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STUDIES OF BEHAVIORAL EFFECTS OF A LIGHTED AND AN UNLIGHTED WHARF ON OUTMIGRATING SALMONIDS - MARCH - APRIL 1978

by

Thomas E. Prinslow, Ernest O. Salo, and Bruce P. Snyder

FINAL REPORT
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ABSTRACT

During 1976-1977 the U.S. Navy constructed a wharf to load and unload the Trident Missile at the Trident Submarine Base at Bangor, Washington. Security lighting at the wharf illuminates the surface of the water under the pier portion of the structure and the covered submarine berth.

Juvenile salmon, primarily chum (Oncorhynchus keta) and pink (O. gorbuscha) migrate past the wharf so the possible adverse effects of the security lighting on their migratory behavior was investigated. Methods used included sampling by beach seine and townet, and by visual observations during a 5-day period in March and a 3-day period in April 1978. Chum salmon marked with fluorescent pigment were used to measure residence time (delay). Smaller fish (new recruits) migrated on the nearshore area (30 m), while the slightly older (3-4 weeks) fish migrated farther offshore. The nearshore outmigration was sampled by beach seine and the offshore component was sampled by townet.

At night, the lighted wharf attracted chum and pink salmon migrating nearshore and offshore. With the security lights off, the wharf did not attract outmigrants during the night, although daytime attraction of offshore outmigrants was suggested. Visual counts in index areas were higher with the lights on than with the lights off (527 to 7). Although numbers of marked chums were recaptured, the determination of residence time in the lighted area was inconclusive.

Over 90% of the offshore catch of juvenile salmon at the wharf was recovered from the enclosed submarine berth, both during the night when it was intensely lit (surface intensity = 200 lux) and during the day when the overhead enclosure shaded the water.

ACKNOWLEDGMENTS

Clifford Whitmus, of the University of Washington, was responsible for the design and execution of the mark-recapture phase of this study, and we thank him for his guidance and support in the field, as well. We wish to thank Matthew Salo of the University of Washington for his advice and strong assistance in the design, field sampling, and analytical phases of this project. Donald Morris and James Reeves of the U.S. Navy Department of Ecology (USNDE) kindly shared the burden of beach seining and townetting. We also thank Wharf Officer George Knudtzon (U.S. Navy) for his cooperation in scheduling lighting and access to the Explosives Handling Wharf, Submarine Base Bangor, where the testing took place.

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INTRODUCTION

During 1976-1977 the U.S. Navy constructed a wharf to load and unload the Trident Missile at the Trident Submarine Base at Bangor, Washington on Hood Canal (Fig. 1). Security lighting at the wharf, called the Explosives Handling Wharf (EHW), illuminates the surface of the water under the pier portion of the structure and the large covered submarine berth (Plate I). Because little was known of the effects of the lighting on migrating salmon and resident fishes in the Canal, the Washington State Department of Fisheries (WDF) required the U.S. Navy to assess any impact of the EHW lighting on outmigrating salmonids - primarily chums (Oncorhynchus keta) on an annual basis and pinks (O. gorbuscha) on the even years (Schreiner 1977). Consequently, two short-term studies were conducted during March-April 1978 to supplement ongoing Navy-supported research by the Fisheries Research Institute (FRI) of the University of Washington on salmon outmigration in Hood Canal (see Schreiner et al. 1977; Bax et al. 1978; and Bax, Salo, and Snyder 1979).

Previous work by Heiser and Finn (1970) had shown that 35-45 mm long chum salmon tended to aggregate at bulkheads during their outmigration while 50-70 mm chum moved past. The effects of any lighting at these structures was not distinguished. In preliminary work at the Trident Base, Salo, Salo and Snyder (1977) observed approximately 30 times more fish under a wharf with lights than the

Plate I. The Explosives Handling Wharf (EHW) during construction showing trestles, pilings, submarine berth area (upper right), and partially completed enclosure. Photo taken 2/77, pier completed 2/78.

