FIN EROSION AMONG FISHES COLLECTED NEAR A SOUTHERN CALIFORNIA MUNICIPAL WASTEWATER OUTFALL (1971-82)[1]

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ABSTRACT

In the Southern California Bight, fin erosion is most frequently encountered among fishes collected near municipal wastewater outfalls. This paper presents an analysis of the trends in the incidence of fin erosion among fishes collected by otter trawls near Los Angeles from 1971 through 1982.

About 24% of the 122 species of fish and 9% of the more than 170,000 individuals collected had the disease. Flatfish (Pleuronectidae, Bothidae, and Cynoglossidae) and rockfish (Scorpaenidae) accounted for 66% of the affected species and 99% of the affected individuals. Dover sole (Pleuronectidae: *Microstomus pacificus*) accounted for 89% of the affected individuals.

The incidence of fin erosion was highest close to the outfalls and declined with increasing distance. The number of species with the disease declined from 1971 to 1982. The incidence of the disease also declined in two of the three most affected species (Dover sole and rex sole, *Glyptocephalus zachirus*). The contemporaneous decline in the number of species and the proportion of individuals with the disease and the decline in surface sediment contaminant levels suggest that the magnitude of contamination and the incidence of fin erosion are directly related.

The effect of fin erosion on the Dover sole population was examined. Dover sole recruit to the study area when they are 40-50 mm SL; the incidence of fin erosion was negligible in new recruits but increased rapidly with increasing fish size. No significant differences were detected in the length-weight relationships or size-at-age data between Dover sole with and without the disease. Survival rates of Dover sole with and without fin erosion were similar until age 3; thereafter, the survival rate of diseased fish was significantly lower.

Fin erosion in the Southern California Bight is most prevalent in fish collected near major municipal wastewater outfalls. Of the major outfalls, the disease is most frequently encountered around the Joint Water Pollution Control Project (JWPCP) outfalls on the Palos Verdes shelf (Mearns and Sherwood 1974, 1977; Sherwood and Mearns 1977). About 20% of the 151 species of fish collected in the Southern California Bight between 1969 and 1976 were affected by the disease. Flatfish (Pleuronectidae, Bothidae, and Cynoglossidae) and rockfish (Scorpaenidae) accounted for 60% of the affected species and 97% of the affected individuals (Mearns and Sherwood 1977; Sherwood 1978).

Municipal wastewater discharge on the Palos Verdes shelf began in the late 1930's. The mass emission of suspended solids increased steadily from about 17,000 metric tons (t) in the early 1940's to a peak of 167,000 t in 1971 (Wilson et al. 1980). Awareness of the problem of discharging excessive amounts of solids and associated contaminants by JWPCP in the early 1970's resulted in the installation of new equipment and more effective treatment procedures to reduce solid emissions. By 1981, discharge of suspended solids had declined to 84,000 t. The mass emission of contaminants also declined from 1971 to 1981 (Schafer 1982). Otter trawling, as part of a regular monitoring program of the animals on the Palos Verdes shelf, began in 1971.

The purpose of this paper is to determine trends in the incidence of fin erosion among fish collected by otter trawls near the JWPCP outfalls from 1971 through 1982. The prevalence of the disease over the size range of individuals collected and the effect of the disease on growth and survival are examined for the most affected species.

METHODS

The data analyzed in this study were collected by the Los Angeles County Sanitation District (LACSD) during regular monitoring cruises on the Palos Verdes shelf; station and transect identifications used herein are LACSD designations. Daytime trawls were made at three depths (23, 61, and

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137 m) at each of seven transects (Fig. 1) with an otter trawl towed along a depth isobath at 1.1 m/s for 10 min. A 7.3 m (headrope length) trawl was used from 1971 to 1974, when it was replaced by a 7.6 m net; a 1.25 cm mesh cod end liner was used in both nets. From 1971 through 1978, two samples—one between April and June and one between October and December—were collected annually at each depth; occasionally, additional trawls were made and these were included in the analyses. Quarterly trawling began in 1979 and has continued to the present. Sampling was discontinued at transects T2, T3, and T6 in 1977.

Trawl catches were sorted by species and processed on board ship. The standard length of each individual was determined on a measuring board (BSL = board standard length). External abnormalities (e.g., fin erosion, parasites, tumors) were recorded along with length.

Trends in the incidence of fin erosion per 10-min trawl were determined from linear regressions of the proportion (p) of fish with the disease (transformed to arcsin $\sqrt{p}$) versus time [numbered in consecutive months from 1971 through 1982 (i.e., 1, 2, 3, ..., 143, 144)]. Collections where only one individual of the species of interest was caught were dropped from the analysis because the resulting transformed datum (either 0 or 90) often had a large effect on the residual sum of squares. Trends in the total catch per 10-min trawl were determined from linear regressions of numbers [transformed to $\log_{10}(x + 1)$] versus time. The null hypothesis that the regression function (slope) was equal to zero was tested with a t-test. The null hypothesis of equality of the regression functions was tested by analysis of covariance (ANCOVA). If the null hypothesis was not accepted, significant differences were detected with a Newman-Keuls multiple range test (Zar 1974). Calico rockfish, *Sebastes dalli*, rex sole, *Glyptocephalus zachirus*, and Dover sole, *Microstomus pacificus*, accounted for 96.6% of the fish with fin erosion (Table 1) so the trend analysis was performed on each species individually. Less than 1% of the fin eroded fish came from the 23 m stations; these stations were then dropped from the analyses.

