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NOAA Technical Memorandum NMFS F/NWC-156

National Benthic Surveillance Project: Pacific Coast

Part 1
Summary and Overview of the Results for Cycles I to III (1984-86)

by
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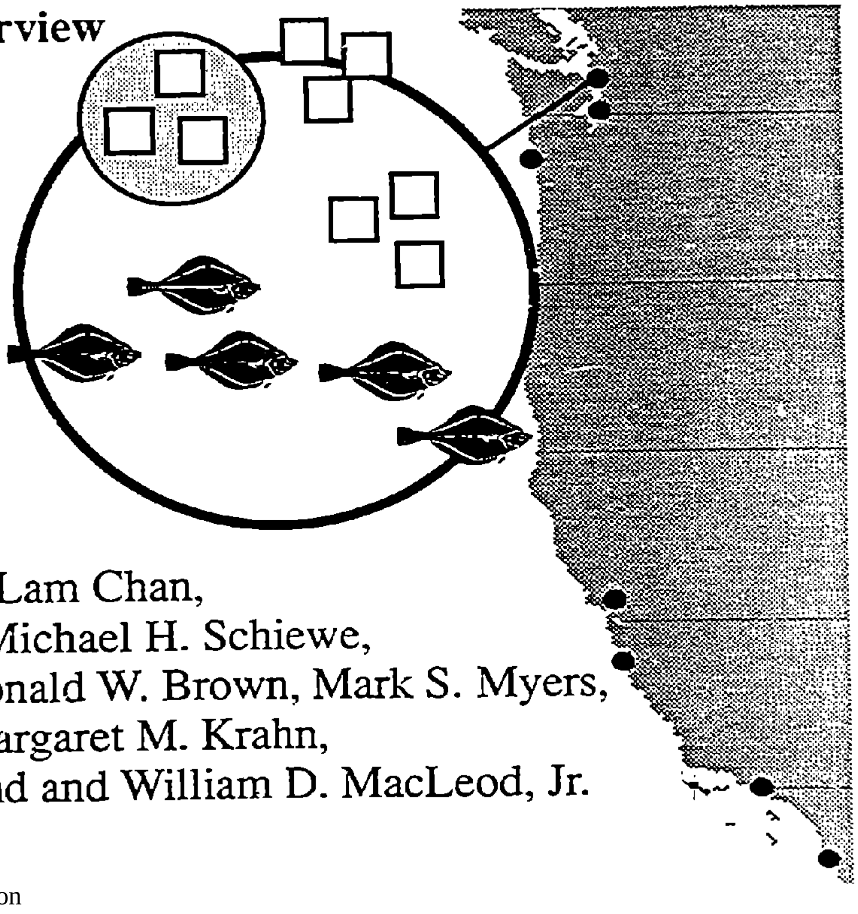

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EXECUTIVE SUMMARY

This report summarizes and interprets the results of the first 3 years of the Pacific Coast phase of the National Benthic Surveillance Project (NBSP). a component of NOAA's National Status and Trends Program- Employing highly uniform sampling protocols and state-of-the-art analytical methods, a comprehensive database has been developed. which includes detailed information on the distribution of a variety of chemical contaminants. These contaminants include selected aromatic hydrocarbons, PCBs, organochlorine insecticides and metals in surficial sediments and in liver tissue, bile, and stomach contents of selected bottom-feeding fish. Also documented were the prevalences of a variety of presumptive pollution-related liver and kidney lesions in the same target fish species. Of the 31 sites sampled in Alaska, Washington, Oregon, and California, 22 were located in or near urban centers. The results from individual sites should not be viewed as representative of entire embayments; however. the locations of the sites in urban embayments were selected to be as representative as possible of waste inputs from multiple sources.

The overall finding from the NBSP for the years 1984-86 indicated -hat the highest concentrations of most sediment-associated contaminants were present in the highly urbanized areas and that contaminants were bioavailable to indigenous marine species. We found, however, no correlation between concentrations of most of the measured metals in sediment and in liver tissue of the target fish species. Of all the sites sampled. the most contaminated sites were located in San Diego Bay, Commencement Bay (Tacoma), Elliott Bay (Seattle), and San Pedro Bay (Los Angeles/Long Beach). Intermediate levels of contaminants were detected at the sites in

Santa Monica and San Francisco Bays, whereas the sites in Alaska and Oregon were among the least contaminated of those sampled The prevalences of most of the detected liver and kidney lesions in bottom-dwelling fish also tended to vary with the degree of urbanization--highest prevalences occurred at the sites with the highest levels of chemical contamination. This finding is similar to that reported for liver lesions in fish from urban sires on the Atlantic Coast, sampled as part of the NBSP. In addition. levels of several chemical contaminants in sediments from many of The urban sires on the Atlantic Coast paralleled, with a few exceptions (e.g.. Boston Harbor), those found on the Pacific Coast. The issue levels of contaminants in fish from highly urbanized sites on both coasts. including fish from the Boston Harbor site. were also comparable.

Overall, the NBSP has been highly successful in generating a comprehensive overview of the present status of environmental quality in coastal waters: however, an evaluation of kg-term trends in coastal environmental quality. has not yet been possible. The relatively high variability of many of the measured parameters due to natural variation or patchiness of contaminant distributions in many urban areas dictates that additional data must be collected before attempting trend analyses. Therefore. in the future. the NBSP will generate not only an in-deprh assessment of environmental quality of coastal areas in the United States. but also an evaluation of temporal trends in that quality. Such knowledge is essential for effective management of the Nation's highly productive coastal habitats and the resources they support.

CONTENTS

PREFACE

The National Benthic Surveillance Project (NBSP) was initiated in 1984 by NOAA as a component of its National Status and Trends Program and was designed to assess and document the status of and long-term changes in the environmental quality of the Nation's coastal and estuarine waters. The NBSP is a cooperative effort between the the National Marine Fisheries Service and the Office of Oceanography and Marine Assessment of the National Ocean Service. The specific objectives of NBSP are to measure concentrations of chemical contaminants in sediment and in species of bottom-dwelling fish at selected sites in urban and nonurban embayments, to determine the prevalences of diseases in these same fish species. and to evaluate temporal trends in the above-mentioned parameters. The initial phase of the NBSP involved a cooperative effort between three NMFS Centers (the Northwest. Northeast and Southeast Centers) using similar protocols and analytical instrumentation. Sixty sires in embayments along the Atlantic, Gulf and Pacific coasts. including Alaska, have been sampled on an annual basis since 1984. with each annual sampling referred to as a “cycle” (e.g.. 1984 = Cycle I).

This technical memorandum is the first part of a two-part report which summarizes the results of the first 3 years of the West Coast portion of NBSP. We divided the report into two parts because of the voluminous amount of data generated by this multidisciplinary effort. Part I is an overview of findings and is not intended to be an in-depth treatment of these data: a more comprehensive presentation and detailed treatment of these data can be found in the Technical Part (Part II) of this report. Neither part is meant to comprehensively review the marine pollution literature: however, pertinent references are included in discussions of the most significant findings.

INTRODUCTION

The use and integration of chemical, physical and biological measures of environmental quality represent an important and unique aspect of the NBSP which sets it apart from previous monitoring pro-grams. By use of uniform sampling protocols and rigorous analytical techniques. a comprehensive database is being assembled which includes information on levels of chemical contaminants in sediments and selected marine organisms and on pollution-associated pathological conditions in selected bottom-feeding fish. The establishment of such a nation-wide database is a fundamental requirement not only for documenting present conditions. but also for establishing a scientifically meaningful baseline from which future changes in environmental quality can be measured

Over the first 3 years of the Pacific Coast phase of the NBSP, samples were collected at 31 sites: Alaska (10 sites), Washington (three sites). Oregon (two sites). and California (16 sites). Twenty-two of the sampling sites were located in or near urbanized embayments: the remaining nine sites were located in nonurban areas. four of which were used as comparison sires. The sampling sites in urban embayments were specifically located in areas that integrate waste inputs from multiple sources. and were not directly adjacent to any known point sources of contaminants or near established dredge disposal areas.

A general overview of the sampling strategy is shown in Fig. 1. Sediments were collected at three stations per site. and approximately 30 of one or more targeted bottom-feeding fish species were obtained by otter trawl- Sediment-sorbed chemical contaminants that were measured included aromatic hydrocarbons (AHs), polychlorinated biphenyls (PCBs).

organochlorine insecticides and selected trace metals. Liver tissue concentrations of PCBs, organochlorine insecticides. and selected metals. as well as fluorescent aromatic compounds (FACs) in bile (predominantly AH metabolites) were also measured in one or more species of target bottom-feeding fish from each site. The measured physical parameters of sediment included grain size distribution and total organic carbon content Biological parameters measured included prevalences of gross external lesions and microscopic lesions in the livers and kidneys of the target fish species. Stomach contents of these fish were also analyzed for AHs, PCBs, and insecticides. Also measured were sediment concentrations of spores of the sewage-associated bacterium *Clostridium perfringens*.

A unique aspect of the NBSP is the determination not only of levels of chemical contaminants in sediments, but also the levels of chemicals or their derivatives in fish tissue and determination of the prevalences of presumptive pollution-related diseases in bottomfish. The measurement of tissue concentrations of contaminants in marine organisms bridges the gap between which chemicals or classes of chemicals are associated with sediment particulates, and which ones are taken up and potentially bioaccumulated by a species. The tissue levels or a xenobiotic chemicaI are of critical importance if the biological impacts of chemically contaminated sediments are to be assessed. In the case of metals and of the metabolically refractory chlorinated hydrocarbons. such as PCBs and the organochlorine insecticides. direct analyses of liver tissue for the element or target compound provide a reliable and direct means of determining levels of exposure (MacLeod et al. 1985). In contrast. in the case of AHs that are rapidly metabolized and ultimately are excreted via bile in many marine species. direct tissue measurement is of limited usefulness (Varanasi and Gmur 1981). However.

the degree of uptake of AHs can be estimated using a method recently developed in our laboratory to quantify FACs in bile (Krahn et al. 1986); this technique uses high-performance liquid chromatography (HPLC) with fluorescence detection to measure levels of aromatic compounds with 4-6 rings and 2-3 rings, broadly defined as FACs-H and FACs-L, respectively.

An additional means of assessing contaminant exposure, used on a limited basis during the first 3 years of the NBSP, was chemical analysis of stomach contents from the target species of bottom-feeding fish. Although the manner and degree to which bottomfish are exposed to the various classes of sediment-sorbed contaminants are poorly understood, it is generally held that diet is a potentially important route. Another important benefit of measuring concentrations of chemical contaminants in both fish and the benthic organisms comprising their diet results from the tendency of mobile species to integrate contaminants from a relatively broad geographic area. Since the distribution of sediment-associated contaminants in a given waterway can be extremely uneven. the concentrations found in benthic species (fish or invertebrate) tend to be more representative of the overall degree of contamination in an area than the concentrations determined from a limited number of sediment samples.

With regard to lesion prevalences, the relationship between selected histopathological conditions in fish and sediment-sorbed chemicals has been the subject of intensive investigation in recent years. Numerous field surveys have documented high prevalences of liver lesions, and to a lesser degree kidney lesions, in a variety of bottom fish inhabiting chemically contaminated urban bays and estuaries (McCain et al. 1988). Particularly noteworthy have been our detailed investigations in Puget Sound, Washington. in which high prevalences of a spectrum of hepatic lesions.

including liver neoplasms, in English sole *(Parophrys vetulus) have* been associated with high concentrations of aromatic compounds in sediment (McCain et al. 1982, Malins et al. 1984a, Myers et al. 1987). The relationship between organic, sediment-sorbed contaminants and liver disease has been further clarified Our recent studies demonstrated that hepatic lesions identical to those observed in English sole from a contaminated area can be produced in the laboratory by exposure of healthy sole to chemicals extracted by organic solvents from the sediment from the same contaminated area (Varanasi et al. 1987). Hence, measurement of lesion prevalence affords an opportunity to monitor a biological change which can be related to the degree of chemical contamination.

The following presentation of findings is organized around the major classes of chemical contaminants and prevalences of liver and kidney lesions in selected bottom-feeding fish. Such an approach allows for preliminary observations on relationships between prevalences of lesions and the degree of urbanization/contamination. It is not intended to be an in-depth treatment of these data: a more comprehensive presentation and detailed treatment of these data can be found in the Technical Part (Part II) of this report These data form a base of information upon which to draw initial conclusions on the status of environmental quality--on a broad scale--on the Pacific Coast Nevertheless, the database will need to be expanded, incorporating results from more intensive sampling and additional years of collection, before trends in environmental quality can be addressed in a scientifically meaningful fashion.

RESULTS AND DISCUSSION

The following summary of findings is organized around the concentrations of chemical contaminants and prevalences of liver and kidney lesions that were found in selected bottom-feeding fish Such an approach allows integration of analytical results with particular emphasis on interrelationships among concentrations of chemicals (or their derivatives) in sediments, in fish stomach contents and in fish tissues. It also allows for preliminary observations on relationships between prevalences of lesions and the degree of contamination / urbanization.

Statements regarding “higher” or “lower” concentrations of chemicals are based on tie GT2 statistical method and those regarding prevalences of lesions on the Heterogeneity G-test (Sokal and Rohlf 1981). The p-values are understood to be < 0.05 unless stated otherwise. Other statistical methods used and p-values obtained are as stated in the text-

Aromatic Hydrocarbons

The AHs are ubiquitous and are commonly associated with sediments in urban coastal and estuarine areas. They are composed of substituted and unsubstituted fused benzene rings and can be generally divided. based on the number of rings. into two classes: the lower molecular weight compounds with 1-3 rings (LAHs), and the higher molecular weight compounds with 4-6 rings (HAHs). Relative to the HAHs. the LAHs tend to be more volatile and water-soluble, tend to be taken up and excreted readily, and are generally known for their acute toxicity. In contrast. the HAHs are less water soluble, tend to remain more tightly sorbed to sediment. are generally not bioaccumulated to any great extent due to more efficient metabolism of HAHs. and are known for their chronic toxicity. One of the more thoroughly studied HAHs, benzo[a]pyrene (BaP), has been shown to be carcinogenic in mammals and fish (Osborne and Crosby 1987, Hendricks et al. 1985).

The majority of AHs found associated with coastal sediments consist of petroleum compounds and combustion products (e.g., from fossil fuel combustion and forest fires). Surface water runoff from urban areas with concentrated automobile use is an important source of AHs. For example, in a recent study conducted in the northeast United States, it was estimated that urban runoff accounted for 71% of the total input of AHs into Narragansett Bay, Rhode Island (Hoffman et al. 1984). Although there is a large volume of data on toxicity of the “water-soluble fractions” of a variety of mixtures of AHs (e.g., crude oils) in several marine species (especially larval invertebrates), there is little information on sediment levels of either LAHs or HAHs that could be considered a threshold for adverse biological effects. Moreover, the prospects of defining such threshold concentrations in the near future are poor given the present limited understanding of how the toxicity of one class of xenobiotics can be modified by co-occurring chemicals of another class.

Despite these limitations, it is well known from laboratory studies that AHs are rapidly taken up from sediment by demersal fish species such as English sole (Stein et al. 1984, 1987). Moreover, the process of metabolism not only serves to detoxicate these compounds by making them more water soluble for easier excretion, but also tends to produce some highly reactive intermediates, some of which bind to DNA and proteins (Varanasi et al. 1986). The binding of xenobiotics to DNA (the process known as adduct formation) is known from studies in mammalian species (e.g. mice. rats) to be a necessary early step in chemical carcinogenesis (Grover 1979). Additionally, certain AHs are known to impair reproductive process in mammals (Stein and Hatch. 1987) and recent studies in Puget Sound indicate that flatfish residing in selected areas where sediments are contaminated with high concentrations of AHs exhibit inhibited ovarian maturation (Johnson et al. 1988). Hence, sediment-sorbed AHs are clearly a toxicologically important class of environmental contaminants

Concentrations of selected AHs (all results in this report are the averages of 1-3 years of data) in sediments along the West Coast ranged from a high of 3800 ng/g at certain urban sites to less than 20 ng/g at the nonurban sites (Fig. 2). High sediment concentrations of HAHs were detected in sediments from the sites in south San Diego Bay. Elliott Bay (Puget Sound). Hunters Point (San Francisco Bay), and north San Diego Bay (mean concentrations of 3800, 3800, 2800, 2800 ng/g,, respectively). These findings are consistent with the high degree of industrialization in these areas and the high potential for inputs of HAHs from a variety of sources including urban runoff.

We also found that the levels of FACs-H in fish bile reflected the sediment concentrations of HAHs in these areas and, more importantly, we documented the bioavailabiiity of the HAHs to indigenous bottom-feeding fish (Figs. 3 and 4). For example, the highest mean level of FACs-H in bile of English sole and flathead sole (Hippglossoides elassodon) were detected in fish from the Elliott Bay site. Similarly the highest mean concentration of FACs-H in white croaker (Genyonemus lineatus) was observed in specimens from the north San Diego Bay site and in barred sand bass (Paralabrux nehulifer) from the south San Diego Bay site. These locations were characterized by sediment concentrations of HAHs which were among the highest observed on the Pacific Coast and were the highest where these species were collected.

Moreover, although interspecies comparisons are complicated by potential species-specific differences, using the Spearman's rank correlation method, a statistically significant association was found between concentrations of FACs-H in bile and sediment concentrations of HAHs when all species were considered together (for details see Part II). Hence, these data emphasize the strong relationship between sediment concentrations of HAHs and bile concentrations of FACs-H in a variety of Pacific Coast bottom fishes.