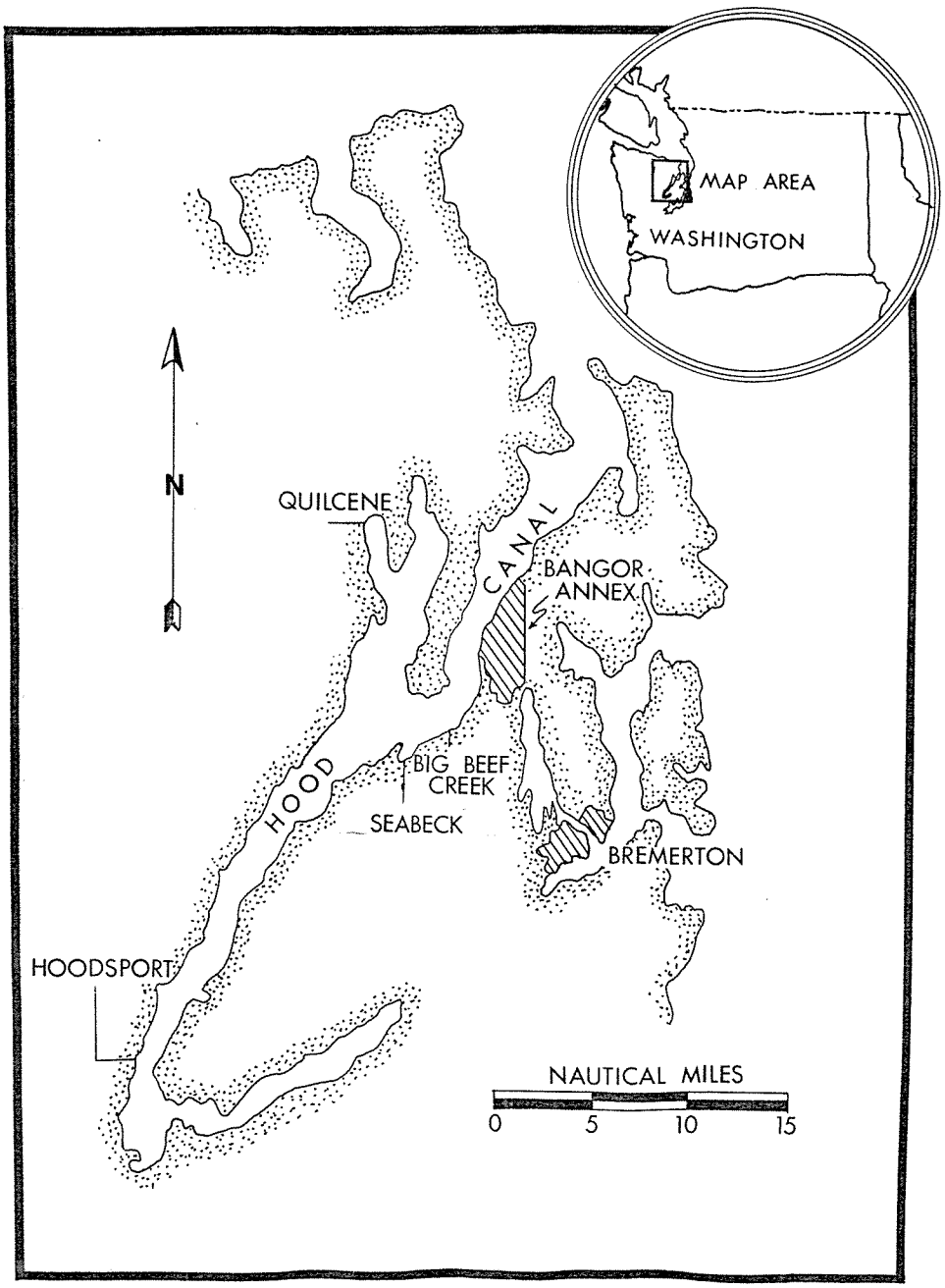

Fig. 1. Area map of Hood Canal showing location of Bangor Annex and Big Beef Creek.

same wharf without lights. The experiments were conducted during July 1976 when the peak of the salmonid outmigration was past, so most of the fish were non-salmonids. Consequently, the attraction of salmonid outmigrants to the lighted wharf was suggested but not substantiated. In a review of the literature, Salo (1976) reported that the wavelength (color) and intensity of light can be distinguished by fish, and continuous or changing exposure to these characteristics may affect fish physiologically or behaviorally. Young salmonids are more sensitive to intensity than wavelength, and are receptive to light at intensities higher than 10^{-4} lux (dimmer than starlight) and often display phototaxis. They feed and school above 10^{-4} and 10^{-3} lux, respectively (Ali 1959; Brett and Groot 1963).

During February 1978 FRI conducted a mark-recapture experiment with outmigrating chum salmon (Whitmus, unpublished data) in the vicinity of the newly completed EHW. Chum salmon were caught in greater numbers at the EHW than at the other sampling sites along the Hood Canal shoreline (Table 1), and as the waters below the wharf were illuminated it appeared that the lights were attracting the chum. No comparisons were made with an unlighted structure comparable to the EHW, so alternatively the chum might have concentrated at the wharf irrespective of lighting (Heiser and Finn 1970). As an extension of this work, the March and April

Table 1. 37-m beach seine catch during February 1978 mark-recapture experiment at EHW (security lights on day and night): total catch, sampling effort and catch per unit of effort (CPUE); CPUE values rounded to nearest tenth. Data provided by C. Whitmus, Fisheries Research Institute, University of Washington.

	EHW			Other Hood Canal Sites		
	Total catch	Effort	CPUE	Total catch	Effort	CPUE
			DAY (lights on)			
Marked Chum	20	10	2.0	4	54	0.1
Unmarked Chum	276		27.6	123		2.3
Unmarked Pink	16		1.6	290		5.4
			NIGHT (lights on)			
Marked Chum	24	3	8.0	(no other sites sampled)		
Unmarked Chum	113		37.7			
Unmarked Pink	1		0.3			

studies sought to determine the effects of the lighted as well as the unlighted wharf on outmigrating salmon.

METHODS

Experimental Design

Experiments, conducted 27-31 March and 26-28 April 1978 were:

March - effect of the wharf in the daytime,
March - effects of lights and wharf (stimuli) at night,
April - effect of wharf in the daytime, and
April - effect of unlighted wharf at night.

Security lights (see description below) were illuminated only during the March night test.

A mark-recapture experiment was also conducted during the 27-31 March test period to measure residence time (delay) of outmigrants at the EHW. A group of 41,500 juvenile chum salmon were marked with a fluorescent pigment ejected from a commercial-type spray gun (see Whitmus and Olsen 1979). The fish were held in pens for 2 days to detect any mortality from the marking procedure, then released during the evening of 26 March from Big Beef Creek on Hood Canal (Fig. 1). During the next 5 days the marked chum were followed as they passed the Navy base and out of Hood Canal.

Sampling Techniques

Three techniques were used to sample the marked and unmarked chum and the unmarked pink salmon: 1) 37-m floating beach seine with a 0.6-cm mesh bag; 2) surface trawl (townet) with a 3- x 6-m net opening and mesh sizes grading from 76 mm at the opening to 6 mm at the bag; and 3) visual observations. Each beach seine set sampled a volume approximately 300 m^2 by 1 m deep, and took 5 min to complete. Surface trawls were 10 min in duration, conducted at a speed of 1.5-2 knot, or a volume approximately 3000 m^2 by 3 m deep. Visual observations were made by counting the fish illuminated by the beam of a 12 VDC, 100,000 c.p. hand-held spotlamp in an area formed by sweeping the lamp in a semi-circular motion (approximately 55 m^2) (Fig. 2). The sample was the number visible in a 1-min sweep search. By observing gross differences in size, color, and swimming behavior, near-surface fish were classified as either juvenile outmigrant salmonids, small (< 5 cm) non-salmonids, or larger (> 5 cm) potential predators.

