National Estuarine Inventory:

Living Marine Resources Component
Preliminary West Coast Study

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Introduction

This report presents the results of a project to compile data on the life history, distribution, and abundance of selected living marine resources in ten estuaries and coastal embayments along the West Coast. The project was undertaken to assess the feasibility of compiling this information for fishes and invertebrates in estuaries throughout the USA. The experience gained from this study will be used to design a major project to develop a comprehensive national data base on the distribution of living marine resources in estuaries.

Compiling this information is part of the National Oceanic and Atmospheric Administration's (NOAA) Ocean Assessments Division (OAD) efforts to develop a National Estuarine Inventory and data base that can be used to conduct comprehensive assessments of estuaries throughout the USA (Monaco et al., 1986). The first major product of this effort is the National Estuarine Inventory Data Atlas (SAB, 1985). The living marine resources project is one of several additions to the inventory and data base.

Background

Estuaries are semi-enclosed coastal bodies of water having a free connection with the open sea; within them, seawater is measurably diluted by freshwater from land drainage (Pritchard, 1967). They are critically important to sustaining many living marine resources, particularly during early life stages (Healey, 1982; Gunter, 1967; Simenstad et al., 1982). Society also places a high value on these areas as places for living, working, and recreating. Because of their importance to both ecological processes and economic development, estuaries are among our most heavily used and highly stressed natural systems (Ehler and Basta, 1984).

However, in spite of their high value, intense use, and frequent overuse, estuaries have not been widely recognized as a unique or important depleted resource base of national significance. Consequently, most decisionmakers and scientists continue to address estuaries on an individual basis only, with little or no directed, comprehensive national focus.

To provide decisionmakers and scientists with the nationwide, comprehensive information needed to manage and maintain the health of the nation's estuaries, OAD has undertaken a series of projects to develop a national estuarine assessment capability. The cornerstone of this effort is the National Estuarine Inventory Data Atlas (SAB, 1985). It is the first of two volumes that present information through maps and tables on important physical and hydrologic characteristics for 92 of the Nation's estuaries and coastal embayments. Volume II, scheduled for completion this fall, is a compilation of the surrounding land use activities affecting each estuary. These estuaries account for approximately 90% of the estuarine water surface area along each of the three coastal regions of the contiguous USA (excluding the Great Lakes) and 90% of the freshwater inflow into those areas. The atlas aggregates physical and hydrologic information on these estuaries into a single document. Figure 1 illustrates the maps and data tables provided for each of the 92 estuaries. Individually, the maps and data tables provide a clear overview of the characteristics of each estuary. Collectively, they can be used to begin comparative analyses among estuaries of the USA.

Information found in the atlas for each estuary includes physical dimensions, freshwater inflow, and tidal data. For this project, the most important information in the atlas are the three salinity zones identified for each estuary. The tidal fresh (0.0 to 0.5 ppt), mixing (0.5 to 25.0 ppt), and seawater (25.0 and greater ppt) zones provide the spatial framework for consistently compiling and organizing information on the distribution of fishes and invertebrates across estuaries by spatial units that strongly affect species presence or absence (the variability of these zones is discussed below). When completed, the data base will contain information on the distribution and relative abundance by life stage by time of year, and by salinity zone for over 150 fishes and invertebrates in the 92 estuaries in the National Estuarine Inventory.

Figure 1. Sample map from National Estuarine Inventory Data Atlas

National Estuarine Atlas

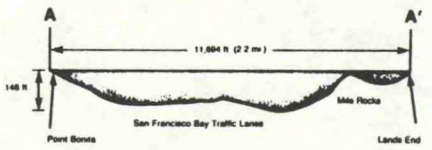
PHYSICAL AND HYDROLOGIC CHARACTERISTICS

PHYSICAL		FRESHWATER INFLOW				TIDAL DATA		
Surface Areas (mi^2)		*Flow Rates (1000 cfs)*				Prevailing Tide: Semidiurnal		
Fluvial Drainage	43,845	Period of Record			1986-1993	Tidal Prism (cf)		4.58×10^{10}
Estuarine Drainage	3,230					*Phase Range of Tide (ft.)*		
Estuarine Zones		Long Term Average Daily			32.4	Map Key	Station	Range
Tidal Fresh	50	Long Term Average Monthly	J	80.9	J 14.7	A	517	4.2
Mixing Zone	131		F	85.1	A 13.5	B	529	4.8
Seawater	271		M	58.6	S 18.1	C	551	4.9
Total	452		A	55.0	O 11.7	D	557	5.4
Dimensions			M	30.3	N 17.5	E	585	5.8
Length (mi.)	82.0		J	24.0	D 38.4	F	623	3.9
Width (mi.) Average	5.2	7 Day 10-Year Low Flow			6.3	G	643	3.5
Minimum	1.0	50-Year Flood			317.8	H	668	3.1
Maximum	10.7	100-Year Flood			375.9	I	653	3.2
Average Depth (ft.)	22.3	*Flow Ratios*				J	673	2.1
Average Depth to Width Ratio	8.1×10^{-4}	Average Annual			0.032	K	695	1.4
Stratification Classification		High Flow Period			0.081	L	681	0.2
3-Month High Flow	MS	Low Flow Period			0.013			
3-Month Low Flow	VH							

Abbreviations: Vertically Homogeneous, VH; Moderately Stratified, MS; Highly Stratified, HS

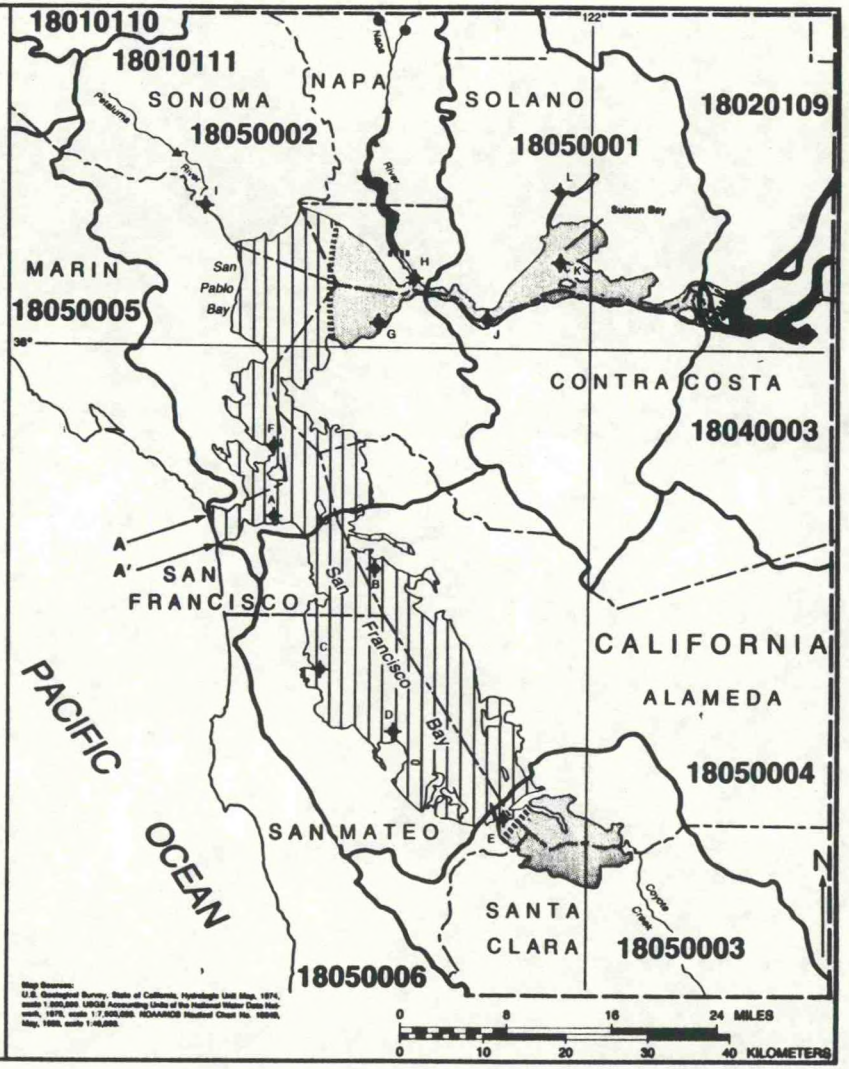
Cross Section (at mean high water)

Scale Ratio



Notes:
Approximately 70% of Estuarine Drainage Area is shown on map.

References:
Hamilton and Macdonald, ND. Fogelman, et al., 1982. Crippen and Beall, 1970. Davis, 1982. Hardner, 1977. Kristof, 1979. U.S. Department of Commerce, 1983a.



Map Sources:
U.S. Geological Survey, State of California, Hydrologic Unit Map, 1974, scale 1:500,000. USGS Accounting Units of the National Water Data Network, 1975, scale 1:7,500,000. NOAA/NOS Nautical Chart No. 18649, May, 1989, scale 1:40,000.

San Francisco Bay CA

- Tide Gage
- Flow Gage
- Head of Tide
- Estuarine Drainage Area (EDA)
- Tidal Fresh Zone
- Mixing Zone
- Seawater Zone
- Hydrologic Cataloging Unit Boundary
- County Boundary
- Salinity Zone Boundary - Low Variability
- Salinity Zone Boundary - Moderate Variability
- Salinity Zone Boundary - High Variability

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Given available information and expert knowledge, the procedures and framework described below present an operational means for collecting and organizing information on the distribution of living marine resources in estuaries throughout the USA. Plans for developing this information base for the 92 estuaries in the inventory are discussed in the last section.

Framework of the Study

Planning and development for this study began in late 1985, and a research strategy was formulated in February, 1986 (SAB 1986). Four steps were required before data collection could begin. First, it was necessary to devise a consistent framework for compiling information on life stage, distribution, abundance within an estuary, and temporal information that could be applied across both estuaries and species. The framework developed, illustrated by the data summaries presented below, was designed so that a relational data base could be constructed from the information collected. Figure 2 summarizes the steps taken to compile and assess the information presented.

Second, a subset of estuaries had to be selected. The selection criteria established were that the estuaries selected would represent (1) a wide range of physical and hydrologic characteristics, including surface area and salinity variability; (2) a wide diversity of surrounding land uses; (3) a large geographical area; and (4) variability in species composition. Of the 17 West Coast estuaries and embayments in the inventory, the 10 selected for this preliminary study (Figure 3); are Hood Canal, Grays Harbor, Columbia River, Coos Bay, Humboldt Bay, Eel River, San Francisco Bay, Santa Monica Bay, San Pedro Bay, and San Diego Bay. Three of these, Hood Canal, and Santa Monica and San Pedro Bays, are not estuaries, but they were included in the National Estuarine Inventory and selected for this study because they are important coastal features and provide critical habitat for many organisms.

Third, a subset of species had to be selected that would not only be useful for assessing the feasibility of the overall project, but also be useful for ultimately assessing the health of estuaries throughout the USA. These include species that are indicators of environmental stress (OAD, 1984). Four general criteria served as guidelines for selecting species:

(1) Commercial value was determined by reviewing catch and value statistics from National Marine Fisheries Service (NMFS), and determining the relative commercial importance within an estuary, a coastal region, and the contiguous USA.

(2) Recreational value was defined as a species that recreational fishermen specifically try to catch that may or may not be commercially important. Recreational species were determined by consulting regional fisheries experts and NMFS documents, and in addition, for some estuaries, species of local recreational value, but otherwise unimportant, were identified.

(3) Indicator species of environmental stress were identified from the literature, discussions with fisheries experts, and from monitoring progams such as NOAA's Status and Trends Program, (OAD, 1984). These species are often mollusks or bottomfishes that consume benthic invertebrates. Their physiological disorders, morphological deformities, and bioaccumulation in tissues and organs of contaminants, such as metals, PAHs, and PCBs, indicate episodes of pollution.

