Stable isotope ratios and contaminant concentrations in a sewage-distorted food web

Robert B. Spies¹, Harold Kruger², Robert Ireland¹, David W. Rice, Jr¹

¹ Environmental Sciences Division, Lawrence Livermore National Laboratory, University of California, Box 5507, Livermore, California 94550, USA

² Kruger Laboratories, 24 Blackstone Street, Cambridge, Massachusetts 02139, USA

ABSTRACT: Concentrations of selected neutral organic contaminants and stable isotope ratios of carbon, nitrogen and deuterium/hydrogen in invertebrates and fish were compared from near a large, 60m deep municipal waste outfall near Los Angeles, California, where waste has a measurable influence on the structure of the marine food web, and from a reference area off Santa Barbara, California. Objectives were to investigate (1) the degree of utilization of sewage organic matter in the food web, especially by 3 species of fish, (2) differences in contaminant accumulation between these benthophagous fish and (3) the behavior of organic contaminants relative to each other and to organic matter through several trophic levels. Isotopically lighter carbon and nitrogen and higher concentrations of most chlorinated hydrocarbons were found in tissues of organisms from near the outfall. On the basis of the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of the fishes, the estimated contribution of nitrogen and carbon from sewage was about 15 to 20% of their requirements for these elements. The $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values increased in the fishes in the order of *Microstomus pacificus*, *Citharichthys sordidus* and *Zaniolepis latipinnis*. The Cs/K ratio of the latter species was also significantly higher than the former 2 species, also indicating its higher trophic position. *C. sordidus* had the highest wet-weight concentrations of chlorinated hydrocarbons and phthalic acid esters; intermediate concentrations of these compounds were found in *Z. latipinnis* and the lowest concentrations were found in *M. pacificus*. Concentrations of chlorinated hydrocarbons on a lipid-weight basis changed this order so that it more closely resembled the trophic structure revealed by the stable isotope ratio and Cs/K ratio data. Increases of both ΣDDT and Aroclor 1254, from deposit-feeding invertebrates through fish, were evident in foodwebs of the outfall and reference areas as positive correlations with $\delta^{13}\text{C}$. A large degree of correlation was evident between contaminants in *Z. latipinnis* but not in the other 2 fish species. These correlations were apparently not a function of liver lipid concentration, but the strengths of the correlations were dependent on the similarities of log K_{ow} values of the correlated compounds.

INTRODUCTION

Over 2×10^5 metric tons of sewage particulate matter are discharged into the Southern California Bight each year (Schafer 1984). Associated with these particles are a variety of xenobiotic contaminants, such as chlorinated hydrocarbons, aromatic hydrocarbons, phthalic acid esters, heterocycles and chlorophenols (Young & Gossett 1980, Eganhouse & Kaplan 1982, Gossett et al. 1982, Schafer 1984). The sewage particles are about 60% organic matter, compared to ca 2% in endogenous marine particulate matter (Sweeney & Kaplan 1980).

As a result of particulate matter settling, sediments have accumulated at the rate of 0.6 to $1.7 \text{ g cm}^{-2} \text{ yr}^{-1}$ (dry) during the 1970's near the Los Angeles County

Joint Water Pollution Control Plant (JWPCP) outfall (Stull et al. 1986a). This deposition of particles with a high organic content has had a marked effect on the food web, changing microbial and invertebrate populations in accordance with effects expected from organic enrichment (Pearson & Rosenberg 1978, Stanley et al. 1978, Stull et al. 1986b). The general effect evident in the invertebrate populations was a stimulation of selected species of deposit-feeding infauna, especially polychaetes, while crustaceans, particularly amphipods, became less numerous (Smith & Green 1976, Word & Striplin 1980).

Changes in populations of benthophagous fish were also noted near the JWPCP outfall during the 1970's (Cross et al. 1985; see Spies 1984 for review). One species in particular, the Dover sole (American appella-

tion) *Microstomus pacificus*, sustained very large populations in the outfall area, while others, such as the yellow chin sculpin *Icelinus quadriseriatus* and the longspine combfish *Zaniolepis latipinnis* appeared to be reduced in numbers compared to nearby areas (Allen 1977, Word & Mearns 1978). There is now evidence that the ability of some fishes to feed on infaunal populations, particularly polychaetes, and the inability of other fishes to switch from a diet of crustaceans to other food items, contributed to these altered fish abundances (Cross et al. 1985).

Sewage particulate matter has stable isotope ratios for nitrogen and sulfur lighter than those of marine particulate matter in the Southern California Bight (Sweeney & Kaplan 1980, Sweeney et al. 1980). Carbon isotope ratios are heavier and the ratio of deuterium to hydrogen is greater in sewage than in marine particulate organic matter (Table 1). However, the sediment

deuterium/hydrogen (δD) than those collected in a reference area near Ventura, California (Rau et al. 1981).

In addition to the stable isotope ratios, the elemental ratios of cesium to potassium have also been used to interpret foodweb structure (Young 1970). In this case the heavier element, rather than the heavier isotope, has a longer residence time in organisms and, hence in the foodweb, resulting in greater Cs/K in higher trophic levels.

Changes in the treatment of sewage to be discharged from the Los Angeles County's JWPCP outfall have resulted in decreasing rates of particulate matter deposition in sediments of the Palos Verdes Shelf as well as lesser concentrations of major contaminants in the surface few cm of sediment (Stull et al. 1986a). However, the inventories of metals and trace organic contaminants show that this portion of the Palos Verdes Shelf is a significant repository of potentially biologically available contaminants.

The existence of unique isotope signatures and high degree of contamination provided an opportunity for the simultaneous study of the transfer of sewage-derived organic material and contaminants to deposit-feeding invertebrates and eventually to benthophagous fish. Such a study would reveal (1) the degree to which coupling was occurring between the benthos and certain fish populations, (2) differences in contaminant accumulation between fish species with disparate diets and (3) the behavior of organic contaminants relative to each other and to organic matter through several trophic levels. Here we report the results of such a study utilizing deposit-feeding infauna, invertebrate predators and 3 species of fish: the longspine combfish *Zaniolepis latipinnis*, the Dover sole *Microstomus pacificus*, and the Pacific sanddab *Citharichthys sordidus*. These organisms were analysed for ΣDDT , polychlorinated biphenyls (PCBs), phthalic acid esters; the ratios of stable isotopes of carbon ($\delta^{13}C$), nitrogen ($\delta^{15}N$) and deuterium/hydrogen (δD); and Cs/K.