Sampling Area

Four beach seine sites and seven townet transects along the east shore of the submarine base (Fig. 3) were sampled during the March and April tests. One of these beach seine sites and two of the townet transects sampled waters in the immediate vicinity of the EHW; samples collected from this area were considered "test" samples, i.e., under the potential influence of the EHW wharf and light stimuli. Samples

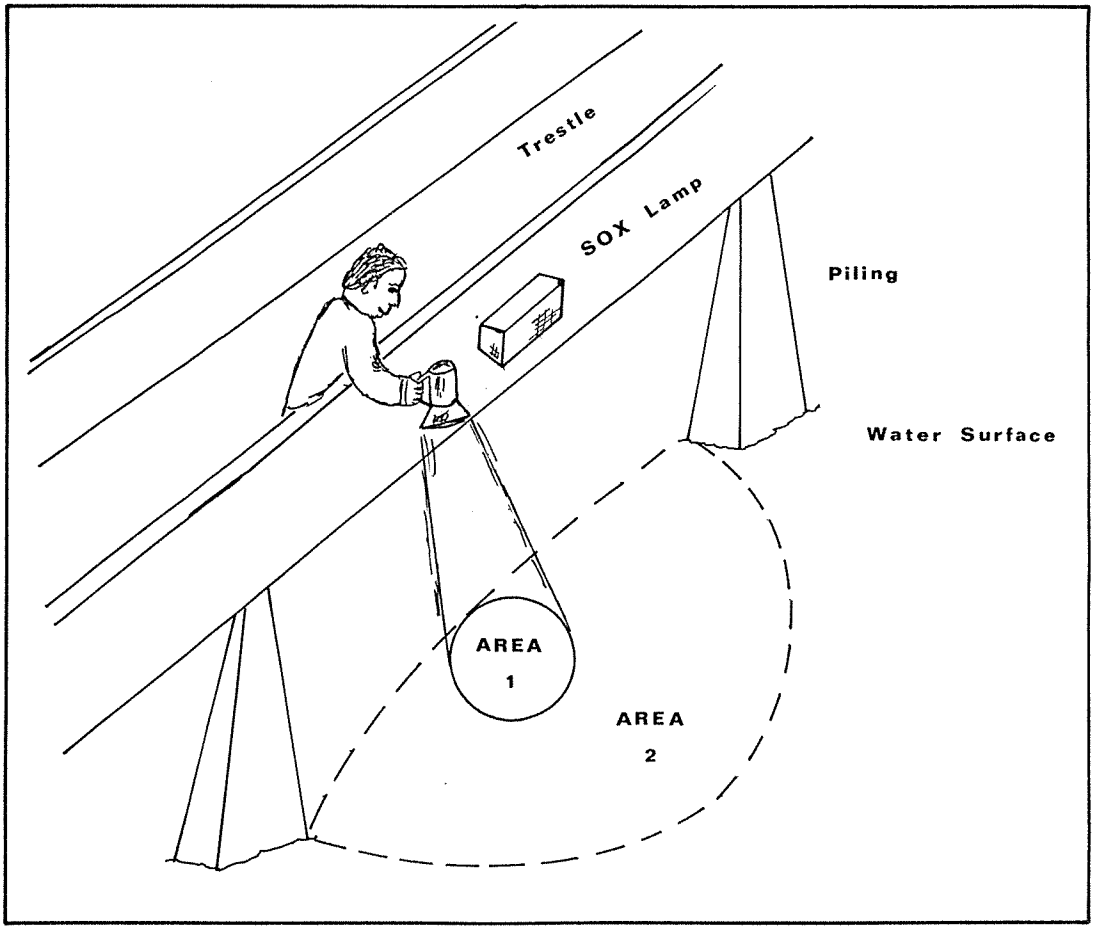

Fig. 2. Perspective view of spot-beam (Area 1) and sweep-search (Area 2) observations.