Generally, there was also a significant ($p < 0.0001$) association between concentrations of HAHs in sediment and HAHs in stomach contents. and between HAHs in sediments and FACs-H in bile ($p <0.0001$). The highest concentrations of HAHs in stomach contents of flathead sole and English sole were detected in specimens from Elliott Bay. Likewise, the highest levels of HAHs in stomach contents of white croaker were in specimens collected at the north San Diego Bay site. In contrast. however. the *highest* concentrations of HAHs in stomach contents of hornyhead turbot *(Pleuronechrhys verricalis)* and starry flounder *(Plarichthys stellatus) were* observed in fish collected at the outer San Diego Bay and Coos Bay sites. respectively (Fig- 4): both locations had relatively low sediment concentrations of HAHs While the high levels of HAHs in stomach contents of the hornyhead turbot may be explained by the proximity to higher sediment concentrations of HAHs inside San Diego Bay, the results with starry flounder from Coos Bay are somewhat anomalous. Clearly. sampling a single location does not begin to characterize the entire Coos Bay area. but the data imply that there may be areas within the bay where starry flounder can feed on invertebrates containing relatively high concentrations of **HAHs.** Hence, these latter findings tend to emphasize the importance of measuring contaminants at different trophic levels of aquatic ecosystems, and also the need to intensify the sampling effort in selected areas. Nevertheless, when viewed in concert all of these data confirm the associations between levels of HAHs in sediments, stomach contents, and bile of bottom-feeding fish from diverse locations.

Concentrations of LAHs in sediments generally paralleled the spatial distribution of the HAHs and therefore tended to reflect the degree of urbanization. as did the concentrations of HAHs (Fig. 2). The Elliott Bay and south San Diego Bay sites had the highest mean sediment concentrations of LAHs (1200 and 1000 ng/g, respectively) on the West Coast

As found with HAHs. there was a statistically significant relationship between concentrations of LAHs in sediment and concentrations of LAHs in stomach contents ($p < 0.01$) and concentrations of FACs-L in bile, ($p < 0.0001$) when all the target species were considered together (Figs. 5 and 6). However, several exceptions are noteworthy. For example, the highest mean concentration of FACs-L observed in English sole occurred in fish from Elliott Bay; however. the highest mean concentration of FACs-L in flathead sole. a species also collected at the Elliott Bay site. was detected in fish from Dutch Harbor, Alaska. Dutch Harbor site had a mean sediment concentration of LAHs about an order of magnitude less than that in Elliott Bay. In addition, despite the high concentration of FACs-L in flathead sole from Dutch Harbor, LAHs were not detected in stomach contents of this species at this location; the highest mean concentration of LAHs in stomach contents of flathead sole was observed in fish from Elliott Bay.

Similar inconsistencies among sediment concentrations of LAHs and the chemical/biological measures of exposure were observed in several of the other bottom-feeding fish species examined over the entire Pacific Coast

Although a variety of chemical and biological factors may contribute to this situation, several are worthy of mention First, the LAHs tend to be rapidly taken up by fish but, in contrast to the HAHs, they also tend to be rapidly excreted via the gills or urine either in original form or after limited metabolism (Varanasi 1988). Hence, measurement of bile levels of FACs-L may not be as reliable a means of assessing exposure to and uptake of sediment-associated LAHs, as the measurement of FACs-H is for assessing exposure to and uptake of sediment-associated HAHs. In addition, since LAHs are among the more water-soluble AHs, uptake of LAHs from water may be as important as sediment and dietary sources. For example, in cases such as Dutch Harbor or Santa Monica Bay where high levels of FACs-L were detected in bile of the sampled fish but low concentrations of sediment LAHs were observed, the fish may have been taking up the LAHs directly from the water. Sources for the LAHs in these locations would logically be from spilled fuels or other petroleum products from the numerous vessels frequenting these waters, or from the natural oil seeps relatively common in some southern California coastal waters. Finally, since different invertebrates take up and metabolize AHs differently (and hence have different tissue levels) (Varanasi et al. 1985), the species composition of the diet will strongly influence concentrations of both LAHs and HAHs detectable in stomach contents. Even with data on taxonomic composition of diet, this factor greatly complicates interpretation of information on stomach content chemistry when dealing with compounds, such as the AHs, that can be metabolized. Nonetheless, the information developed on LAHs tends to indicate high levels of contamination in selected urban areas: however, additional research is needed to address the complexities surrounding the assessment measures used in this study. These data also support the importance of measurements of contaminants in sediment, fish diet, and fish tissue for comprehensive assessment of environmental quality.

Polychlorinated Biphenyls

Polychlorinated biphenyls (PCBs) are among the most widespread and persistent chemical contaminants of estuarine sediments and biota Commercial formulations of PCBs (i.e., Aroclors[1]) consist of mixtures of individual biphenyl congeners which differ both in the degree and ring positions of chlorination. Because of their chemical stability and excellent insulating properties, PCBs were originally used as coolants and dielectric fluids in transformers and capacitors, and as coatings to reduce the flammability of wood products. Prior to the 1975 congressional ban on PCB manufacture, PCBs were also used extensively in paints, waxes, inks, dust control agents, paper and pesticides. Such widespread use, coupled with their continued use in capacitors and transformers in service before 1975, makes the PCBs an environmental contaminant of considerable concern today, almost 15 years after they were last manufactured.

The toxicity of PCBs in terrestrial and aquatic organisms, including man. has been the object of a substantial body of research (e.g.. Safe 1984). A variety of adverse effects. ranging from reduced growth and diminished reproductive potential to immunosuppression and carcinogenicity, have been reported in a variety of species. Based on many of these studies, the U.S. Environmental Protection Agency has recommended a maximum 24-h exposure of 0.03 ug/L PCBs in seawater as the water quality standard. However. few studies with marine species have focused on effects in animals exposed to sediment-sorbed PCBs or to PCBs contaminating their diet. This

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[1] Mention of trade names is for information only and does not constitute endorsement by the U.S. Department of Commerce.

apparent lack of knowledge is surprising since it has been clearly established in laboratory studies that PCBs are indeed bioavailable to a variety of benthic marine species from both the sediments and via food chain transfer (Pizza and O'Conner 1983). In the absence of these critical data on effects of PCBs, the sediment concentrations above which environmental quality is compromised are not known.

It is worth noting, however, that laboratory studies have demonstrated that dietary exposure of selected flatfish species to PCBs will cause induction in liver of activation enzymes comprising the mixed function oxidase (MFO) system (Collier 1988). Although induction of an enzyme system per se cannot be considered an adverse effect of a contaminant it is known that certain other contaminants (e.g.. the HAHs and specifically benzo[a]pyrene) are transformed by MFO-mediated detoxication to highly reactive compounds that bind to DNA (Varanasi 1988). As mentioned earlier, the formation of DNA adducts is generally held to be an important first step in the development of selected pathological conditions. including neoplasms. Moreover, it is also known from laboratory studies that simultaneous exposure of English sole to PCBs and AHs alters the pattern of uptake and metabolism of AHs typically observed when this species is exposed to AHs alone (Stein et al. 1984, 1987). Hence. there exists at least some data suggesting sediment-sorbed PCBs entering the food chain could be a toxicological hazard in the marine environment.

Over the first 3 years of the NBSP the highest mean concentrations of PCBs in sediments on the West Coast were detected at the sites in south San Diego Bay, Elliott Bay. and the outer harbor of San Pedro Bay (520,430. and 320 ng/g, respectively) (Fig. 7). As found with the AHs, the distribution of PCBs in sediments tended to correlate with the degree of urbanization-

Unlike the readily metabolized AHs, the PCBs are relatively resistant to metabolism and tend to readily accumulate to high levels in the lipid-rich tissues of fish (Safe. 1984; Stein et al. 1984). Given this property, it is not surprising that concentrations of PCBs in liver tissue and stomach contents of urbanization, and generally reflected the spatial distribution and concentrations of PCBs measured in the sediment Indeed, when all the fish species were considered together, using Spearman's rank correlation method, statistically significant ($p < 0.0001$) associations were observed between concentrations of PCBs in (a) sediment and liver tissue, (b) sediment and stomach contents, and (c) stomach contents and liver tissue.

The high concordance among PCB levels in sediment, tissue, and diet was evident in most of the target bottom-feeding fish examined (for detailed statistical treatment see Part II). For example, the highest concentrations of PCBs in liver tissue and stomach contents of both English sole and flathead sole (Fig. 8) were detected in fish from the Elliott Bay site. The Elliott Bay site had the highest mean sediment concentration of PCBs of all the sites where these species were collected. Furthermore. barred sand bass from south San Diego Bay, the site with one of the highest mean sediment concentrations of PCBs on the West Coast, had the highest concentrations of PCBs in liver tissue and stomach contents where barred sand bass was collected.

Despite the generally straight forward relationship between concentrations of PCBs in sediment and in stomach contents and liver tissue. there were several notable exceptions. For example. in white croaker, the highest mean liver tissue concentrations of PCBs were detected in fish from the Long Beach, Seal Beach. and north San Diego Bay sites, whereas the highest mean concentration of PCBs in stomach contents of this species was detected in fish from the San Pedro Bay outer harbor site. In addition, although the highest mean concentrations of PCBs in liver tissue and stomach contents of hornyhead turbot were detected in fish from the west Santa Monica Bay site, much lower levels of PCBs were observed in liver tissue and stomach contents of white croaker from the San Pedro Canyon site. The San Pedro Canyon site is characterized by a mean sediment concentration of PCBs similar to that detected at the West Santa Monica Bay site. These latter findings serve to emphasize the complexity of relating contaminant levels in sediments to levels in the tissures of fish and their food organisms. while demonstrating the importance of such measurements in a broad-scale monitoring program. In this instance the poor concordance between sediment concentrations of PCBs and concentrations in liver tissue or stomach contents may be attributable, at least in part. to the patchy distribution of contaminants characteristic of most urban areas and to the natural movement of some bottom-feeding fish.

Organochlorine Insecticides

The organochlorine insecticides include the chlorinated ethane derivatives such as DDT (1.1.1-trichloro-2.2-bis[p-chlorophenyl]ethane): the chlorinated cyclodienes such as chlordane. aldrin. dieldrin. hepatochlor. endrin. and toxaphene: and the hexachlorocyclohexanes such as lindane. Although several of these compounds were detected in varying concentrations in sediment, fish liver tissue, and fish stomach contents sampled along the West Coast (e.g., DDT. chlordane. dieldrin), only DDT and its degradation products occurred at concentrations of potential toxicological concern (McEwen and Stephenson 1979) and hence will be discussed here. The Technical Part and the Appendix (Part II) contain additional data on the concentrations and distribution of some of these other pesticides that were detected

Although originally synthesized in the late 1800s, the effectiveness of DDT as an inexpensive, long-lasting insecticide was not recognized until about 1939. During World War II, DDT was widely used in mosquito control programs and was even applied directly to humans as a means of controlling lice. The agricultural applications of DDT grew rapidly during the ensuing years and so did the recognition that DDT and its metabolites (DDD and DDE) bioaccumulate in natural food chains. It was not. however. until 1972 that the manufacture and use of DDT in the United States was halted after a large body of evidence documented widespread contamination of diverse species, including man. with DDT or its degradation products (the DDEs). Some of the more significant observations in this regard were the association between high tissue concentrations of DDTs and reproductive failure in several species of birds. and the acutely toxic nature of waterborne DDT to a variety of aquatic organisms (Holden 1972).

A large volume of literature has been generated over the years on the toxicity of waterborne DDT to diverse aquatic species (Holden 1972); however. there is extremely limited information on the toxicity of sediment-sorbed DDTs or on toxic effects of dietary intake of DDTs. Moreover. the toxicological significance of the DDT degradation products. DDE and DDD. in sediments or tissues of aquatic or terrestrial organisms is virtually unknown. This void in knowledge is particularly noteworthy because the concentrations reported here as total DDTs consisted, in most instances. of a large proportion of DDE and DDD. with minimally detectable amounts of the parent DDT. However. it is known chat DDE is about eight times less acutely toxic than the parent DDT when administered orally to mice (Sittig

1980). Given these rather severe limitations in knowledge of toxic effects, it would be highly speculative to attempt to define a concentration of DDTs in sediment or biota which should trigger environmental alarm.

The concentrations of DDTs in West Coast sediments generally averaged below 50 ng/g at most sampling sites during the first 3 years of the NBSP (Fig. 7). The notable exceptions were at the sites in San Pedro Canyon (620 ng/g)) and San Pedro Bay outer harbor (590 ng/g). These elevated concentrations in the coastal waters adjacent to Los Angeles can no doubt be attributed to the large-scale dumping of DDT manufacturing wastes during the 1940s and 1950s. and later to discharges of similar manufacturing wastes via the municipal wastewater system up until 1970 (Bascorn 1982).

As found with virtually all xenobiotic chemicals, the potential for species-specific differences in bioaccumulation of DDTs greatly limits the ability to compare Liver tissue levels among the multiple target species of bottom-feeding fish sampled on the Pacific Coast Notwithstanding this caveat there was generally a highly significant. positive association. determined by the Spearman's rank correlation method among concentrations of DDTs in sediments with those in fish stomach contents ($p < 0.0001$) and also with those in fish Liver tissue ($p < 0.0001$). For example, concentrations of DDTs in stomach contents and liver tissue of white croaker from the San Pedro Bay outer harbor and Long Beach sites were among the highest recorded in this species (Fig. 10). Likewise. hornyhead turbot from the sites with the highest sediment DDT concentrations (e.g.. west Santa Monica Bay. San Pedro Canyon. and east Santa Monica Bay) had some of the highest concentrations of DDTs in liver tissue and stomach contents (Fig. 11) Interestingly, starry flounder from several sites in San Francisco Bay (e.g.. Hunters Point. Southampton Shoals.

San Pablo Bay) (Fig. 11) and barred sand bass from the Dana Point and south San Diego Bay sites (Fig. 10) all had moderately elevated concentrations of DDTs in liver tissue and stomach contents despite relatively low mean sediment concentrations. The remaining species examined on the West Coast exhibited relatively low liver and stomach contents concentrations of DDTs.

Overall, these tidings highlight the limited distribution of DDTs on the Pacific Coast, with the major focus of contamination in the waters adjacent to Los Angeles. Since the majority of the detectable DDTs are the metabolites and degradation products. DDE and DDD. rather than the parent DDT. and given the poor understanding of the toxicological properties of these compounds, it is not possible to generalize regarding potential impacts on the marine ecosystem. Clearly, additional research will be needed to resolve these difficulties and allow a more detailed interpretation of these data.

Trace Metals

The metals. unlike the PCBs or AHs. cannot be logically dealt with as a class. but rather must be neared as individual contaminants with unique and varying properties: some are essential for life: others have no known biological function but are not serious toxic hazards: still others have the potential to produce disease (Waldichuk 1974). Perhaps the only generalization that can be made about the metals as a class is the importance of chemical speciation. Indeed. it is the form in which a metal occurs (e.g., valence state, degree of alkylation. etc.) that determines bioavailability and, ultimately, toxicity (Sunda et al. 1978).

Although the Technical Part and Appendix I of this report (Part II) present data on all 16 of the metals and metalloids measured during the first 3 years of the NBSP, only the data for the trace metals chromic copper, lead, silver, cadmium, and mercury are summarized here. These six metals tended to occur at elevated concentrations in many of the urban areas sampled and, depending on speciation, most are presumed to be a significant toxicological hazard to marine life. As found with the other contaminants monitored in the NBSP, the concentrations of metals were determined in sediment (Figs. 12 and 1.5) and in liver tissue of the target fish species (Figs. 13, 14, 16 and 17). However, because of sample size limitations, only a small number of analyses of fish stomach contents were conducted and these data will not be presented here (see the technical details in Part II).

Copper has a variety of industrial applications, with most taking advantage of this metal's conductivity, malleability, and durability. In addition to widespread use in electrical wire and as a component of brass, copper compounds are excellent fungicides and are the active ingredients in many antifouling bottom paints. In mammals, including man, excess copper is deposited in bone and also tends to bioaccumulate in liver tissue. Copper intoxication is often characterized by liver necrosis. Although much is known about the toxicity of copper in water (Mantoura et al. 1978), there is virtually nothing known concerning a threshold concentration of copper in sediment above which adverse biological effects are likely to occur.

The highest concentrations of copper in sediments on the West Coast were detected at sites in south San Diego Bay (190 ug/g), Elliott Bay (105 ug/g), north San Diego Bay (105 ug/g), and San Pedro Bay outer harbor (95 ug/g) (Fig. 12). The only fish species exhibiting an elevated level of copper in liver tissue (elevated when compared to the same species from other sites) was hornyhead turbot from the site at San Pedro Canyon (Fig. 14), a site which is characterized by a low mean concentration of copper in sediment of less than 50 ug/g, even though the site is near the Palos Verdes sewage outfall Moreover, the barred sand bass from the south San Diego Bay site had liver concentrations of copper which were no different from the level detected in liver of this same species from Dana Point (Fig. 13), a site with sediment concentrations about one order of magnitude less than those of south San Diego Bay.

The major sources of lead entering coastal waters are surface runoff and atmospheric fallout Although commonly used in batteries and paints, the use of lead as a gasoline additive is the origin of most of this trace element in urban areas. Sediment quality standards for marine or fresh waters have not been established for lead

Concentrations of lead on the West Coast were highest in sediments at the sites in Long Beach (115 ug/g), south San Diego Bay (82 ug/g), and north San Diego Bay (59 ug/g) (Fig. 12). Of particular note was the finding that there were no significant intraspecific differences in liver concentrations of lead in any of the target bottomfish species examined (Figs. 13 and 14).

Chromium is a widely used element in the metal-plating and leather-tanning industries. It is also a common component of paints and wood preservatives. Although chromium occurs in several valence states, only the trivalent and hexavalent forms are biologically significant. Additionally, hexavalent chromium is a suspected carcinogen (Sittig 1980). For all of the u-ace metals, there are few data on critical sediment concentrations above which biological damage may occur. and no regulatory standards for freshwater or marine sediments exist.

The highest mean concentrations of chromium on the West Coast were detected in San Francisco Bay at the San Pablo Bay (455 ug/g) and Hunters Point (265 ug/g) sites and at the Bodega Bay site (380 ug/g) (Fig. 12). Such a distribution, and particularly the elevated levels at the nonurban Bodega Bay site, suggests a geologic origin for this element in this rather restricted geographic area. Despite these elevated levels. liver tissue concentrations of chromium in the target bottom-feeding fish from these, as well as most other sites, were uniformly low (Figs. 13 and 14). The only instances in which concentrations of chromium were significantly higher in liver tissue of a target species were in flathead sole from Dutch Harbor and starry flounder from Coos Bay. Sediment concentrations were relatively low at both these sites and hence these findings suggest a dietary or water column source of chromium that was not detected.