Table 1. Relative abundances of stable isotopes in marine and sewage particulate matter. All values in ‰

Isotope ratio	Marine	Sewage ^a	Difference
$\delta^{13}C$	-19 to -21	-16.5	2.5 to 4.5
δD	-105 to -139 ^b	-52	57 to 87
$\delta^{15}N$	8 to 12 ^c	1.8	-6.2 to -10.2

^a Monthly composite sample of JWPCP final primary effluent particulate matter, November 1983
^b Stuermer et al. 1978; this is a value for humic acids and kerogen
^c See Wada et al. 1975, Sweeney et al. 1980, Sweeney & Kaplan 1980, Venkatesan et al. 1980

carbon in the vicinity of a large outfall is isotopically lighter (-23.5‰) than sewage particulate matter (Myers 1974). As the organic matter in sediments near the outfall is utilized by the marine food web it would be expected that these stable isotope signatures would undergo small changes with each trophic level (DeNiro & Epstein 1978, 1980, Estep & Dabrowski 1980). For example, laboratory experiments indicate that the stable carbon isotope ratio, $\delta^{13}C$, would be expected to change only about 0.7‰ per trophic step (DeNiro & Epstein 1978), while Rau et al. (1983) reported trophic step factors of about 1.4‰ in Southern California marine ecosystems. Such changes can be used to interpret trophic structures of food webs (McConnaughey & McRoy 1979a, b). Nitrogen isotope changes are usually somewhat larger and vary more from species to species (DeNiro & Epstein 1980, Minagawa & Wada 1984). An earlier study from an area receiving wastewaters showed that *Microstomus pacificus* and the ridgeback prawn *Sicyonia ingentis* were isotopically lighter in carbon and nitrogen and isotopically heavier in

METHODS AND MATERIALS

Sites. The JWPCP outfall, located near Los Angeles, California, USA, discharges an average of 1.35×10^9 l d⁻¹ of effluent and the annual mass-emission rate of all chlorinated hydrocarbons is ca 1100 kg (Young & Gossett 1980). Large amounts of DDT-type compounds (ca 200 metric tons) remain in the outfall area sediments from past discharges (Young et al. 1980). The outfall is located 2 km offshore at a depth of 60 m. The area off Santa Barbara, California on the 60 m isobath served as a reference site. Sewage discharges in Santa Barbara County to the northern part of the Southern

California Bight are only a fraction of the volume discharged from the Los Angeles area outfalls and large-scale disturbances of the bottom communities have not been reported (SCCWRP 1973). In particular, Santa Barbara County discharges ca $0.072 \times 10^9 \text{ l d}^{-1}$ of treated sewage effluent as compared to $2.7 \times 10^9 \text{ l d}^{-1}$ from Los Angeles County (pers. comm., H. Schafer, SCCWRP, Long Beach, CA).

Species selection. The fish species were selected to represent different trophic habits and a range of response to sewage. *Microstomus pacificus* exhibits very high densities in the JWPCP outfall area relative to other sites at the same depth in the Southern California Bight (Word & Mearns 1978). This species also feeds extensively on infaunal polychaetes in outfall sediments (Allen 1982, Cross et al. 1985). In fact, in 1983 trawl-captured specimens near the outfall area had stomach contents consisting almost entirely of the opportunistic polychaete *Tharyx tessellata* (pers. obs., R. Spies). Thus, *M. pacificus* would appear to be one trophic level above detritivores. *Citharichthys sordidus* exhibits a less clear response to sewage, since in one study it appeared to be less dense near the outfall than in other areas (Word & Mearns 1978), while in another study it seemed to exhibit somewhat higher densities and tended to feed on polychaetes close to the outfall (Cross et al. 1985). The food of *C. sordidus* is dependent on the size of fish; smaller individuals eat glycerid polychaetes and other benthic and pelagic organisms, while larger individuals feed almost exclusively on pelagic organisms (Allen 1982). Thus *C. sordidus* appears to be between 1 and 2 trophic levels above detritivores. *Zaniolepis latipinnis* appears to be less dense in sewage-affected areas (Cross et al. 1985); it is benthophagous and piscivorous – feeding on crustaceans, polychaetes and sanddabs (= genus *Citharichthys*) (Allen 1982). Thus, this species also apparently has a higher trophic level than *M. pacificus* and probably higher than *C. sordidus*, since it feeds on this latter species. In general little is known of the movement of these species in the Southern California Bight. Some portion of the population of *M. pacificus* moves to deeper water in winter (Cross 1985), but there is little evidence for extensive lateral movement of any of these species. The differences in chemical composition of the species collected here indicates that movement is not sufficient to obscure site differences. Fish from near the JWPCP outfall carry a clear isotopic and chemical signature that indicates they had been in the vicinity for some time.

The invertebrate species used were those that occurred in high enough densities in the grab samples to obtain enough tissue for the analyses and that were likely to be utilized by benthophagous fish (Allen 1982). Glycerid polychaetes were included as they are

eaten by *Citharichthys sordidus*; the cirratulid polychaete *Tharyx tessellata* was also included, as it forms the diet of *Microstomus pacificus* (see above). An effort was made to include other detritivores and predators based on the trophic analysis of polychaete families (Fauchald & Jumars 1979).

Sampling. Sampling was carried out on August 16 and 17, 1983, around the JWPCP outfall and on September 20, 1983, near Santa Barbara (Fig. 1). The time difference between the 2 samplings was due to limitations of ship scheduling and there is no reason to expect that differences in measured parameters are due to this factor. Fish were captured in 5 or more 10 min otter trawls and invertebrates in 3 to 5 Van Veen grab samples (Fig. 1). Fish were segregated by trawl sample and species in stainless steel trays, wrapped in aluminum foil and refrigerated immediately after collection. Invertebrates were separated from sediments by sieving on a 0.5 mm Nytex screen using water dipped from the ocean in stainless steel buckets. Twenty of each fish species were weighed and then dissected within 10 h of collection. The livers, gonads (when large enough) and 2 flesh samples were then removed by clean techniques, weighed, and frozen on dry ice. The alimentary canals were also removed and preserved in formalin for casual inspection of stomach contents. Benthic invertebrates were kept alive in glass containers with cold seawater (13°C) from the sampling sites. They were allowed to void their guts for 10 h and external sediment was removed with a camel hair brush before preservation by freezing. Composite samples were made for each taxon using only specimens without visible sediments in their guts. In addition a filtered (10 µm) and oven-dried (60°C) composite sample of JWPCP final advanced primary effluent for October 1983 was prepared for analysis.