The quarterly trawl data (1979-82) from transects T4 and T5 were examined for seasonal trends in the total catch of Dover sole, the number with fin erosion, and the proportion with fin erosion with the following model:

$$Y_t = f(T_t, S_t) + \epsilon_t$$

where Y_t = observed abundance (or proportion) in period t, T_t = trend factor of time series in period t, S_t = seasonal factor of time series in period t, f = function relating observed abundance (or proportion) to the trend and seasonal components, and ϵ_t = irregular factor of time series in period t (Bowerman and O'Connell 1979). Multiplicative and additive models were fitted to the quarterly trawl data after transformation [$\log_{10}(x + 1)$ and arcsin $\sqrt{p}$]. Multiplicative models gave the best fit (lowest residual sum of squares) so only those results are presented. After determining the quarterly trends, the original transformed data were "deseasonalized" by dividing each value by the corresponding seasonal factor. Trends in the de-

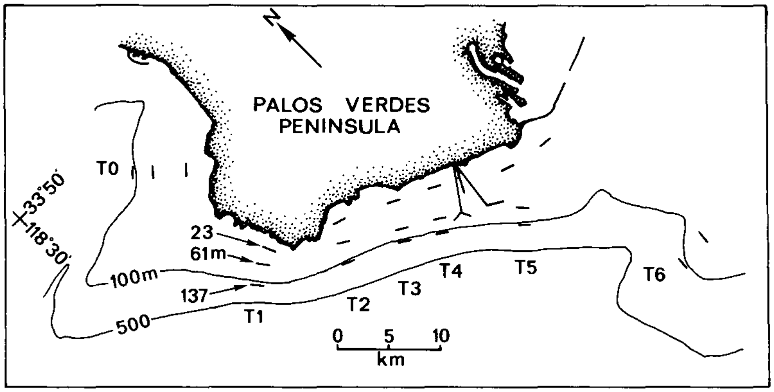

FIGURE 1.—Location of sampling transects on the Palos Verdes shelf. Three depths (23, 61, and 137 m) were sampled at each transect. Joint Water Pollution Control Project outfalls are located between transects T4 and T5. Net current flow is northwest.

TABLE 1.—Taxonomic list of fish affected with fin erosion collected in 622 otter trawls on the Palos Verdes shelf from 1971 through 1982.

Common name	Scientific name	Number collected	Frequency of occurrence (%) in trawl collections	Percent with fin erosion	Percent of all fish with fin erosion
spotted cusk-eel	*Chilara taylori*	191	16.7	0.5	<0.1
blackbelly eelpout	*Lycodopsis pacifica*	2,629	20.6	<0.1	<0.1
shortspine thornyhead	*Sebastolobus alascanus*	312	4.3	1.9	<0.1
calico rockfish	*Sebastes dallii*	9,153	23.6	9.9	5.8
shortbelly rockfish	*Sebastes jordani*	3,247	25.1	0.2	<0.1
stripetail rockfish	*Sebastes saxicola*	18,938	54.5	<0.1	<0.1
vermillion rockfish	*Sebastes miniatus*	382	17.1	0.5	<0.1
pink rockfish	*Sebastes eos*	37	1.1	5.4	<0.1
greenstriped rockfish	*Sebastes elongatus*	263	13.8	2.3	<0.1
splitnose rockfish	*Sebastes diploproa*	6,973	24.0	<0.1	<0.1
sablefish	*Anoplopoma fimbria*	711	15.6	0.3	<0.1
shortspine combfish	*Zaniolepis frenata*	794	20.6	0.1	<0.1
longspine combfish	*Zaniolepis latipinnis*	891	20.7	0.4	<0.1
barred sand bass	*Paralabrax nebulifer*	40	4.0	2.5	<0.1
white croaker	*Genyonemus lineatus*	9,062	20.9	1.6	0.9
white seaperch	*Phanerodon furcatus*	848	12.1	0.2	<0.1
shiner perch	*Cymatogaster aggregata*	9,478	27.1	<0.1	<0.1
Pacific pompano	*Peprilus simillimus*	30	2.0	20.0	<0.1
California tonguefish	*Symphurus atricauda*	1,091	25.4	1.7	0.1
Pacific sanddab	*Citharichthys sordidus*	11,698	61.3	0.5	0.4
speckled sanddab	*Citharichthys stigmaeus*	15,491	39.6	<0.1	<0.1
bigmouth sole	*Hippoglossina stomata*	148	14.6	2.1	<0.1
C-O sole	*Pleuronichthys coenosus*	187	10.8	1.1	<0.1
curlfin sole	*Pleuronichthys decurrens*	3,774	40.4	2.4	0.6
hornyhead turbot	*Pleuronichthys verticalis*	458	25.0	1.1	<0.1
English sole	*Parophrys vetulus*	1,256	44.7	0.9	<0.1
rex sole	*Glyptocephalus zachirus*	4,452	28.0	6.7	1.9
slender sole	*Lyopsetta exilis*	4,674	26.0	3.3	1.0
Dover sole	*Microstomus pacificus*	41,627	62.2	33.5	88.9

seasonalized data were determined by linear regression.

The effects of fin erosion on the population of Dover sole on the Palos Verdes shelf were examined using the original data of Mearns and Harris (1975)[3] that consisted of length, weight, sex, and age (from otoliths) of 328 Dover sole collected in 1972 and 1973.

Size-frequency distributions between Dover sole of the same age with and without fin erosion were compared with a Kolmogorov-Smirnov two sample test (Siegel 1957). A one-tailed test was used because the disease might be expected to reduce the growth rate of affected individuals.

Weight-length relationships among male and female Dover sole with and without fin erosion were compared with the geometric mean regression

$$\log w = \log a + b\ (\log l)$$

where w = weight, l = length, and a and b are fitted constants (Ricker 1973). The regression coefficients were compared statistically using the method of Clarke (1980).

The survival rate of Dover sole with and without fin erosion was compared. Using an age-length key developed from the data, ages were assigned to all Dover sole captured in LACSD monitoring trawls on the Palos Verdes shelf from 1972 through 1975. Survival rate (S) was calculated from age t (in years) to age $t + 1$ from

$$S = \frac{N_{t+1}}{N_t}$$

where N = the number caught (Ricker 1975). Survival rates of fish with and without the disease were compared with a t-test after the data were transformed to the reciprocal ($1/x$) to stabilize the variance. A one-tailed test was used because the disease might be expected to reduce the survival rate of affected individuals.