Figure 2. Steps to conduct study

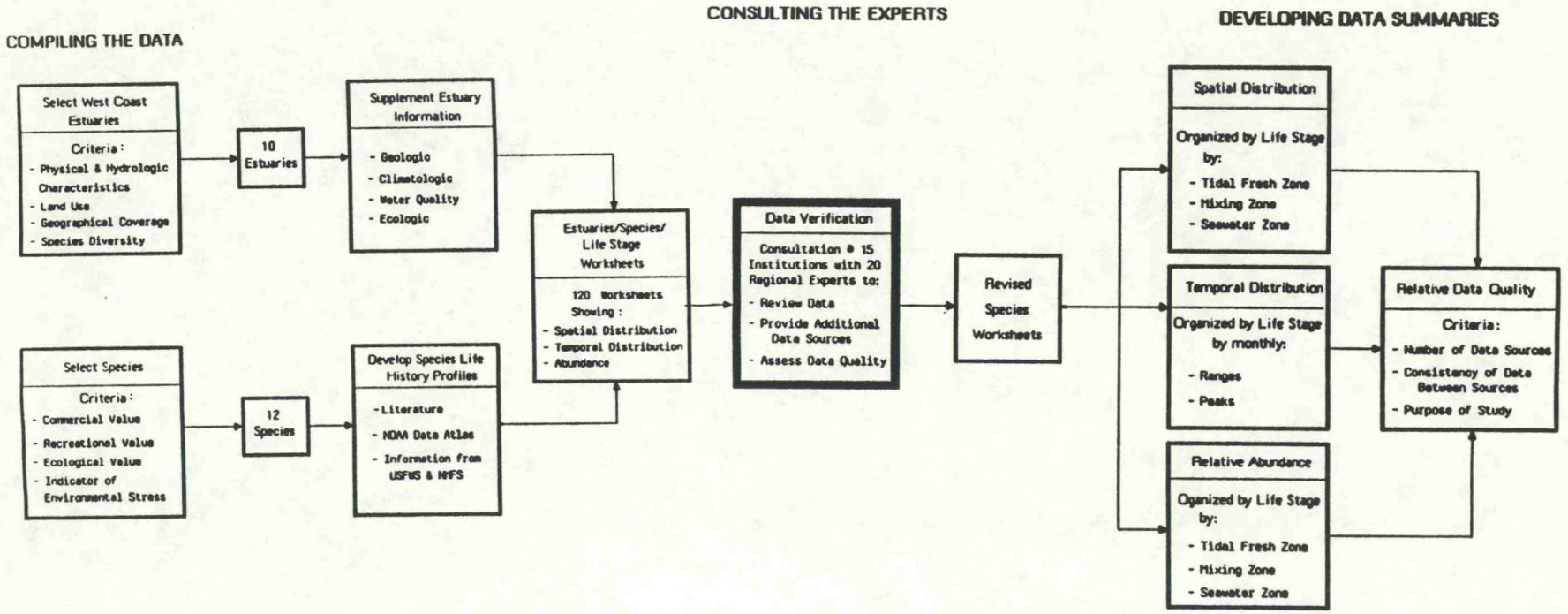
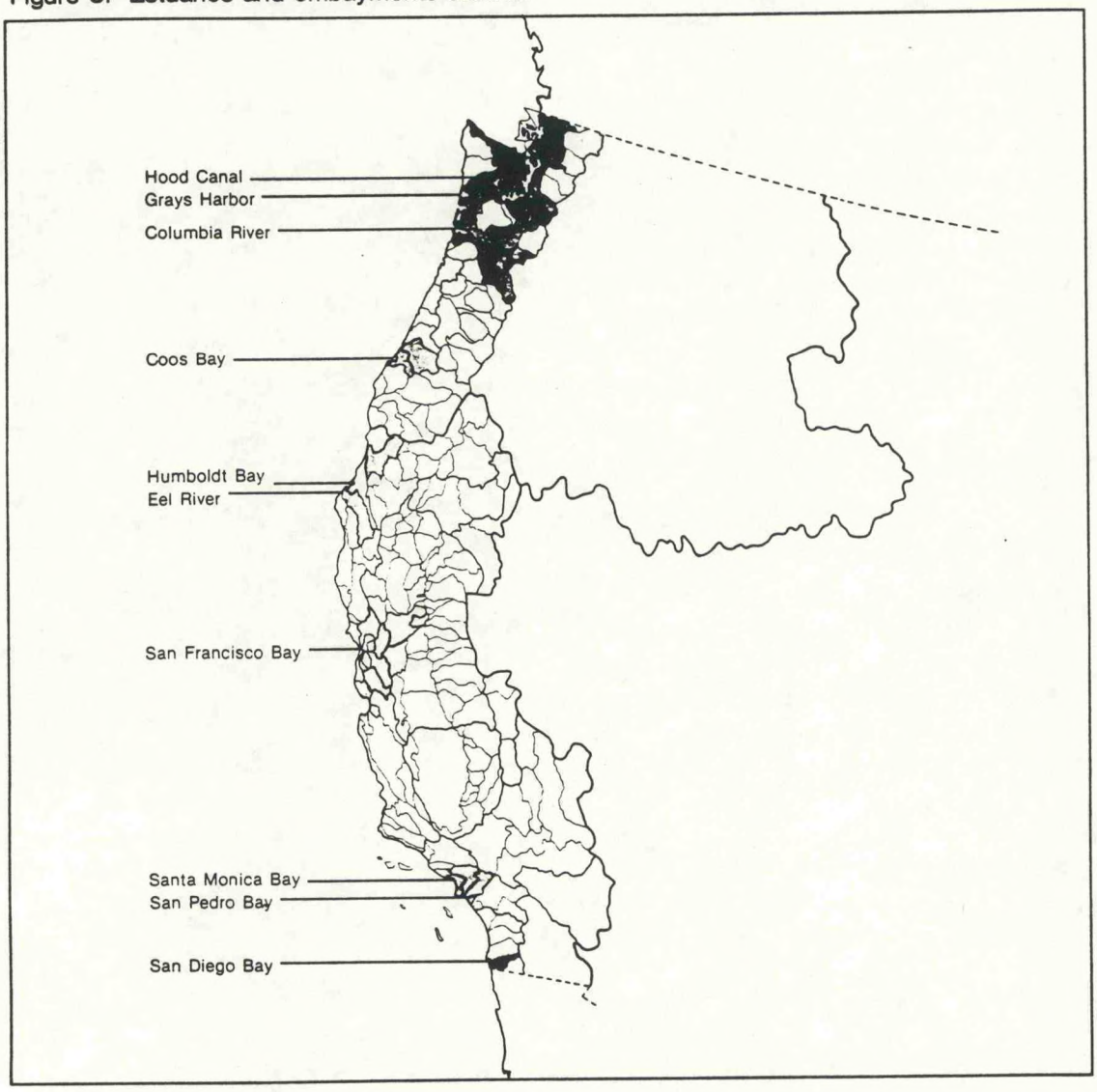


Figure 3. Estuaries and embayments studied



(4) Ecological value of a species was based on several attributes, including trophic level, relative abundance, and fraction of ecosystem biomass. This criterion permits a species to be selected based on its importance to the ecology and productivity of an estuary.

Table 1 lists the 12 species selected for the preliminary study. These criteria, as well as recommendations from local and regional experts, will be used to select species for the nationwide study. Appendix I lists the 37 species that have been selected for the complete West Coast component. Recommendations made by personnel at NOAA's National Marine Fisheries Service's Northwest and Alaska Fisheries Center, and by other experts consulted during the study (listed in Appendix II), were important factors in determining the final species list.

Fourth, additional information had to be collected on the estuaries selected before data collection on species could begin. Although critical for this work, Volume I of the estuarine atlas did not contain sufficient information. Additional information was required on geologic history, bottom type, tidal and freshwater circulation, climate and weather, and water quality to develop each estuary's species composition and to understand the reported distribution of the organisms. For example, data on seasonal wind, freshwater inflow, and salinity for San Francisco Bay (Conomos et al., 1985) help to explain the variability in the seasonal and yearly distribution of fishes in that estuary. Simenstad (1983) provided an ecological overview of Pacific Northeast estuaries and the relative utilization of these systems by living marine resources. In addition, the NMFS's Anglers' Guide to the U.S. Pacific Coast (Squire and Smith, 1977) and Horn and Allen (1976) provided initial information on species presence in a specific estuary and its characteristics. These kinds of data sources helped to filter out seasonal anomalies and unusual species distribution reports. This information was considered when developing the "average" species spatial and temporal distributions depicted.

Table I. Species studied and selection criteria

Species	Commercial	Recreational	Indicator	Ecological
Chinook Salmon (*Oncorhynchus tshawytscha)*	x	x		
Coho Salmon (*Oncorhynchus kisutch*)	x	x		
Sockeye Salmon (*Oncorhynchus nerka*)	x	x		
Starry Flounder *(Platichthys stellatus*)	x	x	x	
Pacific Herring (*Clupea harengus pallasi*)	x	x		
Shiner Surfperch (*Cymatogaster aggregata*)		x		x
Striped Bass (*Morone saxatilis*)		x		
California Halibut (*Paralichthys californicus*)	x	x		
White Croaker (*Genyonemus lineatus*)		x	x	
Dungeness Crab *(Cancer magister*)	x	x		
Pacific Littleneck Clam *(Protothaca staminea*)	x	x		
Pismo Clam (*Tivela stultorum*)		x		

Compiling the Data

Compiling consistent species data nationwide or for a large region limits the amount of information and number of fishes and invertebrates possible to study. Since this study was to serve as a means for assessing the feasibility of developing a nationwide data base, considerable thought was given to how best to structure the information. This exercise included what information should be collected on each species, and how should it be organized. To maximize the effectiveness of discussions with estuarine and fisheries experts, the approach was to compile, and review information from the literature prior to "field" visits and discussions.

Two documents were developed to compile and portray information. First, a species profile was developed for each organism to provide a reasonably complete life history overview. The profiles contain significantly more information than is depicted in the data summaries of this report and were essential to understanding and interpreting the distribution of each species. The profiles were developed from many data sources, including reviews of both published and "gray" literature and fisheries data compiled by the NMFS, U.S. Fish and Wildlife Service, and NOAA through its series of strategic assessment data atlases. Particularly important information sources for the project's initial stages were species life history information compiled for NOAA's Gulf of Alaska and West Coast Data Atlas (SAB and NMFS, in press) and the U.S. Fish and Wildlife Service's regional ecological characterization studies (Jones and Stokes, I98I). Figure 4 is the species profile for starry flounder (*Platichthys stellatus*).

Second, a species worksheet was designed to enable quick compilation and simple graphic representation of the primary data collected. A draft worksheet was developed for each species and estuary before the experts were consulted. The primary data collected on each species include--(1) the salinity zone it occupies; seawater, mixing, and/or tidal fresh; (2) temporal distribution throughout those zones; and (3) life history stage(s) in a particular zone. The I20 species worksheets (12 species for 10 estuaries) compose the data base used to develop the information summaries presented in this paper. Figure 5 shows the worksheet for starry flounder for San Francisco Bay.

Spatial and temporal distribution data and relative species abundance information were recorded on the worksheets. This information was aggregated by estuarine salinity zone and by species life stage, adults, spawning, juveniles, larvae, and eggs. Adults are reproductively mature individuals, juveniles are immature, but otherwise similar to adults, and spawning is defined as the release of eggs and sperm (fertilization). Three steps were taken to compile these data. First, the presence or absence of a species within an estuary was determined. Second, the species' monthly temporal distribution was ascertained and, if possible, peak occurrence of each life stage was noted. Finally, the abundance of a species relative to other species within an estuary was determined based on the following criteria:

1) General Distribution - the species is usually present in this area.

2) Abundant - a moderate concentration of the species is present in this area.

3) Highly Abundant - a very high concentration of the species is present in this area.

