FEEDING HABITS OF BLACKSMITH, *CHROMIS PUNCTIPINNIS*, ASSOCIATED WITH A THERMAL OUTFALL

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ABSTRACT

The availability and use of food by blacksmith, *Chromis punctipinnis*, were examined at a thermal outfall and a control site in King Harbor, California. Stomach analysis showed that blacksmith from the outfall area consumed a significantly greater amount of food, consisting of larger prey items, than control fish. Movements of water created by the outflow may provide dietary benefits by reducing zooplankton predator avoidance and by entraining and entrapping organisms not normally planktonic. This dietary enrichment may result in attraction of blacksmith to the King Harbor outfall.

An increased demand for energy resulting in growth of coastal power plant activity has created concern for the effects of heated effluents upon the fish community (Miller 1977; Stephens 1978,[2] 1980[3]; Stephens and Palmer 1979[4]). Few studies have examined the factors attracting fish to outfall areas. White et al. (1977) found less diversity and lower abundance of fish at an outfall station, while Kelso (1976) and Minns et al. (1978) reported a clustering of fish in the vicinity of thermal outfalls. Underwater observations suggest that fish are attracted to thermal outfalls to feed. Kelso (1976) found that fish in proximity to a thermal discharge exhibited a complex swimming behavior that could represent feeding activity. Moreover, this behavior continued when unheated effluent was discharged.

The blacksmith, *Chromis punctipinnis* (family Pomacentridae), an abundant planktivorous temperate reef inhabitant, has been regularly observed feeding at the thermal outfall of a steam electrical generating station in King Harbor, Redondo Beach, Calif. Recent studies on the effects of thermal effluents upon blacksmith have concentrated on behavioral responses to intermittent chlorination (Hose and Stoffel 1980; Hose et al. in press). The objective of this study was to examine the feeding habits of blacksmith and determine whether the discharge was attracting them through dietary enrichment.

MATERIALS AND METHODS

This study was conducted at King Harbor, Redondo Beach, Calif., at the southern end of Santa Monica Bay, just north of the Palos Verdes Peninsula (Fig. 1, lat. 33°51'N, long. 188°24'W) (Terry and Stephens 1976; Stephens and Zerba 1981). Situated just offshore is the head of the Redondo Submarine Canyon, a source of cold upwelling water for the harbor. In contrast, thermal effluent from Units 7 and 8 of Southern California Edison's Redondo Beach steam electrical generating plant is discharged just inside the harbor mouth.

The thermal outfall study site consists of a vertical conduit, 4 m in diameter, out of which the effluent is pumped. The circular outlet is level with the substrate at a depth of 7 m. Effluent is discharged at a rate of 1.78×10^6 l/min during peak operation.

A control site was chosen about 500 m from the discharge. This area, referred to as the Point, is located at the tip of the breakwater that partially encloses the harbor. This site has been surveyed by Stephens and Zerba (1981) who note that blacksmith are an abundant resident species.

A form of presence/absence monitoring was used as an indicator of fish abundance at the discharge. Mean estimates (0-25, 26-50, 51-75, 76-100, or >100) were made by two scuba divers swimming a circular transect around the discharge. The position of fish was recorded: in the plume (the column of water directly over the discharge), in the outer plume (the area of

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[2] Stephens, J. S., Jr. 1978. Effects of thermal effluent from Southern California Edison's Redondo Beach steam generating plant on the warm temperate fish fauna of King Harbor Marina. Fish and laboratory study reports for Phase III. VANTUNA Research Group, Department of Biology, Occidental College, Los Angeles, CA 90041.

[3] Stephens, J. S., Jr. 1980. Effects of thermal effluent from Southern California Edison's Redondo Beach steam generating plant on the warm temperate fish fauna of King Harbor Marina. Fish and laboratory study reports for 1977-1978. VANTUNA Research Group, Department of Biology, Occidental College, Los Angeles, CA 90041.

[4] Stephens, J. S., Jr., and J. B. Palmer. 1979. Can coastal power stations be designed to offset impacts by habitat enrichment? Gen. Tech. Rep. RM-65, p. 446-450. Paper presented at Mitigation Symposium, U.S. Department of Agriculture, Fort Collins, Colo.