RESULTS

From 1971 through 1982, LACSD made 622 monitoring trawls on the Palos Verdes shelf. Fin erosion was reported for 15,680 individuals (9.2% of all individuals collected) representing 29 species (23.8% of all species collected) (Table 1).

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[3] Mearns, A. J., and L. Harris. 1975. Age, length, and weight relationships in southern California populations of Dover sole. Tech. Memo. 219, 17 p. Southern California Coastal Water Research Project, Long Beach.

Flatfish (Pleuronectidae, Bothidae, and Cynoglossidae) and rockfish (Scorpaenidae) accounted for 65.5% of the affected species and 99.2% of the affected individuals; Dover sole (Pleuronectidae) accounted for 88.9% of the affected individuals.

The number of species affected by fin erosion declined from a high of 18 in 1971 to a low of 3 in 1981 (Fig. 2); the decrease was highly significant ($r = -0.766$, $n = 12$, $0.002 < P < 0.005$). There was no significant change in the number of species collected over the same period (Fig. 2) ($r = -0.291$, $n = 12$, $0.20 < P < 0.50$).

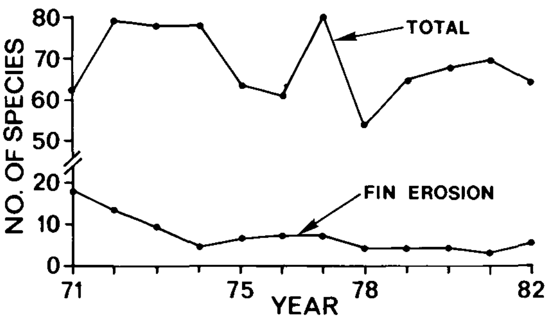

FIGURE 2.—Annual total number of fish species collected and number with fin erosion collected by otter trawl on the Palos Verdes shelf from 1971 to 1982.

CALICO ROCKFISH

Calico rockfish, *Sebastes dallii*, were rarely collected before 1975. Beginning in 1975, they were collected at all stations; the majority (72.4%) were collected at 61 m. Ten percent of the individuals collected had fin erosion; as a species, they accounted for 6% of all fish with the disease (Table 1). The incidence of fin erosion among calico rockfish increased at all 61 m stations from 1975 to 1982, but the increase was not significant at T0 (Table 2). ANCOVA detected a significant difference among the regression coefficients of the 61 m stations ($F = 5.02$, $0.003 < P < 0.005$) (Table 3).

The total number of calico rockfish collected in a 10-min trawl at 61 m decreased significantly at T4, but did not change at T0, T1, and T5 (Table 2). The regression coefficients for these collections were not significantly different ($F = 1.02, P > 0.25$).

REX SOLE

Seven percent of the rex sole, *Glyptocephalus zachirus*, had fin erosion; as a species, they accounted for 2% of all fish with the disease (Table 1). More than 99% of the rex sole collected were caught at 137 m. Less than 1% of the fish collected at station T0-137 m had fin erosion. The incidence of fin erosion among rex sole at the remaining 137 m stations declined significantly (Table 4). ANCOVA did not detect a significant difference among the regression coefficients for these collections ($F = 1.05, P > 0.25$).

The number of rex sole caught in a 10-min trawl at the 137 m stations did not change over the study period (Table 4), and the regression coefficients for these collections were not significantly different ($F = 1.43, 0.10 < P < 0.25$).

DOVER SOLE

Dover sole, *Microstomus pacificus*, was by far the most affected species. Thirty-four percent of Dover sole collected had fin erosion; as a species, they accounted for 89% of all fish with the disease (Table 1). The incidence of fin erosion among Dover sole declined significantly at all stations except T0-137 m (Table 5). ANCOVA detected a significant difference among the regression coefficients

TABLE 2.—Linear regressions of A) the proportion (p) of calico rockfish, *Sebastes dallii*, in one 10-min trawl with fin erosion (transformed to arcsin $\sqrt{p}$) and B) the total number of calico rockfish caught in one 10-min trawl [transformed to $\log_{10}(x + 1)$] against time (numbered in consecutive months from 1971 through 1982). n = sample size; L1 = lower limit of 95% confidence interval of the regression coefficient (b); L2 = upper limit; P = probability that b came from a sampling population with $\beta = 0$.

	Station	$\hat{Y} = a + bX$	n	L1	L2	P
A)	T0-61 m	$Y = -0.384 + 0.010X$	23	−0.020	0.040	$0.20 < P < 0.50$
	T1-61 m	$Y = -7.325 + 0.125X$	26	0.021	0.229	$P = 0.02$
	T4-61 m	$Y = -41.950 + 0.678X$	19	0.178	1.178	$0.01 < P < 0.02$
	T5-61 m	$Y = -20.150 + 0.410X$	21	0.070	0.751	$0.02 < P < 0.05$
B)	T0-61 m	$Y = 1.808 - 0.0027X$	25	−0.0150	0.0096	$P > 0.50$
	T1-61 m	$Y = 1.681 - 0.0015X$	27	−0.0115	0.0085	$P > 0.50$
	T4-61 m	$Y = 1.888 - 0.0098X$	26	−0.0194	−0.0002	$0.02 < P < 0.05$
	T5-61 m	$Y = 0.756 + 0.0021X$	26	−0.0076	0.0118	$P > 0.50$

of these collections ($F = 17.84, P < 0.0001$) (Table 6).

The total number of Dover sole collected in a 10-min trawl declined significantly at three of the eight stations (Table 5). ANCOVA detected a significant difference among the regression coefficients of these collections ($F = 3.43$, $0.001 < P < 0.003$) (Table 6).