For well studied species, such as salmonids, quantitative data were used to estimate the level of abundance. However, quantitative information for specific species within a particular estuary is very limited. Therefore, regional and local experts were consulted to estimate this parameter. The problems associated with estimating relative abundance data are discussed below.

Figure 4. Species profile for starry flounder

Starry Flounder (Platichthys stellatus)

Starry flounder, a common species in the study area, is recreationally important from Alaska to California. It is found in a wide range of salinities and requires estuaries for its larval and juvenile stages.

Value

Commercial – Of minor commercial importance, it is fished by trawls from the Bering Sea and Aleutian Islands to Southern California. Harvests for this species averaged 1,330 tons per year 1981 to 1983, 90% of which was taken by USA fisherman. Most of the catch comes from Puget Sound and the coasts of Oregon and Washington. It is not highly regarded as a food fish, but is marketed as fresh fillets (Frey, 1971; Leaman, 1984; Pacific Fisheries Information Network, 1985).

Recreational -- It is a relatively important recreational species taken from Nome, Alaska to Morro Bay, California. Of the 369,000 fish caught in 1981-1982 by USA sport fishermen, two-thirds were taken in Washington waters. It is fished all year from piers, shore, and skiffs (Frey, 1971; Squire and Smith, 1977, NMFS, 1984; Washington Department of Fisheries, 1984).

Indicator -- This species often accumulates contaminants and is a target species for the National Status and Trends Program (OAD, 1984).

Range

Starry flounder is an Arctic-circumboreal Pacific species ranging from Korea through the Bering and Chukchi Seas to Bathurst Inlet Canada and south along the Pacific Coast to Southern California (Allen and Smith, in press).

Life Mode

As in all flatfishes, eggs and larvae are pelagic and juveniles and adults demersal. Eggs are neritic and inshore, but larvae range from estuarine waters to at least 37 km offshore. Unlike other flatfishes, juvenile starry flounder seem to be restricted to estuaries and the lower reaches of major coastal rivers. Older juveniles and adults range from as far as 120 km upstream to depths of 375 meters on the continental shelf, but are concentrated between the nearshore subtidal waters and 150 meters (Frey, 1971; Moyle, 1976; Richardson and Pearcy, 1977; Garrison and Miller, 1982; Allen and Smith, in press).

Habitat

Type -- Neritic to estuarine and riverine, pelagic to benthic, depending on life stage.

Substrate -- Sand and mud for small juveniles, fine to coarse sediments for adults.

Physical/Chemical – Eggs are in euhaline to polyhaline waters, larvae from euhaline to fresh, juveniles from mesohaline to fresh, and adults from euhaline to freshwaters at temperatures from 0° to 12.5°C (Hart, 1973; Garrison and Miller, 1982; Simenstad, 1983).

Migrations and Movements

The species performs seasonal bathymetric migrations, moving inshore in spring into shallow waters and estuaries and offshore in winter to 300 meters. Coastal movements are mostly limited, but tagged individuals have moved up to 200 km (Morrow, 1980).

Reproduction

Mode -- Sexual, separate sexes, oviparous, with external fertilization.

Mating and Spawning -- Mating and spawning occur offshore near the bottom at 25-45 meters, usually near river mouths and sloughs, into which larvae are carried. Spawning period varies, from November-February off California to July-August in the Bering Sea (Frey, 1971; Garrison and Miller, 1982).

Reproductive Capacity – Fecundity increases with size and ranges from 900,000 eggs at 38 cm to 11 million eggs to 69 cm (Morrow, 1980; Garrison and Miller, 1982).

Growth and Development

Embryonic Development – Indirect, external. Egg size range: 0.9-1.3 mm (Garrison and Miller, 1982).

Larval and Juvenile Development -- Larvae hatch out after 2.8-14.7 days at 1.9-2.4 mm, transforming to juveniles at 10.5-12.0 mm. Juveniles grow to 22-45 cm, depending on area and sex (Frey, 1971; Hart, 1973; Garrison and Miller, 1982).

Age and Size of Adults -- Maturation occurs at 2-3 years and 22-36 cm for males and 3-4 years and 24-45 cm for females. Maximum age is 21 years, maximum size 91 cm (Frey, 1971; Wolotira et al., 1977; Garrison and Miller, 1982).

Food and Feeding

Trophic Mode – Carnivore (Frey, 1971).

Figure 5. Starry flounder worksheet for San Francisco Bay

REGION West Coast

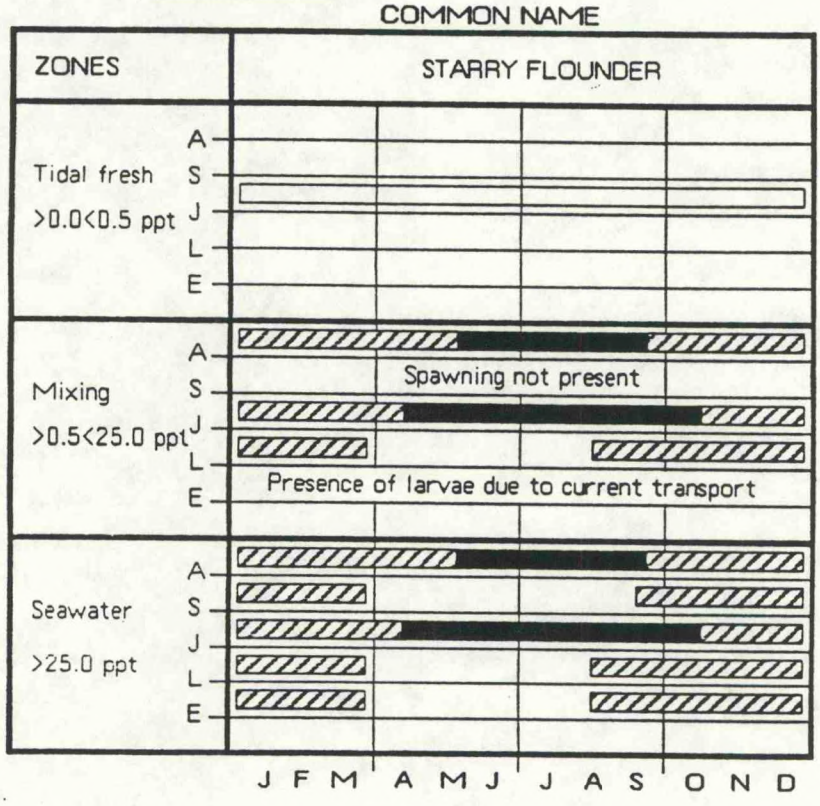
ESTUARY San Francisco Bay

ID# 4.05

DATE 4/23/86

SPECIES Platichthys stellatus

COMMON NAME



NOTES

Distribution variable depending on freshwater inflow

A= Adult
S= Spawning
J= Juvenile
L= Larvae
E= Eggs

Highly Abundant
Abundant
General Distribution

Consulting the Experts

Two one-week surveys were conducted on the West Coast to review, verify, and revise the 120 draft species worksheets (Figure 5) with regional and local experts. The first trip covered from Puget Sound through Humboldt Bay, the second trip from San Francisco Bay through San Diego Bay. Thirty-five individuals at 15 institutions or agencies were contacted. Twenty of these individuals were consulted during the surveys. Their names and affiliations are listed in Appendix II, which also serves as the personal communications reference list. These individuals are also included in Appendix III, which lists the primary data sources for each species by estuary. These scientists and managers were particularly helpful in providing estuary/species specific distribution and abundance data. They also provided additional references and contacts and identified additional species to be included in the data base. Each species worksheet was revised based on the information gained during the surveys.

Data Problems

Although the worksheets greatly assisted and organized data collection efforts, filling them out was not as straightforward as it may seem. For example, salinity zone boundaries, although clearly indicated for each estuary in the estuarine atlas (SAB, 1985), are highly variable throughout a year. The atlas subdivides each estuary into three zones between the heads of tide and the seaward boundaries based on depth-averaged annual salinity concentrations (Figure 1). However, division of an estuary on the basis of salinity is highly variable due to the many interacting factors affecting salinity concentrations, such as variations in freshwater inflow, wind, and tides. The variability between each zone is classified in the atlas as low, moderate, or high. To compile information on species distribution according to these zones, it was assumed that if a particular salinity zone increased or decreased, the distribution of a fish in that zone would correspond to that shift. For example, if increased freshwater inflow shifts the tidal fresh zone further down the estuary, the distribution of a species confined to that zone increases to include the new area. If a species exhibits a wide range in salinity tolerance, a shift may or may not occur. Table 2 shows the variability of the salinity zone boundaries in each estuary studied.

In addition, aggregating species by salinity zones is a fundamental habitat parameter, but a combination of habitat characteristics, such as bottom type and location of submerged aquatic vegetation, would more accurately indicate species distributions. Although, this information does not comprehensively exist for the nation's estuaries at this time, future projects are being discussed to compile it.

Table 2. Salinity zone variability by estuary

Estuary	Salinity Zone Boundary Variability*
1. Hood Canal	Moderate
2. Grays Harbor	High
3. Columbia River	High
4. Coos Bay	High
5. Humboldt Bay	Moderate
6. Eel River	High
7. San Francisco Bay	High
8. Santa Monica Bay	N/A
9. San Pedro Bay	N/A
10. San Diego Bay	Low

*Salinity zone boundaries and variability data from the National Estuarine Inventory Data Atlas, Volume I (SAB, 1985). A salinity boundary is the limit of the average annual location of each salinity zone throughout the water column. Relative variability has been defined as the percentage increase or decrease in the surface area of a salinity zone.

N/A Not Applicable

It was particularly difficult to obtain information on the relative abundance of species both within an estuary relative to other species and across estuaries. Therefore, an attempt was made to only determine relative abundance compared to other species within an individual estuary. Although, for well studied species, such as salmonids and Dungeness crab, quantitative data were used to estimate the level of abundance within an estuary. However, this information maybe of limited use, if quantitative data are not available for other species on which to base relative estimates. Consequently, most of the relative abundance information shown was not determined with quantitative data. It was obtained primarily, by asking regional and local experts to give an opinion based on their knowledge of specific species and estuaries. For example, biologists at the University of Washington were asked what the relative abundance of Pacific herring in Hood Canal is compared to other species in that system. Pacific herring were determined to be highly abundant based on catch records and knowledge of the area and its fishes (Miller and Borton, 1980; Miller, pers. comm., 1986). The fundamental point is:

Except for a relatively few important commercial and/or recreational species, little or no quantitative information is available to determine relative species abundance within and across estuaries. The data that are available are almost impossible to reconcile because of variability in sampling strategies and the inconsistencies of studies done across species and estuaries. The information presented on abundance in the data summaries can be considered only a "best guess" at this time.

However, once the completed data base has been reviewed by experts, it may be possible to make better educated guesses to estimate relative abundance within and across estuaries, based on the information compiled by this effort and knowledge of the species habitat requirements and ecology. For example, striped bass was found in two of the ten estuaries of this investigation, San Francisco and Coos Bays. Striped bass is probably more abundant in San Francisco Bay, because the species was introduced there, suitable spawning streams exist, and the physical and hydrologic characteristics of the system are suitable for this species. The attempt to determine relative abundance during this study is a starting point for developing this important information for the National Estuarine Inventory. The nationwide study will probably show how little is really known quantitatively about the abundance of living marine resources in the nation's estuaries.

Because the quantity and quality of data collected varied significantly among species and estuaries, an attempt has been made to provide an indication of the reliability or certainty of the information presented. Table 5 in the next section assigns a level of reliability to the information presented for each species and life stage by estuary.

