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THERMAL BEHAVIORAL RESPONSES OF THE SPECKLED SANDDAB, *CITHARICHTHYS STIGMAEUS*: LABORATORY AND FIELD INVESTIGATIONS

The speckled sanddab, *Citharichthys stigmaeus*, is a small bothid flatfish that is common in southern California (Ford 1965; Stephens et al. 1974). These authors and Helly[1] have suggested that temperature may have a significant effect on localized population abundances and distributions of speckled sanddabs. No studies to date, however, have examined in detail the relationship between temperature and fish behavior and distribution.

We designed this work to study the speckled sanddab population in King Harbor, Redondo Beach, Calif. This harbor (Figure 1), which receives the thermal effluent from an electricity generating station as well as cold upwelled water from the adjacent Redondo Submarine Canyon, contains a highly diversified thermal environment (Stephens 1972).

[1]Helly, J. J., Jr. 1974. The effects of temperature and temperature selection on the seasonality of the bothid flatfish, *Citharichthys stigmaeus*. Honors Thesis, Occidental Coll., Los Ang., 34 p.

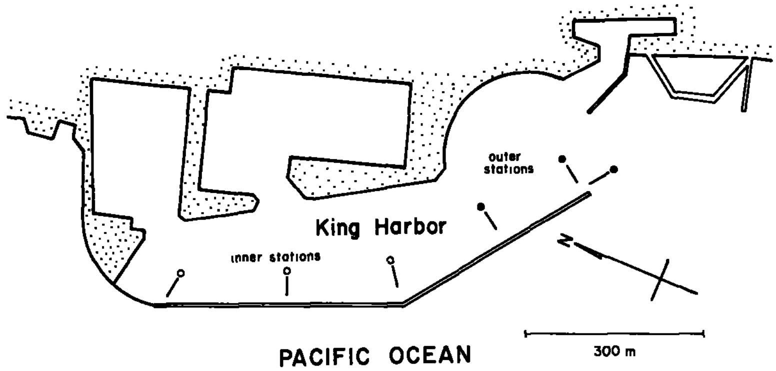

FIGURE 1.—Location of field sampling stations for speckled sanddabs in King Harbor, Redondo Beach, Calif.

Methods

We collected adult speckled sanddabs between August 1975 and January 1976 with a 3-m otter trawl. The fish were transported to the laboratory in aerated seawater and acclimated to a range of normally occurring temperatures (10.0°-19.7°C) according to the methods of Ehrlich et al. (1979). Prior to acclimating the speckled sanddabs, we removed the gill isopod *Livonica vulgaris* individually with forceps. During holding and acclimation, we fed the fish to satiation daily with live and frozen *Artemia salina*. The behavioral responses of the fish to temperature were studied using a 3.6-m long horizontal gradient and employing the techniques of Ehrlich et al. (1978). Each experiment lasted for 7-8 h with observations every 15 min. We shifted isotherm positions during each experiment to separate selection of temperature from preference for a given position within the experimental chamber.

Speckled sanddab abundance and distribution were studied using timed diver transects at six stations (Figure 1). Two divers swimming side by side for 5 min traversed each 6-m wide transect. They recorded the species and number of individuals observed in the same area. The transects by each pair of divers were run in duplicate on a monthly basis at each station from September 1974 through February 1976 and quarterly thereafter. In the analyses, we used the largest number of individual fish counted by either diver, but the average count of the two independent observations was used for estimates of large groups of fishes. The divers recorded the temperature at least twice during each transect, with thermometers readable to 0.5°C.

Results and Discussion

We examined the effects of acclimation temperature, size, and sex of speckled sanddabs on their temperature selection during 11 experiments (Table 1). The presence of some skewed temperature-specific frequency distributions (Table 1) precluded comparison of the results with parametric statistics. We tested these distributions for homogeneity using a Kruskal-Wallis test (Steel and Tor-

TABLE 1.—Temperatures selected by speckled sanddabs in laboratory experiments.