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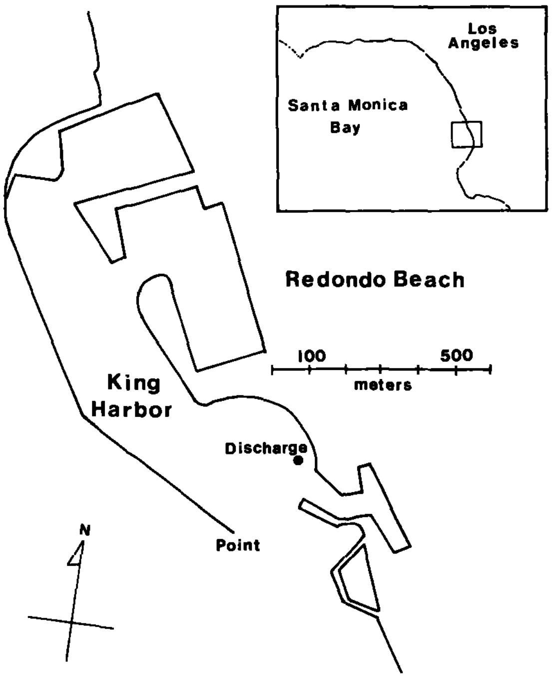

FIGURE 1.—Study area at King Harbor, Redondo Beach, Calif.

water immediately surrounding the plume), or at the base (the substrate surrounding the discharge).

The abundance of fishes at the Point has been documented since 1974 (Stephens and Zerba 1981), and work continued at this area during the same time period the discharge was examined. Two divers equipped with slates and depth gauges swam in one direction along the rock breakwater at a fixed depth for 5 min, counting all fish seen 1.5 m above and below them and within sight to either side. Transects were run at depths of 1.5, 4.5, 7.5, and 10.5 m, with replicates at each depth.

In order to determine the nature of the feeding habits of blacksmith at the discharge versus those feeding at the Point, utilization of food items based on stomach analysis was examined for each area. General availability of food was estimated by sampling plankton at both sites.

Stomach analysis closely followed methods employed by Ellison et al. (1979). Fish were collected from each study site by scuba divers using pole spears. During fish collection, a temperature profile was taken using a temperature probe coupled to a telethermometer (Yellow Springs Instruments Co., Model 431D[5]). After capture the fish were placed on ice. The body wall was cut open and the stomach injected with a 20% Formalin solution. The fish were then preserved in a 10% Formalin solution for at least 48 h, rinsed in running water for 2 h, and placed in 70% isopropyl alcohol.

Within 2 wk from date of capture, fish stomachs were removed and placed in vials of 70% isopropyl alcohol. At this time the standard length, wet weight, and sex of each fish were noted. Each stomach was then blotted dry (with special care taken to remove the internal fluid) and weighed, food items dissected out, and the empty stomach weighed again. Stomach fullness was estimated using a scale from 0 (empty) to 5 (full).

Individual prey items were separated into the lowest identifiable taxa and counted, and the percent of the total volume estimated. In most cases, only whole organisms or whole organism indicators were counted. In prey items which were not eaten whole (i.e., algae and ectoprocts), only the percent volume was estimated.

In 1979-80, 73 fish were collected at the discharge area from 13 sampling days during a 15-mo period. Four sampling days were in the afternoon (1430-1830 h) and 10 were in the morning (0830-1100 h). A total of 35 blacksmith were collected from the Point area before noon (1000-1130 h).

During the study period, 28 plankton samples from the discharge plume and 13 plankton samples from the Point were collected. The mean rank order abundance of prey items from each site was determined for comparison with blacksmith stomach contents.

Observations comparing different prey items from two locations were tested using contingency table analysis, the G-test (Crow 1982), and Kendall's coefficient of rank correlation. When only one variable (fish weight, stomach fullness etc.) was tested between two locations, a two-sample t-test was used, assuming separate variances. Values of the Index of Relative Importance (IRI) were calculated for consumed prey from the sum of the percent number and the percent volume, multiplied by the frequency of occurrence (Foc) (Pinkas et al. 1971).