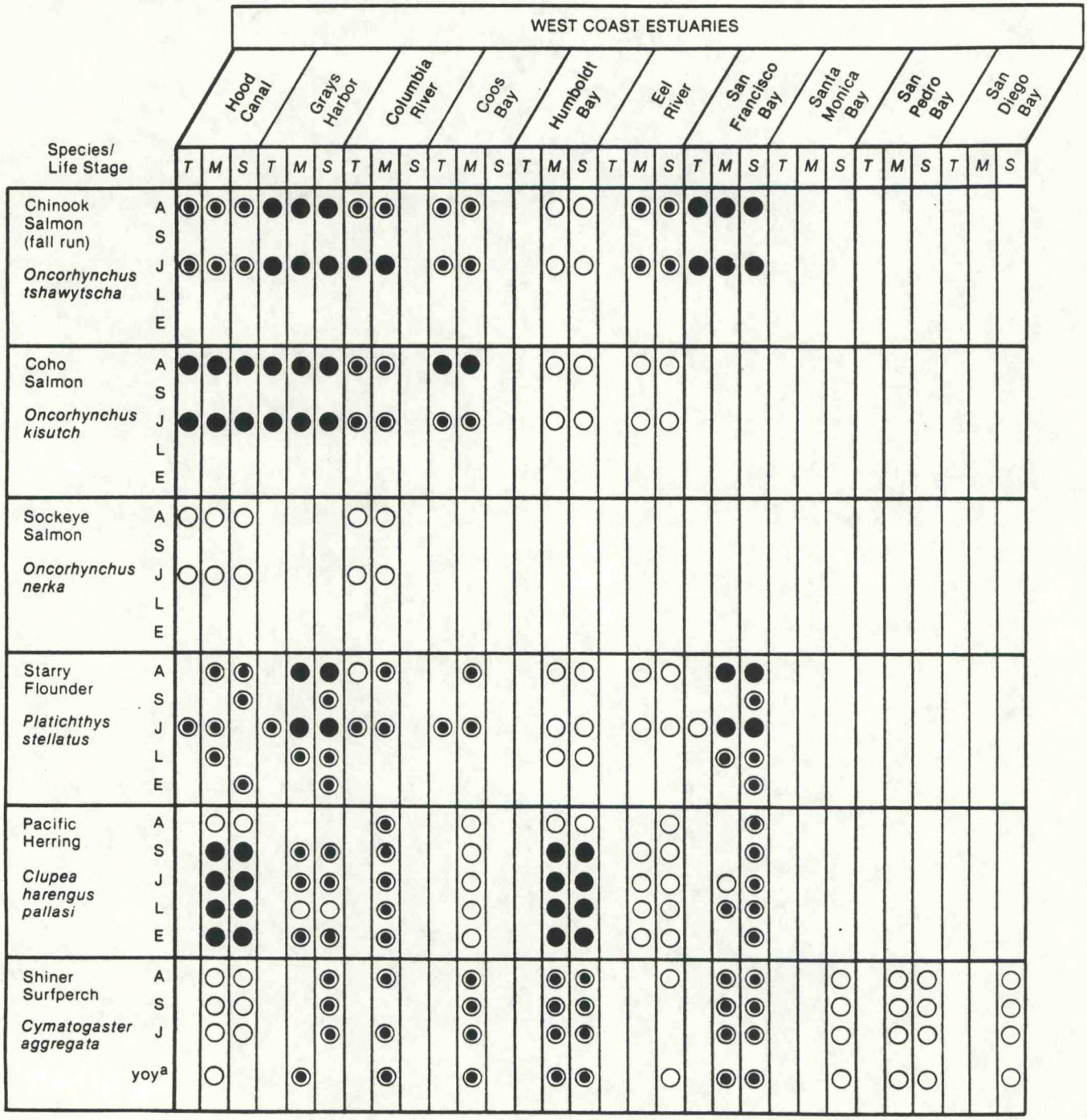
Data Summaries and Results

The information compiled for each species and estuary on the120 worksheets has been synthesized into three data summaries. Each of these summaries attempts to capture the sense of what is known about how the species of interest are distributed across the ten West Coast estuaries by life stage, relative abundance, and time. The formats illustrate how this type of information will be organized for the nation's estuaries.

Table 3 summarizes the distribution and relative abundance by life stage for each species in each estuary, by salinity zone. Reading across the table provides information on how each species and life stage is distributed across the ten estuaries. Reading down the table provides information on the presence and distribution of species within each estuary. The highest level of abundance obtained during one year is depicted.

Although this is a limited study, Table 3 indicates the significance of estuaries or at least their use by specific species. In general, younger life stages occur at lower salinities, while adults are often found in the seawater zone. It is important to note that this study included estuaries

Table 3. Distribution and relative abundance



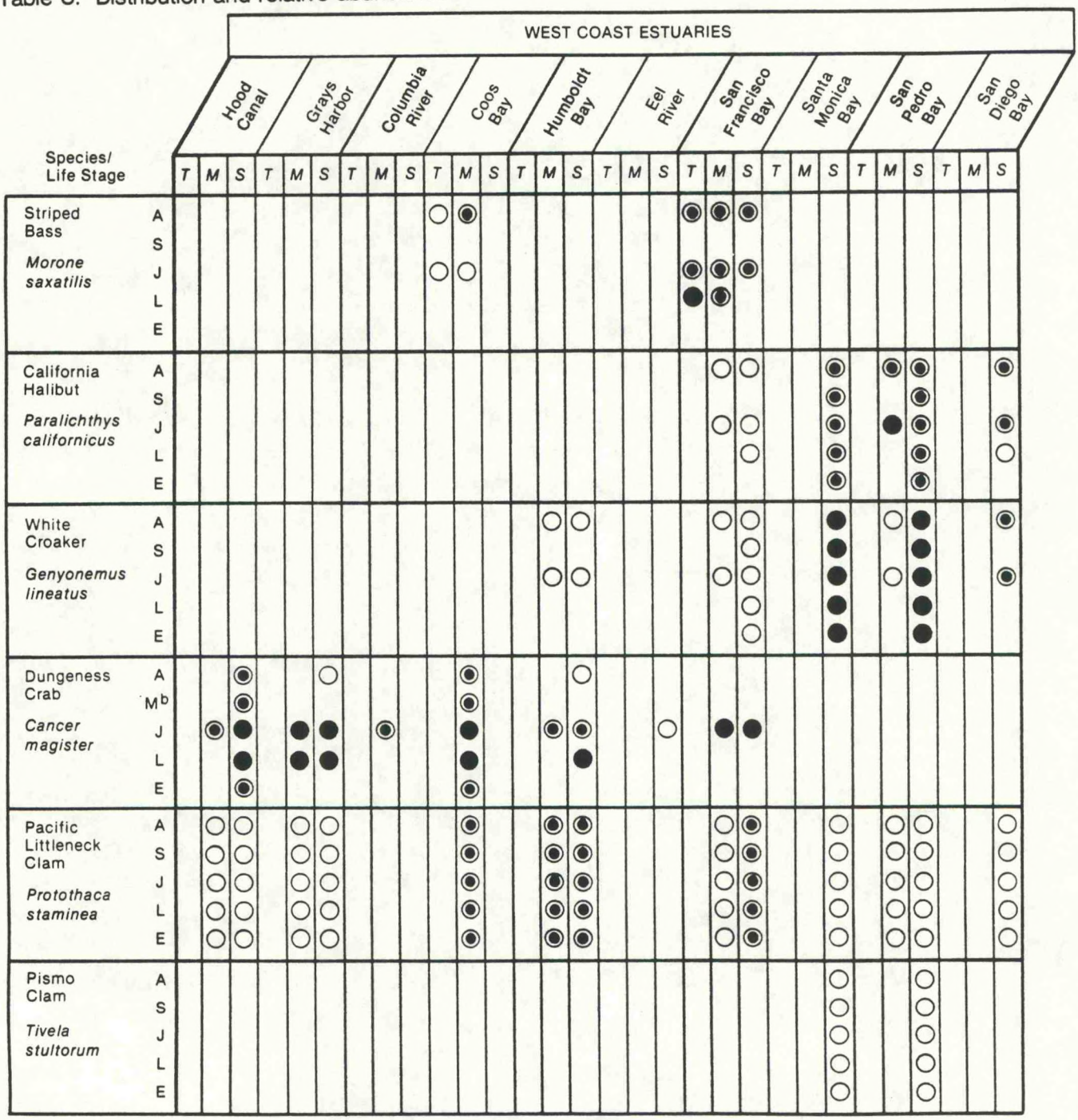
[a] young of year

● Highly Abundant ◉ Abundant ○ Generally Distributed

T - Tidal Fresh *M* - Mixing Zone *S* - Seawater

A - Adult S - Spawning J - Juvenile L - Larvae E - Egg

Table 3. Distribution and relative abundance



[b] mating

● Highly Abundant ◉ Abundant ○ Generally Distributed

T - Tidal Fresh *M* - Mixing Zone *S* - Seawater

A - Adult S - Spawning J - Juvenile L - Larvae E - Egg

between Puget Sound and San Diego Bay only, so it does not necessarily encompass the full range of each species. A brief description of how each species is distributed follows.

Salmonids are present in estuaries as juveniles for a brief time period, and this residence time varies by species (Simenstad et al., 1982). However, estuaries function primarily as migratory corridors to and from spawning areas. For this reason, only the adult and juvenile life stage of chinook (Oncorhynchus tshawytscha), coho (Oncorhynchus kisutch), and sockeye (Onchorhynchus nerka) salmon are depicted. Spawning, eggs, and larvae usually occur in the estuary's freshwater tributaries. The dominant fall chinook run is shown with the species occurring from Hood Canal to San Francisco Bay. Coho and sockeye have a more northern distribution with sockeye generally distributed only in two estuaries: Hood Canal and the Columbia River.

Starry Flounder (*Platichthys stellatus*) is present from Hood Canal to San Francisco Bay and exhibits a wide salinity tolerance range (Hart, 1973). Adults generally occupy the seawater and mixing zones while juveniles are often found in mixing and tidal fresh zones.

Pacific Herring (*Clupea harengus pallasi*) is a predominately marine species that uses West Coast estuaries for spawning and growth of larvae and juveniles (Simenstad, 1983). None of its life stages occur in the tidal fresh zone. It is present from Hood Canal to San Francisco Bay in various levels of abundance.

Shiner Surfperch (*Cymatogaster aggregata*) is ubiquitously distributed throughout the study area and is the only viviparous species in this study. It is abundant in Pacific Northwest estuaries and generally distributed below Point Conception, CA. Large schools are generally found in salinities of 9 parts per thousand or greater (Moyle, 1976), the mixing and seawater zones of this study.

Striped Bass (*Morone saxatilis*) occur in Coos and San Francisco Bays. The resident adult and juvenile life stages of this introduced species may be found in all three salinity zones, but spawning occurs only in freshwater. The presence of larvae in San Francisco Bay's tidal fresh and mixing zones is probably due to current transport (Moyle, pers. comm., 1986, Wong, 1986).

California Halibut (*Paralichthys californicus*) is present from San Francisco Bay to San Diego Bay. This primarily marine species moves inshore in February to spawn in Santa Monica and San Pedro Bays. The importance of Southern California estuaries to this species is not well documented (Nordby, pers. comm. 1986).

White Croaker (*Genyonemus lineatus*) is a marine species found primarily in open bay systems, such as Santa Monica and San Pedro Bays. Spawning occurs in the seawater zone of these coastal areas (Love et al., 1984) and may occur in San Diego Bay, but these data are limited.

Dungeness Crab (*Cancer magister*) is found in all estuaries from Hood Canal to San Francisco Bay in the study area. Juvenile Dungeness crab is the primary life stage to use estuaries since adults normally spawn at sea (Armstrong, pers. comm., 1986). However, in some estuaries such as Coos Bay, all life stages including mating adults are present. This is due to the presence of suitable habitat including high salinities. Although the average annual salinity concentration depicted in the atlas indicates only mixing zone water present, this highly variable zone shifts between mixing and seawater salinities.

Pacific Littleneck Clam (*Protothaca staminea*) is found throughout the region (Morris, 1966). Abundance data range from generally distributed to abundant populations. This species is not found in the tidal fresh zone, but all life stages are found in the mixing and seawater zones.