Date	No. test animals	No. fish observations	Standard length (mm) Mean	SD	Sex	Acclimation temperature (°C)	Selected temperature (°C) Mean	SD	Mode	Coefficient of skewness (g_1)	Coefficient of kurtosis (g_2)
21 Aug. 1975	9	265	96.3	0.6	not noted	14.0	10.5	3.4	10	0.493*	2.788
15 Dec.	8	230	91.5	1.3	not noted	10.0	12.3	4.5	9	0.543*	2.824
18 Dec.	8	218	88.5	3.2	M	19.7	10.5	4.1	8	0.673*	2.928
22 Dec.	9	220	90.3	3.5	F	18.9	10.1	2.6	9-10	0.427	3.438
5 Jan. 1976	9	210	77.1	4.0	M	15.2	10.9	2.6	11	0.220	3.512
8 Jan.	9	251	82.0	6.7	F	15.2	10.4	3.2	8-9	0.465	3.036
9 Jan.	9	250	82.0	6.7	F	15.2	11.6	3.6	8	0.573*	2.673
26 Jan.	6	162	76.3	5.6	M	12.0	9.9	4.3	8	0.400	0.592*
27 Jan.	6	167	71.5	2.7	M	12.0	10.5	2.5	9-10	0.291	2.372
29 Jan.	6	157	73.2	2.6	M	12.0	11.1	3.0	9	0.724*	2.538
30 Jan.	6	160	75.5	5.1	M	12.0	9.8	2.5	8	0.422	2.078

*$P<0.05$.

rie 1960) and detected no significant differences ($\chi^2_{10\,df}$ = 15.99, $P>0.05$). The overall mean selected temperature from pooled data was 10.8°C (SD = 3.1°C), and the mode was 9°C; 70% of all occurrences were in the range of 8°-13°C (Figure 2). The frequency distribution, however, was significantly skewed towards warmer temperatures (Figure 2).

Brett (1971) showed that the preferred temperature coincided with the optimal temperature for growth of sockeye salmon, *Oncorhynchus nerka*. Crawshaw (1977) found that physiological responses are often optimized in a zone of efficient operation rather than at a peak, and temperature preference reflects this. We are not aware of any work on the effects of temperature on the physiology of speckled sanddabs.

Considering the work of Brett (1971) and Crawshaw (1977), it is not unreasonable to suspect that speckled sanddabs may have a range of temperatures (approximately 8°-13°C) for efficient growth. The skewness may partially be due to activity increasing with temperature that could have resulted in occasional excursions into a greater number of compartments (temperatures) than at colder temperatures. Ehrlich et al. (1978) also suggested that skewness of a temperature-specific frequency distribution could result from preferred temperatures approaching lethal limits. These limits are not known for speckled sanddabs. DeWitt (1967) suggested that skewness of distribution could result from the regulation of body temperature by the animals depending on "... detection of deviations from a set point of some rate process bearing a direct exponential relation to body temperature.... Since physiological activity bears a direct exponential relation to temperature, the corresponding body-temperature distribution for the animals concerned would necessarily be negatively skewed." Speckled sanddabs, however, show a positively skewed mesokurtic distribution. A mesokurtic frequency distribution is not overly peaked (leptokurtic) or flat (platykurtic). Ivlev and Leizerovich (1960) and Ehrlich et al. (1979) used kurtosis to quantify the strength or precision of the preference: leptokurtic distribution indicates greatest preference.