Silver. like copper. is used extensively in electrical circuitry because of its high conductivity; however, a major source of input into the marine environment can be attributable to the use of silver halides in photographic emulsions and subsequent discharge via effluent wastewater. Mining operations can also be a significant source in selected coastal areas.

The highest levels of silver in West Coast sediments were found at the sites in west Santa Monica Bay (56 ug/g) and Nakhu Bay (44 ug/g) (Fig. 15). As found for the other trace metals. there was little indication of a relationship between sediment concentrations and liver tissue levels of silver (Figs. 16 and 17). Indeed, the only species and site where levels of silver in the liver appeared elevated was starry flounder from Bodega Bay, a site with sediment silver concentrations less than 1.0 ug/g.

Cadmium is perhaps one of the most notorious of the toxic heavy metals. Although vapor emissions of cadmium during the smelting process appear to be the most significant source of input into the environment. cadmium also enters from discharges from metallurgic plants, plating operations. and battery and plastics manufacturing. Dietary or waterborne exposure of fish to cadmium is characterized by the induction of lesions in the liver and small intestine (Waldichuk 1974).

The highest sediment concentrations of cadmium on the Pacific Coast were recorded in San Pedro Canyon and Nakhu Bay (1.2 ug/g each); elevated levels were also detected at the sites at Long Beach west Santa Monica Bay, and south San Diego Bay. As found for lead, there were no intraspecific differences in liver concentrations of cadmium, irrespective of site. in any of the bottom-feeding fish examined.

Mercury is another toxic metal which is also notorious for having caused a serious outbreak of disease in humans. So-called "Minimata disease" in Japan was caused by consumption of seafood contaminated with mercury discharged in industrial waste. In addition to widespread industrial applications (e.g., batteries, lights, thermometers), mercury-containing fungicides and herbicides were once commonly used Thus, most of the mercury in coastal waters comes from a combination of surface runoff and industrial discharge.

The highest levels of sediment-associated mercury on the West Coast were found in the waters off southern California (Fig. 15). Sediments from the sites in south San Diego Bay and Seal Beach bad concentrations of 0.86 and 0.60 ug/g, respectively. Of all the species of fish in which liver concentrations of mercury were measured, only flathead sole from Dutch Harbor had elevated tissue levels of mercury. Once again this represents a case where elevated tissue levels occurred even though sediment contamination was extremely low.

Overall, these data on metal levels in West Coast sediments generally indicate that concentrations tend to vary with the degree of urbanization, with the highest concentrations of several metals usually found in the industrial areas with high levels of vessel-related activity, and industrial and domestic sewage discharge. Although a significant ($p < .01$) positive corelation was found between concentrations of selected metals in sediments and in stomach contents when data for all target fish species were combined, no significant correlations were found between levels of metals in sediment and in fish livers or between levels in stomach contents and in liver. These tidings indicate that metals tend not to be bioavailable to bottom-feeding fish (as determined by levels in liver) in a sediment concentration-dependent fashion. This observation is supported by preliminary findings from our laboratory studies in which flatfish held for up to 4 months on metal-contaminated sediments show no indication of appreciable bioaccumulation of the metals in liver tissue (Malins et al. 1984b). Such a situation could clearly be a function of metal speciation; however, other factors may also be important Among these factors is the tendency of selected metals to bioaccurrulate in organs other than the liver (e.g., kidney, brain, bone). Such a circumstance suggests that further research is necessary before undertaking analyses of metals in future years of the NBSP.

Clostridium perfringens Spores in Sediments

Sediment samples from Pacific Coast sites were collected and analyzed for concentrations of *Clostridium perfringens* spores (Emerson and Cabelli 1982) only in 1984. Concentrations ranged from 28 to 7.000 spores/g (dry weight). Highest concentrations were found at the Elliott Bay (7,000 spores/g), San Pedro Canyon (6.400 spores/g). and Commencement Bay *(4,800* spores/g) sites. The sites in San Pedro Canyon (Bascom 1982) and Commencement Bay were located in the vicinity of municipal waste discharges from treatment facilities, whereas the site in Elliott Bay was near a combined-sewer-overflow (Malins et al 1984a). Nonurban sites generally had concentrations <100 spores/g.

Liver and Kidney Lesions

As alluded to previously, results from a growing number of studies suggest a causal link between a variety of liver lesions, including hepatic neoplasms, in several bottom-dwelling marine fish and elevated concentrations of sediment-associated chemical contaminants in coastal urban waters. In addition, based on a number of laboratory studies. the kidney is also known to be a critical target organ for many toxic chemicals. particularly the trace metals (Hook 1980). Indeed, the detailed studies of English sole in Puget Sound have revealed not only higher prevalences of hepatic lesions but also higher prevalences of degenerative disorders of the kidney in sole from the highly contaminated urban sites when compared to sole from nonurban sites (Malins et al. 1984a. Myers et al. 1987. Rhodes et al. 1987). Our studies on the prevalence of various types of liver lesions in English sole from urban areas have allowed us to propose a scheme of co-occurrence of pollution-associated lesions (e.g.. foci of cellular alteration. specific degeneration/necrosis, hepatocellular regeneration) involving a sequence of lesions that progresses over time toward neoplasms in a manner that parallels the same process in experimental mouse and rat liver carcinogenesis. Moreover. the relationship between organic. sediment-sorbed contaminants and liver lesions has been further clarified. For example. hepatic lesions (i.e.. foci of cellular alteration. specific degeneration/necrosis. hepatocellular regeneration) identical to those observed in English sole from a contaminated area were produced in the laboratory by exposure of healthy sole to chemicals extracted by organic solvents from the sediment from the same contaminated area (Varanasi et al 1987). Hence, the histological examination of the fish livers in the NBSP not only provides the opportunity to directly assess the prevalences of pollution-associated early lesions, but also allows for an assessment of the potential of these lesions to form neoplasms. Such information allows comparisons of data on lesion prevalence for a given species collected at an urban site to similar data on prevalences of lesions in that species from a nonurban site. Moreover, as the NBSP database expands. prevalences of selected lesions can be related to sediment and tissue levels of selected contaminants.

Since different species often respond to. or are affected by, contaminants in unique ways, it is not surprising that the different species of bottom-feeding fish examined in the West Coast phase of the NBSP tended to develop different types of presumptive pollution-related liver and kidney lesions- The pollution-related liver lesions that were observed in one or more species of fish were (a) neoplasms: (b) foci of cellular alteration. a category which included several putative preneoplastic lesions: (c) specific degeneration/necrosis, which includes megalocyric hepatosis and nuclear pleomorphism: (d) proliferative lesions. non-neoplastic lesions consisting of hepatocellular regeneration. bile duct hyperplasia. and cholangiofibrosis; (e) chromatin margination, a condition indicative of early stages of hepatocellular degeneration: and (f) vascular lesions, lesions indicative of hemodynamic imbalances. such as intrahepatic blood cysts and venular hemorrhagic congestion. In English sole. specific degeneration/necrosis. foci of cellular alteration, and the most common proliferative lesion. hepatocellular regeneration. are thought to be early pathological changes involved in the sequential process leading toward the formation of chemically induced liver neoplasms. These lesions in other bottomfish species may have a similar role. The types of pollution-associated kidney lesions included proliferative lesions, necrotic disorders, sclerotic lesions, cytologic alteration.

Prevalences of liver and kidney lesions are summarized in Figs. 18-21. Flathead sole generally exhibited low prevalences of liver lesions; however, prevalences of several types of kidney lesions were higher (compared to overall average) at selected locations. Elevated prevalences of proliferative kidney lesions and necrotic kidney lesions were detected in flathead sole from the Commencement Bay and Elliott Bay (Washington) sites. respectively. Moreover, prevalences of sclerotic renal lesions were significantly elevated in this species from the Elliott Bay and Boca de Quadra (Alaska) sites when compared to overall average.

In contrast English sole from urban sites exhibited relatively high prevalences of both liver and kidney lesions. In addition to the detection of 4.2 and 3.7% prevalences of hepatic neoplasms in sole from the Elliott Bay and Commencement Bay sites, respectively. significantly elevated prevalences of additional pollution-associated liver lesions (foci of cellular alteration, proliferative lesions, specific degeneration/necrosis) were detected in fish from the Elliott Bay site. Moreover. significantly elevated prevalences of proliferative renal lesions and of necrotic and sclerotic renal lesions were detected in Elliott Bay and Commencement Bay English sole, respectively, when compared to the overall average.

Pollution-associated liver lesions were generally found at low prevalences in starry flounder. These findings are in agreement with our earlier observations of starry flounder in Puget Sound (McCain et al. 1982). In contrast to the relatively low overall prevalence of hepatic lesions, renal lesions were detected at significantly elevated prevalences at several sites.

including the Youngs Bay site in the Columbia River and the Hunters Point and Southampton Shoal sites in San Francisco Bay.

Although four white croaker with hepatic neoplasms were found [two from San Pedro Bay sites (Long Beach and outer harbor) and two from the Bodega Bay sire], the overall prevalences of hepatic lesions were relatively low in this species. The significance of finding two croaker with liver neoplasms at the Bodega Bay site is not clear. Both affected fish were at least 12 years old (approximately 9 years older than the average age of the other fish from this site), suggesting that they may have had prior exposure to other. more-contaminated coastal environments. Although the croaker with liver neoplasms from the San Pedro Bay sites were both 9 years old, the average age of croaker from these sites was similar to the unaffected croaker from Bodega Bay. However, croaker from the San Pedro Bay outer harbor site had significantly elevated prevalences of a variety of pollution-associated liver lesions, including proliferative lesions, specific degeneration/necrosis, and necrosis. In addition, significantly elevated prevalences of proliferative kidney lesions were detected in croaker from the San Pedro Canyon and Seal Beach sites. Moreover, an elevated prevalence of necrotic kidney lesions was observed in fish from the Long Beach site.

Hepatic lesions were detected in hornyhead turbot from a variety of sites; however, few renal lesions were evident in this species. A significantly elevated prevalence of hepatic vascular lesions was detected in turbot from the east Santa Monica Bay site, and a unique degenerative condition, chromatin margination of hepatocytes, was found exclusively in hornyhead turbot from the west Santa Monica Bay.

In addition to liver and kidney lesions, several species of the target bottom-feeding fish exhibited another condition, fin erosion. Particularly noteworthy were flathead sole from the Commencement Bay site and barred sand bass from south San Diego Bay; both species had significantly elevated prevalences of fin erosion when compared to the same species from the other sites.

Although the physiological consequences of liver and kidney lesions, as well as fin erosion, and their ultimate effect on the health of these fish species are not known, the correlations between prevalences and degree of urbanization provide initial insight into their possible causes. Clearly, however. carefully controlled laboratory studies will be needed to establish the critical link between cause and effect- Nonetheless. the continued monitoring of liver and kidney lesions and fin erosion in bottom-feeding species provides valuable information on the potential long-term effects of chemical contaminants in coastal waters.

CONCLUSIONS

The results of the West Coast portion of the NBSP have so far demonstrated that concentrations of AHs and CHs in sediments were generally highly correlated with levels of these compounds or their derivatives in fish. However. although concentrations of a number of trace metals were highest in sediments from urban sites, no positive correlations were found between concentrations of metals in sediment and those in the livers of target fish species. Such findings emphasize the importance of measuring contaminant levels in both the physical (sediment) and biological compartments. In addition, the *highest* prevalences of pathological conditions were found in fish from sites with the highest levels of contaminants. These conditions included fin erosion and lesions of the liver and kidney. By subjecting the chemical data from the sediment and tissue (liver and bile) and the fish disease data to statistical analysis, the sampling sites can be ranked in order of chemical concentration or lesion prevalence. Based on these rankings, it is then possible to arrange the sites into the following categories according to severity of pollution: highly, moderately, and minimally polluted (see Part II for details).

The highest levels of pollution were found in sites in San Diego Bay, Commencement Bay (Tacoma), Elliott Bay (Seattle), and San Pedro Bay (Los Angeles/Long Beach). Both sampling sites in San Diego Bay had sediment concentrations of AHs and copper which were among the highest of all the sampling sites. in addition. the site in south San Diego Bay had some of the highest sediment concentrations of PCBs, chlordanes (summed concentrations of alpha-chlordane and trans-nonachlor), lead, and mercury found in any of the west coast sites. Accordingly, in barred sand bass from the south bay site and in white croaker from the north bay site concentrations of AH metabolites in bile and of PCBs in liver tissue were among the highest found so far in -the study.

The primary pathological condition found in barred sand bass was tin erosion. Although fin erosion has been reported in several bottomfish species at prevalences ranging from 3 to 35% in other studies (McCain et al. 1988) of urban sites on the West Coast, its relationship to pollution is not well understood. At the present time. there is no clear understanding of how. or if, this pathological condition in barred sand bass affects the viability of diseased individuals. A degenerative liver lesion was also found in white croaker from the north San Diego Bay site as well as from four other sites in southern California. including the nonurban site at Dana Point. However, the fact that the highest prevalences of this degenerative lesion and several other liver lesions, including neoplasms, were found in white croaker from the highly contaminated site in the Outer Harbor of San Pedro Bay near Los Angeles suggests that pollution-related factors may play a significant role in the induction of these lesions.

The San Pedro Bay Outer Harbor site and a nearby site just seaward of the western entrance to breakwater, the San Pedro Canyon site, had the highest sediment concentrations of DDTs found among the West Coast sites. Sediments from this latter site also had concentrations of cadmium which were among the highest found in this study. Also, at the San Pedro Bay Outer Harbor site and a site near Long Beach in San Pedro Bay, sediment concentrations of PCBs were high compared to the other sites along the West Coast. Concentrations of lead, copper, and selected pesticides were high in sediments from the Long Beach site. White croaker from the Long Beach site also had the highest levels of chlordanes in liver tissue of any of the target fish species.

The site in Seattle's Elliott Bay had concentrations of AHs, PCBs, and copper in sediments which were among the highest on the West Coast. The two target fish species from this site, English sole and flathead sole, had concentrations of AH metabolites in bile and PCBs in liver which were also among the highest found for any species from any other sampling sire. The prevalences of four liver lesions, including neoplasms, in English sole from this site were significantly higher than the prevalences from any of the other sites where this species was examined. Moreover, flathead sole from Elliott Bay exhibited the highest prevalences of kidney lesions detected in this species.

In terms of concentrations of chemical contaminants in sediment, the site in Commencement Bay could be considered moderately polluted. However. English sole from this site had liver levels of chlorinated hydrocarbons (i.e..

PCBs, chlordanes, HCB) which were as high or higher than those found in English sole from the Elliott Bay site. In addition, three types of pollution-related liver lesions were detected in English sole from the Commencement Bay site which were not detected in sole from the Nisqually Reach nonurban site, and fin erosion was found in 10% of the flathead sole from this site. Therefore, based on the levels of chlorinated hydrocarbons and the presence of lesions in fish, this site was placed in the “highly polluted” category.

More moderate levels of pollution were found at sites in Santa Monica Bay and San Francisco Bay. The site in West Santa Monica Bay, in the vicinity of the Hyperion sewer outfall, had sediment with silver concentrations which were highest among sites in California, Oregon, and Washington. Municipal wastes are known to he a major source of silver. Of the two sites in Santa Monica Bay, hornyhead turbot from the west Santa Monica Bay site had the highest liver concentrations of PCBs, DDTs, and chlordanes, and the highest prevalence of degenerative liver lesions characterized by chromatin margination. Turbot from the other Santa Monica Bay site. located in the southeast part of the bay. had the highest prevalence of a different type of liver lesion characterized by vascular changes. The significance of -these conditions to the health or viability of these fish is not known.

High levels of relatively few contaminants were found in sediment and fish tissues from sites in San Francisco Bay. Levels of AHs, nickel, and arsenic in sediments from the site near Hunters Point were among the highest of all the West Coast sites. Also. for starry flounder. the mean PCB concentrations in liver tissue were significantly higher in fish from the Hunters Point site and the Southampton shoal site than those in flounder from the other sites. Similar levels of PCBs were found in the livers of white croaker from the Hunters Point site; however, these levels were significantly lower (> 2 z) than those found in croaker from the Long Beach site in southern California. Levels of selected insecticides (e.g., dieldrin) in the livers of both species from the Hunters Point site were significantly higher than those in any other species from any of the other sites. Low prevalences (< 4%) of a variety of pollution-related liver lesions were found in starry flounder from sites in San Francisco Bay which were not detected in flounder from the Bodega Bay nonurban site or the site in Coos Bay, Oregon.

The sites in Alaska and Oregon were among the least polluted. Even though high levels of selected metals were found in sediments from some Alaskan sites, their primary sources are thought to be nonanthropogenic rather than urban or industrial. For example, the site in Nakhu Bay near Skagway had some of the highest sediment concentrations of cadmium and selenium found among the West Coast sites and the sites in Boca De Quadra and Dutch Harbor also had high sediment levels of selenium Highest liver concentrations of PCBs were found in flathead sole from Dutch Harbor. however. these levels were 7 to 15 times lower than those found in flathead sole from the Elliott Bay site. Very low prevalences of serious lesions were detected in flathead sole from Alaska.

Relatively low concentrations of chlorinated hydrocarbons and trace metals were found in sediment and fish (starry flounder) from the three sites in Oregon (Coos Bay and the two sites in the Columbia River estuary). At the Coos Bay site and the mid-Columbia River site, moderate concentrations of AHs were found in sediments, and the bile of starry flounder had AH metabolite levels which wore not significantly different from the levels found in flounder from sites in San Francisco Bay. Nevertheless, starry flounder and English sole from the Coos Bay site were free of detectable liver lesions.

Starry flounder from the two Columbia River sites had low prevalences of Liver lesions, and the prevalences were also not significantly different from those in starry flounder from the San Francisco Bay sites.

In summary, results of the first three years of the Pacific Coast portion of the NBSP have demonstrated that the highest levels of pollution were found in sites in San Diego Bay, Commencement Bay (Tacoma), Elliott Bay (Seattle), and San Pedro Bay (Los Angeles/Long Beach). Intermediate levels of pollution were found in San Francisco Bay and Santa Monica Bay, whereas sites in Oregon and Alaska were among the least polluted. In the context of -he data generated from the nation-wide NBSP. the concentrations of sediment-associated contaminants at the most-polluted sites on both the Pacific and Atlantic Coasts are comparable, with the exception of very high concentrations of organic contaminants in Boston Harbor; interestingly however, tissue levels of contaminants and prevalences of pollution-related liver lesions in fish from all polluted sites on both coasts appear to be similar.