Dietary overlap between blacksmth from the Point and discharge was examined using the formula of Schoener (1970):

$$a = 1 - 0.5 \left(\sum_{i=1}^{n} |Px_i - Py_i| \right)$$

where n is the number of food categories, x_i is the average percentage of estimated volume that food category i contributed to species at location x, and y_i is the average percentage of estimated volume that food category i contributed to species at location y.

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

An estimate of mean prey size was obtained by dividing the total number of prey consumed into the stomach weight for each fish collected.

RESULTS

Thirty species of fish were identified from the area surrounding the discharge. Blacksmith were the most abundant and frequently occurring fish (mean estimate of abundance per transect >100 individuals, rank of the mean number per transect = 1, and frequency of occurrence per transect = 92.3). Large schools arrived in the morning and began feeding in the plume and outer plume. When feeding in the outer plume, blacksmith would orient themselves toward the plume, surrounding it, and feed on the organisms that settled out of the rising effluent. When in the plume, blacksmith were in constant motion, being tossed about by the irregular flow, but it was apparent from mouth action that these fish were also feeding on suspended food items.

The mean abundance per transect of blacksmith at the Point for the quarterly sampling days in 1979 and 1980 was 148.4. They ranked first in mean number per transect, with a mean frequency of occurrence of 86.2, and used the breakwater as their primary nocturnal sheltering site.

There were no significant differences in either fish length or fish weight, but there were significant differences in stomach weight and stomach fullness between the two collection sites (Table 1). Fish collected from the discharge had a greater amount of food in their stomachs (an increase of 138%).

Stomach fullness was not influenced by collection time. The stomach weight and stomach fullness were not significantly different between morning and afternoon collections (t-test: $t = 1.359, P = 0.181$ and $t = 1.471, P = 0.147$, respectively). Consequently, the data collected from the discharge samples were combined.

TABLE 1.—Comparison of blacksmith, *Chromis punctipinnis*, collected from the discharge (thermal outfall) and the Point (Control Site), King Harbor, Calif.

	Discharge $n = 73$	Point $n = 35$
Fish weight (g)	Mean = 175.6 g SD = 38.4 $t = 0.819$ $P = 0.416$	Mean = 168.3 g SD = 44.7
Fish length (SL mm)	Mean = 172.8 mm SD = 12.9 $t = 0.569$ $P = 0.571$	Mean = 172.2 mm SD = 14.3
Stomach weight (g)	Mean = 1.10 g SD = 0.53 $t = 9.726$ [1]$P < 0.001$	Mean = 0.30 g SD = 0.25
Stomach fullness (0-5)	Mean = 3.89 SD = 1.06 $t = 10.175$ $P < 0.001$	Mean = 1.63 SD = 1.09

[1] *Note: The statistical package (SPSS) used was unable to compute P values lower* than 0.001. Values below this number are represented as $P < 0.001$.

The mean prey abundance, percent number, percent volume, frequency of occurrence, and the calculated IRI value of the 30 most abundant prey items from each location are given in Table 2. A contingency table analysis of the mean abundance indicates that there was a significant difference in the stomach contents between the two locations ($G = 570.6, P < 0.001$, df = 17). The 10 most abundant prey from each site (eliminating the smaller values) are significantly different ($G = 561.1, P < 0.001$, df = 12). A comparison of the 10 highest IRI values from each site are not significantly correlated (Kendall's tau, $t = 0.1868, P = 0.324, n = 14$). A pictorial representation of the IRI values is given in Figures 2 and 3.

A comparison of the mean prey weight from each sampling site revealed that blacksmith from the discharge ate larger prey than blacksmith from the Point (discharge mean prey weight = 3.22 mg, SD = 4.01, Point = 0.82 mg, SD = 0.81, $t = 4.439, P < 0.001$).

Temperatures from the discharge plume and base were compared with surface and bottom temperatures at the Point. The mean plume temperature (26.3°C, SD = 3.3, $n = 15$) was significantly greater (t-test: $t = 5.69, P < 0.001$) than the mean surface temperature from the Point (20.8°C, SD = 2.5, $n = 30$). Similarly, the mean base temperature (18.2°C, SD = 2.4, $n = 17$) was significantly greater ($t = 4.12, P < 0.001$) than the mean bottom temperature from the Point (15.2° C, SD = 2.4, $n = 30$).