The peak abundance of speckled sanddabs in King Harbor occurred from winter through spring and early summer when bottom temperatures were low (Figure 3). During the late summer and fall breakdown of stratification, warm bottom water was associated with a pronounced decrease in the number of fish observed. Stephens et al. (1974) found a similar decrease in abundance of speckled sanddabs during destratification in Los Angeles Harbor. Figure 3 also shows that the lower winter and early spring temperatures dur-

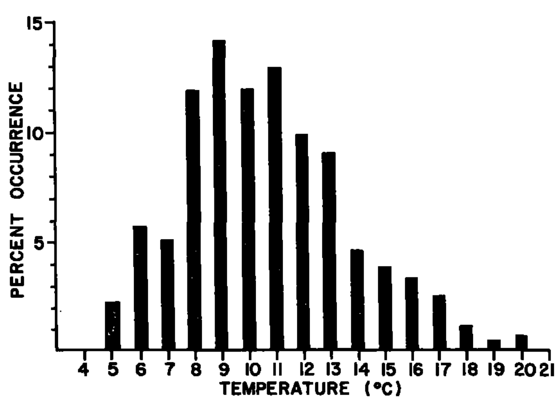

FIGURE 2.—Temperature-specific occurrences of speckled sanddabs, based on pooled data from 2,290 fish observations. The frequency distribution was significantly skewed toward warmer temperatures (g_1 = 0.571, $t_{99\,df}$ = 2.33, $0.01<P<0.025$) but was mesokurtic, that is not overly peaked or flat (g_2 = 3.078, $t_{99\,df}$ = 1.59, $0.1<P<0.2$).

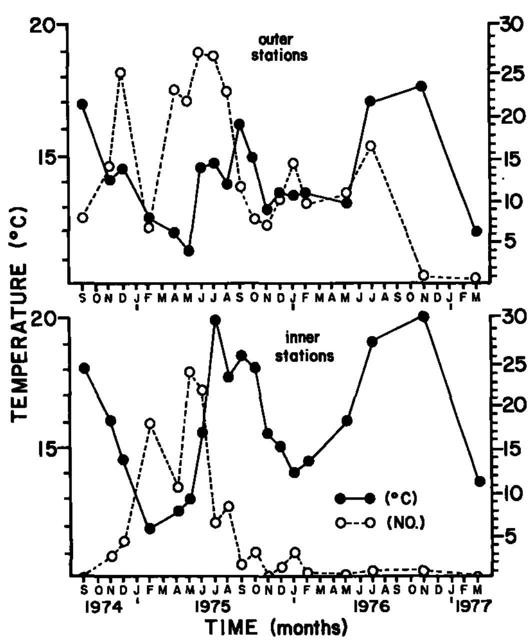

FIGURE 3.—Bottom temperatures and number of speckled sanddabs per transect at inner and outer stations in King Harbor, September 1974 to March 1977.

ing 1974, as compared with 1 yr later, coincided with a larger population of speckled sanddabs. The population density variability shown in Figure 3 results, at least in part, from the patchy distribution of the fish. Even at the time of year of greatest density the occasional transect found no fish. When fish were observed at these times of year, however, the numbers were high.

We grouped the abundance of speckled sanddabs per transect data according to the observed field temperature at the time of the survey to help explain the distribution of the fish (Table 2). The mean abundance per transect was determined for each observed field temperature (11°-20°C), and we calculated the percent occurrence at each temperature after correcting for the variation in occurrence of each temperature. This correction was accomplished by dividing the fish abundance at each temperature by the number of times the temperature occurred. We compared the temperature-specific field distribution with the temperatures selected in the laboratory by speckled sanddabs as a step in trying to understand the effect of temperature on field distributions. The laboratory data of temperature-specific occurrences was recalculated using only data for fish that were observed at 11°C or higher temperatures as if we had only sampled that part of the population occurring above 11°C (Figure 4). Statistical analysis of the arc sine transformed frequency distributions revealed no significant difference between laboratory and field data ($\chi^2_{9\,df}$ = 10.75, 0.25<P<0.50). We found a significant correlation between percent occurrence (arc sine transformed) and field temperature ($r_{8\,df}$ = −0.869, P<0.01) of the data in Table 2. This high degree of correlation indicates that 76% (r^2 × 100) of the variation in