Stable isotope analyses. Flesh samples of fish were prepared for analysis by oven drying at 60°C and whole invertebrates were dried with anhydrous Na_2SO_4 . Analyses were carried out at Kruger Laboratories, Cambridge, Massachusetts, USA, by combusting at least 10 mg of material in the presence of O_2 , followed by condensation of water of combustion, which was collected for determination of δD . Combustions were carried out in closed tubes in the presence of CuO_2 . A single combustion was used to obtain all the analyses of a tissue. Differential low temperature distillation of gases was used to separate oxides of nitrogen for determination of $^{15}\text{N}/^{14}\text{N}$, and CO_2 for determination of $^{13}\text{C}/^{12}\text{C}$. Isotope ratios were determined in model VG903 and VG602D quadrupole mass spectrometers. Shifts were calculated as $\delta R = [R_{\text{unknown}} \times R_{\text{standard}} - 1] \times 1000$, where $R = ^{13}\text{C}/^{12}\text{C}$, $^{15}\text{N}/^{14}\text{N}$ or D/H and the standards were Pee Dee Belemnite (carbon), atmospheric air (nitrogen) and Standard Mean Ocean

Fig. 1. Sampling locations near Los Angeles and off Santa Barbara, California. Trawls are indicated by straight lines and are numbered. The grab sample is indicated by a filled circle between the ends of the westernmost line of the JWPCP outfall

Water (deuterium:hydrogen). Precision for organic matter samples in this system, based on many analyses of replicates and standards is $\pm 2.0\%$ for δD ; ± 0.1 to 0.2% for $\delta^{13}C$ and ± 0.2 to 0.3% for $\delta^{15}N$.

Several samples of *Microstomus pacificus* flesh which appeared particularly oily were reanalysed for all isotopes after lipids were extracted with refluxing toluene, as lipids are known to be often isotopically lighter than other major classes of compounds (Estep & Hoering 1980), and lipid content can vary significantly among individuals.

Cesium and potassium analyses. As an independent measure of trophic level, the Cs/K of each species was measured (Young 1970). These elements were measured in the dorsolateral muscle of 5 specimens of each fish species from the JWPCP outfall collections. Potassium concentrations in ashed samples were determined by atomic absorption spectrometry by Soil Control Laboratories, Watsonville, California. A National Bureau of Standards (NBS) orchard leaves standard analysed at the same time gave values within 1% of the expected concentrations of potassium. Cesium was measured in ashed samples by neutron-activation analysis by Nuclear Energy Services, Raleigh, N. Carolina, USA. Analysis of NBS orchard and citrus

leaves standards produced values within 5% of the expected concentration of cesium. Potassium measurements were not corrected for chemical recovery before calculating Cs/K on a wet-weight basis. Likewise cesium concentrations were not corrected for possible losses during ashing.

Organic contaminant analyses. We generally followed the methods of Ozretich & Schroeder (1986) for analysis of neutral organic contaminants in marine samples. In preparation for extraction, invertebrates and fish livers were thawed at room temperature in glass beakers. Tissues were diced or torn into small pieces with stainless steel spatulas. Approximately 5 g of Na_2SO_4 (analytical grade, was heated to $600^\circ C$ for 12 to 24 h) was added for every 1 g of tissue to remove unbound water. For contaminant extraction, 15 to 30 ml of spectrographic-grade acetonitrile (Burdick and Jackson®) was added to each sample. Two ml of an internal standard consisting of $1.0 mg\ ml^{-1}$ of 4,4'-dibromobiphenyl was added to each sample. The sample was then ground into a slurry with the stainless steel head of a Brinkman Polytron® homogenizer. This mixture was allowed to settle and the extractant was decanted. The extraction was carried out twice more, with centrifugation following the last extraction.

The extracts from fish livers were made up to 100 ml in a volumetric flask, a 1 ml subsample was removed for the gravimetric determination of lipid, and the remainder was stored for 12 to 24 h at 4 °C. A variable amount of the extract, usually 15 to 25 ml, was removed for cleanup and analysis. Sample cleanup was performed with disposable solid-phase extraction columns (Baker®), using C₁₈ and NH₂ as the solid phase absorbents. The C₁₈ columns were conditioned with acidified (pH 2) methanol (6 ml) followed by a methanol rinse. A column/reservoir (6 ml capacity) was added above and a NH₂ column below. Approximately 0.2 g of anhydrous Na₂SO₄ (cleaned as described above) was added to the filtration column to ensure that all water would be removed from the extractant. The serial 3-column assembly was then mounted on a suction manifold and conditioned with a 10 ml rinse of acetonitrile. The samples were reduced to 4 ml by rotary evaporation before being introduced to the columns. They were slowly pulled through the columns under vacuum. This was followed by 2 sample (0.5 ml) and 2 column (1 ml) rinses. Usually 4 or 5 samples and a blank would be processed simultaneously on the manifold. Cleaned-up samples were reduced to a final volume of 0.1 ml by a combination of rotary evaporation and a stream of cold, pure nitrogen. This chemical procedure routinely produced good blanks with only a few phthalic acid esters as contaminants. In all cases concentrations of these compounds reported in tissues were more than 10 times the amounts in blanks. For 1 to 2 g liver samples, sufficient biogenic materials were removed to allow clear resolution of a variety of organic contaminants by gas chromatography.

A Hewlett-Packard 5880 gas chromatograph, equipped with an electron-capture detector (ECD), capillary injector and a fused-silica capillary column (SE 54) and run on a mixture of 90 % argon and 10 % methane carrier gas, was used for resolving organic contaminants. Compounds were identified on the basis of retention time of EPA-supplied authentic standards and some mass spectrometry (Hewlett Packard, 5985). Response factors were empirically determined for each compound by injecting known amounts of authentic standards. Raw data from each chromatographic run were stored in a Hewlett Packard 3354 automated laboratory data system. Concentrations of each contaminant were calculated based on the original sample weight, portion of extractant used, injection volume, response factor and recovery of the internal standard.

Because some interconversion of DDT-type compounds appeared to be occurring during chromatography of our standards, we have reported only Σ DDT value: the sum of ortho, meta and para-isomers of DDT, DDD and DDE. Quantification of PCB's as Aroclor mixtures (1242, 1254 and 1260) was based on compar-

ing the height of a single peak in each sample to a corresponding unique peak in the reference mixtures for each Aroclor.

Statistical analyses. All data were log-transformed or arcsin-transformed before statistical analyses. Statistical analyses were carried out on a VAX computer using a statistical analysis package (SAS 1985).

RESULTS

Stable isotope ratios of sewage particles and invertebrates

In Table 1 the stable isotope abundances of the sewage particles from the JWPCP composite sample are compared with values from the literature for marine particulate matter elsewhere in the Southern California Bight. The JWPCP outfall sediments are isotopically lighter in carbon ($\delta^{13}\text{C} = -23.5$; Meyers 1974) than endogenous marine particulate matter and sewage particulate matter is heavier in deuterium relative to hydrogen and lighter in nitrogen than the marine particulate matter. The reason for the discrepancy in carbon isotope ratios between sewage particulate matter and outfall sediments has not been demonstrated, but may be related to microbial processing.

In Table 2 stable isotope abundances of infaunal invertebrates from Santa Barbara and the JWPCP outfall are compared. Although statistical analysis of the carbon shifts is not possible because of single composite samples for each taxon, it can be seen that JWPCP invertebrates are consistently isotopically lighter for carbon than those from the Santa Barbara reference area. The amount of material for determination of δD and $\delta^{15}\text{N}$ was limited, but glycerid polychaetes were isotopically lighter in N at JWPCP than at the reference area.