The rank of the 10 most abundantly consumed prey items was compared with the rank of the 10 most abundant plankton items for both the discharge and Point. There was no significant correlation for either study site (discharge $t = 0.0110, P = 0.956, n = 14$; Point $t = 0.2051, P = 0.329, n = 13$).

Between-site comparisons of the mean abundance of six abundantly consumed prey items from both stomach contents and plankton samples (Table 3) show that two prey items, gammarids and *Polyophthalmus pictus*, had a significantly higher usage and availability at the discharge than the Point, and that *Calanus* sp. and mysids had a higher usage at the discharge but were not significantly more available. There was no significant difference in the usage or availability of *Oikopleura* sp. between the Point and discharge (although blacksmith from the Point tended to eat a greater amount).

The diets of blacksmith at the discharge and Point

TABLE 2.—The 30 most abundant food items consumed by blacksmith, *Chromis punctipinnis*, at the discharge (thermal outfall) and the Point (control site), King Harbor, Calif. Foc = frequency of occurrence; IRI = index of relative importance.

	Point					Discharge				
	$\bar{x}$ no.	% no.	% vol.	Foc.	IRI	$\bar{x}$ no.	% no.	% vol.	Foc.	IRI
Oikopleura	430.49	77.5	41.3	77.1	9,159.5	290.63	33.7	10.8	87.7	3,902.7
Acartia	59.03	10.6	3.2	71.4	985.3	46.38	5.4	2.1	67.1	503.3
Calanoids, misc.	26.11	4.7	3.2	71.4	564.1	14.86	1.7	1.4	75.3	233.4
Polychaeta, misc.	8.03	1.4	1.6	57.1	171.2	2.53	0.3	1.2	50.7	76.1
Corycaeus	6.51	1.2	1.4	45.7	118.8	3.68	0.4	0.5	42.5	38.3
Calanus	5.29	0.9	5.7	62.9	415.1	298.36	34.6	11.0	76.7	3,497.5
Chaetognath	4.51	0.8	3.4	57.1	239.8	4.14	0.5	0.5	34.2	27.4
Labidocera	2.60	0.5	2.2	48.6	131.2	2.12	0.2	0.6	52.1	41.7
Brachyuran zoea	1.89	0.3	0.9	22.9	27.5	8.14	0.9	1.2	46.6	97.9
Gammaridae	1.83	0.3	1.1	42.9	60.1	111.33	12.9	25.3	91.8	3.506.8
Pagurid zoea	1.63	0.3	0.6	25.7	23.1	3.27	0.4	0.5	43.8	39.4
Cladocera	1.60	0.3	0.4	28.6	20.0	0.49	0.1	0.1	20.5	5.7
Rhincalanus	1.17	0.2	0.6	34.3	27.4	2.27	0.3	0.6	41.1	30.9
Euphausids	0.97	0.2	0.4	25.7	15.4	0.82	0.1	0.1	26.0	5.2
Tortanus	0.77	0.1	1.2	28.6	37.2	1.52	0.2	0.4	32.9	17.2
Cypris larvae	0.54	0.1	0.2	22.9	6.9	1.10	0.1	0.2	37.0	11.1
Fish eggs	0.49	0.1	0.2	28.6	8.6	0.53	0.1	0.1	24.7	4.9
Cirripide exoskel.	0.46	0.1	0.1	14.3	2.9	0.42	0.1	0.6	27.4	10.0
Polyophthalmus pictus	0.34	0.1	0.1	2.9	0.3	25.70	3.0	6.8	28.8	282.2
Gastropoda	0.34	0.1	0.2	22.9	6.9	0.37	0.1	0.1	20.5	4.1
Fish larvae	0.31	0.1	0.3	17.1	6.8	3.29	0.4	1.4	35.6	64.1
Mysids	0.31	0.1	0.2	20.0	6.0	36.01	4.2	7.7	80.8	961.5
Opheliidae	0.14	0.1	0.1	8.6	1.7	0.90	0.1	0.3	30.1	12.0
Decapoda, misc.	0.06	0.1	0.2	5.7	1.1	0.55	0.1	0.9	30.1	30.1
Caprellidae	0.03	0.1	0.1	2.9	0.3	1.90	0.2	1.0	46.6	55.9
Porcellanid zoea	0.03	0.1	0.1	2.9	0.3	0.89	0.1	0.2	32.9	9.9
Pelecypoda	0	0	0	0	0	0.60	0.1	0.4	24.7	12.4
Anemone	0	0	0	0	0	3.29	0.4	0.5	15.1	13.6
Ecto-Entoprocta	—	—	0.1	2.9	0.3	—	—	1.5	8.6	12.9
Unidentified, misc.	—	—	11.2	35.3	395.4	—	—	6.9	42.9	296.0

