protozoans).

2. NATIVE REGION

The numbers of species per native region were tabulated with regard to eleven marine regions and five continental regions. The marine regions consist of the eastern and western portions of the North and South Atlantic oceans and the North and South Pacific oceans, the Indian Ocean, the Mediterranean Sea, and the Black and Caspian Seas. The Western South Pacific region consists primarily of waters around Australia and New Zealand. The five continental regions consist of North America, South America, Eurasia, Africa, and Australia/New Zealand. Where an organism's native range included more than one region, that organism's count was split proportionally.

3. TIMING

We analyzed the timing of introductions in terms of both the date of first record in the Estuary, and the date of first record in the northeastern Pacific. The numbers of species were tabulated in four 30-year periods with the first beginning in 1850 and the last ending in 1969, and one 26-year period (1970-1995). In the few cases where an organism's date of first record was a period that spanned parts of two tabulation periods, that organism's count was proportionally divided between the periods.

We distinguished two different types of dates of first record. The first and preferred type is the date of initial planting or first observation or collection of the species in the area. Where this was unavailable, we reported the earliest date available (date of writing, submission or publication) of the first written account of the species in the area. In Table 1, dates of first written account are preceded by the symbol '≤', meaning that the date of first planting, observation or collection was on or before (in some cases, perhaps a considerable time before) the indicated date. Dates of first written account were excluded from the quantitative analysis.

We also excluded from the analysis those dates of first record that we judged to be a clear artifact of collecting bias, or a fortuitous discovery of a species in a restricted habitat or locality, and whose inclusion would have contributed to a misleading picture of the temporal pattern of invasions in the Estuary. This is discussed further in Chapter 5 under "Results." These dates are marked by asterisks (*) in Table 1.

4. TRANSPORT MECHANISMS

We analyzed the stocks of organisms that have been introduced to the Estuary in terms of the transport mechanisms (also called "transport vectors," "means of introduction" and "dispersal mechanisms") that brought them to the northeastern Pacific. We utilized thirteen categories of mechanisms, as defined in Table 1 and discussed in Chapter 5 under "Results." Where multiple possible transport mechanisms were determined for an organism, that organism's count was divided proportionally among the possible mechanisms.