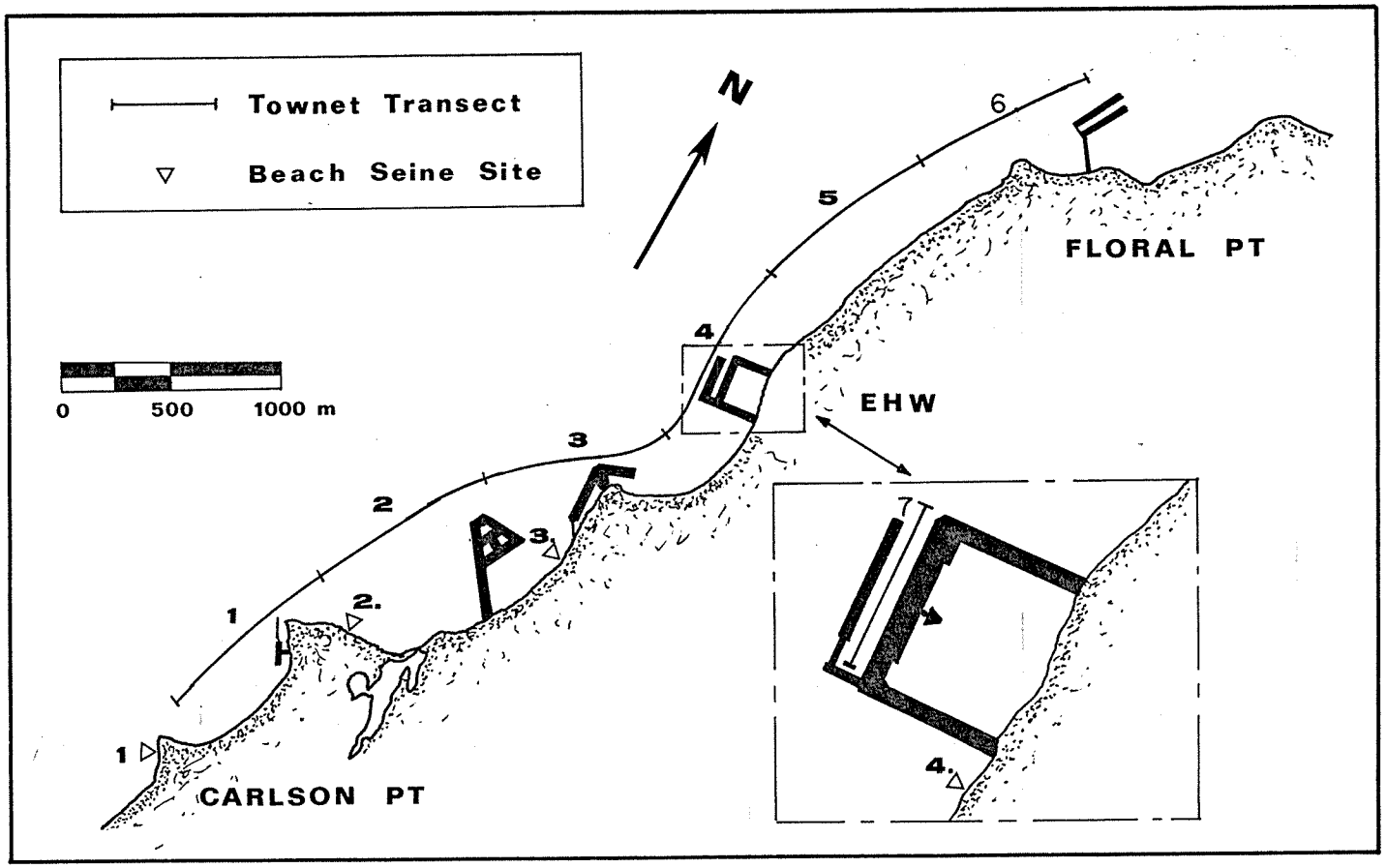

Fig. 3. Beach seine and townet sites during lighting tests, March and April 1978. Beach seine sites: 1) Carlson Pt. (CARL); Devil's Hole (DH); 3) Marginal Wharf (MW); 4) South Explosives Handling Wharf (SEHW). Townet transects: 1) Carlson Pt. to Service Pier (CARL-SP); 2) Service Pier to Refit Pier (SP-RP); Refit Pier to Marginal Wharf (RP-MW); 4) west side of Explosives Handling Wharf (EHW out), 5) Explosives Handling Wharf to Floral Pt. (EHW-FP); 6) Floral Pt. to Magnetic Silencing Facility (FP-MSF); 7) inside submarine berth of Explosives Handling Wharf (EHW in).

collected from the remaining beach seine sites and townet transects were considered "controls," i.e., not influenced by the EHW stimuli.

Visual observations were conducted twice nightly during the March and April tests at 20 stations along the EHW trestles (Fig. 4). The stations were checked in the same order, one round taking 60-75 min to complete.

The mark-recapture experiment sampled 21 beach seine sites and 41 townet transects (including those described above) from Seabeck to Port Gamble on Hood Canal (Figs. 5 and 6). Three beach seine sites and two townet transects at EHW were considered as "test" locations.

Description of Security Lighting at EHW

Wharf lighting consisted of fifty-three 35-W low pressure sodium (SOX) lamps along the perimeter of the wharf, one-hundred and fourteen 150-W underwharf spotlamps (Fig. 7) located below the trestles and the east side of the submarine berth area, and sixteen 400-W metal halide lamps (Fig. 8) approximately 35 m above the submarine berth area (Figs. 9 and 10). Underwater light intensities were measured with a LI-COR Model LI-185 Quantum/Radiometer/Photometer equipped with an LI-212S Underwater Photometric Sensor (Lambda Instruments Corp., Lincoln, Nebraska). Surface intensities were measured at the 20 visual observation stations around EHW.

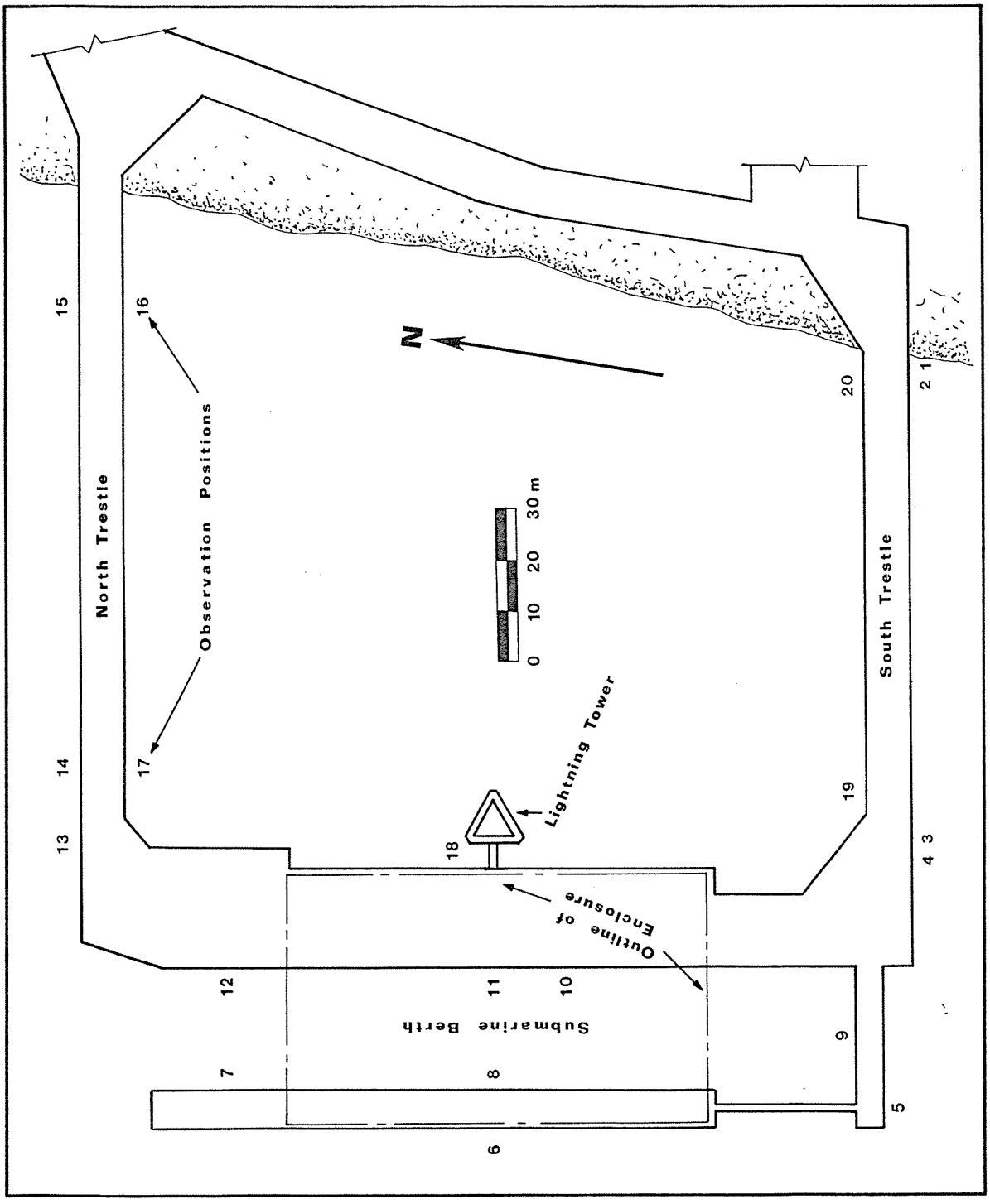

Fig. 4. Overhead view of EHW showing location of visual observation positions.