TABLE 3.—Usage and availability of selected prey items from the Point (control site) and discharge (thermal outfall), King Harbor, Calif.

	In stomachs[1]		In plankton[2]	
Prey items	Discharge	Point	Discharge	Point
Polyophthalmus pictus				
Mean	25.70	0.34	30.59	0
SD	67.49	2.03	86.52	0
	$t = 3.207$	$P = 0.002$	[3]$P < 0.001$	
Acartia				
Mean	46.38	59.03	181,987.13	167,487.59
SD	112.02	130.95	323,297.81	133,525.13
	$t = 0.492$	$P = 0.625$	$t = 0.031$	$P > 0.840$
Calanus				
Mean	299.36	5.29	364.41	721.00
SD	753.29	11.96	717.27	1,260.84
	$t = 3.323$	$P = 0.001$	$t = -0.959$	$P = 0.353$
Mysidacea				
Mean	36.01	0.31	943.28	306.38
SD	75.38	0.72	3,562.00	568.29
	$t = 4.046$	$P < 0.001$	$t = 0.981$	$P = 0.333$
Grammaridae				
Mean	111.33	1.83	6,291.81	472.92
SD	174.51	4.52	10,784.44	845.73
	$t = 5.357$	$P < 0.001$	$t = 3.029$	$P = 0.005$
Oikopleura				
Mean	290.63	430.49	6,829.81	4,582.08
SD	471.00	557.59	19,821.55	9,906.22
	$t = -1.281$	$P = 0.205$	$t = 0.505$	$P = 0.616$

[1] Mean number of prey consumed per fish.

[2] Mean number per 100 m^3 of water sampled.

[3] Note: The statistical package (SPSS) used was unable to compute P values lower than 0.001. Values below this number are represented as $P < 0.001$.

did not overlap ($\alpha = 0.522$, with a value >0.60 considered significant, Zaret and Rand 1971).

DISCUSSION

Blacksmith were a numerically dominant species at both study sites. The daytime abundance of blacksmith was similar at the discharge and the Point. Blacksmith may travel to the discharge from the breakwater and other nearby jetties during the day, since they do not seek shelter around the discharge at night. Such diel migrations of blacksmith between the Units 7 and 8 intake of Southern California Edison's Redondo Beach Station and the nocturnal rocky shelters at the Point have been previously observed.[6]

The feeding habits of blacksmith were significantly different between the Point and discharge (Figures 2 and 3 best illustrate this difference). At the Point, *Oikopleura* and calanoid copepods (primarily *Acartia*) were the most heavily utilized organisms. At the discharge, blacksmith consumed larger organisms, gammarids, calanoid copepods of the genus *Calanus*,

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[6] M. Helvey, VANTUNA Research Group, Occidental College, Los Angeles, CA 90041, pers. commun. 1980.