RECOMMENDATIONS

A comprehensive database focusing on environmental quality is essential if -the Nation is to effectively manage its biologically productive estuarine and near-shore coastal habitats. The NBSP was conceived to satisfy this need. This pro-gram, set into motion in 1983, has generated significant new information on levels of chemical contaminant in surficial sediments, in stomach contents and tissues of selected bottom-feeding fish, and on prevalences of pollution-associated liver and kidney lesions in these same species. Although these data allow some conclusions about geographic distribution of contaminants and putative contaminant effects, the NBSP objective of evaluating environmental trends is not yet possible. Moreover, it is clear from these first data that programmatic changes are needed to accomplish this important objective. In addition, some changes--as listed below- should be considered to accommodate new knowledge gained and unforeseen complexities encountered during interpretation of these first 3 years of data.

The following list of recommendations was developed based on the above-cited needs. It should be noted that for virtually every recommendation, a certain amount of research and development would be required before full-scale implementation- Although such an effort would require either new funds or a redirection of existing funds, the long-term benefits would clearly justify the effort

- *Intensify sampling in selected urban areas:* Results from the first 3 years of the Pacific Coast portion of the NBSP suggest that in several areas there were much higher levels of contaminants available to the target bottom fish species (based on analyses of tissues or stomach contents, or both) than would be anticipated from the chemical analysis of sediments from. these areas. This finding is not surprising in light of the known patchy distribution of contaminants in many urban areas and the tendency of many of the target species to range over a broad area. Because knowledge of concentrations of contaminants in sediments will always be an important component of the NBSP, one means of assuring that the sediment samples are representative of an area would be to increase their number. On a limited basis this modification has already been instituted beginning in Cycles IV and V with the increased sampling in San Francisco and San Diego Bays. Additionally, based on the first 3 years of sampling, the San Pedro, Santa Monica, and Coos

Bays and Dutch Harbor areas should also be considered for more intensive sampling. In considering this recommendation it should be kept in mind that recent technical advances in our laboratories (Krahn et al. 1988) have significantly reduced the cost of chemical analyses and, as a result, additional samples could be analyzed without markedly increasing the cost. Analysis of additional samples would provide several scientific benefits. Fit, it would provide a more solid basis for definition of contaminant levels at a location- Second, with a better definition of concentrations of chemicals present at each site, the objective of temporal trends could be dealt with in a more meaningful way. Finally, additional sampling in an urban area would likely generate data on sediments that vary in nature and degree of chemical contamination- Rather than have data from a limited number of sites (1 or 2 sites are presently typical for most urban areas) to compare to a single nonurban site, there would be information from multiple sites. Therefore, correlations of prevalences of a specific kidney or liver lesion with concentrations of individual contaminants or classes of contaminants would be more meaningful.

- ***Increase the number of nonurban sites:*** The relatively small number of nonurban sites and minimally contaminated sites sampled in this study greatly limits the ways in which these data can be analyzed to examine relationships between levels of contaminants in sediments or tissue and presumptive pollution-related biological effects. Moreover, in several instances the dissimilar physical characteristics of sediments in nonurban sites (e.g., grain size distribution) limits the usefulness of comparisons with the contaminated urban sites Although the identification of additional nonurban sites would require some exploratory sampling, the ability to analyze and relate findings more rigorously would be greatly improved.

- ***Augment the biological measures of response to and effects of contaminants:*** The only measures of contaminant effects used during the first three cycles of the NBSP were prevalences of selected kidney and liver lesions. In subsequent cycles, the activity of the liver enzyme, aryl hydrocarbon hydroxylase, AHH (as a measure of contaminant exposure) was measured and the sample sizes of fish collected for histological analyses was increased to enhance the ability to detect pollution conditions which occur at low prevalences. Additional means of evaluating contaminant exposure and effects are clearly needed. One such means of assessing the acutely toxic effects is bacterial bioluminescence (Microtox) testing of organic extracts of sediments. This bioassay provides an extremely cost-effective means of comparing and ranking the toxicity of contaminated marine sediments. Moreover, although existing means of assessing sublethal effects of contaminants within the framework of such a large-scale environmental monitoring program are extremely limited, there are suitable techniques that might be brought on line with additional research and development Examples would include measures of genetic damage (e.g., DNA adducts), reproductive success, and immune dysfunction, all events or processes that are known to be influenced by chemical contaminants based on laboratory studies.

- *Improve the methods for assessing the bioaccumulation and biological effects of metals:* These initial data from the Pacific Coast portion of the NBSP did not show a consistent relationship between sediment metal concentrations and concentrations of metals in liver tissue. Because metal speciation may be a major factor determining bioavailability and toxicity, consideration should be given to altering the protocols for metal analyses to determine, where technically feasible, the proportion of each target metal in the toxicologically important forms. Such an approach would require additional research: however, the effort should result in producing a more meaningful database for the metals than is presently being produced. Moreover, the determination of metal concentrations in tissue (presently only in liver) could be expanded to include new tissues (e.g., kidney, neural tissue, bone) which may be the more important sites of bioaccumulation. In addition, it may prove useful, if supported by results of laboratory studies. to assess metal exposure of the target bottom-feeding fish based on serum concentrations of the inducible metal-binding proteins such as metallothionein.
- *Chemical analyses* ***of*** *selected invertebrates: The analyses* of selected invertebrates. particularly those comprising the diet of the target bottom-feeding species, would not only provide insight into routes of exposure and effective dose of chemical contaminants, but improve the ability to characterize the sampling locations as well. The patchiness of contaminant distribution and the inherent variability of analytical data for the sediment are always going to be a factor in trend analysis. However, the tendency of benthic fish

and mobile invertebrates to integrate biologically and hence reflect contaminant levels over a broader area could be used to great advantage. Indeed, results of analyses of fish and invertebrates for contaminants or their derivatives may provide the most meaningful basis from which to evaluate temporal trends.

A final issue that clearly needs to be addressed, either within the framework of the NBSP or under the auspices of a separate program, is that of relating specific sediment contaminant concentrations to specific effects. One of the major obstacles to agressive interpretation of these data generated in the NBSP is the inability to analyze the findings in the context of biological/toxicological impact. Although there is a wealth of published information on toxicity of many of the measured contaminants, virtually all of these data address critical freshwater or seawater levels. There is extremely limited knowledge of critical sediment or dietary concentrations of most contaminants above which biological damage is likely to occur. Moreover, the use of empirical techniques such as the “Apparent Effects Threshold” approach or tie partition coefficient-driven “Sediment Quality Criteria” method to address this need is severely limited because virtually no information exists on the toxicity of complex mixtures of contaminants. Clearly, a strong, parallel emphasis on developing information on cause-and-effect relationships in both rigorously controlled laboratory studies and intensive field studies is needed. It is through such concerted efforts that we will be able to interpret the findings of the annual field surveys conducted under the NBSP and protect our important coastal resources and their habitats.

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FIGURES

For the NBSP, the following figures show sampling strategy (Fig. 1). concentrations of organic compounds and trace metals in fish stomach contents, bile and livers (Figs. 2-17), and prevalences of fish liver and kidney lesions (Figs. 18-21). Nonstandard abbreviations in the figure captions are defined as follows: x + SD, grand mean of all years (1-3 years) sampled and standard deviation of the mean; AHs, aromatic hydrocarbons; HAHs. aromatic hydrocarbons with 3-6 rings: LAHs, aromatic hydrocarbons with 1-3 rings; FACs-H, fluorescent aromatic compounds With 4-6 rings and FACs-L, fluorescent aromatic compounds with 2-3 rings.

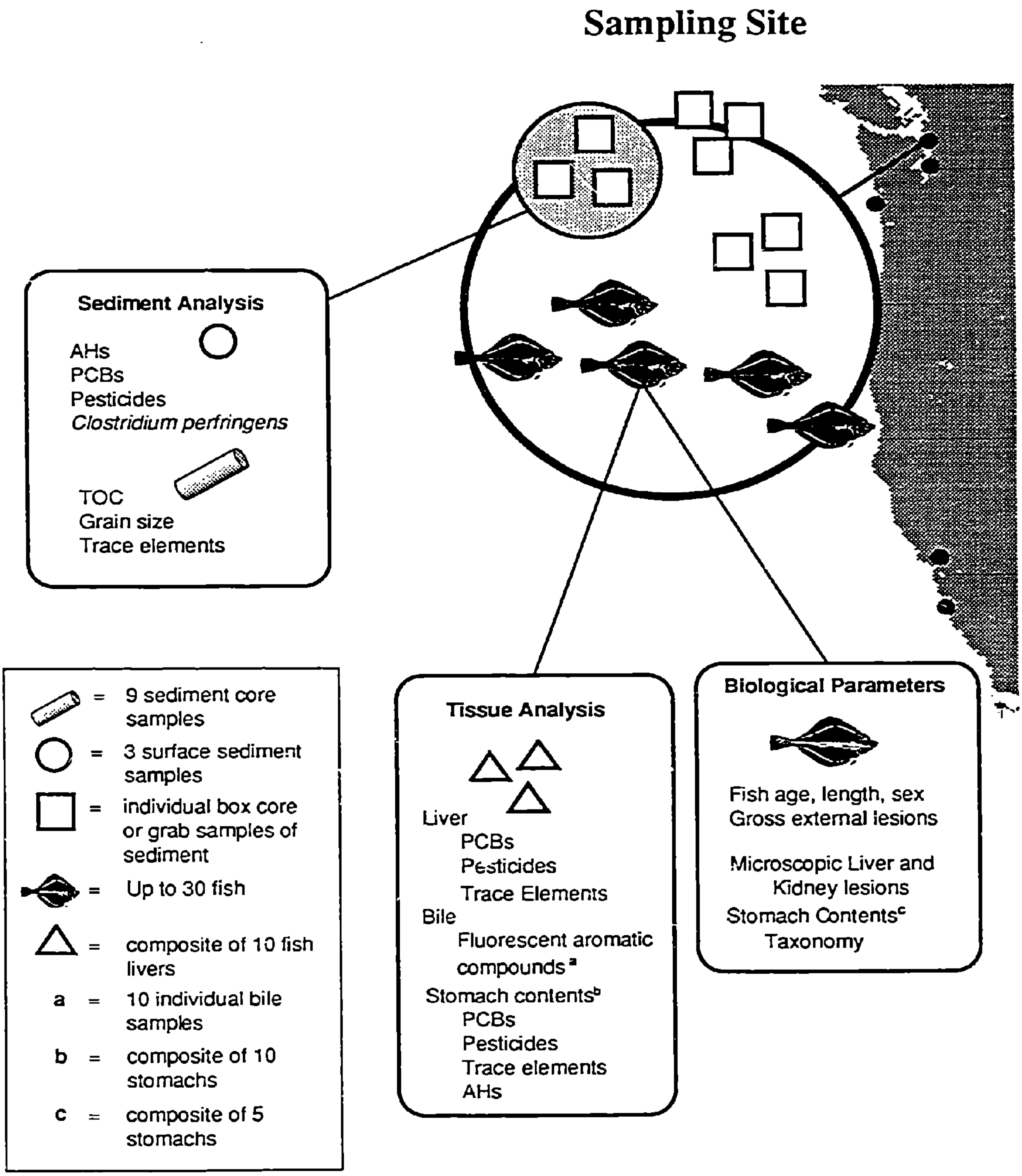

Figure 1. The sampling strategy of the National Benthic Surveillance Project. Each sampling site consisted of three stations at which grab samples of sediment were taken.

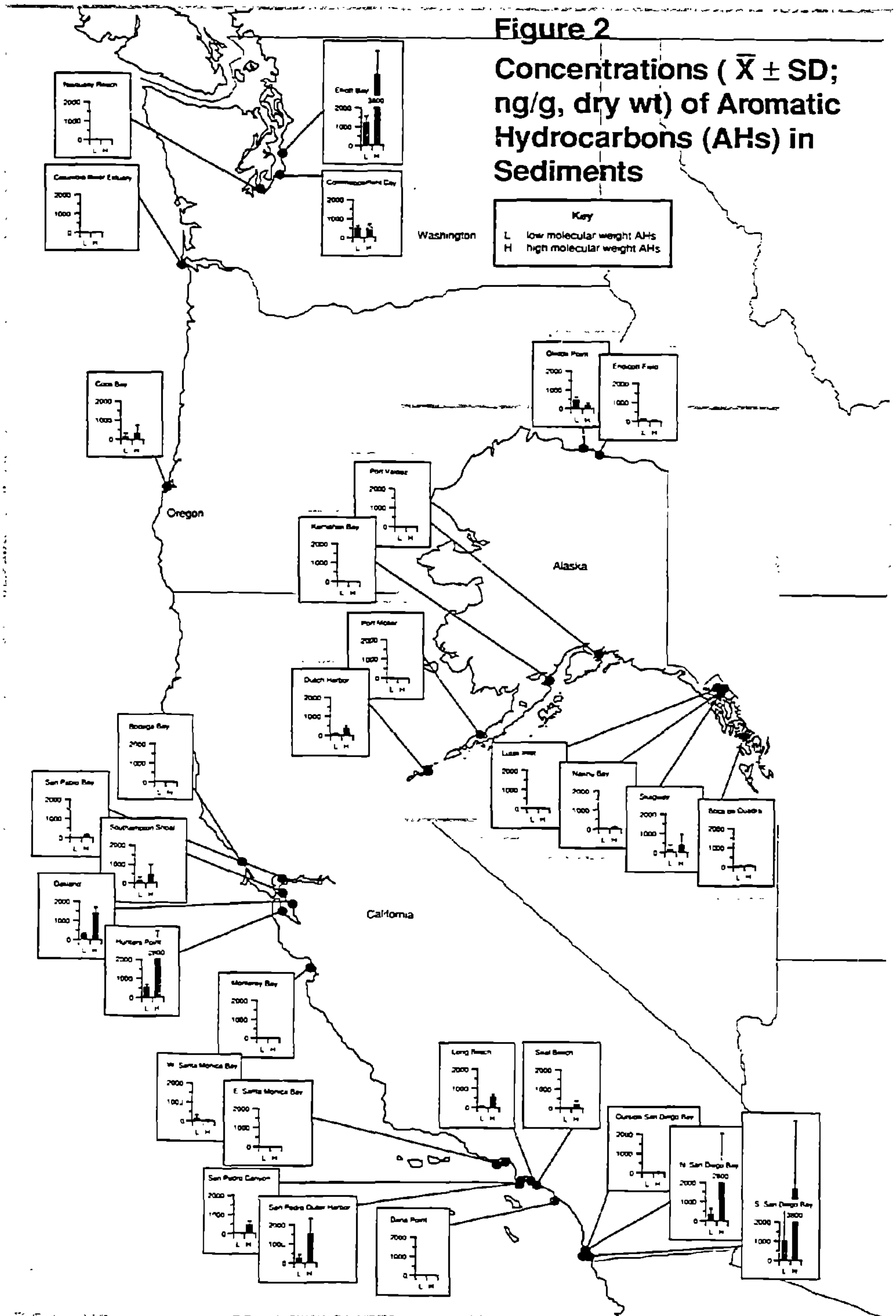

Figure 2. Concentrations (X̄ ± SD; ng/g, dry wt) of AHs in sediments.

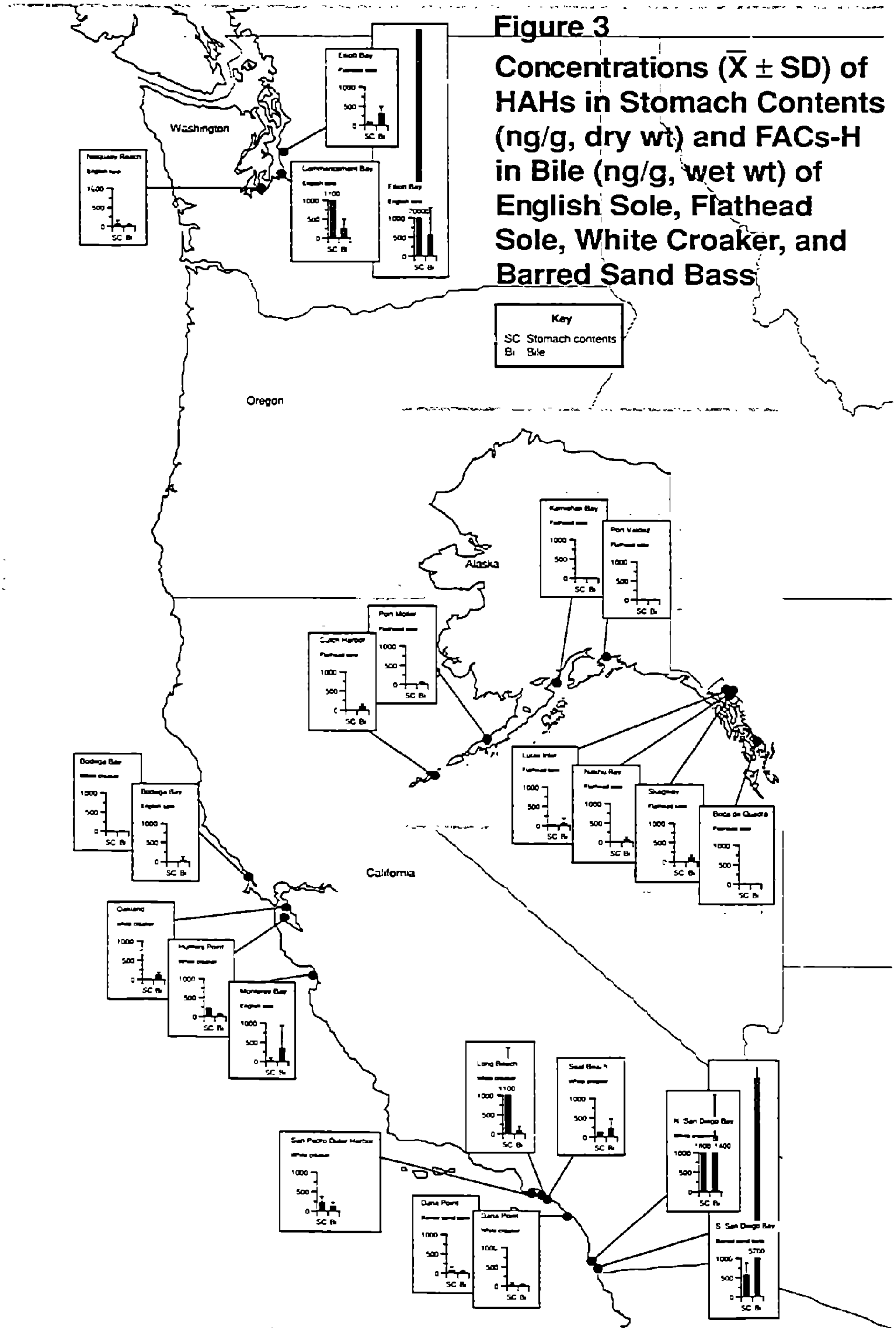

Figure 3. Concentrations (x + SD) of HAHs in stomach contents (ng/g. dry wt) and FACs-H in bile (ng/g. wet wt) of English sole. flathead sole, white croaker. and barred sand bass.