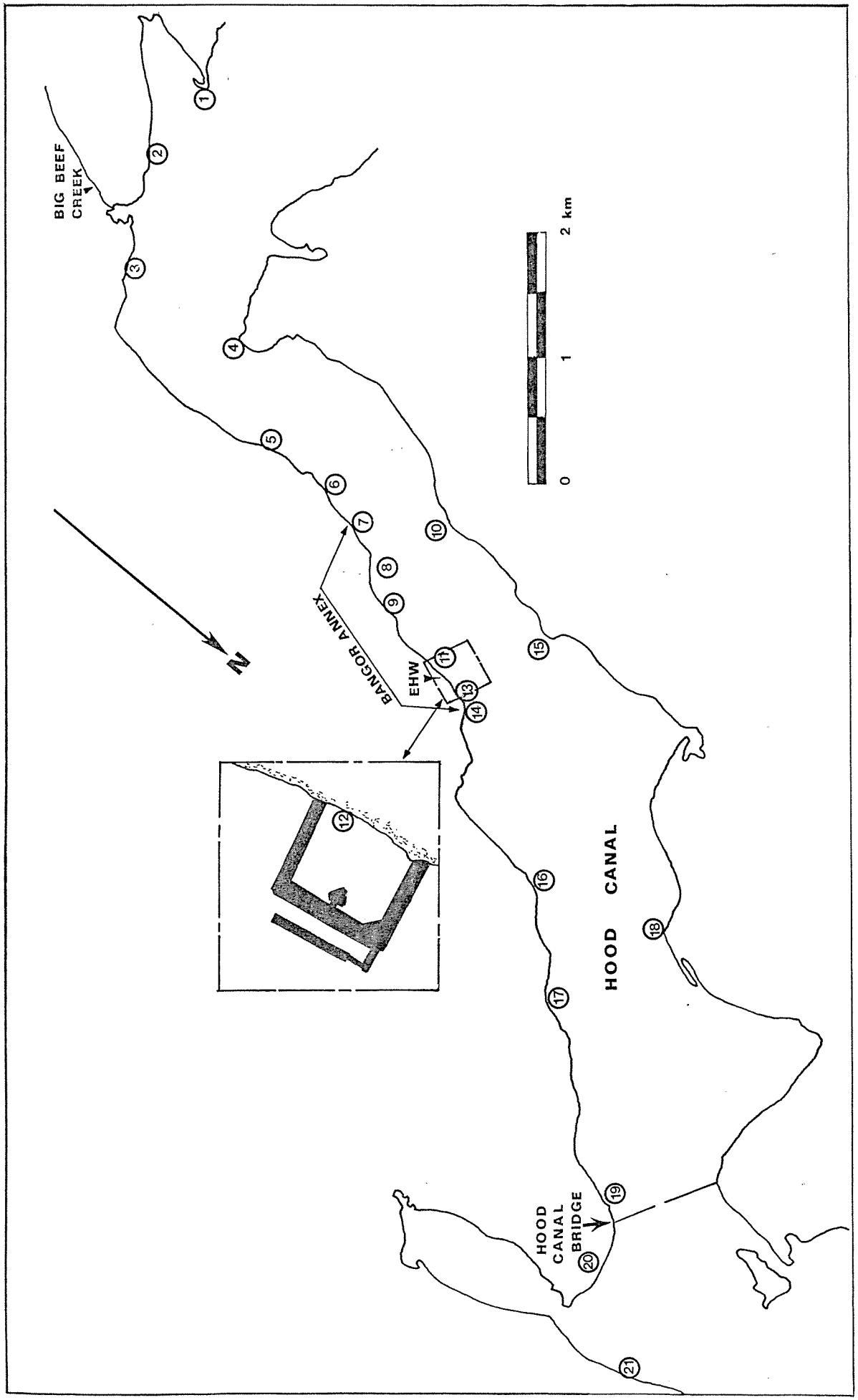

Fig. 5. Beach seine sites, mark-recapture experiment, March 1978: no. s 11, 12, and 13 are test sites, 1-10 and 14-21 are control.