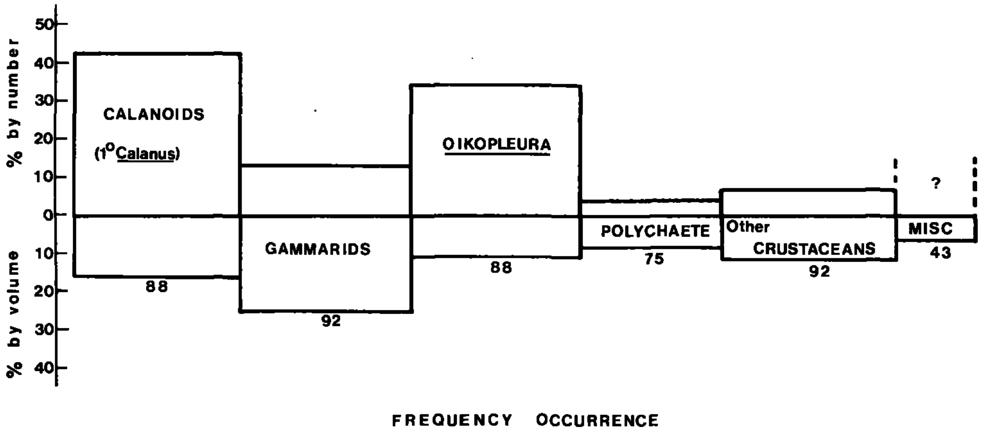

FIGURE 2.—Graphic representation of the Index of Relative Importance of prey items consumed by blacksmith, *Chromis punctipinnis*, at the discharge (thermal outfall) in King Harbor, Calif.

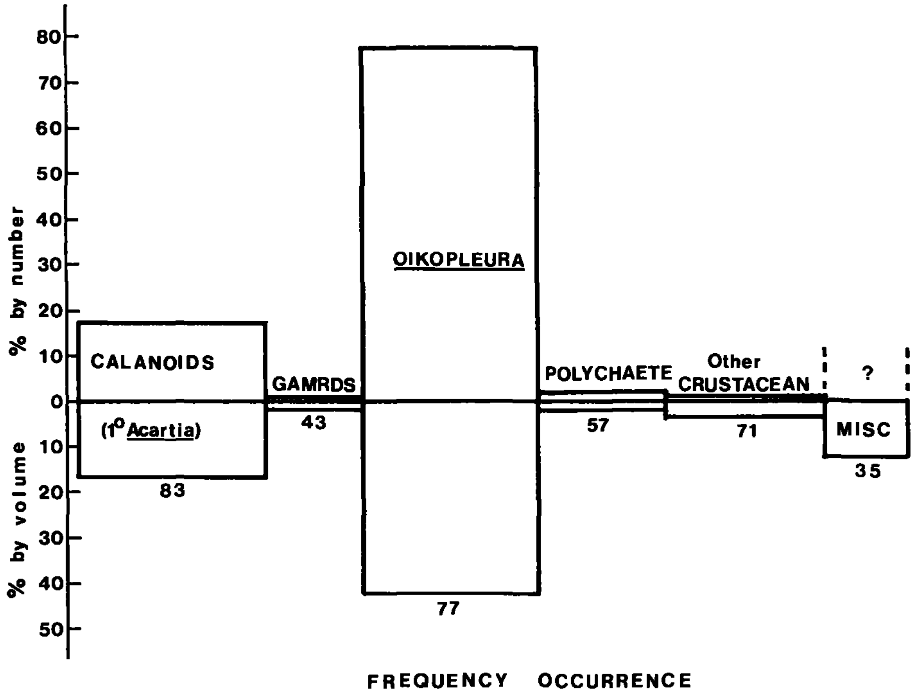

FIGURE 3.—Graphic representation of the Index of Relative Importance of prey items consumed by blacksmith, *Chromis punctipinnis*, at the Point (control site) in King Harbor, Calif.

large polychaetes, other crustaceans, as well as *Oikopleura*. At both sites blacksmith were selective in their planktonic feeding, consuming the largest prey items available. Brooks (1968) stated that there is selection for larger zooplankters, with smaller ones eaten as the larger ones become scarce. At the Point, *Oikopleura* was the largest prey item found in abundance, while at the discharge other larger food items were common along with *Oikopleura* (gammarids, *Polyophthalmus pictus*, and mysids). The amount of dietary overlap between the two locations was not considered significant.

Although more abundant at the Point, a significantly greater amount of *Calanus* sp. was eaten by blacksmith at the discharge than at the Point. A possible explanation for the high usage of *Calanus* at the discharge could be the increased susceptibility of zooplankton to predation as a result of turbulent outflow. Entrained *Calanus* are more accessible to planktivorous fishes, since the mortality rate of copepods passing through a power plant may reach 70% (Carpenter et al. 1974). Dead or damaged copepods would appear as viable prey upon discharge from the plant and could be easily consumed. Increased mortality from turbulence has also been shown for other zooplankters (Gregg and Bergersen 1980).