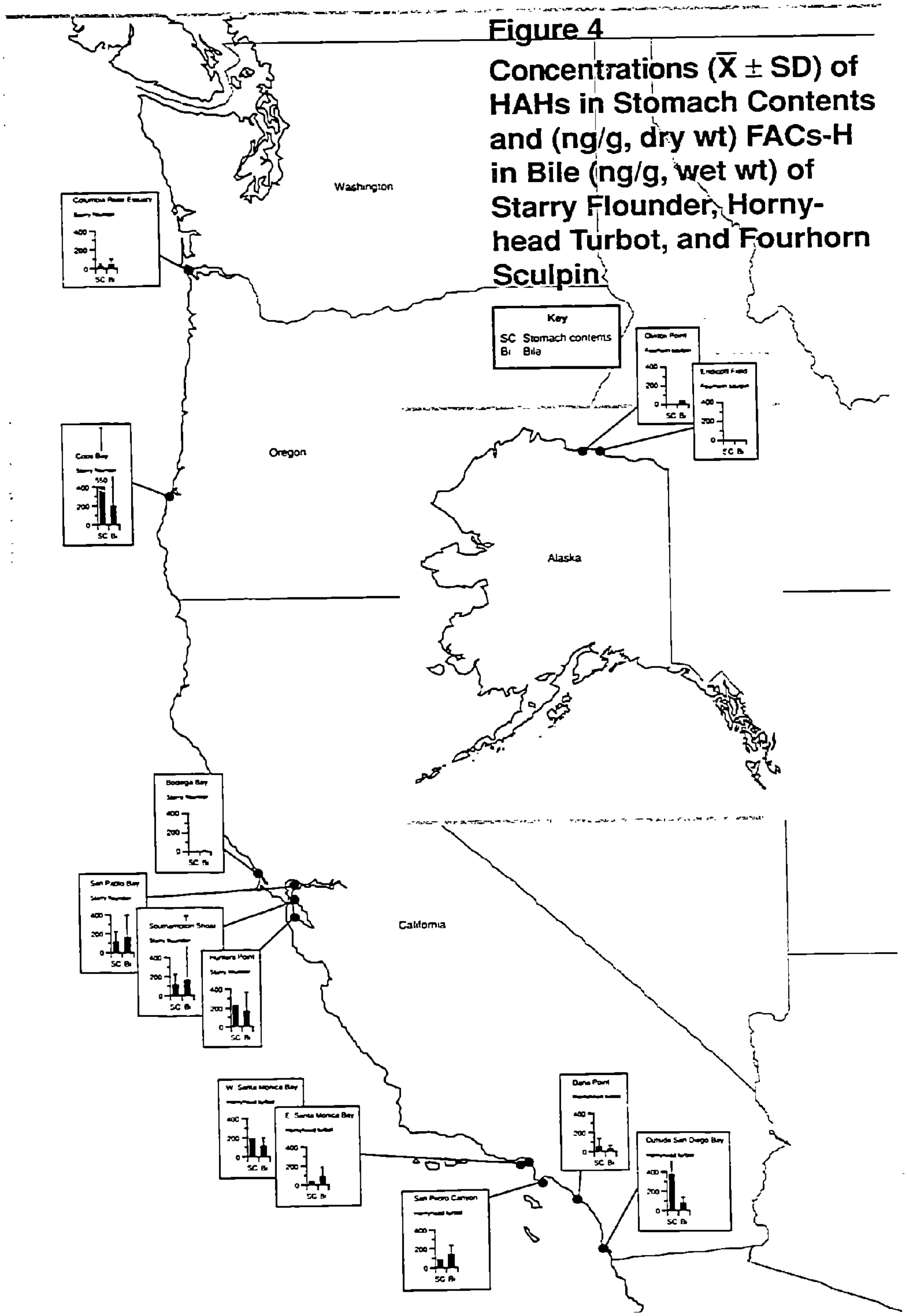

Figure 4

Concentrations ($\overline{X}$ ± SD) of HAHs in Stomach Contents and (ng/g, dry wt) FACs-H in Bile (ng/g, wet wt) of Starry Flounder, Hornyhead Turbot, and Fourhorn Sculpin

Figure 4. Concentrations (X + SD) of HAHs in stomach contents (ng/g. dry wt) and FACs-H in bile (ng/g, wet wt) of starry flounder, hornyhead turbot. and fourhorn sculpin.

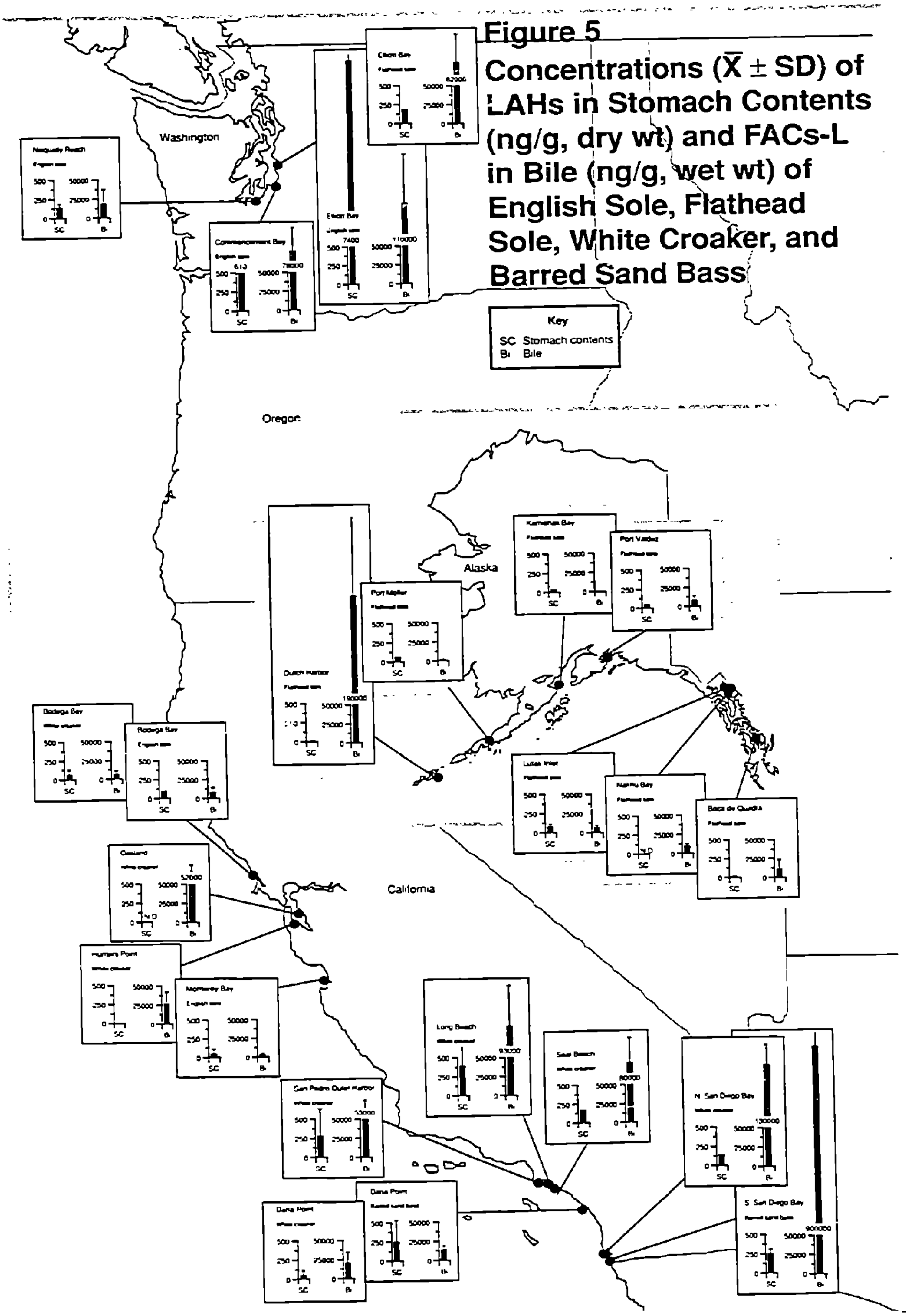

Figure 5. Concentrations (x + SD) of LAHs in stomach contents (ng/g. dry wt) and FACs-L in bile (ng/g. wet wt) of English sole, flathead sole. white croaker, and barred sand bass.

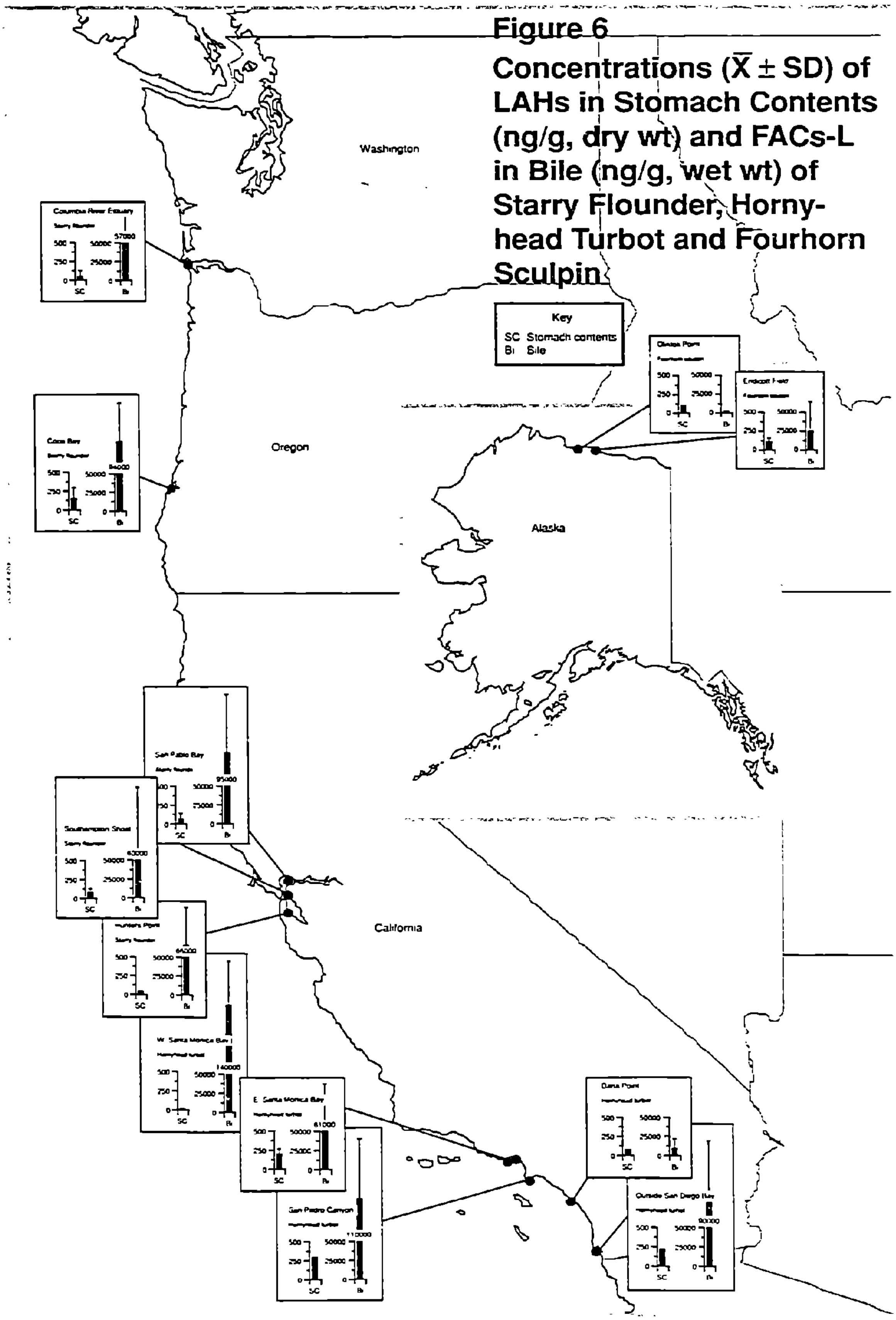

Figure 6. Concentrations (X + SD) of LAHs in stomach contents (ng/g. dry wt) and FACs-L in bile (ng/g. wet wt) of starry flounder, hornyhead turbot and fourhorn sculpin.

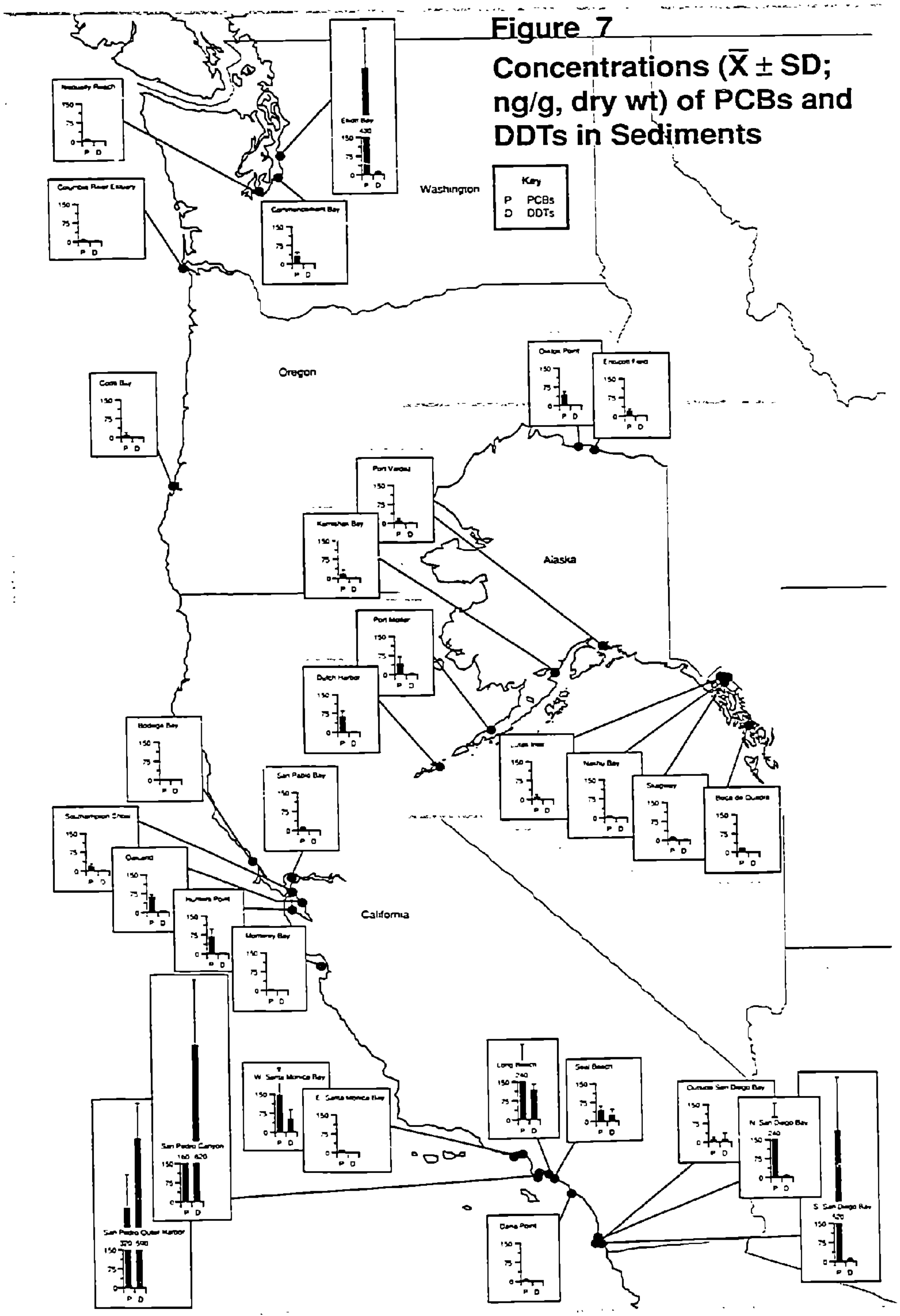

Figure 7. Concentrations (X + SD: ng/g. dry wt) of PCBs and DDTs in sediments.