Pismo Clam (*Tivela stultorum*) was once a highly abundant species in Southern California (Frey, 1971). This study found Pismo clam to be only generally distributed in Santa Monica and

San Pedro Bays. This is a result of a decline in the species populations and its requirement for a high energy surf zone habitat, which is not found in estuaries.

Table 4 summarizes the temporal distribution by month for each species, by life stage, for each of the ten estuaries. An individual table is presented for each species. Each table shows the time periods over which a species is generally known to be present within an estuary as either an adult, juvenile, or during spawning. Peak periods, when a species is known to occur more frequently are also shown. When peak periods are not indicated, it is generally because data were unavailable. If a species is not present or not generally distributed (rare occurrence) in an estuary the notation SNP (species not present) is used. Temporal distribution data often vary due to seasonal factors such as temperature and freshwater inflow. The data for adults and juveniles are more reliable than time of spawning.

An important aspect of a study based on literature reviews and consultations is to determine the quality of the data compiled. The overall quality of the data was assessed among estuaries and species to provide an estimate of the reliability of the preliminary data compiled. Table 5 shows the reliability of the data by estuary, species, and life stage based on the following criteria:

1) Highly Certain--Considerable sampling data available. Distribution, behavior, and preferred habitats well documented within an estuary.

2) Moderately Certain--Some sampling data available for an estuary. Distribution, preferred habitat, and behavior well documented in similar estuaries.

3) Reasonable Inference--Little or no sampling data available. Information on behavior and preferred habitats documented in similar estuaries.

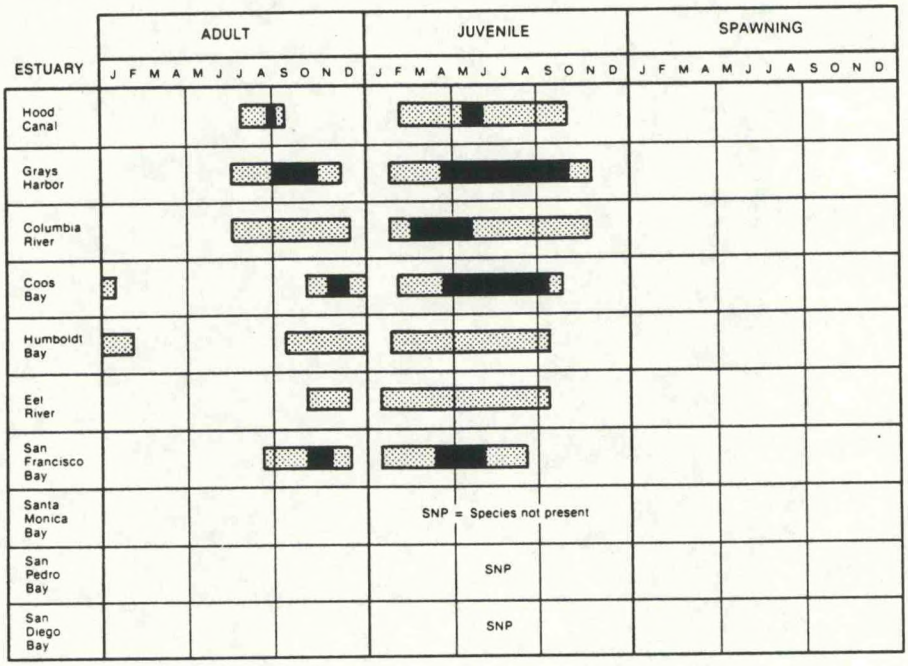
The quality of the information varies by species and by estuary. For example, a large amount of information is available on salmonids because they are highly valued both commercially and recreationally. For these species, the reliability of the data is often highly certain. Also, considerably more information was readily available for fishes than for invertebrates. The reliability of the data decreases the younger the life stage. Often adult and juvenile catch data are available from the National Marine Fisheries Service or state creel surveys. However, abundance and distribution data for larvae and eggs vary dramatically, due to the varying levels of research efforts to determine the presence and abundance of these life stages for specific species in individual estuaries. Data reliability was also based on the number of data sources for a specific estuary and whether the studies were specifically designed to identify and quantify species and their life stage. For example, the studies undertaken in the Columbia River and San Francisco Bay to identify and quantify living marine resources are large compared to those for smaller, less studied estuaries. In the case of limited studies, information was often inferred, but was occasionally based on incidental data, such as data contained in masters theses. Because this report is a preliminary study, primarily major information sources were obtained and key individuals interviewed. A more rigorous investigation will be conducted during the complete study. The data compiled during this effort will be reviewed, and it is likely that there will be minor changes for some species and an increase in data reliability will probably occur.

Concluding Comments and Future Plans

The results of this study demonstrate that it is possible to develop a comprehensive data base on the life history distribution and relative abundance of fishes and invertebrates throughout estuaries of the USA. Although the knowledge available to manage and effectively preserve these resources continues to be limited, the data base, when completed, will enable simple comparisons among species, groups of species, specific life stages, times of year, within estuaries, among estuaries, or by geographic regions. In addition, the effort will identify information gaps, such as limited abundance and life history information. Most important, will be its

Table 4. Temporal distribution

SPECIES: CHINOOK SALMON, *Oncorhynchus tshawytscha* (Fall Run)



Peak Period

SNP = Species Not Present

SPECIES: COHO SALMON, *Oncorhynchus kisutch*

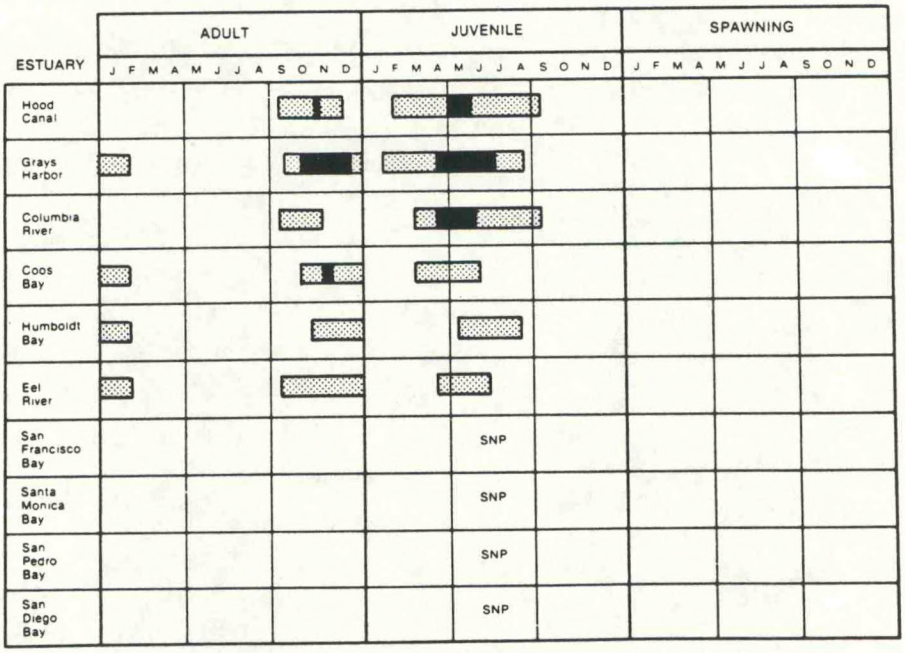
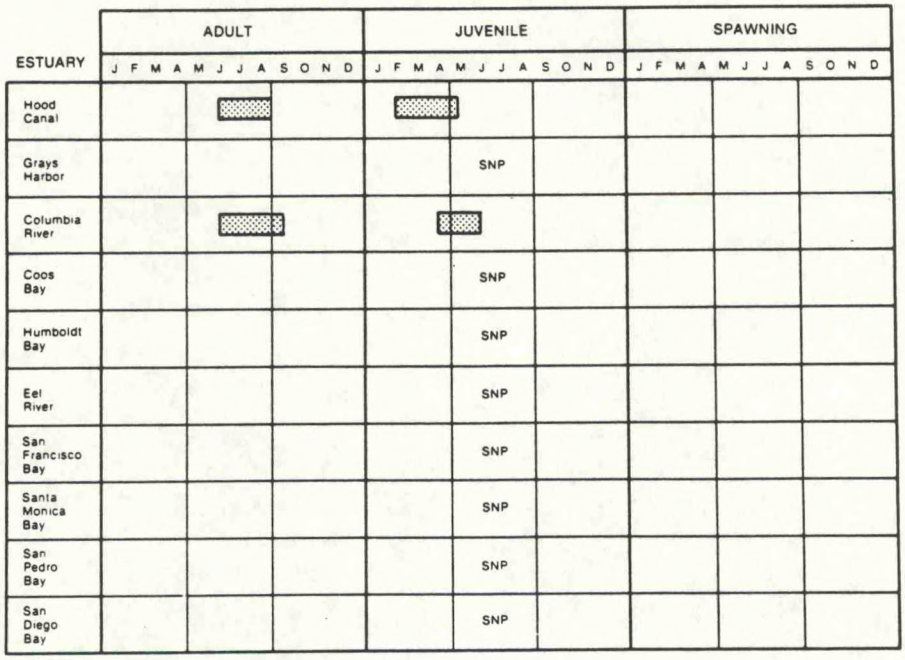


Table 4. Temporal distribution

SPECIES: SOCKEYE SALMON, *Oncorhynchus nerka*



Peak Period

SNP = Species Not Present

SPECIES: STARRY FLOUNDER, *Platichthys stellatus*

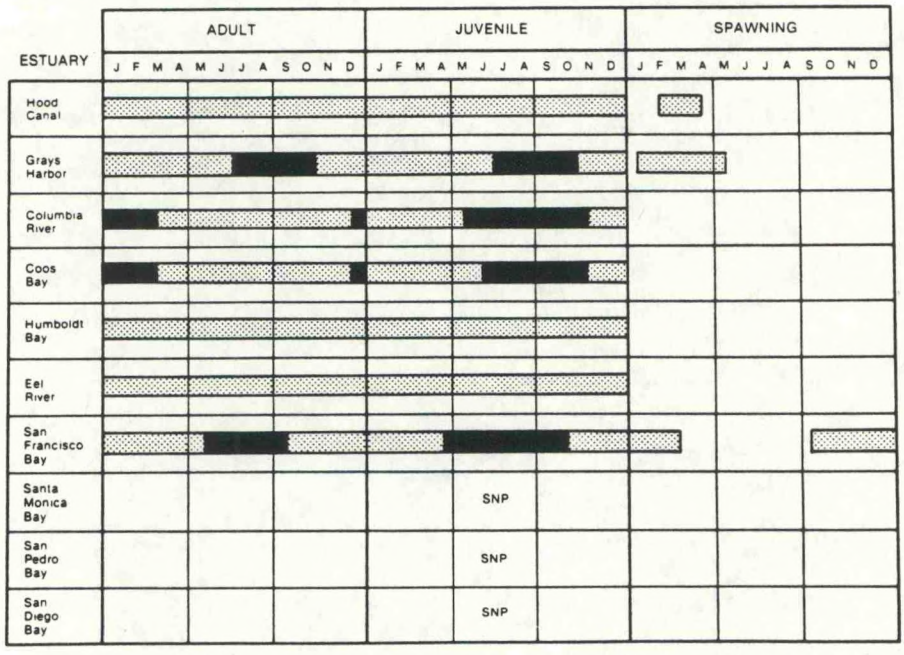
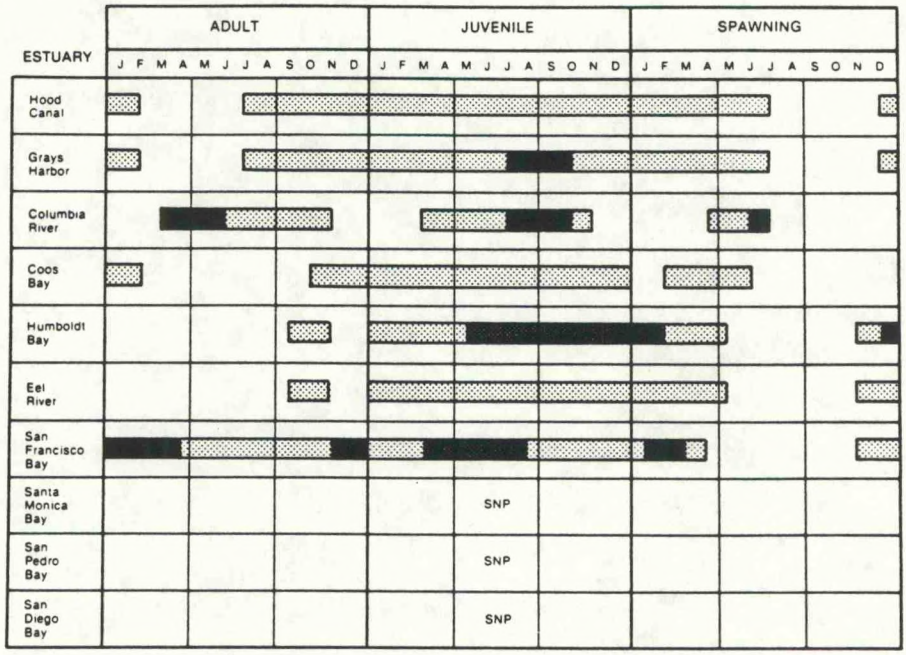