Comparison of stable isotope ratios between fish species and sites

The stable isotope ratios of each species from the JWPCP outfall area and the Santa Barbara reference station are compared in Table 3 and Fig. 2. Significant site and species differences are evident for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$; species but no site differences occurred for δD . For $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, *Microstomus pacificus* was the most dissimilar of the 3 species, having isotope values consistently lighter for $\delta^{13}\text{C}$ (by about 0.9 ‰) and $\delta^{15}\text{N}$ (by about 1.7 ‰) at both sites, relative to the other species. *Zaniolepis latipinnis* and *Citharichthys sordidus* did not differ significantly from each other for either carbon or nitrogen isotope ratios. *Z. latipinnis* was significantly

Table 2. Comparison of relative abundances of stable isotopes in invertebrates between taxa and sites. SB: Santa Barbara, JWPCP: Los Angeles County Outfall

Taxon	Site	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	δD
Glycerid polychaetes	SB	-17.6	10.9	-91
	JWPCP	-18.7	7.5	-
	Δ^a	- 1.5	-3.4	-
Lumbrinerid polychaetes	SB	-17.6	11.9	-103
	JWPCP	-19.7	-	-
	Δ	- 2.1	-	-
<i>Pectinaria californiensis</i>	SB	-18.0	-	-
	JWPCP	-21.6	-	-
	Δ	- 3.0	-	-
<i>Tharyx tessellata</i>	SB	-17.0 ^b	-	-
	JWPCP	-19.6	-	-
	Δ	- 2.6	-	-
Misc. polychaetes	SB	-18.2	-	-
	JWPCP	-20.0	-	-
	Δ	- 1.8	-	-
Nemertean	SB	-16.6	-	-100
	JWPCP	-24.0	0.1	-
	Δ	- 7.4	-	-

^a Difference in isotope values between sites, in ‰

^b Value from Spies & DesMarais (1983), in 15 m of water near Campus Point, Santa Barbara Channel (comparison station for petroleum-seep study)

isotopically heavier for deuterium/hydrogen, but the other 2 species were similar.

There were consistent differences in isotope ratios of nitrogen and carbon between the 3 species that are evident at both sites (Fig. 2). Such differences are consistent with increasing trophic level from *Microstomus pacificus* to *Citharichthys sordidus* to *Zaniolepis latipinnis*. In fact among the 60 measured JWPCP outfall fish belonging to these 3 species, there was a highly significant correlation between these isotope ratios ($r = 0.52$; $F = 21$; $p > 0.0001$).

Rau et al. (1981) described a positive correlation between $\delta^{15}\text{N}$ and body weight in *Microstomus pacificus* from the area of the JWPCP outfall. We found a nearly identical relationship (Fig. 3a). However a significant negative relation between these 2 parameters was found for *Zaniolepis latipinnis* (Fig. 3b); no significant relation was found for *Citharichthys sordidus*.

Cs/K in fish

Significant differences in Cs concentrations and in Cs/K occurred between species (Table 4). *Zaniolepis*

latipinnis had significantly higher values for these measures than the other 2 species, which did not differ from one another. Based on the arguments and evidence presented by Young (1970 and references therein) that Cs is retained longer in organisms than potassium and therefore the Cs/K increases with trophic level, these data indicate that *Z. latipinnis* occupies a higher trophic level than the other 2 fish species. The ranking of the species by Cs/K thus results in the same relative trophic relationships as with the carbon and nitrogen stable isotope data.

Contributions of sewage-derived carbon and nitrogen in benthophagous fish

The proportions of sewage-derived carbon and nitrogen can be estimated in organisms from the outfall area based on differences in their stable isotope ratios between the outfall and reference areas and the stable isotope ratios of the sewage particulate matter. The mixing model takes the form:

$$1.0 (\delta R_{oo}) = X (\delta R_{sp} + b) + (1-X) (\delta R_{ro}) \quad (1)$$

where δR_{oo} = relative stable isotope abundances in organisms from outfall; δR_{sp} = relative stable isotope abundances in sediments or sewage particulate matter; δR_{ro} = relative stable isotope abundances in organisms from reference area; b = trophic step factor (this applied in the case of carbon based on the +0.7 ‰ per trophic level step reported by DeNiro & Epstein 1978); and X = proportion of sewage-derived element R in organism.

The results of solving this equation for X using $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ in the 3 species of fish are given in Table 5. Based on the stable isotope ratio and Cs/K differences between species we assumed 2 trophic steps between carbon in outfall sediments and *Microstomus pacificus* and *Citharichthys sordidus* and 3 steps for *Zaniolepis latipinnis*. We did not correct for a trophic effect with nitrogen as this can vary widely between species. It can be seen that, except for the carbon value for *M. pacificus*, the calculated values fall within a range from 14 to 22% using either element. The difference in the contribution of sewage to the diet of *M. pacificus* observed when the present data are used (7%) and those of Rau et al. (1981) are used (33%) are almost entirely due to different isotope values obtained for the control samples in the 2 studies, -16.6‰ and -17.8‰ respectively. The intraspecific carbon and nitrogen values are also remarkably similar for *Z. latipinnis* (22 and 16‰) and *C. sordidus* (16 and 14‰). The estimated proportions of sewage carbon and nitrogen for this latter species are less than for the other species, indicating less

Table 3. Comparison of stable isotope ratios between fish species and sites. (A) Cell and marginal means ($\pm$ SD); (B) ANOVA table

A.						
Isotope	Site	<i>Microstomus pacificus</i>	<i>Zaniolepis latipinnis</i>	<i>Citharichthys sordidus</i>	Mean	
$\delta^{13}\text{C}$	SB	-17.8 ± 0.8 (5) ^a	-15.9 ± 0.4 (5)	-16.5 ± 1.0 (5)	-16.7	
	JWPCP	-18.1 ± 1.3 (19)	-17.1 ± 0.3 (20)	-17.3 ± 0.5 (18)	-17.5	
	Mean	-18.1	-16.9	-17.1	-17.3	
δD	SB	-81.8 ± 8.0 (5)	-69.2 ± 6.0 (5)	-76.8 ± 14.6 (5)	-75.9	
	JWPCP	-75.8 ± 13.4 (19)	-69.8 ± 5.8 (20)	-76.3 ± 6.0 (18)	-73.8	
	Mean	-77.0	-69.6	-76.4	-74.3	
$\delta^{15}\text{N}$	SB	-13.7 ± 0.4 (5)	15.9 ± 0.5 (5)	14.6 ± 1.1 (5)	14.7	
	JWPCP	-11.2 ± 2.0 (19)	13.2 ± 0.7 (20)	12.8 ± 1.3 (19)	12.4	
	Mean	-11.7	13.7	13.1	12.9	
B.						
Isotope	Source	df	MS	F	p	Multiple comparison ^b
$\delta^{13}\text{C}$	Species	2	9	14.04	<0.0001	<u>Z C M</u>
	Site	1	7	11.14	0.00014	<u>S L</u>
	Interaction	2	1	1.27	0.2874	
	Error	66	1	—	—	
δD	Species	2	377	4.34	<0.0169	<u>Z C M</u>
	Site	1	47	0.54	0.4632	<u>S L</u>
	Interaction	2	49	0.57	0.5703	
	Error	66	87	—	—	
$\delta^{15}\text{N}$	Species	2	17	9.67	0.0002	<u>Z C M</u>
	Site	1	66	37.11	<0.0001	<u>S L</u>
	Interaction	2	1	0.44	0.6488	
	Error	67	2	—	—	