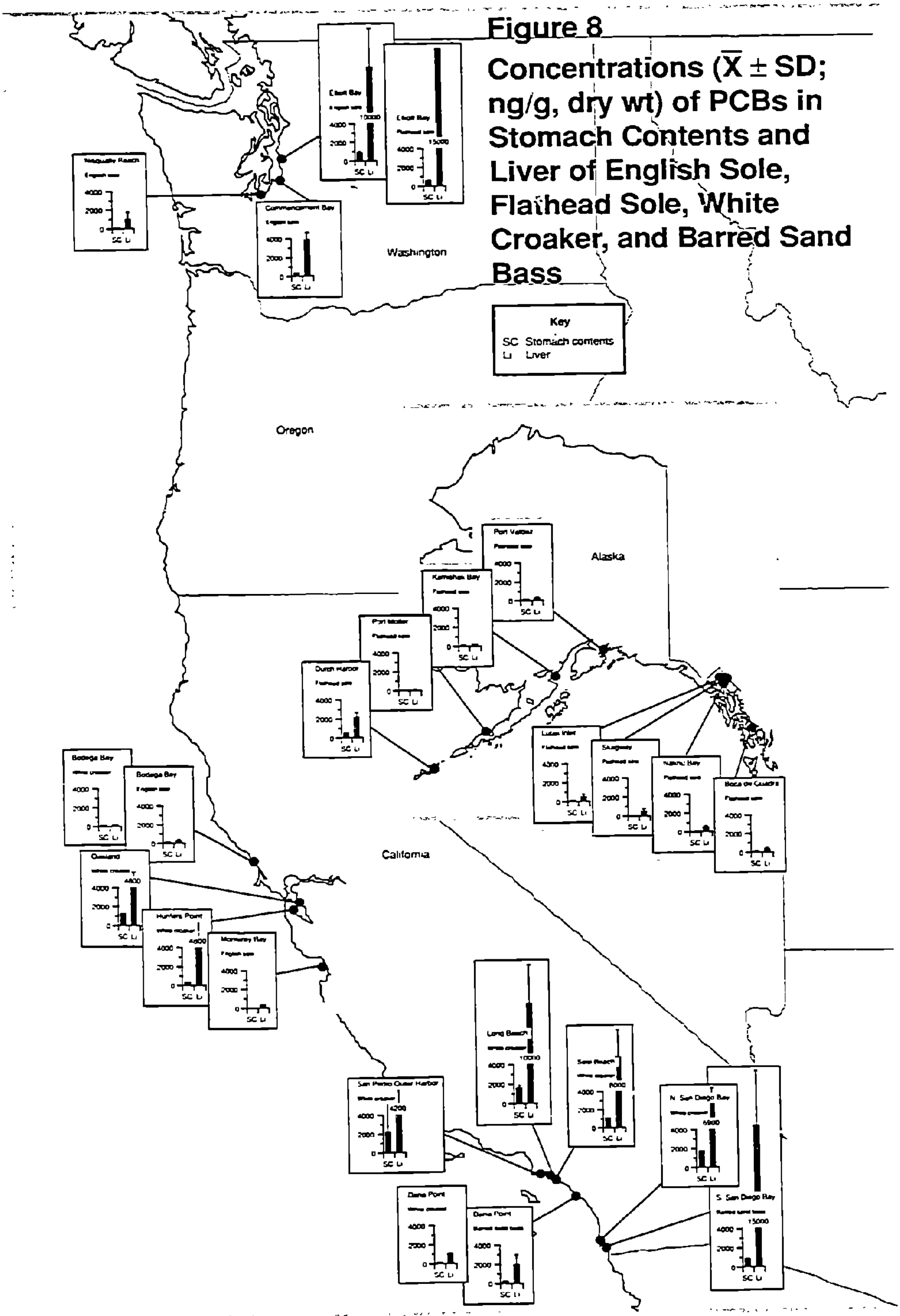

Figure 8. Concentrations (x + SD; ng/g. dry wt) of PCBs in stomach contents and liver of English Sole. flathead sole. white croaker, and barred sand bass.

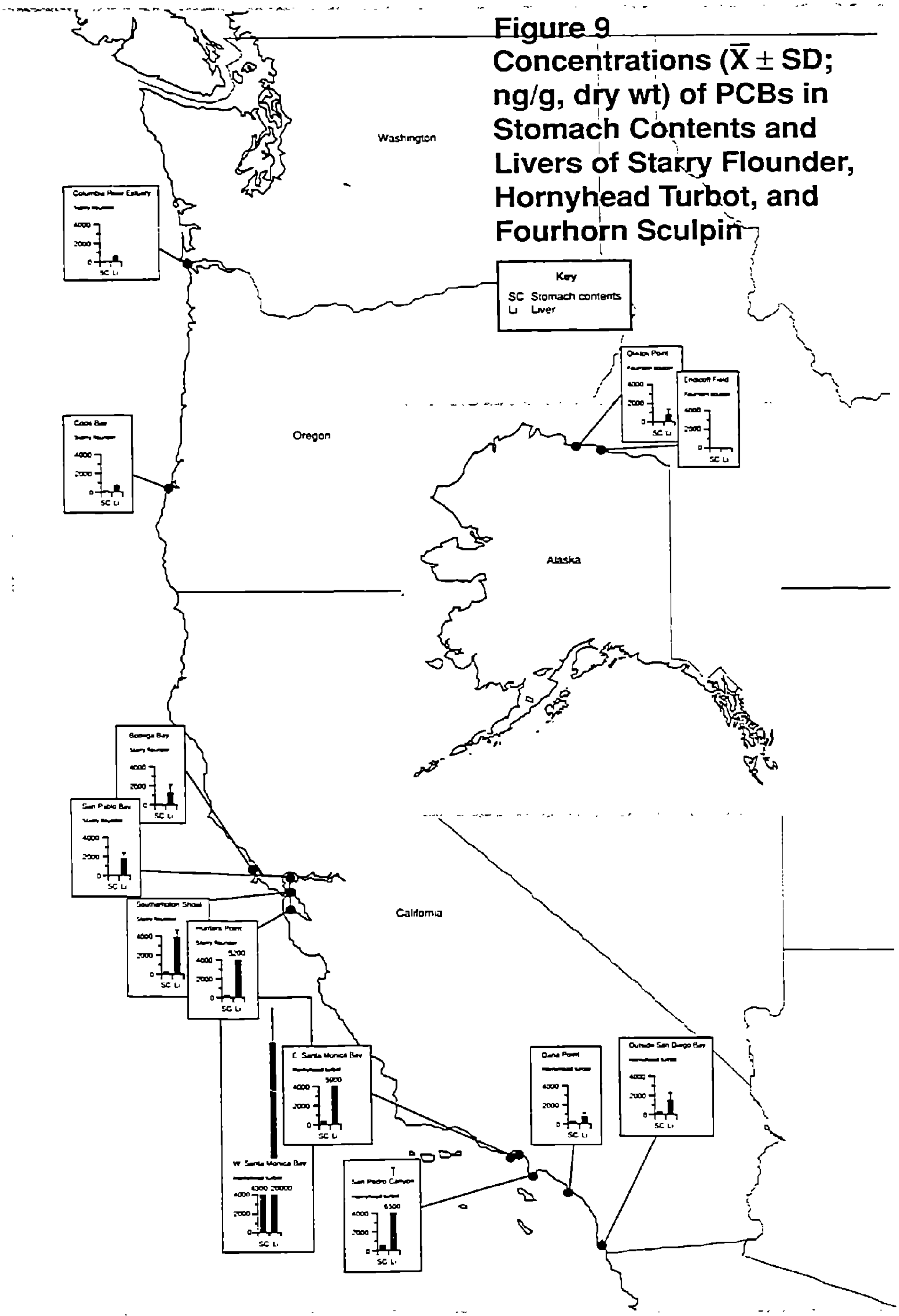

Figure 9. Concentrations (X+ SD: ng/g, dry wt) of PCBs in stomach contents and liver of starry flounder. hornyhead turbot, and fourhorn sculpin.

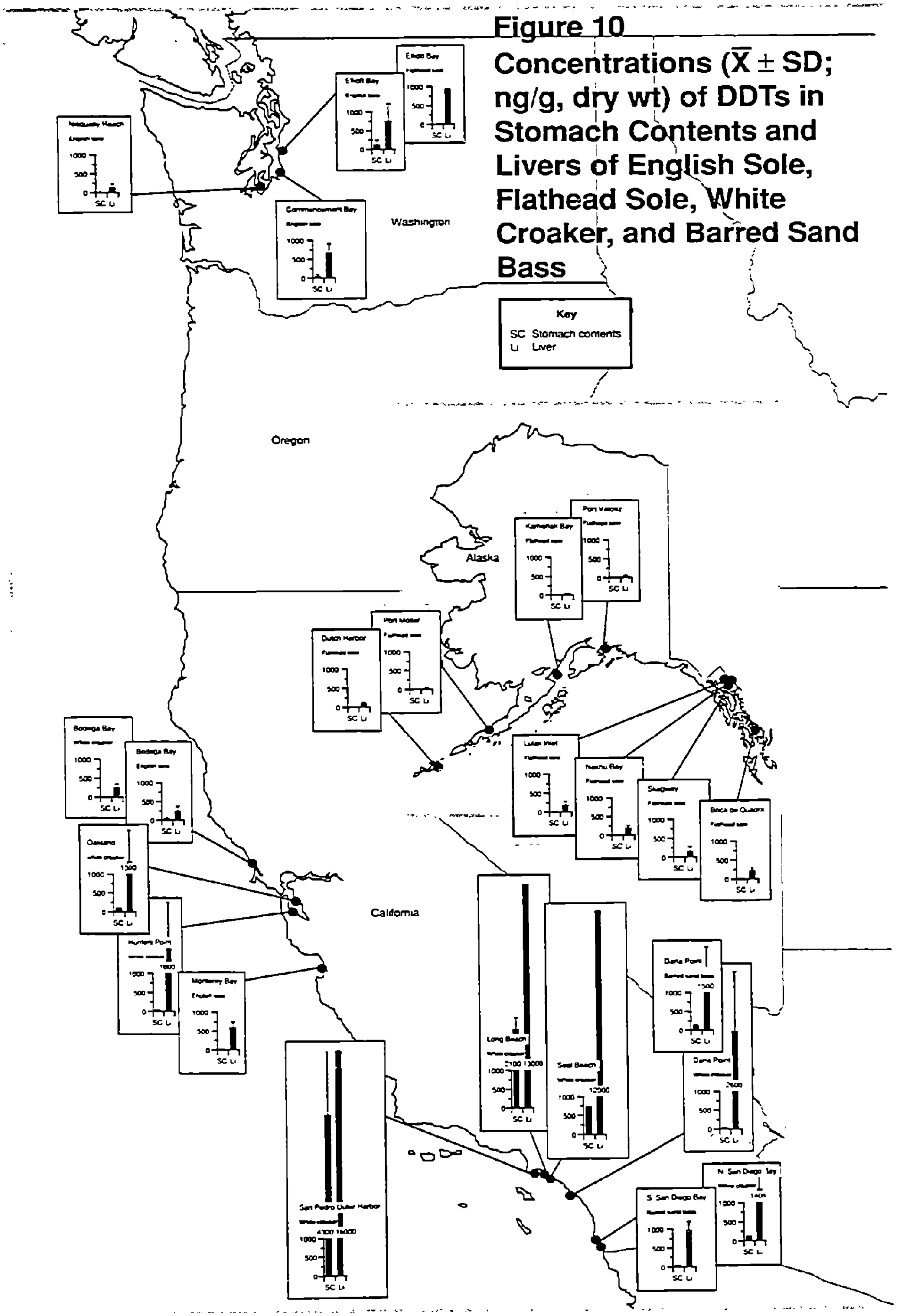

Figure 10. Concentrations (X + SO: ng/g, dry wt) of DDTS in stomach contents and livers of English sole. flathead sole, white croaker, and barred sand bass.

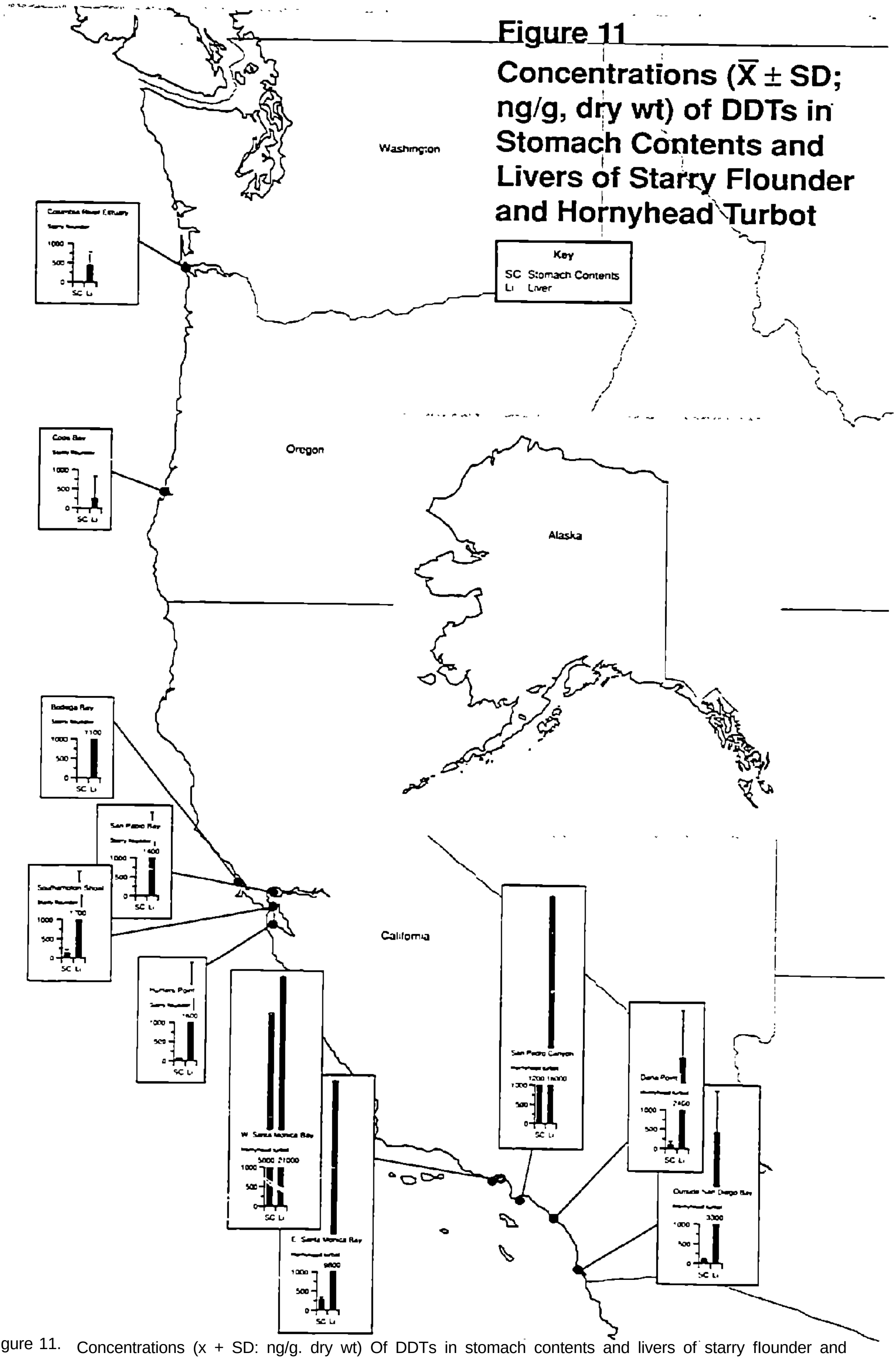

Figure 11. Concentrations (x + SD: ng/g. dry wt) Of DDTs in stomach contents and livers of starry flounder and hornyhead turbot.

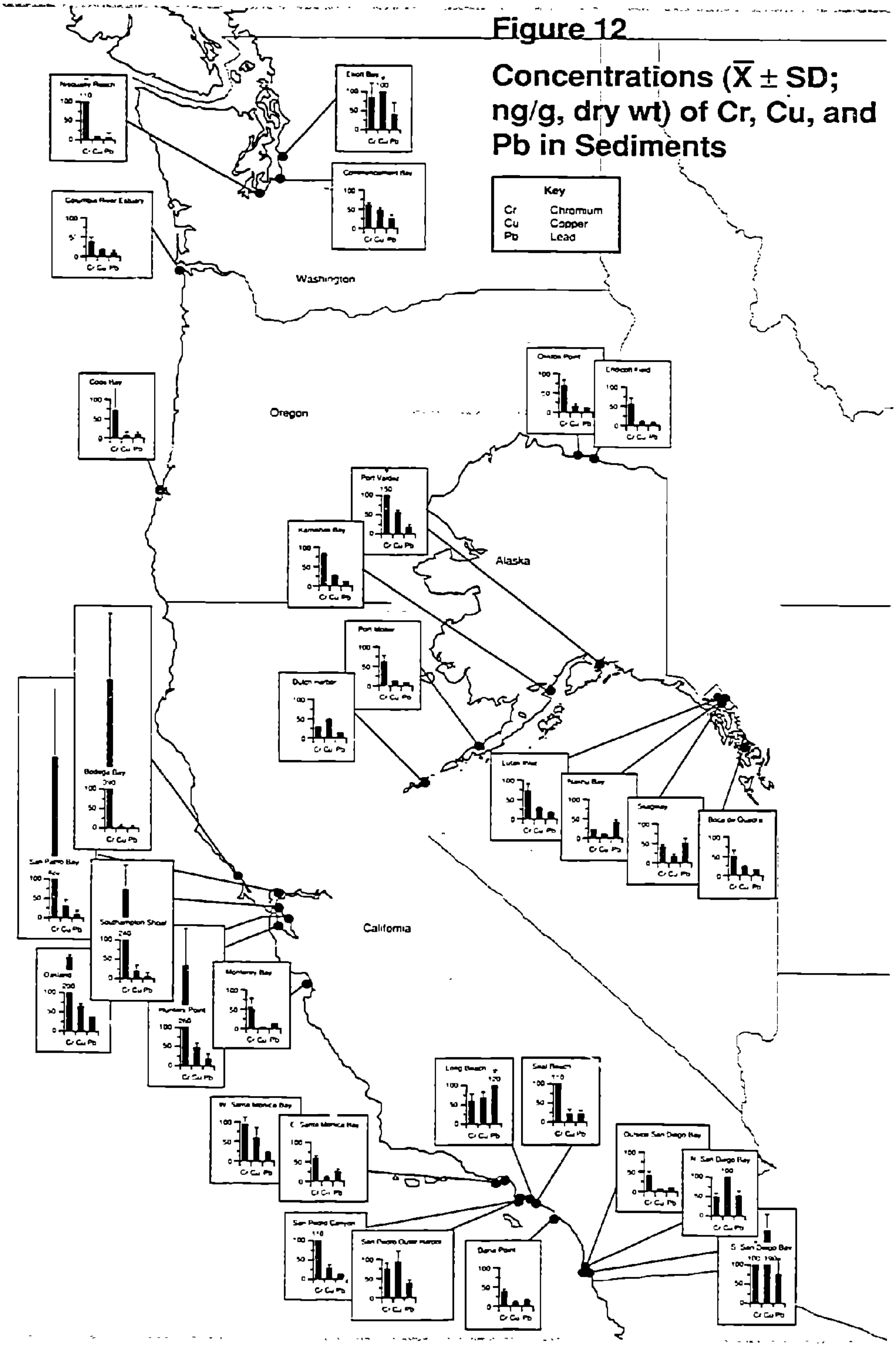

Figure 12. Concentrations (x + SD: ng/g. dry wt) of Cr. Cu. and Pb in sediments.