Table 4. Temporal distribution

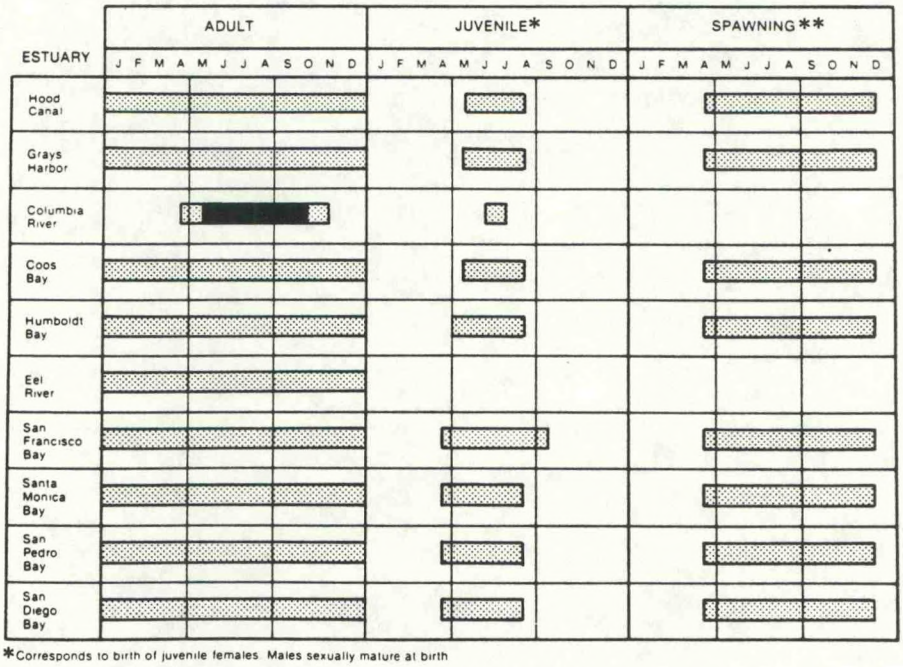
SPECIES: PACIFIC HERRING, *Clupea harengus pallasi*



Peak Period

SNP = Species Not Present

SPECIES: SHINER SURFPERCH, *Cymatogaster aggregata*



*Corresponds to birth of juvenile females. Males sexually mature at birth

**Not spawning, corresponds to time period consisting of mating (~April-July), storage of sperm (~July-November), and fertilization (~November-December)

Table 4. Temporal distribution

SPECIES: STRIPED BASS, *Morone saxatilis*

ESTUARY	ADULT	JUVENILE	SPAWNING
	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D
Hood Canal		SNP	
Grays Harbor		SNP	
Columbia River		SNP	
Coos Bay			
Humboldt Bay		SNP	
Eel River		SNP	
San Francisco Bay			
Santa Monica Bay		SNP	
San Pedro Bay		SNP	
San Diego Bay		SNP	

Peak Period

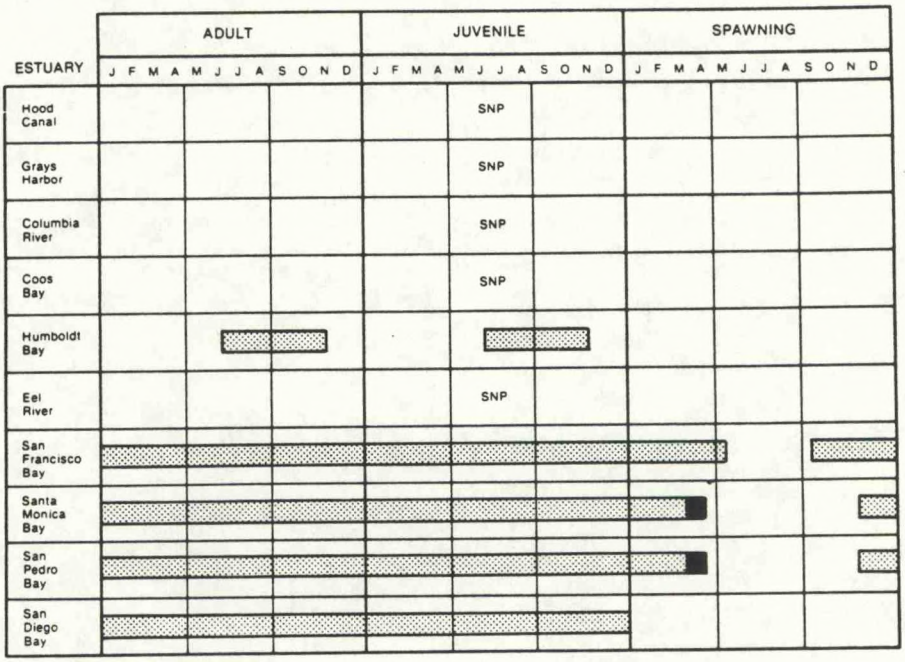
SNP = Species Not Present

SPECIES: CALIFORNIA HALIBUT, *Paralichthys californicus*

ESTUARY	ADULT	JUVENILE	SPAWNING
	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D
Hood Canal		SNP	
Grays Harbor		SNP	
Columbia River		SNP	
Coos Bay		SNP	
Humboldt Bay		SNP	
Eel River		SNP	
San Francisco Bay			
Santa Monica Bay			
San Pedro Bay			
San Diego Bay			

Table 4. Temporal distribution

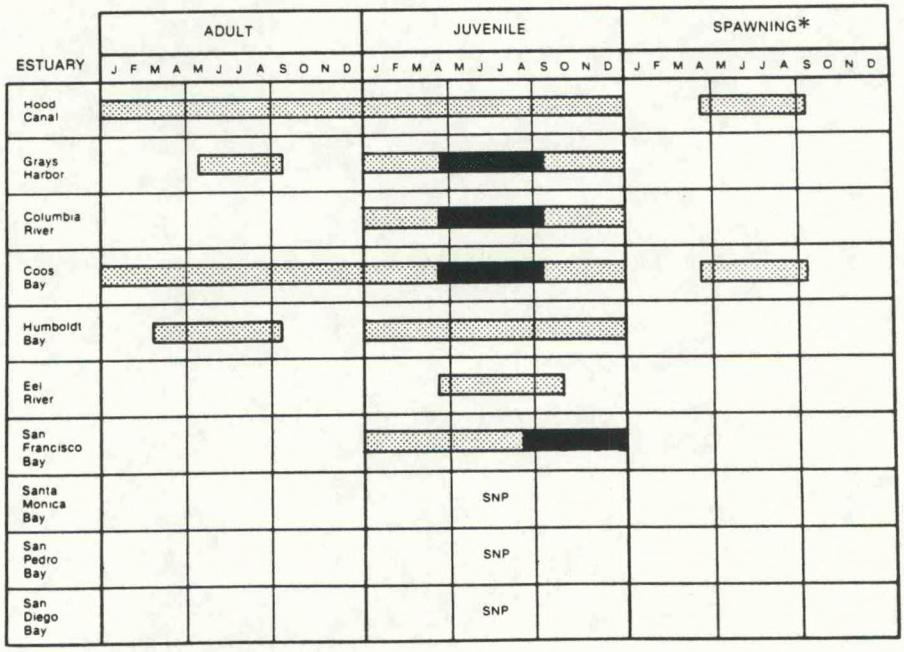
SPECIES: WHITE CROAKER, *Genyonemus lineatus*



Peak Period

SNP = Species Not Present

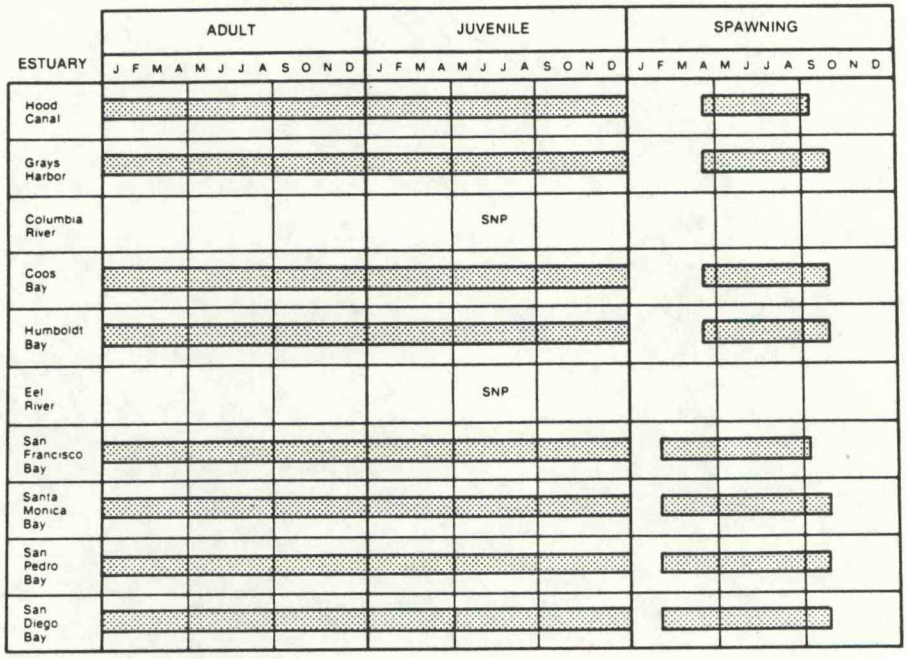
SPECIES: DUNGENESS CRAB, *Cancer magister*



*Refers to mating not release of larvae by adult female.