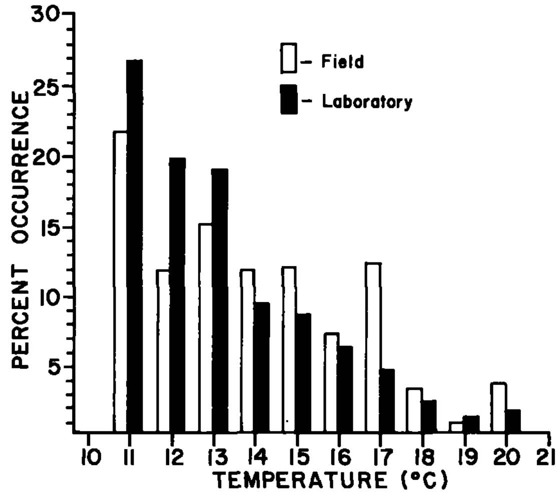

FIGURE 4.—Correspondence of temperature-specific occurrences of speckled sanddabs in the laboratory and field. The frequency distribution for the laboratory data was obtained from Figure 2 using only data for fish that occurred at 11°C or higher, which matched the range of observed field temperatures.

the field occurrence of speckled sanddabs in King Harbor seems explained by temperature. The similarity in temperature-specific distributions for the laboratory and field data (Figure 4) indicates that speckled sanddabs in King Harbor represented only that portion of the population found in warm water. Comparison of Figures 2 and 4 indicates that the greatest density of these fish may occur outside of the harbor in deeper, colder water. Furthermore, these fish in King Harbor do not appear to be a subpopulation endemic to this harbor. This would be in agreement with Taylor (1957) who suggested that there is but one popula-

TABLE 2.—Frequency of occurrence of temperatures and speckled sanddabs in King Harbor, Redondo Beach, Calif.

Parameter	11°C	12°C	13°C	14°C	15°C	16°C	17°C	18°C	19°C	20°C
Temperature occurrences (X)[1]	1	5	6	9	3	5	2	5	1	2
Fish abundance (Y)[2]	21.8	18.0	24.0	4.2	1.2	2.7	8.0	0.0	0.8	6.5
		10.5	24.7	3.0	27.0	21.8	16.6	8.5		0.8
		7.0	7.0	0.7	7.8	0.2		1.5		
		23.0	10.3	0.0		0.5		3.0		
		0.5	14.5	14.0		11.5		1.0		
			10.8	25.0						
				27.3						
				22.8						
				9.5						
ΣY	21.8	59.0	91.3	106.5	36.0	36.7	24.6	14.0	0.8	7.3
$\Sigma Y/X$	21.8	11.8	15.2	11.8	12.0	7.3	12.3	2.8	0.8	3.6
% occurrence[3]	21.9	11.9	15.3	11.9	12.1	7.3	12.4	2.8	0.8	3.6

[1] X is number of surveys that occurred at the indicated temperature.
[2] Y is number of fish observed per transect during each survey that occurred at the indicated temperature.
[3] % occurrence = $[(\Sigma Y/X)/\Sigma(\Sigma Y/X)] \times 100$, where $\Sigma(\Sigma Y/X)$ = 99.4. It is coincidental that this number approximates 100.

tion of speckled sanddabs over its entire open coast range.

Biotic and abiotic factors, in addition to temperature, must be considered when relating temperature preference data to field situations. Factors such as the presence of predators or prey, nutritive condition, light levels and/or physical substrate can influence the temperature selected under natural conditions (Fleming and Laevastu 1956; Brett 1970, 1971; Blackburn and Williams 1975; Beitinger and Magnuson 1975). Stephens (in press) reported that the speckled sanddab prefers sand (outer stations in King Harbor) rather than mud substrate (inner stations in King Harbor). These types of parameters are probably particularly responsible for the 22% variation in field occurrences that was not explained by temperature. In the laboratory where we controlled these variables, we found a higher correlation ($r_{8\,df} = -0.976$) between fish occurrence and temperatures, which accounted for 95% of the variation in fish position.