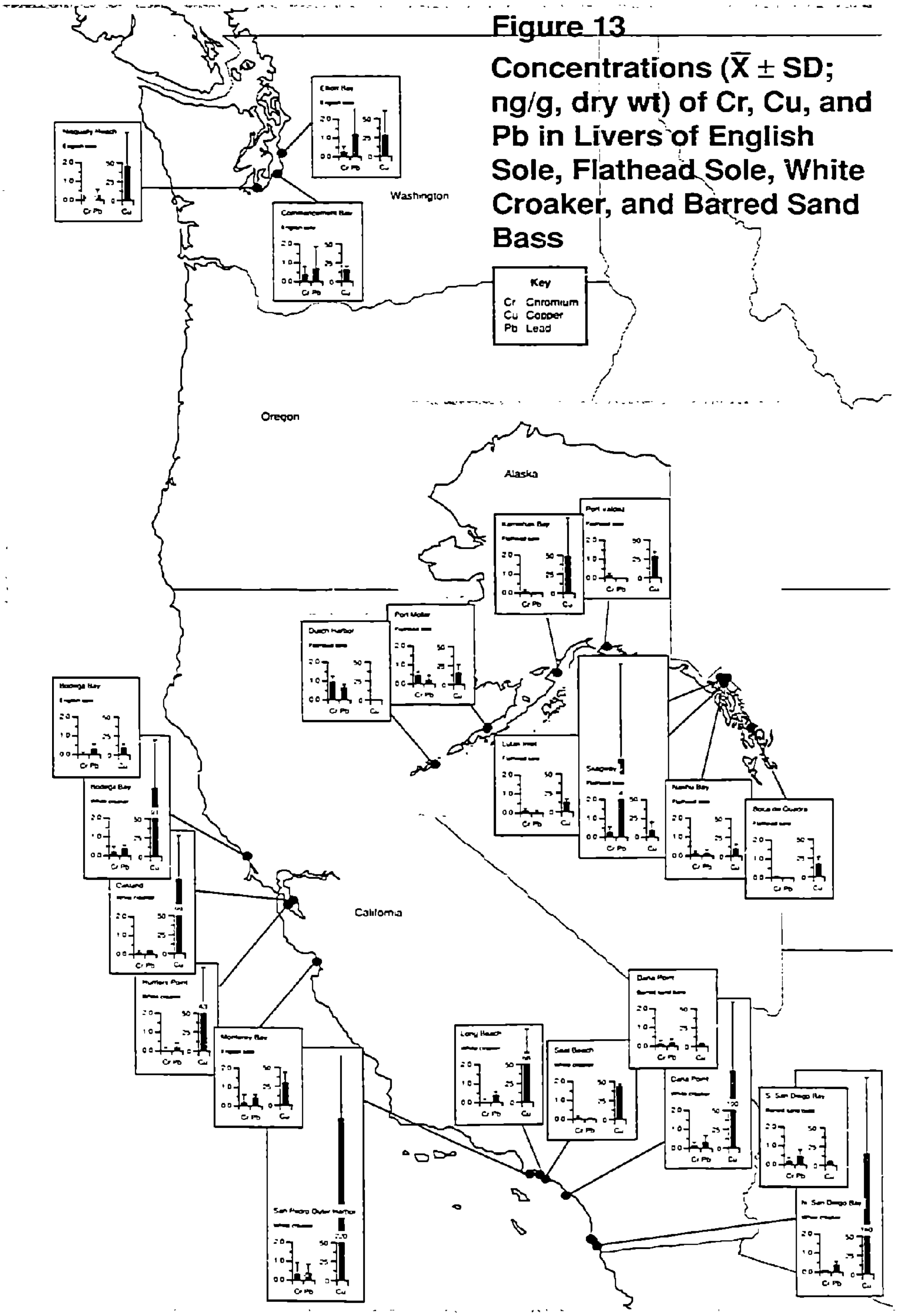

Figure 13. Concentrations (X̄ ± SD; ng/g, dry wt) of Cr, Cu, and Pb in livers of English sole, white croaker, and barred sand bass.

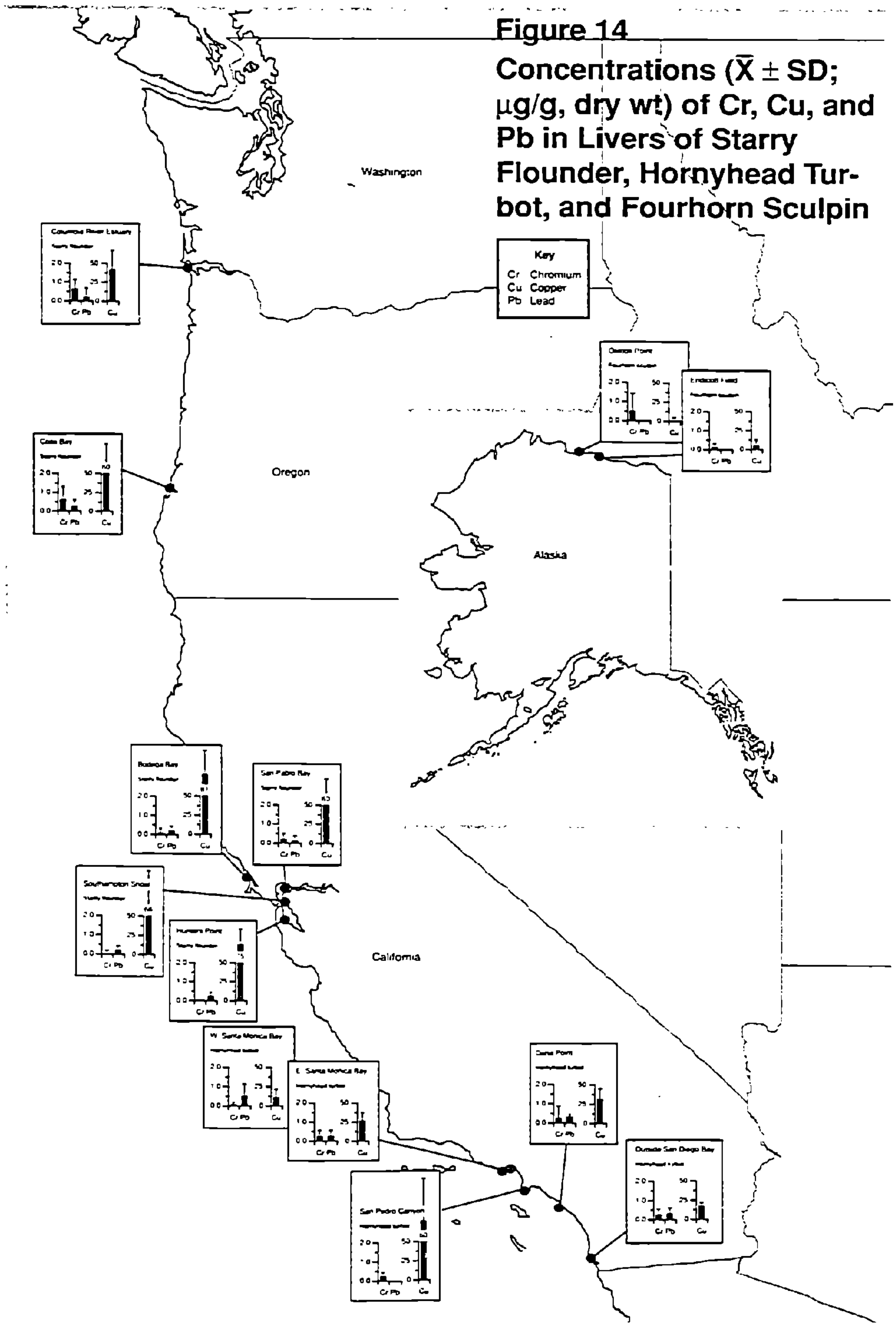

Figure 14. Concentrations (X + SD; ng/g., dry wt) of Cr. Cu. and Pb in livers of starry flounder. hornyhead turbot. and fourhorn sculpin.

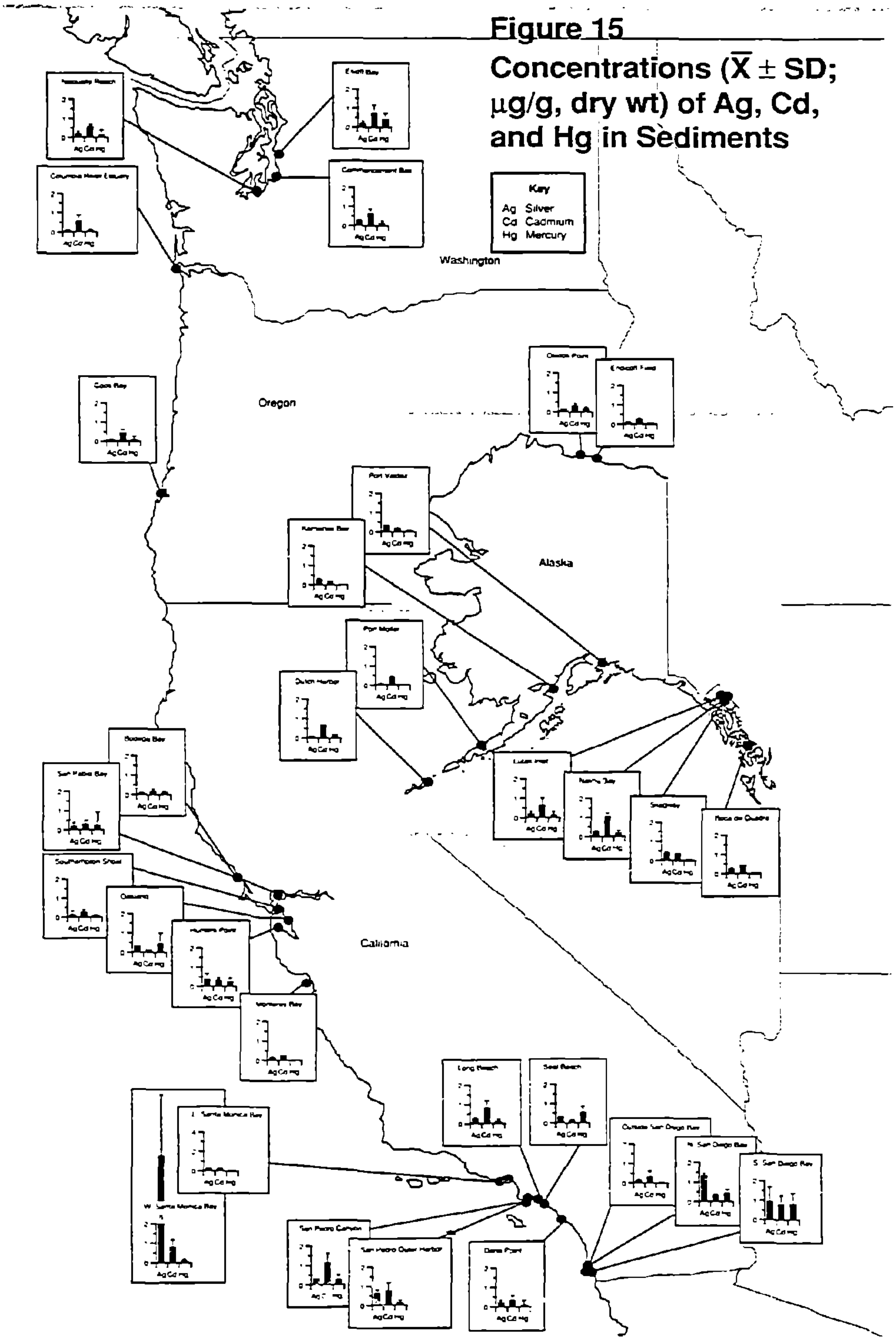

Figure 15. Concentrations (x + SD; ng/g. dry wt) of Ag, Cd, and Hg in sediments.

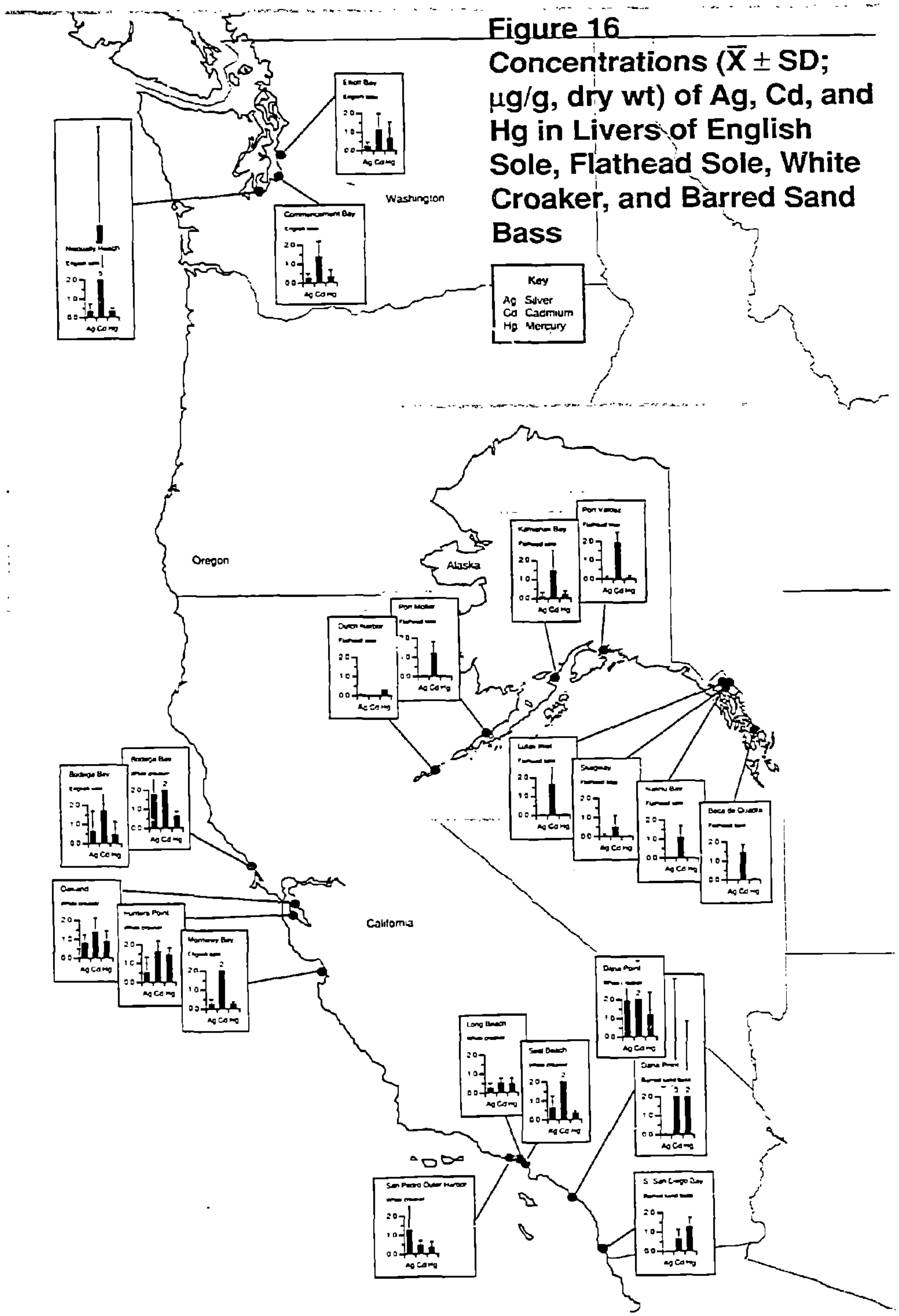

Figure 16. Concentrations (x + SD; ng/g, dry wt) of Ag. Cd, and Hg in livers of English sole, white croaker. and barred sand bass.