Table 4. Temporal distribution

SPECIES: PACIFIC LITTLENECK CLAM, *Protothaca staminea*



Peak Period

SNP = Species Not Present

SPECIES: PISMO CLAM, *Tivela stultorum*

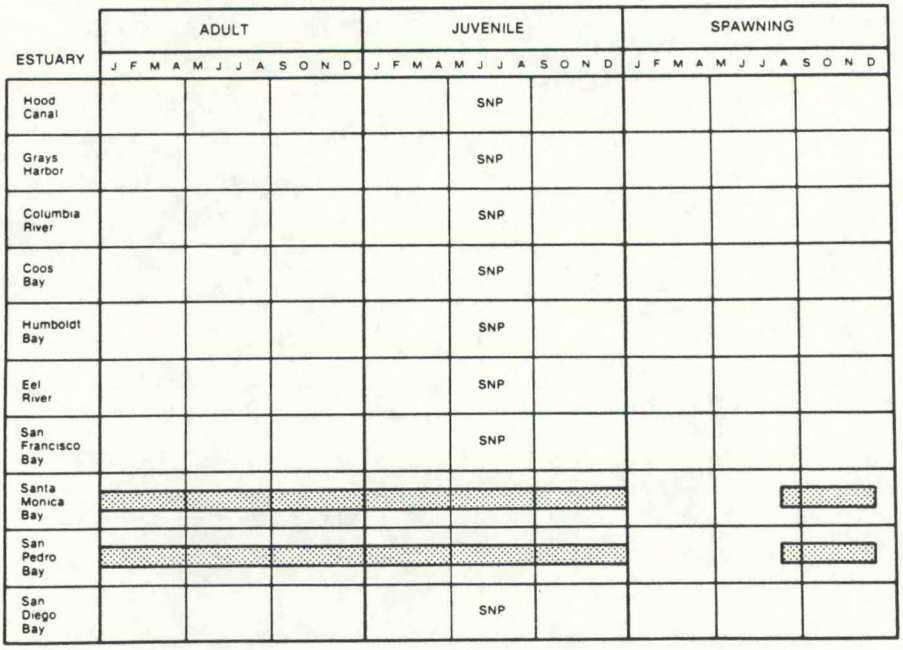


Table 5. Data reliability

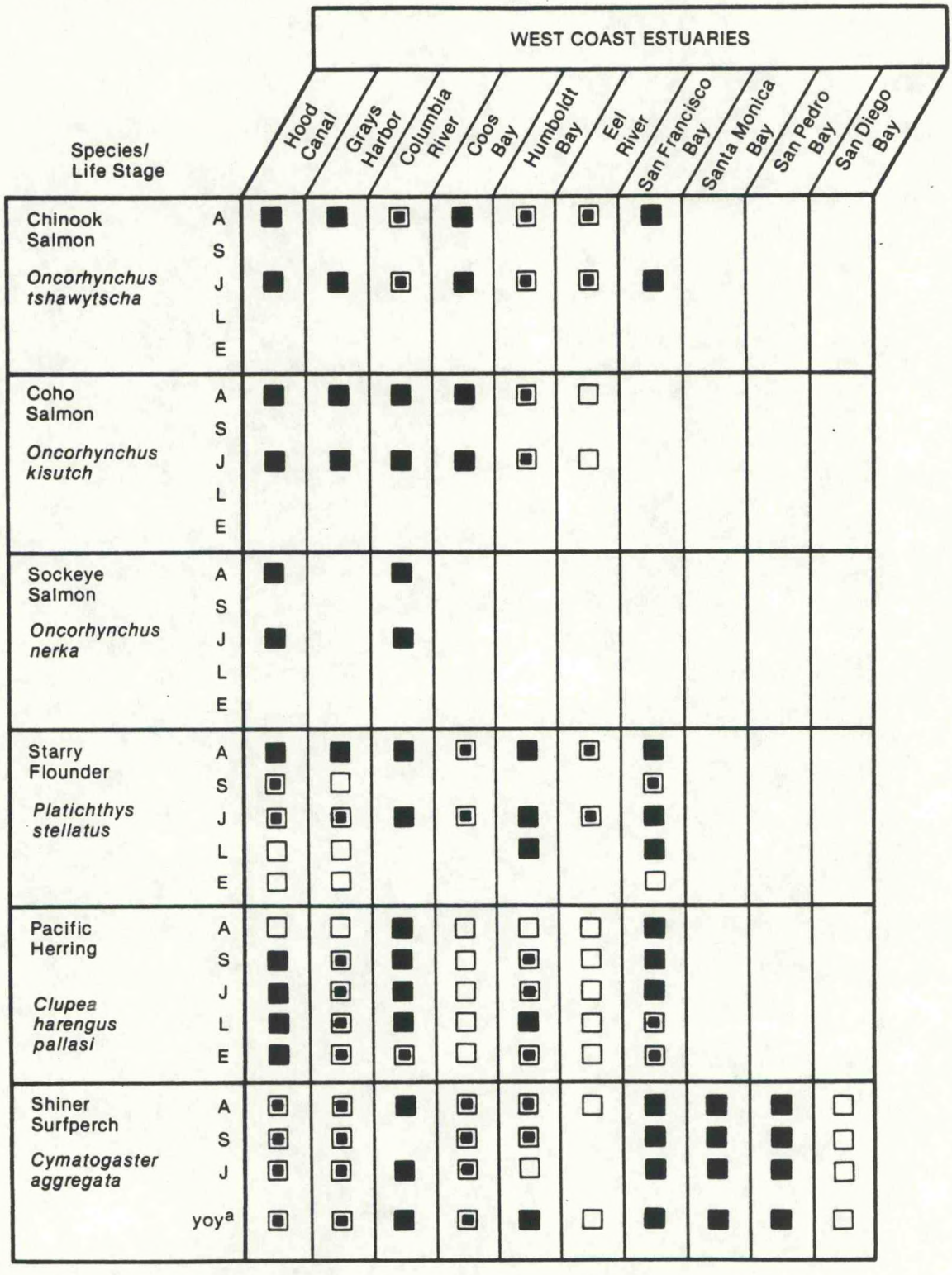
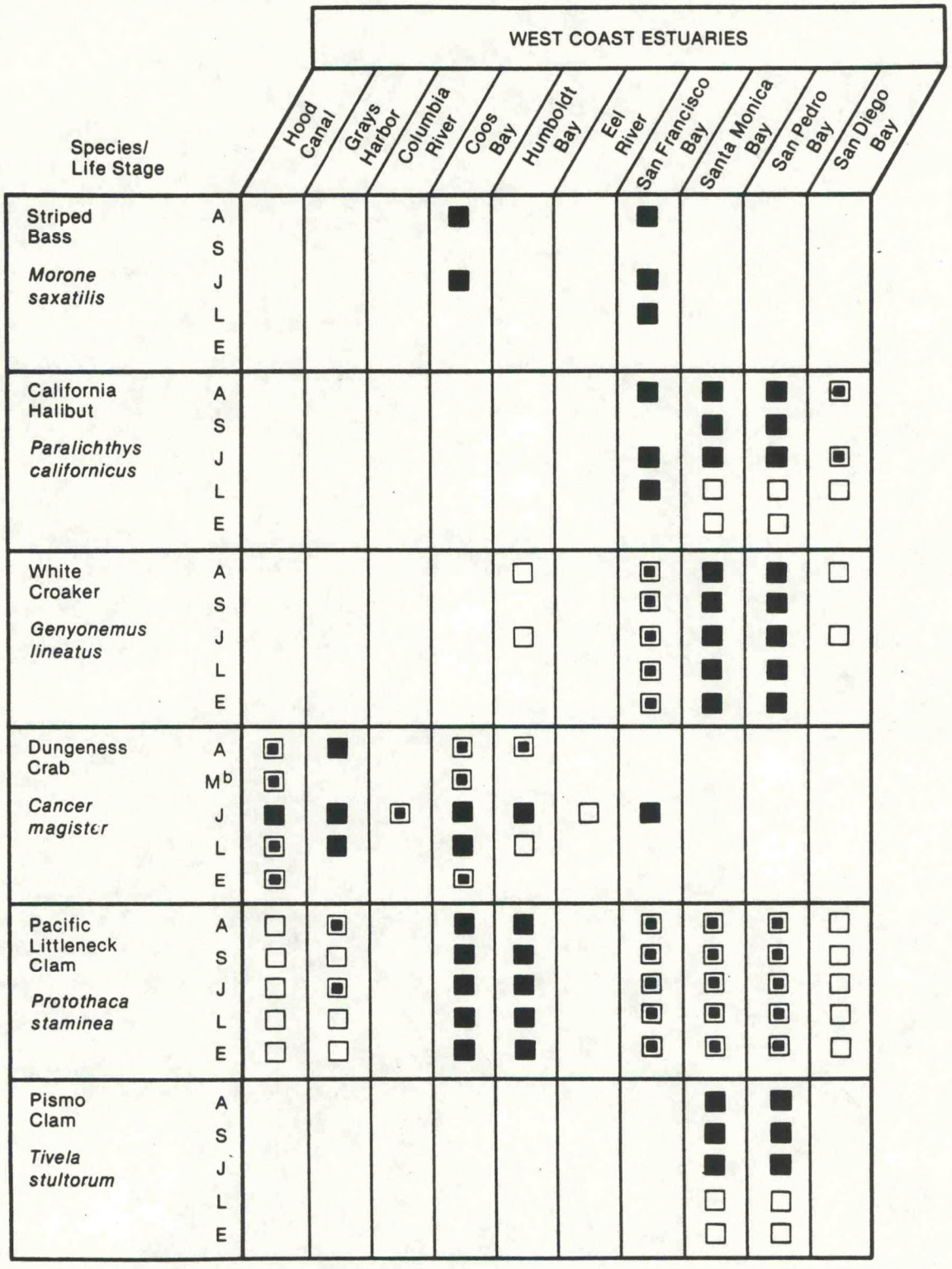


Table 5. Data reliability



use in posing questions and developing and testing hypotheses, when these data are combined with other **National Estuarine Inventory** information being developed by OAD on habitat, pollutant loadings, and contaminant levels. Examinations of these sets of data and related analyses can reveal patterns and specific relationships that indicate the scale and scope of existing or potential conflicts among resource uses throughout the nation's estuarine resource base.

Given that the amount and quality of available information varies by species, by life stage, between estuaries, and even within an estuary, considerable scientific judgement is required to infer or extrapolate spatial and temporal distributions from existing data and available literature. But even the most informed judgement is far from perfect, even if complete information existed. Consequently, information on the level of certainty associated with each data element, such as presented in Table 5, Data Reliability, will continue to be an important part of this work, along with a clear and complete summary of the primary references and personal communications used (Appendix III).

Plans are to conduct the overall project on a regional basis, first completing the West Coast component (37 species and 17 estuaries) and then moving to the East Coast and Gulf of Mexico. The experienced gained in the project and other similar SAB projects, has underscored the importance of meeting with local and regional experts and jointly evaluating available information. In fact, much of the information available is in the file cabinets of these experts or in "gray" literature reports at local institutions. Identifying these individuals and institutions is an important first step in each region, as well as a thorough literature review. Plans are to eventually establish a "steering committee" for each region to review and assess the data base. A tentative schedule is as follows:

Region	Completion Date
West Coast	
Preliminary Study	July 1986
Final	December 1986
East Coast	
Northeast	April 1987
Southeast	July 1987
Gulf of Mexico	December 1987

In summary, this study has provided a starting point for compiling living marine resources information for the nation's estuaries. As it continues to evolve, so will the content, quality, and utility of the information developed.