^a Sample size^b Tukey multiple comparison test, ranked highest to lowest, underlined species and sites are not different. C: *Citharichthys sordidus*; M: *Microstomus pacificus*; Z: *Zaniolepis latipinnis*. S: Santa Barbara; L: JWPCP Fig. 2. *Microstomus pacificus*, *Citharichthys sordidus*, *Zaniolepis latipinnis*. Plot of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ in 3 species of fish from the JWPCP outfall and near Santa Barbara. Lengths of crossed lines indicate standard deviations of the means

dependence on sewage-derived organic matter in its diet. The calculated proportions of carbon and nitrogen from sewage in *Z. latipinnis* indicate that although this species may not be abundant in the outfall area it derives substantial amounts of its carbon and nitrogen from sewage. The estimated proportions of nitrogen utilized by each species are conservative as inclusion of trophic step factors for nitrogen in the mixing model would have increased the estimated amount of sewage-derived nitrogen.

Contaminant concentrations in invertebrates

Concentrations of organic contaminants in composite samples of invertebrates are given in Table 6. For all contaminants and for all taxa, except glycerid polychaetes, JWPCP invertebrates have higher concentrations. The Aroclor 1254 and 1260 concentrations in glycerid polychaetes are higher than expected in the one composite sample from Santa Barbara; the reason for this is not known.

Fig. 3. Relationships between $\delta^{15}\text{N}$ and body weight in 2 species of fish from the JWPCP outfall area: (a) *Microstomus pacificus*; (b) *Zaniolepis latipinnis*

Table 4. Mean cesium and potassium concentrations in the muscle tissue of 3 species of benthophagous fish from the JWPCP outfall. Concentrations ($\pm$ SD) are in $\mu\text{g kg}^{-1}$ wet wt

	<i>Microstomus pacificus</i>	<i>Citharichthys sordidus</i>	<i>Zaniolepis latipinnis</i>	F	p	MCT ^a
Cesium	10.8 $\pm$ 2.7	12.1 $\pm$ 2.7	22.4 $\pm$ 10.9	7.3	0.009	<u>MCZ</u>
Potassium	2.1 $\pm$ 0.32	2.4 $\pm$ 0.63	2.2 $\pm$ 2.2	0.36	0.70	<u>MCZ</u>
Cs/K	5.1 $\pm$ 1.2	5.2 $\pm$ 1.2	10.2 $\pm$ 4.8	7.0	0.01	<u>MCZ</u>

^a MCT: multiple comparison test. Underlined species are not significantly different. M: *M. pacificus*; C: *C. sordidus*; Z: *Z. latipinnis*

Table 5. Estimates of the proportions of sewage-derived carbon and nitrogen in three species of benthophagous fish collected near the JWPCP outfall

	Carbon	Nitrogen
<i>Microstomus pacificus</i>	0.07 ^a , (0.33) ^b	0.21
<i>Zaniolepis latipinnis</i>	0.22	0.18
<i>Citharichthys sordidus</i>	0.16	0.14

^a Calculated from values obtained in our study
^b Calculated from values in Rau et al. (1981)

Contaminant concentrations in fish livers

The mean contaminant concentrations in the livers of the 3 fish species are given in Table 7. As expected, the concentrations of Σ DDT were much greater for the JWPCP fish. The high concentrations of Aroclor 1242 in *Microstomus pacificus* and of Aroclor 1260 in all 3 species from Santa Barbara were somewhat surprising; the Santa Barbara collections had concentrations equal to or greater than those from the JWPCP outfall area. The higher Σ DDT and Aroclor 1254 concentrations in fish from JWPCP and the higher Aroclor 1260 concentrations in Santa Barbara fish were significant. There were significant interspecific differences in concentrations of Aroclor 1254 but not Σ DDT.

Normalization of the chlorinated hydrocarbons to lipid content affected some of the species differences in the outfall collections. No significant species differences were observed for Σ DDT or Aroclor 1260, although in both cases the lowest concentrations occurred in *Microstomus pacificus*. The mean concentration of Aroclor 1242 in *Citharichthys sordidus* ($6.0 \pm 4.5 \mu\text{g g}^{-1}$ lipid) was significantly less than in either *Zaniolepis latipinnis* ($12.1 \pm 8.0 \mu\text{g g}^{-1}$ lipid) or *M. pacificus* ($11.0 \pm 3.5 \mu\text{g g}^{-1}$ lipid). For Aroclor 1254 *Z. latipinnis* ($76.6 \pm 63 \mu\text{g g}^{-1}$ lipid) was not significantly different from *C. sordidus* ($66.5 \pm 87 \mu\text{g g}^{-1}$ lipid), but was different from *M. pacificus* ($22.7 \pm 9.7 \mu\text{g g}^{-1}$ lipid).

Relationships among stable isotope ratios and contaminant concentrations in outfall fish

If the concentrations of the 2 chlorinated hydrocarbons that were significantly elevated in the JWPCP outfall fish livers, Σ DDT and Aroclor 1254, are compared to the $\delta^{15}\text{N}$ in *Citharichthys sordidus*, significant negative relationships are seen (Fig. 4). Normalization of Σ DDT and Aroclor 1254 to lipid content resulted in loss of significance for the relationship between Σ DDT and $\delta^{15}\text{N}$ ($r = 0.22$; $F = 0.98$; $p = 0.35$), but the relation was still significant for Aroclor 1254 ($r = 0.47$; $F = 5.2$;

Table 6. Comparison of contaminant concentrations in invertebrates between sites. Concentrations are in $\mu\text{g kg}^{-1}$ wet wt. SB: Santa Barbara; JWPCP: Los Angeles County Outfall. BD: below detection limit

Taxon	Site	ΣDDT	1242	Aroclors 1254	1260
<u>Polychaetes</u>					
Glycerids	SB	807	150	815	461
	JWPCP	7140	117	321	134
Lumbrinerids	SB	469	164	321	100
	JWPCP	22400	BD	511	5800
Nephtthyids	SB	266	116	97	601
<i>Heteromastus</i> sp.	JWPCP	7030	95	185	70
<i>Tharyx tessellata</i>	JWPCP	6090	376	164	20
<i>Pectinaria californica</i>	SB	57	53	55	18
	JWPCP	5270	1030	140	103
Misc. polychaetes	SB	82	39	50	67
	JWPCP	4260	471	140	89
<u>Other invertebrates</u>					
Nemerteans	SB	57	53	54	18
	JWPCP	2980	215	91	224
<i>Lytechinus pictus</i>	SB	23	26	41	24
Ophiuroids	SB	23	10	12	9

$p = 0.03$). Such relationships would be consistent with the thesis that as individuals feed more in the outfall area their nitrogen content becomes isotopically lighter and they accumulate greater amounts of lipids and attain higher concentrations of the contaminants elevated in the outfall area.