TABLE 3.—Results of Newman-Keuls multiple range test for equality of regression coefficients (*b*) for the incidence of fin erosion among calico rockfish. s = station; underscored stations are not significantly different.

b:	0.678	0.410	0.125	0.010
s:	T4-61 m	T5-61 m	T1-61 m	T0-61 m

Size-Frequency Distributions

The size distributions of Dover sole with and without fin erosion were examined (Fig. 3). Most Dover sole recruit to the study area when they are 40-50 mm BSL (broad standard length). Fin ero-

TABLE 4.—Linear regressions of A) the proportion (p) of rex sole, *Glyptocephalus zachirus*, in one 10-min trawl with fin erosion (transformed to arcsin $\sqrt{p}$) and B) the total number of rex sole caught in one 10-min trawl [transformed to $\log_{10}(x + 1)$] against time (numbered in consecutive months from 1971 through 1982). See Table 2 for explanation of column headers.

	Station	$\hat{Y} = a + bX$	n	L1	L2	P
A)	T0-137 m	[only 7 of 1,520 fish (0.5%) had fin erosion]				
	T1-137 m	$Y = 10.217 - 0.085X$	33	−0.132	−0.038	$0.002 < P < 0.005$
	T4-137 m	$Y = 18.259 - 0.151X$	35	−0.239	−0.064	$0.001 < P < 0.002$
	T5-137 m	$Y = 10.733 - 0.087X$	29	−0.151	−0.023	$P = 0.01$
B)	T0-137 m	$Y = 1.828 - 0.0038X$	33	−0.0081	0.0005	$0.05 < P < 0.10$
	T1-137 m	$Y = 1.326 - 0.0012X$	33	−0.0053	0.0029	$P > 0.50$
	T4-137 m	$Y = 0.976 + 0.0023X$	36	−0.0020	0.0066	$0.20 < P < 0.50$
	T5-137 m	$Y = 1.182 - 0.0013X$	32	−0.0064	0.0038	$P > 0.50$

TABLE 5.—Linear regressions of A) the proportion (p) the Dover sole, *Microstomus pacificus*, in one 10-min trawl with fin erosion (transformed to arcsin $\sqrt{p}$) and B) the total number of Dover sole caught in one 10-min trawl [transformed to $\log_{10}(x + 1)$] against time (numbered in consecutive months from 1971 through 1982). See Table 2 for explanation of column headers.

	Station	$\hat{Y} = a + bX$	n	L1	L2	P
A)	T0-61 m	$Y = 0.861 - 0.0076X$	29	−0.0148	−0.0004	$0.02 < P < 0.05$
	T0-137 m	$Y = 0.907 - 0.0047X$	33	−0.0120	0.0026	$P = 0.20$
	T1-61 m	$Y = 29.526 - 0.240X$	24	−0.308	−0.172	$P << 0.001$
	T1-137 m	$Y = 28.048 - 0.201X$	33	−0.274	−0.128	$P << 0.001$
	T4-61 m	$Y = 54.520 - 0.332X$	29	−0.511	−0.154	$P < 0.001$
	T4-137 m	$Y = 48.157 - 0.224X$	36	−0.336	−0.112	$P < 0.001$
	T5-61 m	$Y = 54.732 - 0.374X$	31	−0.482	−0.266	$P << 0.001$
	T5-137 m	$Y = 38.618 - 0.214X$	30	−0.300	−0.128	$P << 0.001$
B)	T0-61 m	$Y = 1.601 - 0.0075X$	37	−0.0128	−0.0022	$0.005 < P < 0.01$
	T0-137 m	$Y = 1.981 - 0.0017X$	34	−0.0066	0.0032	$P > 0.50$
	T1-61 m	$Y = 1.603 - 0.0077X$	34	−0.0136	−0.0018	$0.01 < P < 0.02$
	T1-137 m	$Y = 2.432 - 0.0072X$	34	−0.0115	−0.0029	$0.001 < P < 0.002$
	T4-61 m	$Y = 0.688 + 0.0043X$	40	−0.0010	0.0096	$0.10 < P < 0.20$
	T4-137 m	$Y = 2.118 - 0.0007X$	36	−0.0044	0.0030	$P > 0.50$
	T5-61 m	$Y = 1.354 - 0.0018X$	39	−0.0067	0.0031	$0.20 < P < 0.50$
	T5-137 m	$Y = 2.592 - 0.0037X$	31	−0.0082	0.0008	$P = 0.10$

TABLE 6.—Results of Newman-Keuls multiple range test for equality of regression coefficients (*b*) for A) the proportion of Dover sole, *Microstomus pacificus*, with fin erosion and B) the total catch of Dover sole. s = station; underscored stations are not significantly different.

A)	*b*:	−0.374	−0.332	−0.240	−0.224	−0.214	−0.201	−0.008	−0.005
	s:	T5-61 m	T4-61 m	T1-61 m	T4-137 m	T5-137 m	T1-137 m	T0-61 m	T0-137 m
B)	*b*:	−0.0043	−0.0007	−0.0017	−0.0018	−0.0037	−0.0072	−0.0075	−0.0077
	s:	T4-61 m	T4-137 m	T0-137 m	T5-61 m	T5-137 m	T1-137 m	T0-61 m	T1-61 m