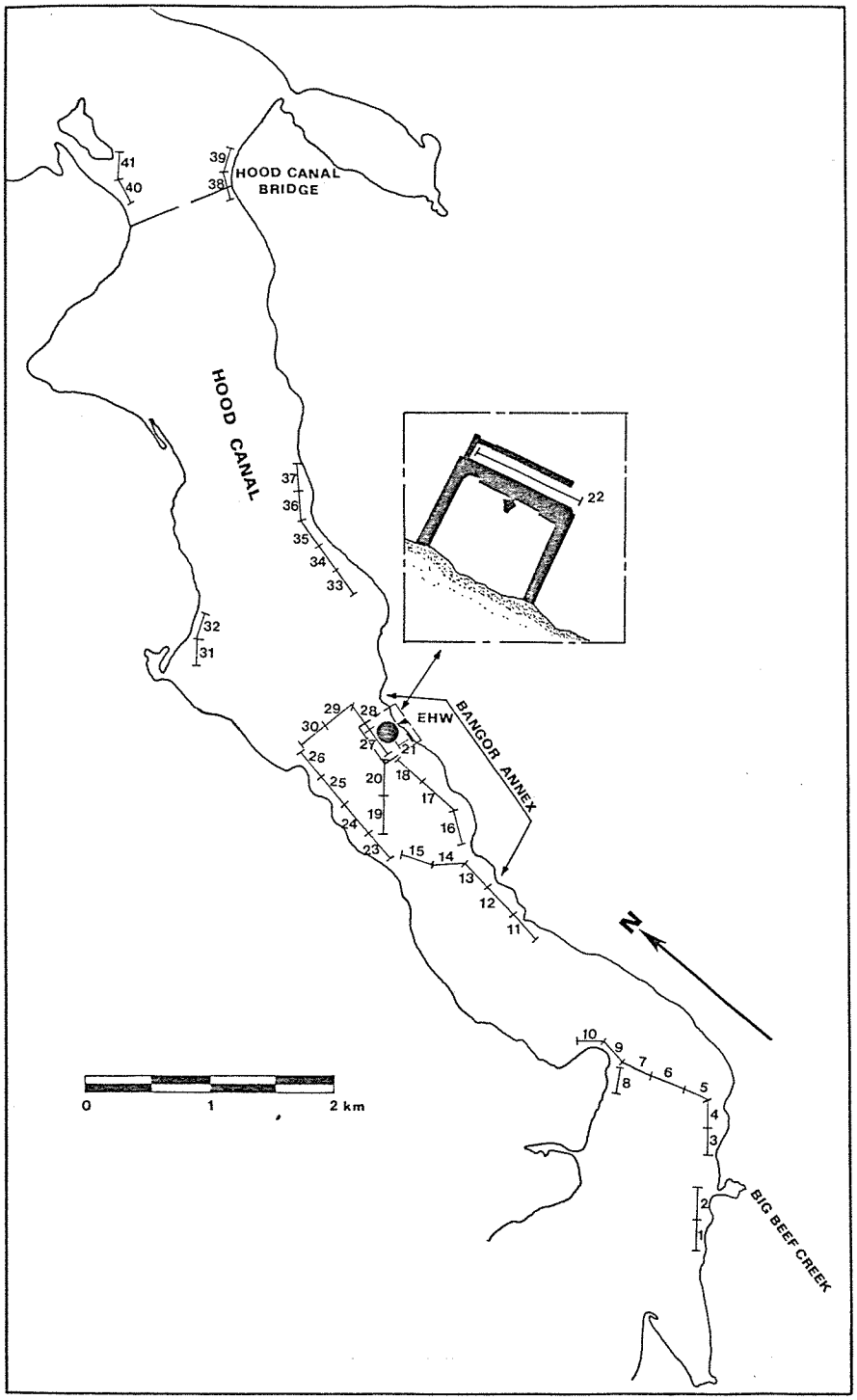

Fig. 6. Townet sites, mark-recapture experiment, March 1978; no. s 21, 22, and 27 are test sites; remaining sites are control.

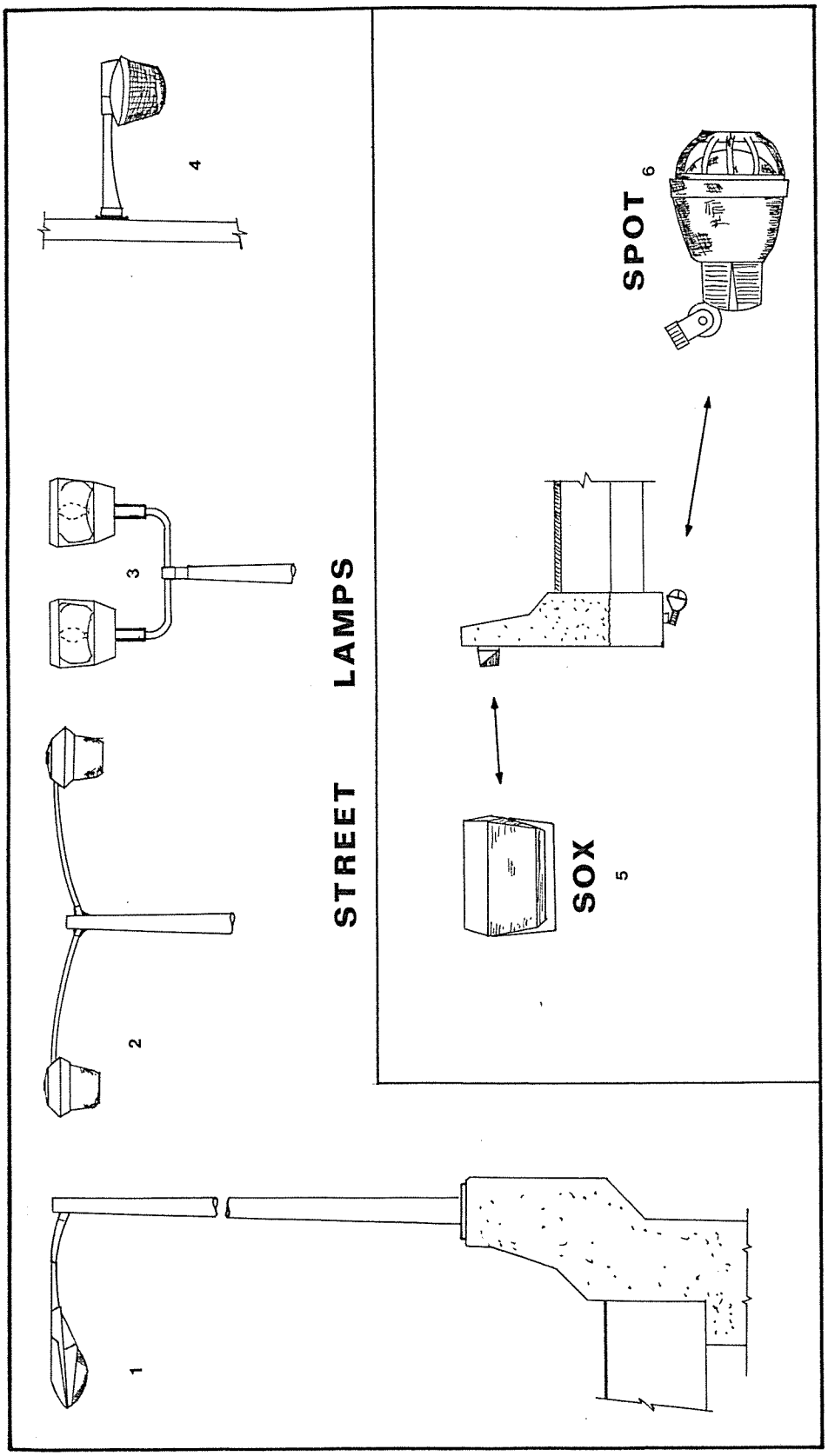

Fig. 7. Types of lamps used at EHW; street lamps: (1) one 400-W high pressure sodium, (2) two 500-W incandescent, (3) two 400-W high pressure sodium, (4) one 250-W sodium vapor; sox lamp, (5) one 35-W low pressure sodium; spot lamp, (6) one 150-W incandescent.