Citharichthys sordidus was the only species that showed a relationship between $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ ($r = 0.69$; $F = 15.4$; $p = 0.001$), such relationships are probably being obscured in the other species by body-size effects (Fig. 3). It is therefore not too surprising that relationships between isotope shifts and contaminant concentrations were not seen for the other 2 species. The lack of such relationships in the case of carbon isotopes may have been due to the effect variable lipid content of muscle had on $\delta^{13}\text{C}$ (Table 8). Lipids in organisms are isotopically lighter in carbon than proteins and carbohydrates due to isotopic fractionation associated with lipid synthesis (DeNiro & Epstein 1977). The δD values of fish were not different between sites and the lack of correlation with contaminant concentrations was therefore not surprising. Although comparison of trophic level with contaminant concentrations in 3 species of fish did not produce clear evidence of a positive correlation, such comparisons over a larger range of trophic levels does reveal such trends. In Fig. 5 the plot of mean ΣDDT and $\delta^{13}\text{C}$ for outfall organisms reveals large increase of ΣDDT with more positive values of $\delta^{13}\text{C}$ over a wide range of trophic levels. A similar relationship exists for Aroclor 1254 (not shown). To make this comparison, invertebrates were assigned to either a detritivore-grazer group (*Tharyx tessellata*, *Pectinaria californica*, nephtthyids,

Lytechinus pictus and ophiuroids) or a carnivore group (glycerids, lumbrinerids) based on the known feeding habits of each taxon. Assignment of polychaete feeding habits was based mainly on the work of Fauchald & Jumars (1979). In Fig. 5 the mean $\delta^{13}\text{C}$ value increases by ca 0.7 to 1.0 and ΣDDT concentrations by approximately an order of magnitude per trophic level. This relationship is based on chemical data that are not normalized to lipid content and the values for the fish species are only for the livers and not the whole fish. If it is assumed that there is as much as a 10 times lower concentration of ΣDDT in whole fish there would still be a similar relationship, due to the logarithmic increase of ΣDDT with each trophic step. The relationship in Fig. 5 is consistent with previous knowledge of the accumulation of lipophilic contaminants in higher trophic levels of food webs (see Murty 1986 for a discussion of the controversy surrounding the concept of food web magnification of chlorinated hydrocarbons).

Behavior of contaminants in the food web

Contaminant concentrations tended to be positively correlated in *Zanillepis latipinnis* but not in *Microstomus pacificus*. In Table 9 the correlations between lipid-normalized contaminant concentrations are presented for the 3 fish species. It can be seen that only a small number of significant correlations occur between chemicals in *M. pacificus* (6/55), a larger number (14/55) in *Citharichthys stigmaeus* and a much greater number in *Z. latipinnis* (47/55). This mirrors the trophic

Table 7. Comparison of contaminant concentrations in livers between fish species and sites. Mean ($\pm$ SD). Values in $\mu\text{g kg}^{-1}$ wet wt

Variable	Site	Species			Significant differences	
		<i>Microstomus pacificus</i>	<i>Zaniolepis latipinnis</i>	<i>Citharichthys sordidus</i>	Site	Species
HCB ^a	SB	54.4 $\pm$ 64.7 (4) ^b	10.9 $\pm$ 10.0 (5)	37.0 $\pm$ 38.9 (4)		
	JWPCP	6.02 $\pm$ 4.34 (19)	3.86 $\pm$ 3.31 (20)	34.0 $\pm$ 110.0 (18)		
Σ DDT	SB	2040 $\pm$ 2020 (4)	3900 $\pm$ 2840 (5)	1630 $\pm$ 548 (4)	***	
	JWPCP	23800 $\pm$ 9400 (19)	42400 $\pm$ 12900 (20)	60000 $\pm$ 39100 (21)		
Aroclor 1242	SB	1280 $\pm$ 1550 (4)	165 $\pm$ 146 (4)	264 $\pm$ 47 (4)		*
	JWPCP	653 $\pm$ 182 (19)	1080 $\pm$ 476 (20)	1300 $\pm$ 1280 (21)		
Aroclor 1254	SB	1260 $\pm$ 1460 (4)	388 $\pm$ 138 (4)	337 $\pm$ 218 (4)	*	***
	JWPCP	1330 $\pm$ 470 (19)	6550 $\pm$ 3610 (20)	9200 $\pm$ 11200 (21)		
Aroclor 1260	SB	2720 $\pm$ 2700 (4)	1630 $\pm$ 933 (4)	5320 $\pm$ 2040 (4)	***	***
	JWPCP	876 $\pm$ 781 (19)	2010 $\pm$ 1390 (20)	3920 $\pm$ 3000 (21)		
Phthalates						
Dimethyl	SB	169 $\pm$ 236 (4)	50.8 $\pm$ 39.0 (4)	131 $\pm$ 169 (4)		
	JWPCP	11.4 $\pm$ 17.1 (19)	13.1 $\pm$ 12.2 (19)	238 $\pm$ 858 (18)		
Diethyl	SB	365 $\pm$ 324 (4)	189 $\pm$ 128 (4)	257 $\pm$ 187 (4)		
	JWPCP	46.0 $\pm$ 37.9 (19)	29.2 $\pm$ 21.7 (20)	200 $\pm$ 661 (18)		
Dibutyl	SB	186 $\pm$ 113 (4)	20.0 $\pm$ 16.8 (4)	28.2 $\pm$ 24.4 (4)	**	***
	JWPCP	17.4 $\pm$ 12.2 (19)	11.1 $\pm$ 8.4 (20)	55.4 $\pm$ 83.7 (18)		
Butyl benzyl	SB	39.0 $\pm$ 47.5 (4)	2.6 $\pm$ 2.0 (4)	28.8 $\pm$ 35.3 (4)	***	***
	JWPCP	3.4 $\pm$ 4.0 (19)	3.2 $\pm$ 1.6 (20)	6.3 $\pm$ 4.0 (18)		
Dioctyl	SB	531 $\pm$ 731 (4)	42.9 $\pm$ 20.7 (4)	188 $\pm$ 301 (4)	**	**
	JWPCP	33.2 $\pm$ 12.2 (19)	66.8 $\pm$ 33.8 (20)	10.7 $\pm$ 78.7 (18)		
Bis(-2 ethylhexyl)	SB	173 $\pm$ 154 (4)	54.3 $\pm$ 28.5 (4)	254 $\pm$ 406 (4)	**	*
	JWPCP	46.4 $\pm$ 46.3 (19)	40.7 $\pm$ 23.9 (20)	83.1 $\pm$ 74.5 (18)		
Σ Phthalates	SB	1460 $\pm$ 823	360 $\pm$ 197	890 $\pm$ 1112	*	
	JWPCP	158 $\pm$ 84	164 $\pm$ 72.2	751 $\pm$ 1564		

^a HCB: hexachlorobenzene^b Sample size* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ by ANOVA

order of these species suggested by the carbon and nitrogen isotope data (Fig. 2) and the Cs/K data (Table 4). The cause of this phenomenon is unclear.