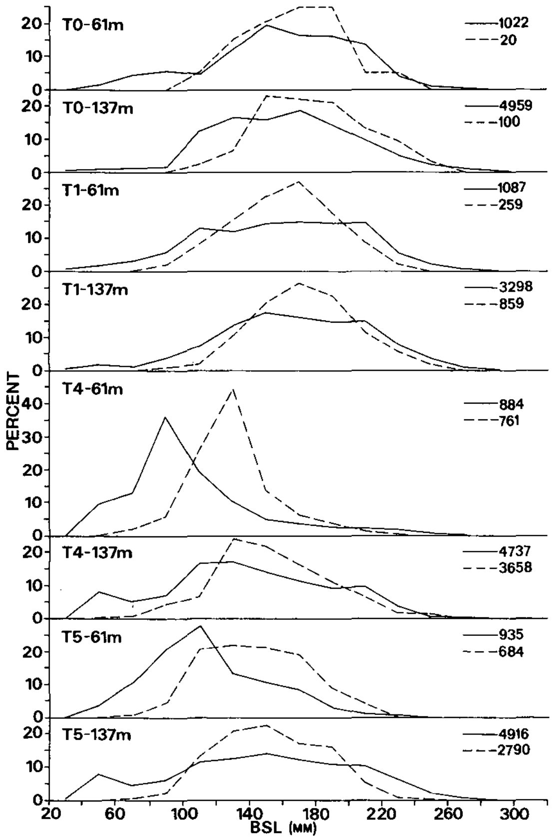

FIGURE 3.—Size distributions of Dover sole, *Microstomus pacificus*, with fin erosion (dashed line) and without fin erosion (solid line) by 20 mm size class (i.e., 20-39 mm, 40-59 mm, ..., 300-319 mm) for all collections (1971-82) combined. The number of individuals is presented to the right. BSL = board standard length.

sion was observed in 0.3% of the fish between 40 and 59 mm BSL, 3.8% of the fish between 60 and 79 mm BSL, and 17.7% of the fish between 80 and 99 mm BSL. The incidence of fin erosion peaked in fish 120-139 mm BSL at stations close to the outfalls, and in fish 140-179 mm BSL at more distant stations. The proportion of fish with fin erosion in a particular size class was greatest at stations close to the outfalls and declined progressively with increasing distance (Fig. 4).

Seasonal Trends

Time series analyses of the quarterly trawl data (1979-82) for Dover sole at T4 and T5 showed consistent seasonal peaks in the total catch and in the number of individuals with fin erosion, but not in the proportion of individuals with the disease (Fig. 5). The seasonal indices of total catch and number with fin erosion were highest in the second (April-June) and third (July-September) quarters at 61 m and in the third and fourth quarters at 137 m. The magnitude of the seasonal swing was greater at 61 m.

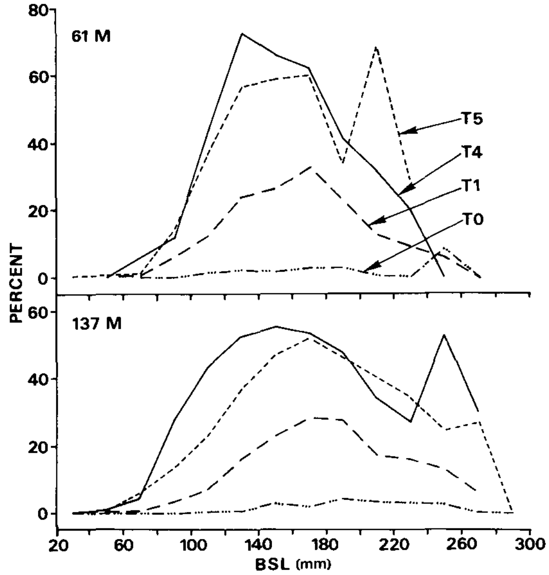

FIGURE 4.—Percent of Dover sole, *Microstomus pacificus*, with fin erosion in each 20 mm size class (i.e., 20-39 mm, 40-59 mm, ..., 280-299 mm) at 61 m and 137 m on the sampling transects. Data for each station are 12-yr totals. BSL = board standard length.

Examination of the deseasonalized data revealed that there was no change in the total catch of Dover sole, the number of individuals with fin erosion, or the proportion of individuals with fin erosion at 61 m between 1979 and 1982 (Table 7). At 137 m, there was a significant decline in the number of Dover sole with fin erosion at T4 and T5, and a significant decline in the total catch and proportion of individuals with fin erosion at T4 (Table 7).

Size at Age

The Mearns and Harris (footnote 3) data were examined for differences in the size-frequency distributions between Dover sole with and without fin erosion at a particular age. There were no significant differences for fish age 2 ($\chi^2 = 0$, df = 2, $P > 0.90$), age 3 ($\chi^2 = 1.27$, df = 2, $0.50 < P < 0.70$), age 4 ($\chi^2 = 1.71$, df = 2, $0.30 < P < 0.50$), or age 5 ($\chi^2 = 2.12$, df = 2, $0.30 < P < 0.50$).