Based on the laboratory data, it appears that the water in King Harbor is usually warmer than that preferred by speckled sanddabs. This is particularly true if one considers the modal selected temperature (9°C). Reynolds (1977) suggested that the mode is the best indicator of fish's thermal preference. Occurrence of speckled sanddabs in King Harbor, where their modal preferred temperature was not observed on any of the surveys indicates that this harbor (particularly the inner part) may be a marginal area for this species. We observed a high rate of parasitism by the isopod *Livonica vulgaris* in King Harbor on speckled sanddabs (virtually 100% infection), compared with the lower levels (approximately 25% infection) observed in this species collected in La Jolla, Calif. (Ford 1965). This appears to support our hypothesis that this area may be of marginal value to speckled sanddabs and that they may be under stress and more susceptible to infection. Snieszko (1974) reported such a relationship between stress and infection for some fish species.

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MERCURY AND SELENIUM IN BLUE MARLIN, *MAKAIRA NIGRICANS*, FROM THE HAWAIIAN ISLANDS

In a previous study, nine species of pelagic and inshore fish caught in Hawaiian waters were analyzed for total and organic mercury (Rivers et al. 1972). In all but one species the organic mercury was >80% of the total, a finding consistent with other mercury values reported (Kamps et al. 1972; Westöö 1973). In muscle and liver tissues of blue marlin, *Makaira nigricans* Lacépède, however, only a small portion of the total mercury was found to be organic mercury. Additional studies on marlin landed during fishing tournaments in 1972 (Schultz et al. 1976) and 1973 (Schultz and Crear 1976) revealed low levels of organic mercury in six other tissues. These studies also showed that the difference between total and organic mercury was indeed inorganic mercury. G. Westöö (National Swedish Food Administration, Stockholm. Pers. commun., 1972) had previously identified the organic fraction as methyl mercury.

An assessment of mercury is complicated by the presence of selenium. Selenium has been shown to reduce the toxicity of mercuric chloride and methyl mercury in laboratory animals when given as selenite, selenomethionine, or as selenium present in tuna (Pařízek et al. 1971; Ganther and Sunde 1974). The presence of selenium in tuna, a principal food item of marlin (Naughton[1]), indicates that it should also be present in marlin.

For this report, nine tissues from blue marlin were analyzed for selenium, total mercury, and organic mercury.

Materials and Methods

Samples of muscle, liver, kidney, spleen, pyloric caecum, stomach, gill, gonad, and blood were collected from 46 marlin landed during a fishing tournament in Kailua-Kona, Hawaii, during August 1974. The tissues were ground with Dry Ice[2] in a blender and stored in acid-washed plastic vials.

The organic extraction was carried out as described by Rivers et al. (1972), i.e., a benzene extraction of the methyl mercury was reextracted with cysteine, oxidized with permanganate, and reduced to elemental mercury with stannous ion prior to being volatilized into the flameless atomic absorption apparatus. Total mercury digestions were performed (Rivers et al. 1972) but with 10 ml of concentrated nitric acid instead of 30 ml. All analyses were made with a Perkin-Elmer 303 atomic absorption spectrophotometer equipped with a vapor chamber (Manning 1970).

Selenium was determined by a fluorometric technique (Watkinson 1966), as modified by S. Nishigake (Tokyo Metropolitan Research Laboratory of Public Health, Tokyo, Japan. Pers. commun., 1975), i.e., following sample digestion with nitric and perchloric acids, the selenium was complexed with 2,3-diaminonaphthalene and this fluorescent compound then extracted into cyclohexane. All analyses were made using a Turner Model 110 fluorometer equipped with a primary filter at 369 nm and a secondary filter at 522 nm.

[1]Naughton, J. J. 1973. To all billfishermen. (Summary report of 15th Hawaiian International Billfish Tournament, 27-31 August 1973), 9 p. Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, Honolulu, HI 96812.

[2]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.