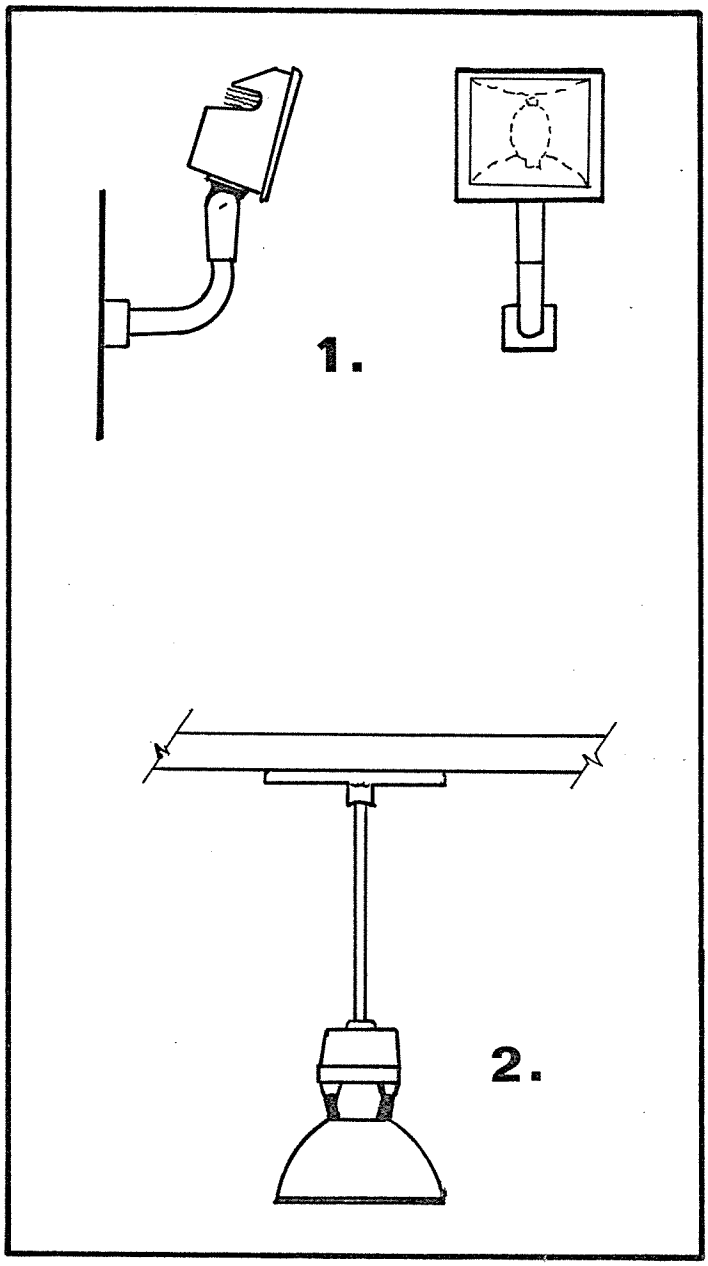

Fig. 8. Types of lamps used in enclosed area (submarine berth) of EHW; (1) one 1000-W metal halide or one 1500-W quartz; (2) one 400-W metal halide.

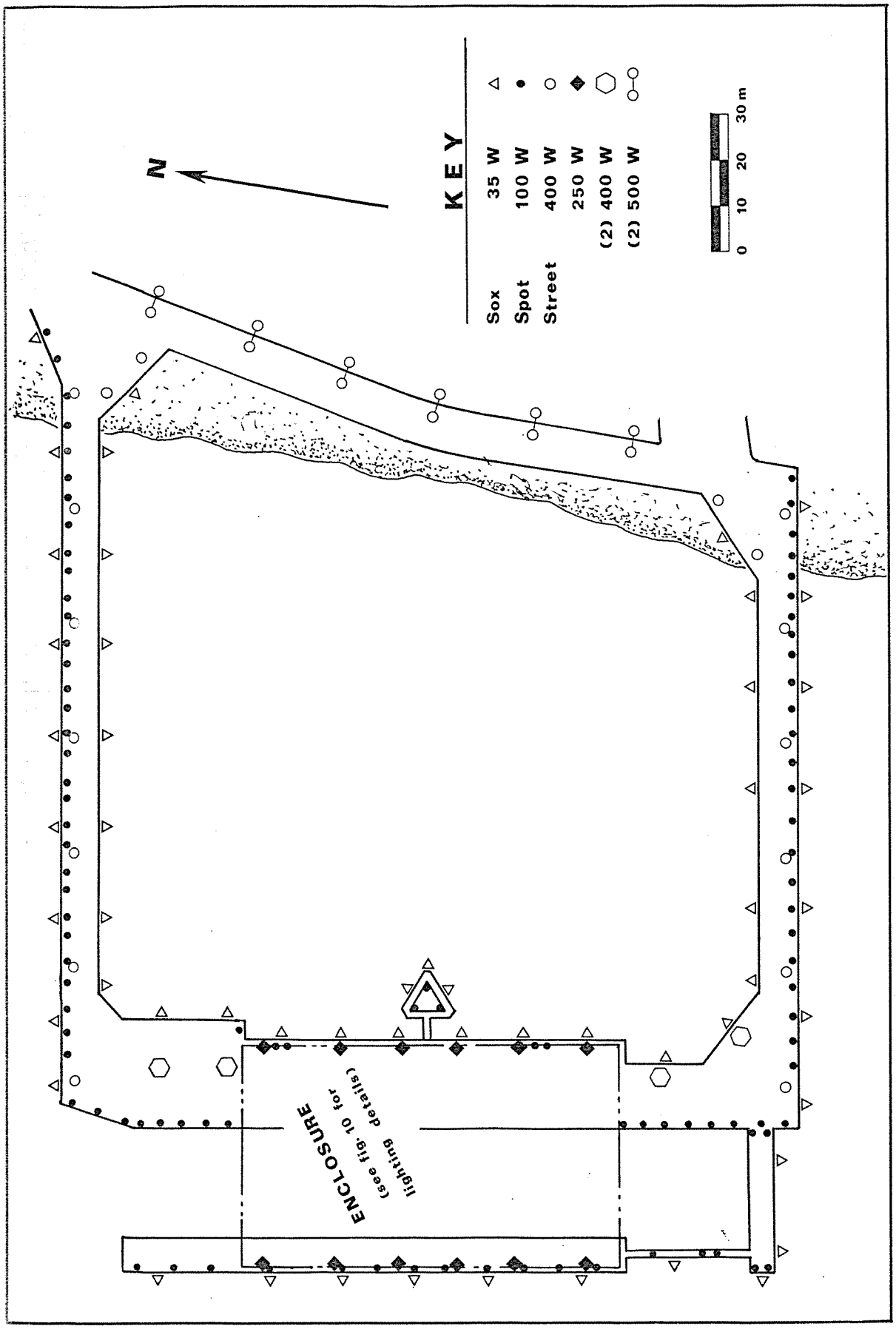

Fig. 9. Positions of lights at EHW.