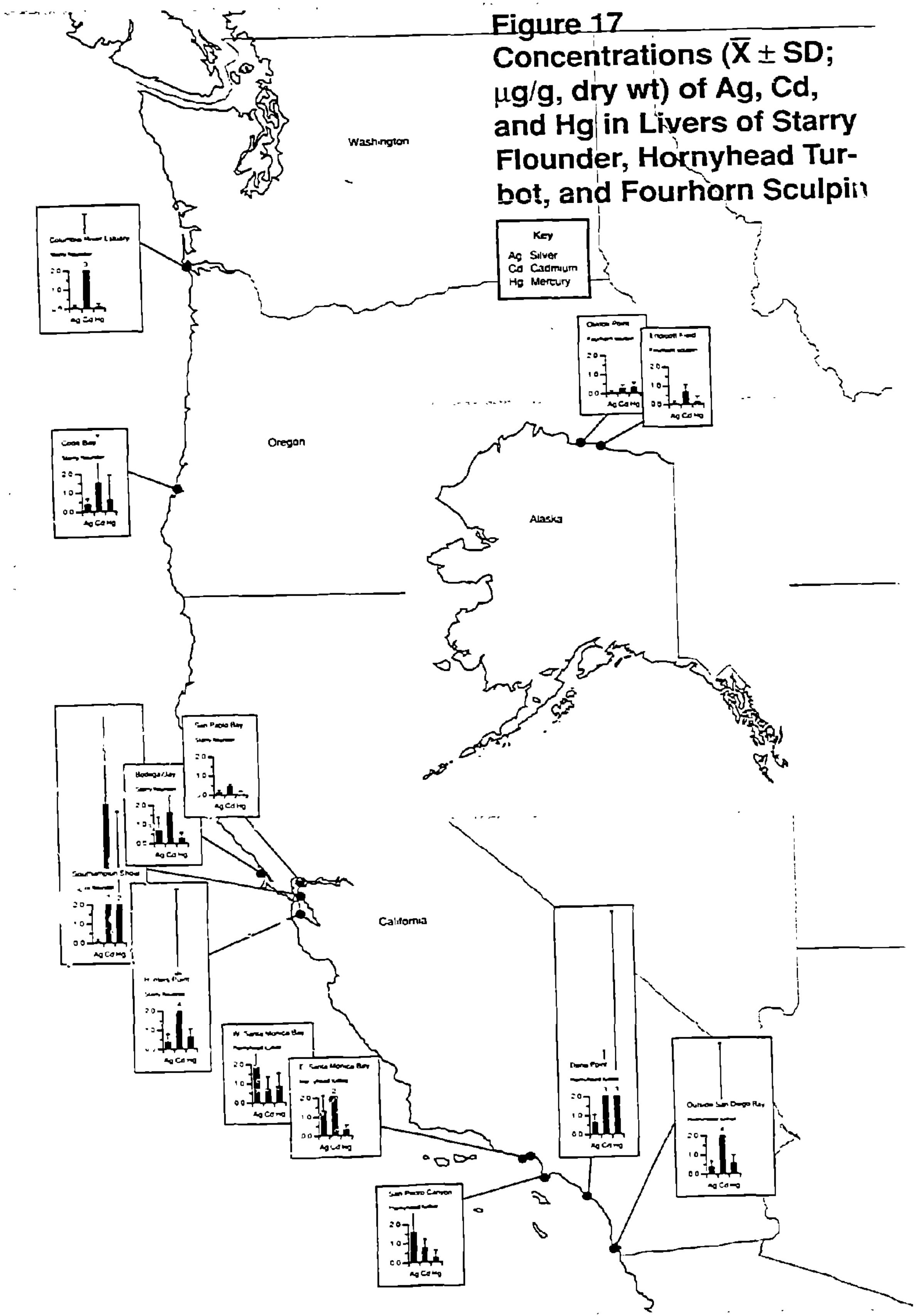

Figure 17. Concentrations (x + SD; ng/g, dry wt) of Ag, Cd, and Hg in livers of starry flounder. hornyhead turbot. and fourhorn sculpin.

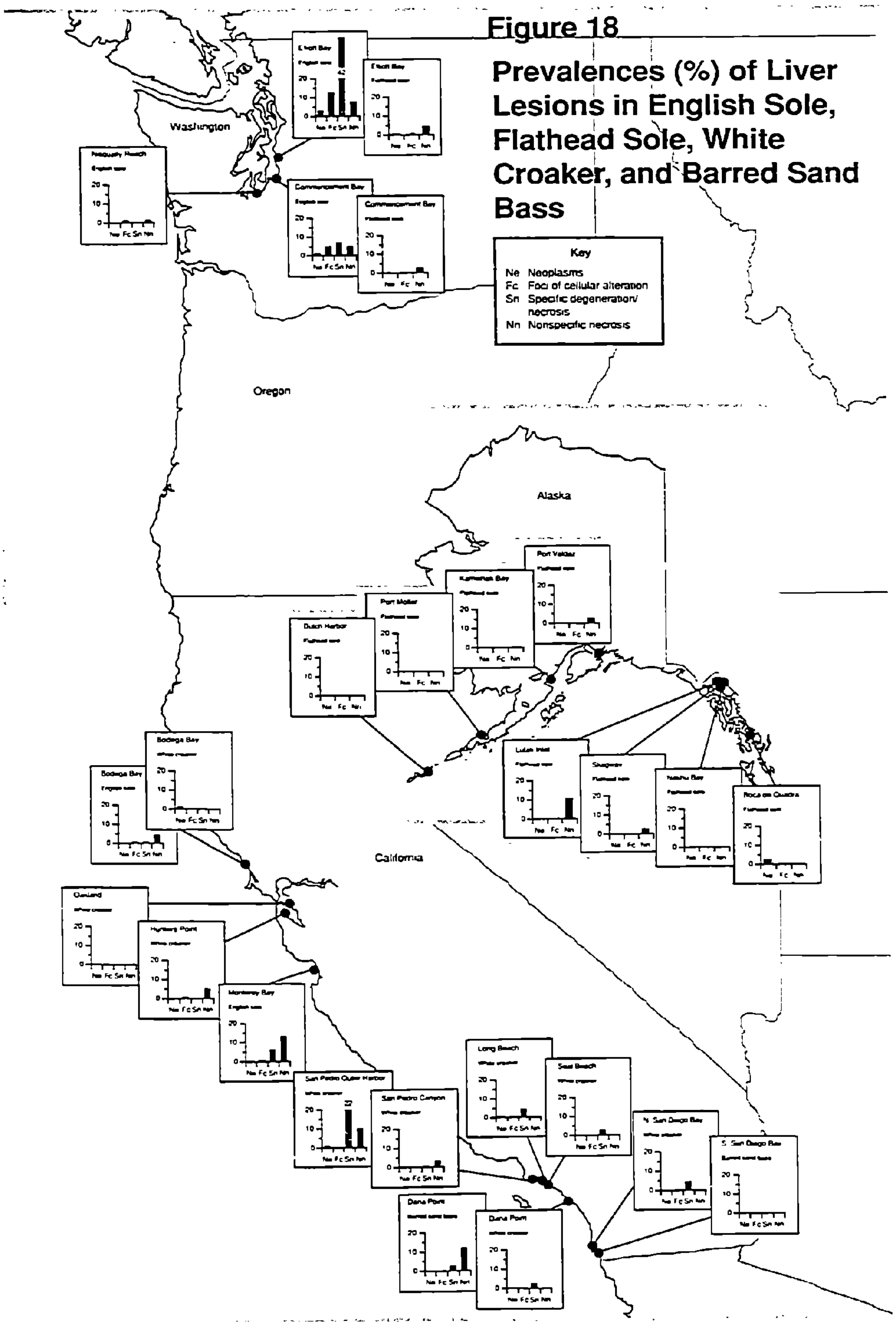

Figure 18. Prevalences (%) of liver lesions in English sole, flathead sole, white croaker. and barred sand bass.

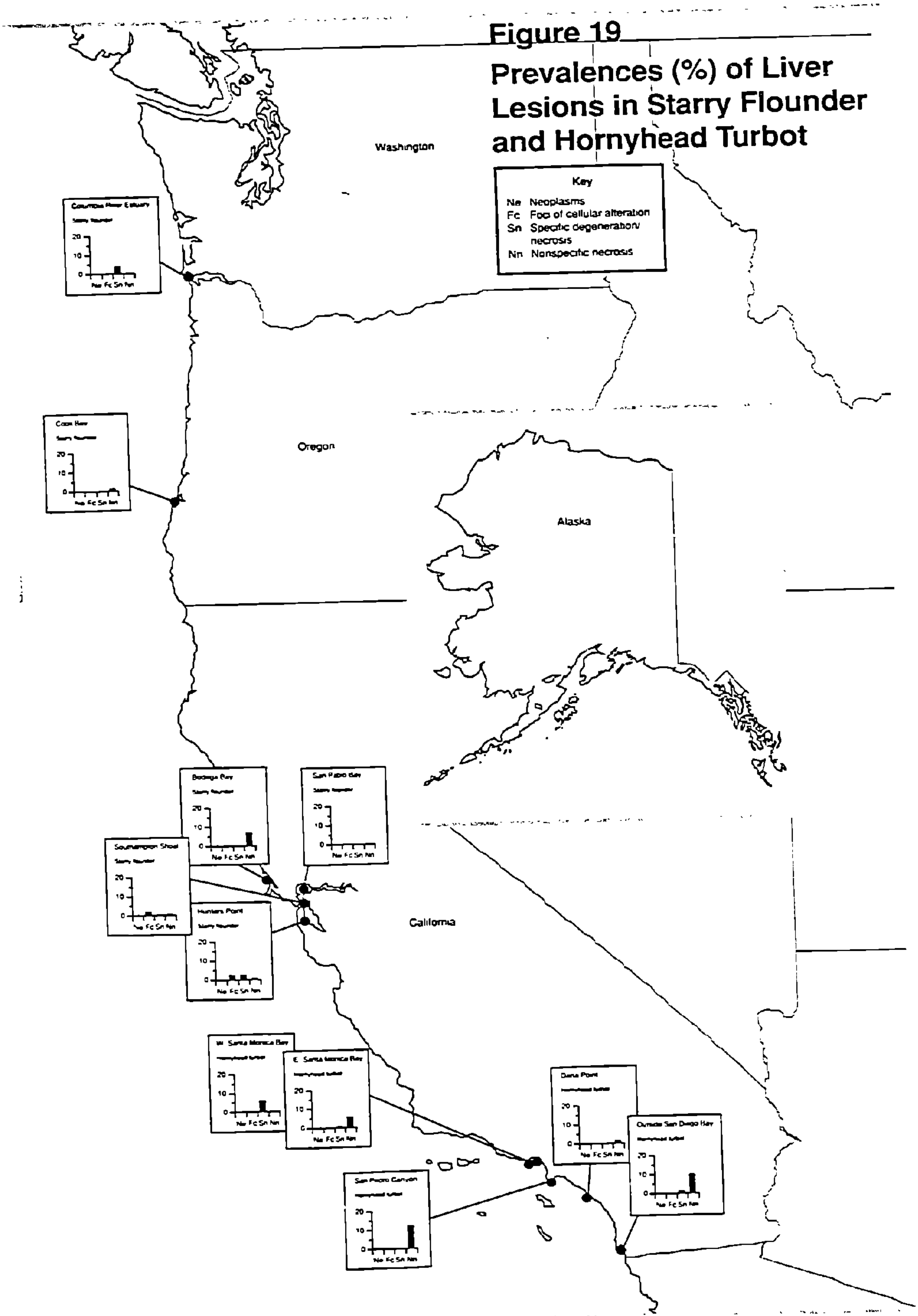

Figure 19. Prevalences (%) of liver lesions in starry flounder. and hornyhead turbot.

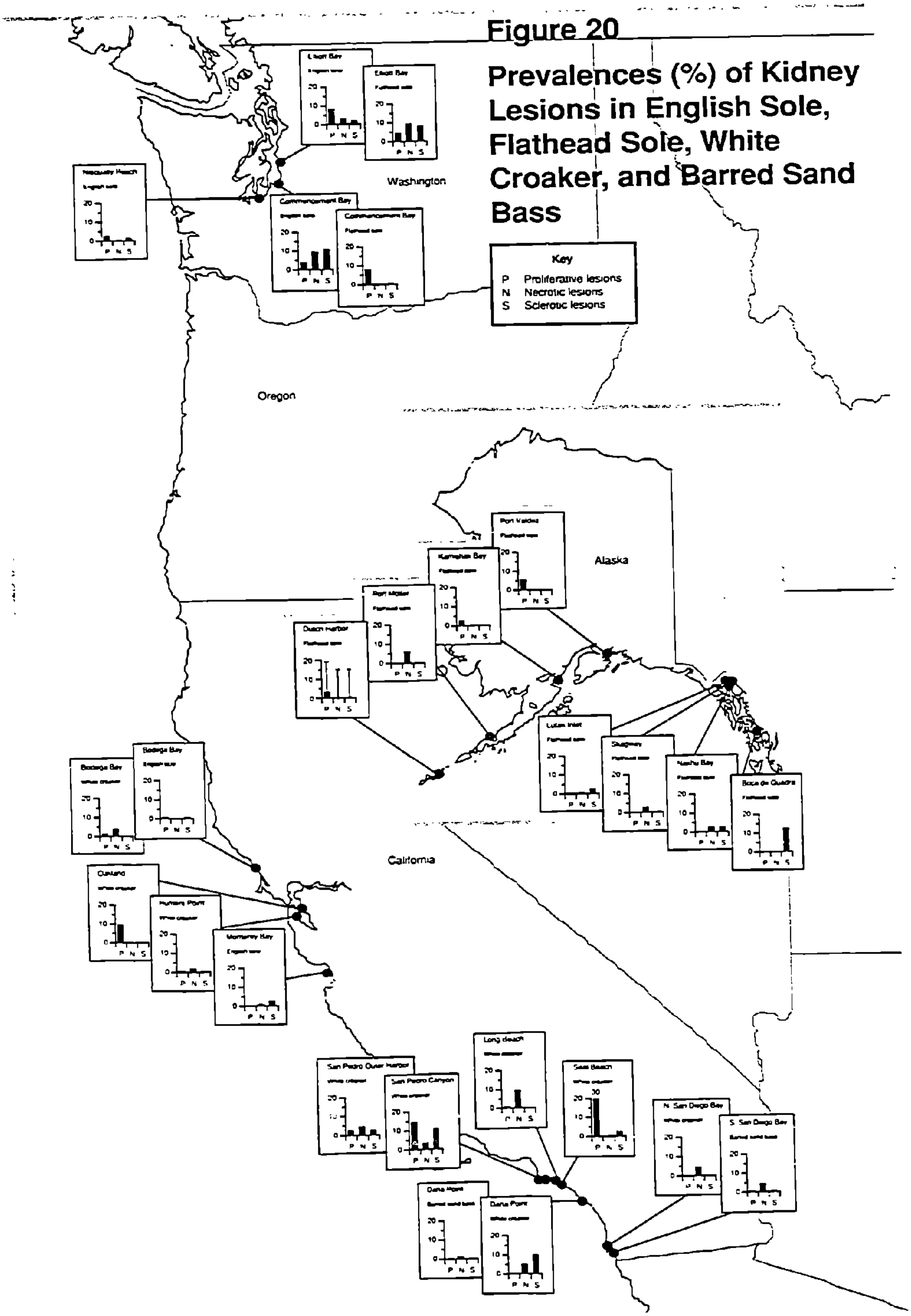

Figure 20

Prevalences (%) of Kidney Lesions in English Sole, Flathead Sole, White Croaker, and Barred Sand Bass

Key

P Proliferative lesions
N Necrotic lesions
S Sclerotic lesions

Figure 20. Prevalences (%) of kidney lesions in English sole, flathead sole. white croaker, and barred sand bass.

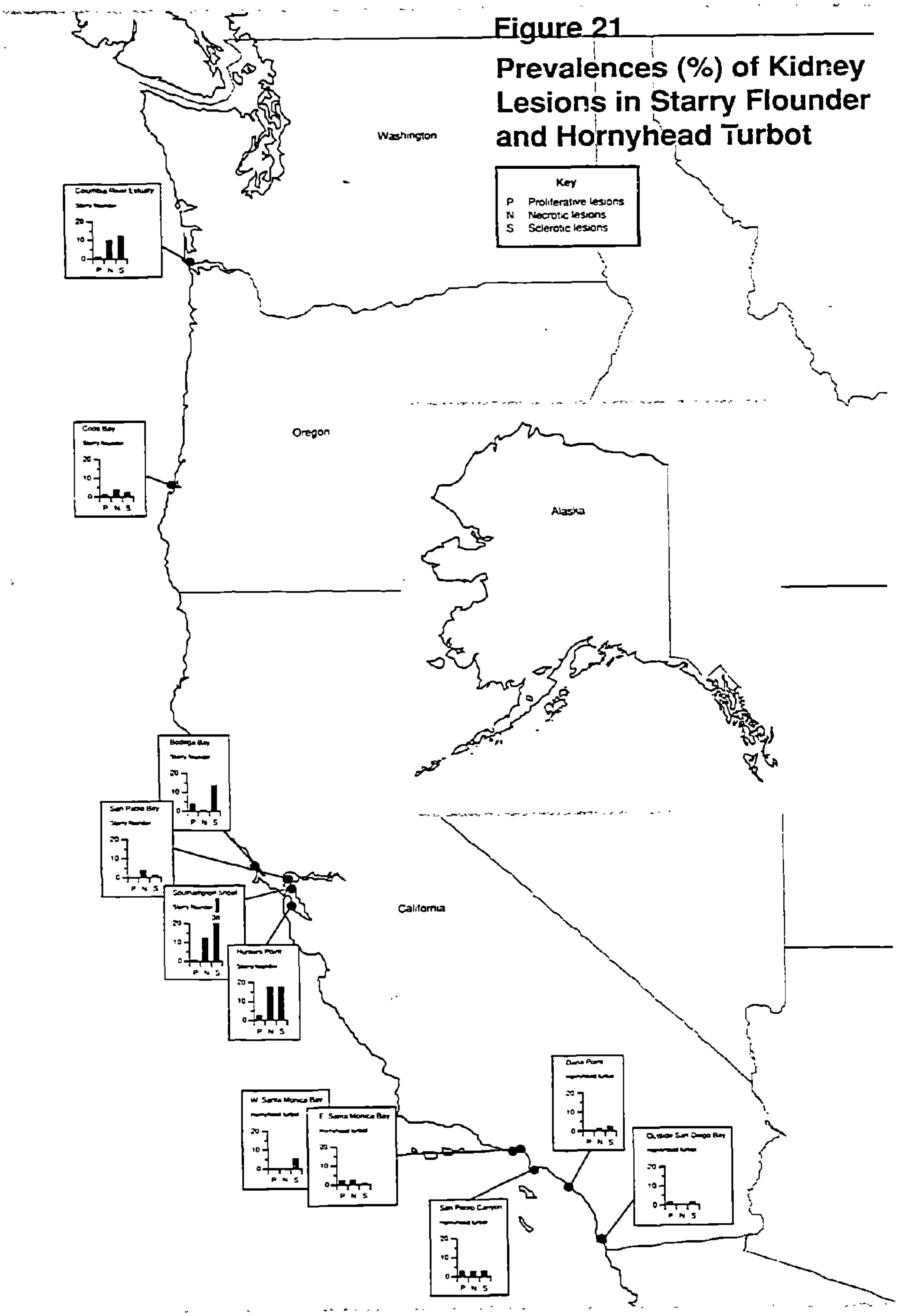

Figure 21. Prevalences (%) of kidney lesions in starry flounder and hornyhead turbot.