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Appendix I. Complete species list for West Coast study

Species	Region: Southern California	Central California	North Coast	Puget Sound
Topsmelt (*Atherinops affinis*)	x	x	x	
White Croaker (*Genyonemus lineatus*)	x	x		
Diamond Turbot (*Hypsopsetta guttulata*)	x	x		
Shiner Surfperch (*Cymatogaster aggregata*)	x	x	x	x
California Halibut (*Paralichthys californicus*)	x	x		
Pacific Staghorn Sculpin (*Leptocottus armatus*)	x	x	x	x
Barred Sand Bass (*Paralabrax nebulifer*)	x	x		
Kelp Bass (*Paralabrax clathratus*)	x	x		
Pacific Tomcod (*Microgadus proximus*)		x	x	x
American Shad (*Alosa sapidissima*)		x	x	
3-Spine Stickleback (*Gasterosteus aculeatus*)		x	x	x
Green Sturgeon (*Acipenser medirostris*)		x		
Delta Smelt (*Hypomesus transpacificus*)		x		
English Sole (*Parophrys vetulus*)		x	x	x
Striped Bass (*Morone saxatilis*)		x	x	
Rainbow Trout (*Salmo gairdneri*)		x	x	x
Coho Salmon (*Oncorhynchus kisutch*)		x	x	x
Sockeye Salmon (*Oncorhynchus nerka*)			x	x
Pink Salmon (*Oncorhynchus gorbuscha*)				x
Chinook Salmon (*Oncorhynchus tshawytscha*)		x	x	x
Chum Salmon (*Oncorhynchus keta*)			x	x
Cutthroat Trout (*Salmo clarki*)			x	x
Starry Flounder (*Platichthys stellatus*)		x	x	x
Eulachon (*Thaleichthys pacificus*)			x	x
Pacific Herring (*Clupea harengus pallasi*)		x	x	x
Lingcod (*Ophiodon elongatus*)		x	x	x
California Jacknife Clam (*Tagelus californianus*)	x	x		
Pismo Clam (*Tivela stultorum*)	x	x		
Pacific Littleneck Clam (*Protothaca staminea*)	x	x	x	x
Washington Clam (*Saxidomus nuttalli*)		x	x	x
Pacific Gaper (*Tresus nuttallii*)		x	x	x
Pacific Oyster (*Crassostrea gigas*)		x	x	x
Bay Shrimp (*Cragon franciscorum*)		x		
Dungeness Crab (*Cancer magister*)		x	x	x
Manila Clam (*Tapes philippinarum*)		x	x	x
Pacific Geoduck Clam (*Panope abrupta*)				x
Fat Gaper Clam (*Tresus capax*)				x

Appendix II. Individuals and institutions consulted

Individuals Consulted	Agencies/Institutions
James Allen	NMFS, Seattle, WA
Allen Mearns	OAD, Seattle, WA
Charles Simenstad	University of Washington, Seattle, WA
Bruce Miller	University of Washington, Seattle, WA
David Armstrong	University of Washington, Seattle, WA
Daniel Bottom	Oregon Dept Fish & Wildlife, Corvallis, OR
Ronald Fritzsche	Humboldt State University, Arcata, CA
George Allen	Humboldt State University, Arcata, CA
Roger Barnhart	Coop. Fishery Res. Unit, USFWS, Arcata, CA
Frederick Nichols	U.S. Geological Service, Menlo Park, CA
Robert Tasto	Cal. Fish & Game, Menlo Park, CA
Peter Moyle	University of California - Davis, Davis, CA
Perry Herrgesell	Cal. Fish & Game, Stockton, CA
Charles Armor	Cal. Fish & Game, Stockton, CA
Jeffery Cross	S. Cal. Coastal Water Res. Project, Long Beach, CA
Herbert Frey	Cal. Fish & Game, Long Beach, CA
Larry Allen	Cal. St. Univ - Northridge, Northridge, CA
Robert Hoffman	NMFS, Terminal Island, CA
Richard Ford	San Diego State Univ., San Diego, CA
Christopher Nordby	San Diego State Univ., San Diego, CA

Appendix III. Primary references and personal communications (PC)★

Species	Hood Canal	Grays Harbor	Columbia River	Coos Bay	Humboldt Bay
Chinook Salmon Oncorhynchus tshawytscha	Simenstad, 1983 Simenstad, et al., 1982 Beauchamp, et al., 1983 Simenstad, 1986 PC	Grays Harbor Management Plan, 1983 Simenstad, 1983 Squire & Smith, 1977	Columbia River Atlas, 1984 Simenstad, 1983 Bottom, 1986 PC Squire & Smith, 1977	Thompson et al, 1972 Roye, 1979 Bottom, 1986 PC Squire & Smith, 1977 Cummings & Schwartz, 1971	Gotshall,et al., 1980 Barnhart, 1986 PC Allen G., 1986 PC Fritzsche, 1986 PC
Coho Salmon Oncorhynchus kisutch	Simenstad, 1983 Simenstad, 1986 PC Miller & Borton, 1980	Grays Harbor Management Plan, 1983 Simenstad, 1983	Columbia River Atlas, 1984 Simenstad, 1983 Bottom, 1986 PC	Thompson, et al., 1972 Roye, 1979 Bottom, 1986 PC Squire & Smith, 1977 Cummings & Schwartz, 1971	Gotshall, et al., 1980 Squire & Smith, 1977 Jones & Stokes, 1981
Sockeye Salmon Oncorhynchus nerka	Simenstad, 1983 Miller & Borton, 1980 Simenstad, 1986 PC Miller, 1986 PC		Columbia River Atlas, 1984 Simenstad, 1983 Bottom, 1986 PC		
Starry Founder Platichthys stellatus	Miller & Borton, 1980 Miller, 1986 PC Squire & Smith, 1977 Garrison & Miller, 1972	Grays Harbor Management Plan, 1983 Squire & Smith, 1977	Columbia River Atlas, 1984 Bottom, 1986 PC	Roye, 1979 Squire & Smith, 1977 Bottom, 1986 PC Cummings & Schwartz, 1971	Eldridge & Bryan, 1972 Gotshall, et al., 1980 Fritzsche, 1986 PC
Pacific Herring Clupea harengus pallasii	Miller & Borton, 1980 Miller, 1986 PC Simenstad, 1983 Simenstad, 1986 PC	Grays Harbor Management Plan, 1983 Simenstad, 1983 Jones & Stokes, 1981 Miller, 1986 PC	Columbia River Atlas, 1984 Simenstad, 1983 Bottom, 1986 PC	Roye, 1979 Squire & Smith, 1977 Bottom, 1986 PC Cummings & Schwartz, 1971	Eldridge & Bryan, 1972 Jones & Stokes, 1981 Gotshall, et al., 1980 Fritzsche, 1986 PC Rabin & Barnhart, 1986
Shiner Surfperch Cymatogaster aggregata	Simenstad, 1983 Miller & Borton, 1980 Allen J., 1986 PC	Grays Harbor Management Plan, 1983 Allen J., 1986 PC	Columbia River Atlas, 1984 Odenweller, 1975	Roye, 1979 Simenstad, 1983 Odenweller, 1975 Cummings & Schwartz, 1971	Gotshall, et al., 1980 Odenweller, 1975
Striped Bass Morone saxatilis				Jones & Stokes, 1981 Roye, 1979 Bottom, 1986 PC Squire & Smith, 1977 Cummings & Schwartz, 1971	
California Halibut Paralichthys californicus					
White Croaker Genyonemus lineatus					Gotshall, et al., 1980 Eldrige & Bryan, 1972
Dungeness Crab Cancer magister	Simenstad, 1983 Armstrong, 1986 PC Jones & Stokes, 1981	Stevens & Armstrong, 1984 Simenstad, 1983 Armstrong, 1986 PC	Columbia River Atlas, 1984 Stevens & Armstrong, 1984 Simenstad, 1983 Armstrong, 1986 PC	Roye, 1979 Simenstad, 1983 Armstrong, 1986 PC	Jones & Stokes, 1981 Frey, 1971 Armstrong, 1986 PC Fritzsche, 1986
Pacific Littleneck Clam Protothaca staminea	Rodnick & Li, 1983 Allen, et al., in prep Schink, et al., in 1983 Allen J., 1986 PC	Simenstad, 1983 Allen, et al., in prep Grays Harbor Management Plan, 1983	Columbia River Atlas, 1984	Allen, et al., in prep Schink et al, 1983	Allen, et al., in prep Schink et al, 1983
Pismo Clam Tivela stultorum					

*Refer to literature cited for all references and complete citations.

Appendix III. Primary references and personal communications (PC)★

Species	Eel River	San Francisco Bay	Santa Monica Bay	San Pedro Bay	San Diego Bay
Chinook Salmon Oncorhynchus tshawytscha	Barnhart, 1986 PC Fritzsche, 1986 PC Allen G., 1986 PC Squire & Smith, 1977	Ganssle Kjelson, et al., 1981 Jones & Stokes, 1981 Ocean Salmon Review, 1985			
Coho Salmon Oncorhynchus kisutch	Jones & Stokes, 1981 Barnhart, 1986 PC Fritzsche, 1986 PC Allen G., 1986 PC				
Sockeye Salmon Oncorhynchus nerka					
Starry Flounder Platichthys stellatus	Squire & Smith, 1977 Fritzsche, 1986 PC Barnhart, 1986 PC Allen G., 1986 PC Allen J., 1986 PC	Moyle, 1986 PC Wong, 1986 Squire & Smith, 1977 Eldridge, 1977			
Pacific Herring Clupea harengus pallasii	Data Inferred From Humboldt Bay Allen J., 1986 PC	Ganssle, 1966 Wong, 1986 Spratt, 1981 Armor, 1986 PC Herrgesell, 1986 PC Moyle, 1986 PC Armor & Herrgesell, 1985 Moyle, et al., 1986			McGowen, 1977
Shiner Surfperch Cymatogaster aggregata	Jones & Stokes, 1981 Squire & Smith, 1977	Odenweller, 1975 Squire & Smith, 1977 Armor, 1986 PC Moyle, 1986 PC	Odenweller, 1975 Fay, et al., 1978 Squire & Smith, 1977 Cross, 1986 PC	Odenweller, 975 Fay, et al., 1978 Squire & Smith, 1977 Cross, 1986 PC Allen, 1985	Odenweller, 1975 Fay, et al., 1978 Squire & Smith, 1977 Ford, 1986 PC
Striped Bass Morone saxatilis		Turner, 1976 Wong, 1986 NMFS, 1980 Moyle, 1986 PC Armor, 1986 PC			
California Halibut Paralichthys californicus		Wong, 1986 Amor & Herrgesell, 1985 Haaker, 1975 Moyle, 1986 PC	Wong, 1986 Frey, 1971 Haaker, 1975 Allen L., 1986 PC Allen, 1985	Haaker, 1976 Allen L., 1986 PC Wong, 1986 Frey, 1971 Allen, 1985	Squire & Smith, 1977 Ford, 1986 PC Nordby, 1986 PC McGowen, 1977
White Croaker Genyonemus lineatus		Wong, 1986 Armor & Herrgesell, 1985 Armor, 1986 PC Herrgesell, 1986 PC	Love, et al., 1984 Watson, 1982 SCCWRP, 1983-84 Cross, 1986 PC	Klingbell, et al., 1975 Love, et al., 1984 Watson, 1982 Allen L., 1986 PC Cross, 1986 PC SCCWRP, 1983-84	McGowen, 1977 Squire & Smith, 1977 Ford, 1986 PC Nordby, 1986 PC Allen J., 1986 PC
Dungeness Crab Cancer magister	Armstrong, 1986 PC Fritzsche, 1986 PC Jones & Stokes, 1981	Wild & Tasto, 1983 Tasto, 1986 PC Jones & Stokes, 1981			
Pacific Littleneck Clam Protothaca staminea		Allen, et al., in prep Allen J., 1986 PC Schink, et al., 1983 Jones & Stokes, 1981	Allen, et al., in prep Schink,et al., 1983 Rodnick & Li, 1983 Jones & Stokes, 1981	Schink, et al., 1983 Allen, et al., in prep Jones & Stokes, 1981 Rodnick & Li, 1983	Distribution Inferred Allen, et al., in prep Schink, et al., 1983
Pismo Clam Tivela stultorum			Frey, 1971 Fitch, 1950 Morris, 1966 Jones & Stokes, 1981	Frey, 1971 Fitch, 1950 Morris, 1966 Jones & Stokes, 1981	

For additional information on this project or other OAD estuarine related activities, contact

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Major Estuarine-Related Projects

- National Estuarine Inventory: Physical & Hydrologic Characteristics
- National Estuarine Inventory: Land Use
- National Coastal Pollutant Discharge Inventory
- 1985 National Shellfish Register of Classified Estuarine Waters
- National Coastal Wetlands Data Base
- Water Quality Screening Model Framework, for Estuaries
- An Economic Survey of Outdoor Marine Recreation in the USA
- The National Status and Trends Program for Marine Environmental Quality