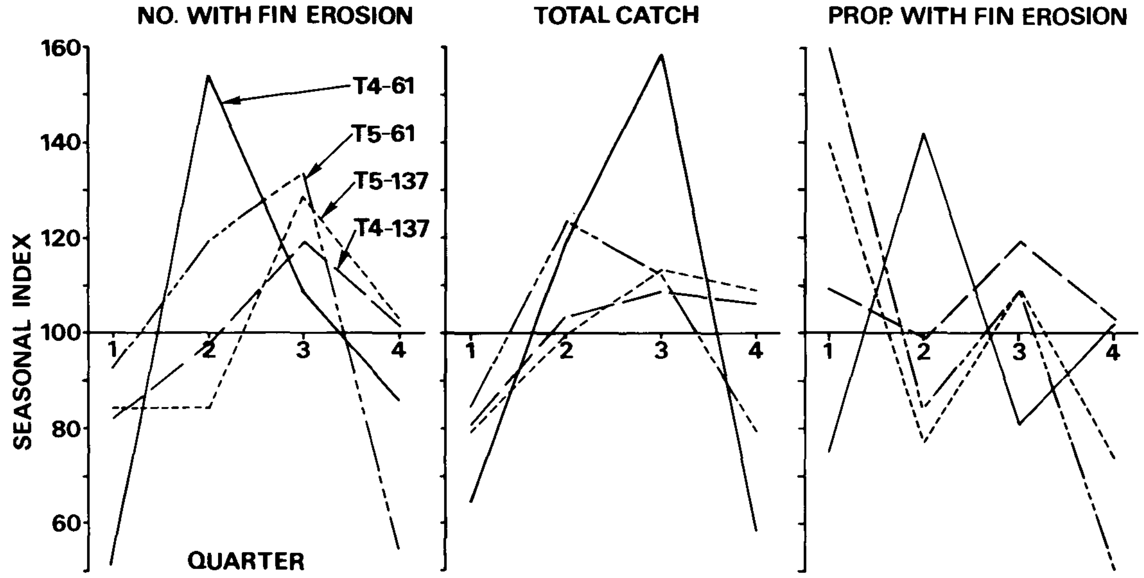

FIGURE 5.—Quarterly seasonal trends in the total catch of Dover sole, *Microstomus pacificus*, the number of individuals with fin erosion, and the proportion of individuals with fin erosion collected at 61 m and 137 m at T4 and T5 from 1979 through 1982. Quarter 1 = Jan.-Mar., 2 = Apr.-June, 3 = July-Sept., 4 = Oct.-Dec.

TABLE 7.—Linear regressions of the deseasonalized A) total catch of Dover sole, *Microstomus pacificus*, in one 10-min trawl [transformed to $\log_{10}(x + 1)$], B) number of Dover sole with fin erosion [transformed to $\log_{10}(x + 1)$], and C) proportion (p) of Dover sole with fin erosion (transformed to arcsin $\sqrt{p}$) regressed against time (numbered in consecutive quarters from 1979 through 1982). See Table 2 for explanation of column headers.

	Station	$\hat{Y}_t = a + bt$	n	L1	L2	P
A)	T4-61 m	$Y_t = 1.176 + 0.014t$	16	−0.057	0.085	$P > 0.50$
	T4-137 m	$Y_t = 2.467 - 0.036t$	16	−0.069	−0.003	$0.02 < P < 0.05$
	T5-61 m	$Y_t = 1.303 - 0.007t$	16	−0.082	0.068	$P > 0.50$
	T5-137 m	$Y_t = 2.509 - 0.041t$	16	−0.115	0.033	$0.05 < P < 0.10$
B)	T4-61 m	$Y_t = 0.370 + 0.043t$	16	−0.028	0.114	$0.20 < P < 0.50$
	T4-137 m	$Y_t = 2.303 - 0.075t$	16	−0.121	−0.029	$0.002 < P < 0.005$
	T5-61 m	$Y_t = 0.708 + 0.002t$	16	−0.056	0.060	$P > 0.50$
	T5-137 m	$Y_t = 2.082 - 0.067t$	16	−0.121	−0.013	$0.01 < P < 0.02$
C)	T4-61 m	$Y_t = 22.09 + 0.350t$	16	−1.616	2.316	$P > 0.50$
	T4-137 m	$Y_t = 48.45 - 1.470t$	16	−2.819	−0.121	$0.02 < P < 0.05$
	T5-61 m	$Y_t = 29.32 - 0.267t$	16	−2.055	1.521	$P > 0.50$
	T5-137 m	$Y_t = 40.87 - 0.982t$	16	−2.635	0.671	$0.20 < P < 0.50$

Weight-Length Relationships

The Mearns and Harris data were examined for differences in the weight-length relationships among males and females with and without fin erosion. There were no significant differences in the regression coefficients between males with and without the disease ($T_{12} = 1.587$, df = 38, $0.10 < P < 0.20$) and between females with and without the disease ($T_{12} = 0.508$, df = 56, $P > 0.50$) (Table 8). There was a significant difference between males and females without the disease ($T_{12} = 3.189$, df = 64, $0.002 < P < 0.005$), but not between males and females with the disease ($T_{12} = 0.713$, df = 37, $0.20 < P < 0.50$).

TABLE 8.—Results of the geometric mean regression of log w = log a + b (log l), where w = weight and l = length, for male and female Dover sole with and without fin erosion. L1 = lower limit of 95% confidence interval of the regression coefficient (b); L2 = upper limit.

Fin erosion	log w = log a + b (log l)	L1	L2
Males without	log w = −4.514 + 2.864 (log l)	2.663	3.065
Males with	log w = −4.994 + 3.114 (log l)	2.852	3.376
Females without	log w = −5.564 + 3.310 (log l)	3.116	3.504
Females with	log w = −5.379 + 3.234 (log l)	3.002	3.466

Survival Rates

The survival rates of Dover sole with and without fin erosion from Palos Verdes were not significantly different from age 1 to age 2 ($t = 1.267$, df $= 4$, $0.10 < P < 0.25$) and from age 2 to age 3 ($t = 0.741$, df $= 4, P = 0.25$) (Fig. 6). The survival rates were significantly lower for individuals with fin erosion from age 3 to age 4 ($t = 2.826$, df $= 4$, $0.01 < P < 0.025$) and from age 4 to age 5 ($t = 2.890$, df $= 4$, $0.01 < P < 0.025$). No individuals with fin erosion older than age 5 were collected (Fig. 6).

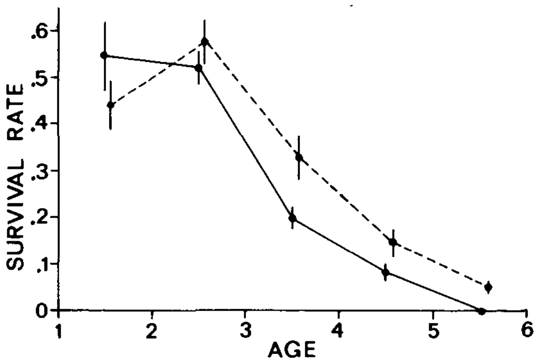

FIGURE 6.—Survival rate of Dover sole, *Microstomus pacificus*, with fin erosion (solid line) and without fin erosion (dashed line) from year t to year $t + 1$. Data presented as mean and 1 SE (vertical line).