A related trend is that the organic compounds measured in *Zaniolepis latipinnis* tend to vary similarly between individuals when the compounds have a similar K_{ow} . (K_{ow} is the *n*-octanol/water partitioning coefficient of a compound.) This tendency is illustrated in Fig. 6, where the ratio of K_{ow} for pairwise comparison of compounds is weakly correlated ($p = 0.047$) to their correlation coefficients among individuals collected at JWPCP. This relationship was not evident in *Citharichthys stigmaeus* or *Microstomus pacificus*.

DISCUSSION

The lack of site differences for δD for all 3 species of fish was surprising since Rau et al. (1981) had found

differences between the JWPCP outfall area and the reference area near Ventura (southeast of Santa Barbara) for *Microstomus pacificus* and the shrimp *Sicyonia ingentis*, based on values for 5 specimens from each site. Our δD values for fish from both sites are very similar to values Rau et al. obtained in 1980 for *M. pacificus* from Ventura, while the values they obtained for this species from the JWPCP area were about -58‰ , much more closely aligned with our values for sewage particulate matter. This difference indicates a change in the organic matter utilized by the food web in the outfall sediments between 1979 and 1983, becoming more marine in character. During the 1970's and the early 1980's large reductions in mass-emission rates of suspended solids were achieved through improvements in the sewage treatment facilities by the County of Los Angeles (Stull et al. 1986a). Such drastic reductions have probably affected the balance of terrestrial and marine-derived organic matter in these

Fig. 4. *Citharichthys sordidus*. Relationships between $\delta^{15}\text{N}$ in flesh and concentrations of contaminants in livers (wet wt basis) of individuals from the JWPCP outfall area (a) ΣDDT and $\delta^{15}\text{N}$; (b) Aroclor 1254 and $\delta^{15}\text{N}$.

Table 8. *Microstomus pacificus*. Relative abundances of stable isotopes in muscle tissue from JWPCP fish before and after extraction of lipids

Sample	Material	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	δD
29618	Original sample	-21.7	9.3	-150
	Re-run	-19.7	9.3	-102
	Extracted lipids	-23.3	—	-160
	Lipid-free fish	-18.0	9.4	-85
29625	Original sample	-20.6	14.1	-116
	Re-run	-20.1	16.2	-114
	Extracted lipids	-23.4	—	-157
	Lipid free fish	-17.2	15.4	-72

sediments. Also in 1983 very severe storms disturbed sediments to depths greater than 60 m and it is not known what effect this may have had on the relative availability of sewage and endogenous organic matter in these sediments previous to our collections later that year.

There is relatively little information available on concentrations of neutral organic contaminants in marine invertebrates from the Los Angeles area. Concentrations of ΣDDT from 100 to 2100 $\mu\text{g kg}^{-1}$ wet wt have been reported in various whole crabs near the JWPCP outfall (Young & McDermott 1974). Our values for

Fig. 5. *Zaniolepis latipinnis*. Relation between correlation coefficients (Pearson's r) for pairs of chemicals on a lipid-weight basis and the ratios of their n -octanol/water partitioning coefficients ($\log K_{ow}$)

Fig. 6. Relation between trophic level, $\delta^{13}\text{C}$, and DDT concentrations in invertebrates and fish from the 2 study sites in the Southern California Bight

ΣDDT in infaunal invertebrates range from ca 4000 to 22000 $\mu\text{g kg}^{-1}$ wet wt. This difference may be due partly to differences in exposure or partly to different methods of estimating chemical recovery (Gossett pers. comm.). Also our determinations were made mainly on infaunal invertebrates and earlier measurements were made on epifaunal invertebrates.

Concentrations of ΣDDT have been reported from 19000 to 250000 $\mu\text{g kg}^{-1}$ wet wt in the livers of *Microstomus pacificus* (McDermott & Heesen 1975, Young & Heesen 1976, Gossett et al. 1982) and 125000 $\mu\text{g kg}^{-1}$ wet wt in the liver of *Citharichthys sordidus* (Gossett et al. 1982). Our mean values for *M. pacificus* are in the low end of the range previously reported and for *C. sordidus*, approximately half the previously published concentrations. Since our concentrations are corrected

Table 9. Pearson correlation coefficients between lipid-normalized concentrations of pairs of chemical contaminants in livers of 3 fish species collected near the JWPCP outfall. Significant correlations are underlined. Numbers refer to appropriate aroclors. Abbreviations: HCB, hexachlorobenzene; phthalic acid esters: DMP, dimethyl; DEP, diethyl; DBT, dibutyl; BBT, butylbenzyl; DOP, doctyl; DEHP, bis(-2 ethylhexyl)