There is evidence that alterations in plankton distributions at outfall areas are the result of upward vertical displacement of deep-water organisms. Evans (1981) noted that deeper living zooplankton are carried vertically upward to the turbulent waters over the discharge jets. Although analysis of plankton sampled did not prove the existence of such currents, in a previous study at King Harbor dye injections were carried to the plume from bottom water 20 m away from the discharge.[7]

Large gammarids, polychaetes, and juvenile anemones, all of which were common in stomachs of blacksmith from the discharge, are not normal constituents of King Harbor plankton. The force of the swirling effluent is strong enough to detach and entrap these organisms from their normal habitat inside and around the discharge pipe. Once entrapped in the plume, these large invertebrates are accessible to the planktivorous blacksmith.

Zooplankton avoid predation through escape movements upon detection of suction currents created by predatory fish (Dreener et al. 1978; Kettle and O'Brien 1978). Once entrained in the effluent plume, the ability of zooplankton to detect these currents becomes impaired (Evans 1981). As a result, fish frequenting the plume have the potential for feeding on a high concentration of zooplankton with limited predator avoidance. The greater stomach weight and stomach fullness of blacksmith feeding at the discharge support this theory.

Results from other studies examining the feeding habits of blacksmith appear to be similar to those found at the Point. The food items consumed by blacksmth at Santa Catalina Island are (listed in decreasing abundance) *Oikopleura*, calanoid and cyclopoid copepods, fish eggs, cladocerans, and other crustaceans (Hobson and Chess 1976). At Naples Reef, off Santa Barbara, Calif., Bray (1981) found the diet of blacksmith to consist of larvaceans (*Oikopleura*), copepods, cladocerans, chaetognaths, decapods, and polychaetes. In the two abovementioned studies and from the Point, blacksmith consumed at least twice as many *Oikopleura* as any of the other food items, while at the discharge, *Calanus* was the most abundantly consumed prey and gammarids comprised the greatest volume of prey eaten (Table 2). When *Calanus*, gammarids, mysids, and the polychaete *Polyophthalmus pictus* are removed from the analysis of the 10 most abundant prey consumed, no significant difference was observed between the two locations ($G = 9.4$, n.s. at $P = 0.05$, df = 7).

It has long been recognized that blacksmith forage on plankton in areas where currents are present (Limbaugh 1955, 1964; Feder et al. 1974; Ebeling and Bray 1976; Hobson and Chess 1976; Bray 1981). The tropical species of damselfish (family Pomacentridae) also prefer feeding in areas where currents are strong (Hobson and Chess 1978). Blacksmith have been shown to prefer incoming currents (Limbaugh 1955, 1964; Ebeling and Bray 1976; Bray 1981), and Limbaugh believed they materially affected the amount of plankton entering the kelp beds. In Bray's (1981) study, stomach fullness was greater in fish at the incurrent end of the reef than in fish at the excurrent end.

Areas of strong currents are rich in zooplankters (Hobson and Chess 1978) as is the discharge which receives both entrained and entrapped organisms. Although the discharge releases warm water, the current created by the outflow is the major attractant. Blacksmith, a species which prefers warm water (mean preferred temperature = 14°-15°C), are found in 26°-32°C discharge plume water, above their upper temperature avoidance limit of 23°-25°C (Shrode et al. 1982). In the presence of food, blacksmith will disregard their normal avoidance limits for chlorine, intermittently present in most power plant effluents (Hose and Stoffel 1980).

It can be concluded that the outflowing effluent and its related phenomena attract blacksmith to the discharge. This theory is further supported by documentation of similar attraction and rheotropic behavior by blacksmith at an offshore water intake structure (Helvey and Dorn 1981).

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[7] Kinnetic Laboratories, Inc. 1981. Hydrodynamic characteristics of offshore intake structures. Field verification studies. Kinnetic Labs., Inc., P.O. Box 1040, 1 Potrero St., Santa Cruz, CA 95061.

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