DISCUSSION

Current and Sediment Characteristics on the Palos Verdes Shelf

Near the outfalls, the net current movement 20 m from the bottom in 61 m of water is 5.5 cm/s upcoast (northwest). Both net flow and major current fluctuations are oriented in the upcoast direction (Hendricks 1980). Sewage particles suspended in freshwater are discharged from the outfalls, rise in the water column, and are carried generally upcoast as they settle back to the bottom. Trace metal and chlorinated hydrocarbon contaminants measured in surface sediments reveal the characteristic "footprint" of the settled particles (Fig. 7) (Young and Heesen 1978; Young et al. 1978). The concentrations of DDT (Table 9), trace metals (Table 10), and organic material (Table 11) in surface sediments are highest around the outfalls and decline upcoast, and generally have declined during the study period.

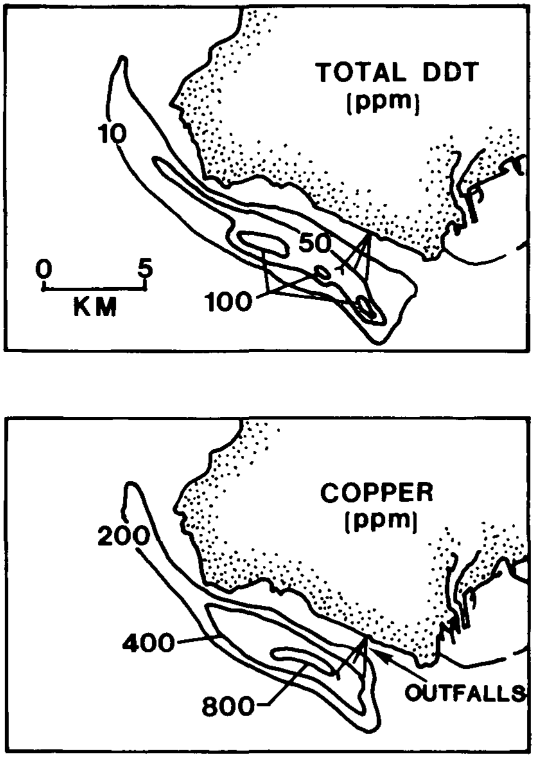

FIGURE 7.—Contour maps of total DDT (ppm dry weight) and copper (ppm dry weight) concentrations in surface sediments on the Palos Verdes shelf in 1975. Maps redrawn from Hershelman et al. (1977).

TABLE 9.—Total DDT concentration (ppm dry weight) of surface sediments at the sampling transects from 1972 to 1981. Note that the deeper samples were taken at 152 m while the trawls were made at 137 m. Depth of sediments analyzed at bottom of the table. (SCCWRP and LACSD, unpubl. data.)

	Year							
Station	1972	1973	1975	1977	1979	1980	1981	1982
T0-30 m		0.9				0.3		
T0-61 m		2.6	3.5			1.3	1.9	
T0-152 m		2.6	3.7			1.6		
T1-61 m		160	62		11	13	4	
T1-152 m		55	17					
T4-30 m		31				1.1		
T4-61 m		440	70	175	12	14	9	7.4
T4-152 m		220	133			72		
T5-61 m	130	95	29	20		12	12	
T5-152 m	80	95	124					
Depth (cm)	0-2	0-5	0-5	0-2	0-2	0-2	0-2	0-2

Spatial Disease Patterns

Of the three depths sampled (23, 61, and 137 m), <1% of the fish with fin erosion were collected at 23 m. This is probably a function of low sediment contamination at the shallowest stations (Table 9). Coastal sediments in southern California are

TABLE 10.—Copper, cadmium, and chromium concentrations (ppm dry weight) in surface sediments at the sampling transects from 1975 to 1980. Note that the deeper samples were taken at 152 m while the trawls were made at 137 m. Depth of sediments analyzed at bottom of table. (SCCWRP, unpubl. data.)

	Copper			Cadmium			Chromium		
Station	1975	1978	1980	1975	1978	1980	1975	1978	1980
T0-61 m	48	42		1.7	1.3		137	119	
T0-152 m	66	66		3.3	2.6		170	174	
T1-61 m	362			21			828		
T1-152 m	148			11			317		
T4-61 m	937	427	352	61	28	31	1,480	1,042	972
T4-152 m	555	408		66	24		968	862	
T5-61 m	134	234		8.3	9.2		254	521	
T5-152 m	433	301		41	16		769	605	
Depth (cm)	0-5	0-2	0-2						

TABLE 11.—Mean organic content (percent) of surface sediments at 61 m from 1972 to 1981 and correlation between organic content and years. $\bar{x}$ = mean, SD = one standard deviation, n = sample size, r = correlation coefficient, P = probability that the calculated r came from a population with $\rho = 0$.

Transect	$\bar{x}$	SD	n	r	P
T0	2.13	0.18	13	0.052	0.50
T1	6.83	1.45	17	−0.761	0.001
T4	11.21	1.39	17	−0.831	0.001
T5	7.83	1.62	17	−0.532	0.05

coarser and lower in volatile solids in shallow water, and become finer and higher in volatile solids with increasing depth. Contaminants are generally attached to the finer particles and thus increase in concentration with increasing depth (Hershelman et al. 1982).

The incidence of fin erosion in Dover sole followed the spatial pattern of sediment contaminant distribution. The incidence was highest near the outfalls (44.0% of all Dover sole collected at T4 and 37.3% at T5) and decreased with increasing distance upcoast (20.3% at T1 and 2.0% at T0). The relationship between disease incidence and sediment contaminant levels suggests that fin erosion is the result of contamination and that the incidence of the disease is directly related to the magnitude of contamination. Because preimpact data do not exist, gradients of contamination and disease are assumed not to have existed before sewage discharge began. It is generally accepted that the presence of fin erosion in the environment is the result of contamination (Murchelano and Ziskowski 1976; Sindermann 1979). Controlled laboratory experiments demonstrated that Dover sole exposed to sediments from the Palos Verdes shelf developed fin erosion (Sherwood 1976; Mearns and Sherwood 1977).