	1242	1254	1260	ΣDDT	HCB	DMP	DEP	DBT	BBT	DOP	DEHP
A. <i>Microstomus pacificus</i>											
1242	1.0										
1254	0.24	1.0									
1260	0.32	0.28	1.0								
DDT	-0.16	0.67	-0.05	1.0							
HCB	<u>0.55</u>	-0.10	<u>0.55</u>	-0.34	1.0						
DMP	<u>0.20</u>	-0.17	<u>0.19</u>	-0.38	<u>0.51</u>	1.0					
DEP	-0.10	-0.41	-0.27	-0.32	0.21	0.39	1.0				
DBT	-0.22	-0.03	-0.26	0.41	-0.20	-0.25	0.45	1.0			
BBT	-0.15	-0.28	-0.09	-0.19	0.35	0.31	0.70	-0.11	1.0		
DOP	0.27	0.23	0.38	0.09	0.32	<u>0.68</u>	0.03	0.13	-0.04	1.0	
DEHP	0.37	0.30	0.39	0.32	0.30	0.41	0.05	0.41	0.13	<u>0.69</u>	1.0
B. <i>Citharichthys sordidus</i>											
1242	1.0										
1254	-0.07	1.0									
1260	0.38	-0.10	1.0								
DDT	0.37	<u>0.45</u>	0.31	1.0							
HCB	-0.07	-0.12	0.24	-0.08	1.0						
DMP	-0.18	-0.16	0.26	-0.20	<u>0.96</u>	1.0					
DEP	0.03	-0.22	0.36	0.07	<u>0.94</u>	<u>0.87</u>	1.0				
DBT	0.02	-0.03	0.30	<u>0.57</u>	0.11	0.18	0.21	1.0			
BBT	0.46	0.22	0.40	<u>0.78</u>	0.25	0.03	0.42	0.36	1.0		
DOP	0.45	<u>0.48</u>	0.38	<u>0.89</u>	0.11	-0.07	0.25	0.38	<u>0.95</u>	1.0	
DEHP	0.63	0.15	<u>0.70</u>	<u>0.80</u>	0.17	0.05	0.33	<u>0.50</u>	<u>0.76</u>	<u>0.77</u>	1.0
C. <i>Zaniolepis latipinnis</i>											
1242	1.0										
1254	<u>0.95</u>	1.0									
1260	<u>0.85</u>	<u>0.92</u>	1.0								
DDT	<u>0.85</u>	<u>0.92</u>	<u>0.85</u>	1.0							
HCB	<u>0.76</u>	<u>0.62</u>	<u>0.71</u>	0.50	1.0						
DMP	<u>0.57</u>	<u>0.66</u>	<u>0.70</u>	<u>0.52</u>	0.38	1.0					
DEP	<u>0.52</u>	<u>0.50</u>	<u>0.67</u>	<u>0.67</u>	<u>0.51</u>	<u>0.48</u>	1.0				
DBT	<u>0.86</u>	<u>0.84</u>	<u>0.83</u>	<u>0.83</u>	<u>0.70</u>	<u>0.49</u>	<u>0.74</u>	1.0			
BBT	<u>0.82</u>	<u>0.88</u>	<u>0.87</u>	<u>0.92</u>	<u>0.52</u>	<u>0.51</u>	<u>0.72</u>	0.88	1.0		
DOP	<u>0.84</u>	<u>0.85</u>	<u>0.83</u>	<u>0.90</u>	<u>0.57</u>	<u>0.44</u>	<u>0.69</u>	<u>0.87</u>	<u>0.97</u>	1.0	
DEHP	<u>0.49</u>	<u>0.43</u>	<u>0.35</u>	0.45	0.30	0.15	0.14	0.39	<u>0.52</u>	<u>0.60</u>	1.0

for recovery of the internal standard and those from previous studies have not been so corrected (Gossett pers. comm.), the actual differences are greater than the data indicate. It should again be emphasized that contaminated sediments in the outfall area have been covered with a layer of less contaminated material in recent years (Stull et al. 1986a). This could have resulted in less of the contaminants entering the food web at the time of this study and could partially explain the observed concentration differences between this and previous studies.

The correlation between body weight and $\delta^{15}\text{N}$ and *Microstomus pacificus* noted here was also seen by Rau et al. (1981), and the slope of their relation was identical to ours (0.06) (Fig. 3a). Rau et al. interpreted the

$\delta^{15}\text{N}$ shifts with size to indicate a metabolic effect, with more ^{15}N remaining in the fish with age. One would expect this metabolic effect to be a fairly general phenomenon, occurring in many fishes. We did not, however, find this same relationship in the other 2 species of fish, which indicates that the $\delta^{15}\text{N}$ trend in this species may be more related to ecological factors. Rau et al. (1981) found a 4.7‰ difference in $\delta^{15}\text{N}$ between fish from Ventura and the JWPCP area in 1979, while the difference we found between samples taken in similar areas in 1983 was 2.4‰. There were no significant differences in $\delta^{15}\text{N}$ between *M. pacificus* collected in the 2 studies from near the JWPCP ($p = 0.23$). Mean $\delta^{13}\text{C}$ in this species from near the JWPCP were nearly identical from the 2 studies. While we

ascribe size-related differences in $\delta^{15}\text{N}$ in *M. pacificus* mainly to changing diet with size rather than an isotope effect due to metabolism, the specimens analysed from Santa Barbara were much smaller (ca 8 g each) than those from the JWPCP outfall area (from 42 to 110 g each). Therefore, if there were really a relationship between size and $\delta^{15}\text{N}$ due to an isotope effect, the use of larger fish from the control area would have resulted in an even greater difference in $\delta^{15}\text{N}$ than observed.

The local movement of *Citharichthys sordidus* in and out of the outfall area is a behavior pattern consistent with the ecological data that indicate there is not a strong attraction of this species for the outfall area (Cross et al. 1985). This behavior pattern would be expected to result in both a greater accumulation of those contaminants that were elevated near the outfall and in isotope ratio shifts that were different in the outfall area in some individuals. Therefore, it might be expected that contaminant concentrations and shifts in stable isotope ratios might be correlated. Indeed, Aroclor 1254 and ΣDDT are elevated in these species relative to the SB reference site (Table 7) and their concentrations correlate with $\delta^{15}\text{N}$ (Fig. 4). An alternative explanation is that the switch from partly benthic to wholly pelagic prey in larger specimens (Allen 1982) would result in greater contaminant concentrations along with isotopic shifts toward lighter carbon and nitrogen. However, size did not correlate with either of these measures in this species.

It has now been well established that $\delta^{13}\text{C}$ increases slightly with each trophic transfer (DeNiro & Epstein 1978, Teeri & Schoeller 1979, Stephenson et al. 1986). This phenomenon has been utilized to interpret the structure of complex food webs where it is not entirely clear that the trophic level assignments should be for animals that feed on organisms from various trophic levels (Haines & Montague 1979, McConnaughey & McRoy 1979a, b, Rau et al. 1983). Data presented here indicate that a combination of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ predicts trophic level better than Cs/K. However, we used about 20 of each species for the isotope ratio analyses and only 5 of each species for the Cs and K analyses. Perhaps with more Cs/K values clearer separations between species, such as those observed from the isotope ratio data, would be evident.

The data support the following conclusions: (1) the 3 species of fish collected in the outfall area obtained about 15 to 20% of their carbon and nitrogen from sewage and this varied little between species; (2) carbon and nitrogen became isotopically heavier and Cs/K increased in the 3 species in the order of: *Microstomus pacificus*, *Citharichthys sordidus* and *Zaniolepis latipinnis*, which suggests strongly that trophic levels increase in this order; (3) *M. pacificus*, a species that apparently occupies a lower trophic level than the

other 2 species, accumulated the lowest concentrations of ΣDDT and PCBs; (4) Aroclor 1254 and ΣDDT bioaccumulate through the food web, from invertebrate detritus feeders to predatory fish, although for ΣDDT in fish this may relate to lipid content; (5) contaminants tend to correlate positively between individuals of a fish species with increasing trophic level, and the reason for this remains unclear.

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