Temporal Disease Patterns

The number of species affected by fin erosion declined significantly from 1971 to 1982 and was most rapid from 1971 to 1974 following the wastewater treatment modifications made in the early 1970's. This pattern suggests that the decline was related to reduced surface sediment contamination.

The incidence of fin erosion also declined in two of the three most affected species (Dover and rex soles). The declines were greater at T1 than at T4 or T5; the incidence of the disease at T0, the station farthest from the outfalls, was always low. There was a significant correlation between the sediment concentration of DDT (Table 9) and the proportion of Dover sole with fin erosion (determined by dividing the total number of Dover sole with the disease by the total number of Dover sole collected within a year) at T4-61 m (Spearman $r_s = 0.821$, $n = 7$, $0.02 < P < 0.05$).

The seasonal trends in the catch of Dover sole and the number of Dover sole with fin erosion are the result of recruitment and depth-related migrations. Recruitment occurs at 61 and 137 m, but more fish settle out at 137 m. The magnitude of the seasonal swing appears greater at 61 m where few Dover sole were captured in the first and fourth quarters. Large numbers of Dover sole were collected at 137 m in the fourth quarter but, by the first quarter, the catches had declined substantially. Dover sole apparently move off the shelf into deeper water in the winter and back onto the shelf in the summer. Hagerman (1952) reported an annual depth-related migration of Dover sole into deeper water in the winter related to reproduction and a return migration into shallower water in the summer related to feeding.

Examination of the deseasonalized data revealed that fin erosion declined over the last 4 yr at the deeper (137 m) stations near the outfalls but not at the depth of the outfalls (61 m). The total catch of Dover sole also declined at 137 m but not at 61 m. The declines in Dover sole abundance in the long-term (1971-82) and deseasonalized quarterly (1979-82) data coincide with declines in surface sediment contamination and therefore are somewhat surprising.

In southern California, Dover sole are an order of magnitude more abundant around the outfalls than in distant control areas. This probably is a function of the distribution of their preferred prey (polychaetes) which are more abundant around the outfalls (Cross et al. in press). Pearcy and Hancock (1978) found a positive correlation between the standing crop of Dover sole and the standing crop of their preferred prey off Oregon. A decrease in the quantity of sewage particles settling at stations distant from the outfalls might cause a reduction in the preferred prey populations accounting for the reduced abundance of Dover sole. The decrease in organic content of surface sediments at T1, and the low value at T0, which was within the 95% confidence interval (2.12-2.84%) for reference areas in northern Santa Monica Bay (Cross, unpubl. data), support this hypothesis.

The trends in fin erosion among calico rockfish were different from those of the two soles. The general increase in disease incidence may result from differential susceptibility.

Effect of Fin Erosion on the Dover Sole Population

Although fin erosion has been reported in fishes from a number of areas around the world [southern California, Puget Sound, and the New York Bight (Sherwood 1982); Japan (Nakai et al. 1973); and northern Europe (Perkins et al. 1972)], no one has yet shown that the disease is harmful to the affected individuals (Murchelano and Ziskowski 1982).

Dover sole recruit to the study area between February and May when they are 40-50 mm SL (Allen and Mearns 1976; Sherwood 1980; Cross unpubl. data). Fin erosion is negligible in new recruits. By the time the fish are 80-100 mm BSL [about 100 d after settlement, based on growth curves presented in Sherwood (1980)], 18% have the disease. The size distributions of Dover sole with fin erosion are narrower than the size distributions of fish without the disease (Fig. 3). Underrepresentation in the lower tail of the size distribution of Dover sole with the disease occurs because the fish do not contract fin erosion until sometime after settlement. Underrepresentation in the upper tail suggests increased mortality among fish with the disease.

A size difference between Dover sole with and without fin erosion was not detected in the data. The χ^2 values increased with successive ages suggesting a significant difference in the size-frequency distributions may occur at an older age. Dover sole older than 7 yr were rarely encountered on the Palos Verdes shelf.

No significant differences were found in the weight-length relationships between males with and without the disease and between females with and without the disease. The significant difference observed between males and females without the disease is characteristic of Dover sole (Hagerman 1952). The lack of significant difference between males and females with fin erosion is difficult to interpret at this time.

Fin erosion appears to have a detrimental effect on the survival rate of Dover sole. Survival rates for Dover sole with and without the disease were similar up to 3 yr of age; thereafter, the survival rate of diseased fish was significantly lower.

CONCLUSIONS

The data presented in this study suggest that 1) fin erosion is the result of exposure to contaminants discharged from the outfalls and 2) the magnitude of disease incidence is directly related to the magnitude of sediment contamination. Disease incidence and sediment contaminant concentrations decrease with increasing distance from the outfalls. Disease incidence is negligible in Dover sole recruits but increases rapidly with increasing body size, and presumably contaminant exposure, after settlement. The number of species affected by the disease, the disease incidence in Dover sole, and the contaminant concentrations of surface sediments have declined over time.

While the prevalence of fin erosion has declined, the disease remains a problem. Fin erosion was observed in 5.9% of the fishes collected at 61 m and 137 m at T4 and T5 in 1982 and appears to affect at least one population causing increased mortalities.

Sindermann (1979) described fin erosion as "Probably the best known but least understood disease of fish from polluted waters..." (p. 719) and concluded "...that generalized disease signs, such as fin rot... may be characteristic of fishes resident in degraded habitats, where environmental stresses of toxic chemicals, low dissolved oxygen, and high microbial populations exist" (p. 722). The etiology of the disease is unknown. "The multifactorial genesis of disease in marine species is becoming apparent, involving environmental stress, facultative pathogens, resistance of hosts, and latent infections" (Sindermann 1979:741).

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