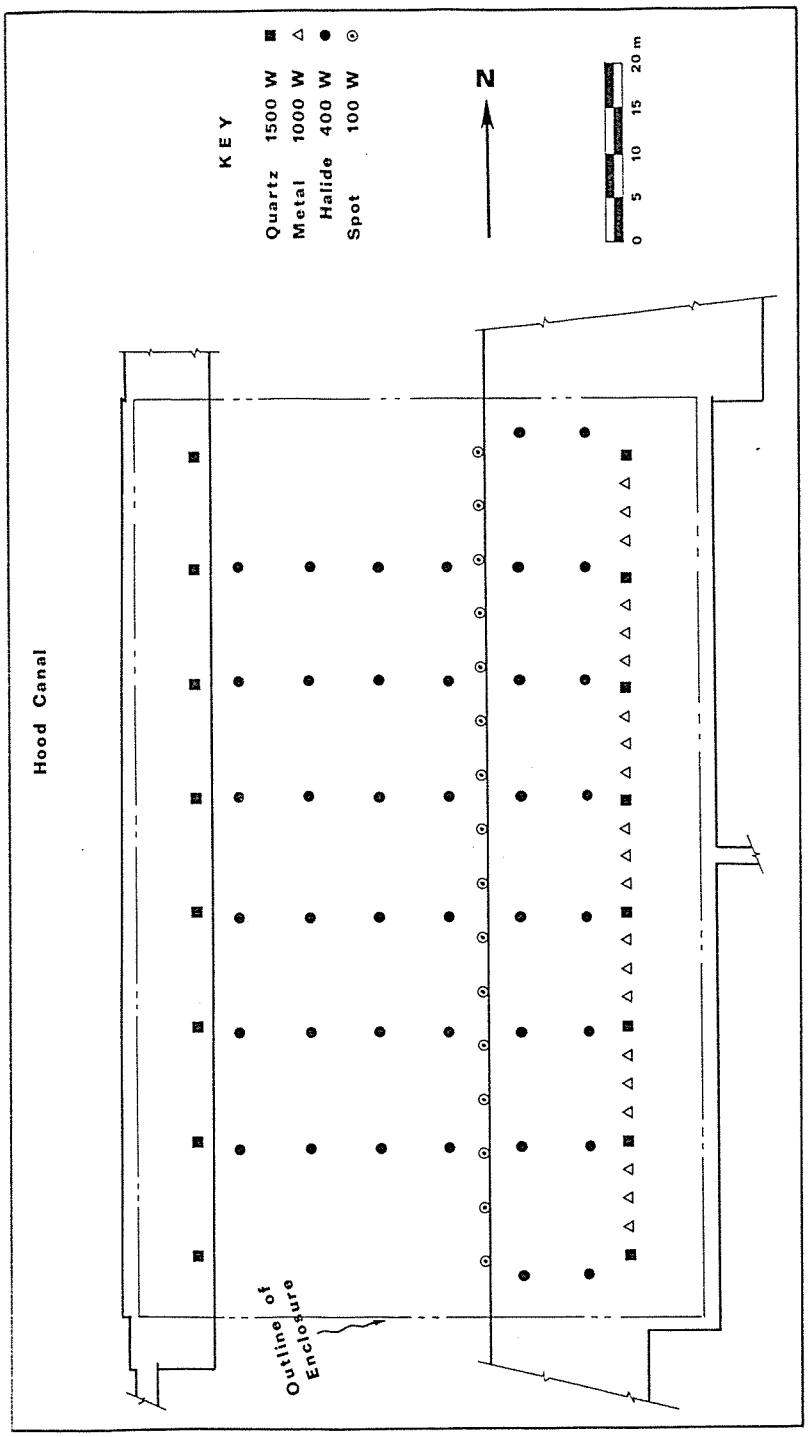

Fig. 10. Positions of lights in enclosed area (submarine berth) of EHW.

Statistical Analysis of Catch Data

The two hypotheses - H_1: no difference in the catch of outmigrating salmon between the unlighted wharf and control areas (hereafter referred to as the "wharf hypothesis"), and H_2: no difference in salmon catch between the lighted wharf and control areas (hereafter the "lights hypothesis") - were tested in the following manner:

H_1, "wharf hypothesis": A Friedman 2-way ANOVA by ranks; treatment A - day, treatment B - location. This was a Model I test as the two treatments were independent. Four tests were run: beach seine catch of chums 1) and pinks 2); townet catch of chums 3) and pinks 4) using data from the transect along the west trestle "outside EHW." Insufficient samples from the submarine berth "inside EHW" transect precluded testing catch distributions from this area. Daytime catch data were the variates since nighttime test stimuli in March included lights.

H_2, "lights hypothesis": A Mann-Whitney rank sum comparison of March night catches with April night catches. In effect, this test "subtracts" any effect of the wharf from the effect of lights plus wharf (the March night data). To adjust for seasonal differences in catch, the beach seine catch at EHW was compared to the catch at Devil's Hole for both March and April. This ratio,

$$\frac{\text{EHW Beach Seine Catch}}{\text{Devil's Hole Beach Seine Catch}}$$

was the variate. Tests of townet catch used values from the "outside EHW" transect (numerator) and the EHW-to-Floral Pt. transect (denominator). Four tests were run following the format presented for the first hypothesis.

The comparison of March with April catches assumes no difference in the behavior of the outmigrating salmon with respect to the different sampling sites between the 2 months. Bax (unpublished data) found that there was no interaction between sample location and time for townet sampling during the 1978 and 1979 outmigrations in Hood Canal. There was significant interaction for beach seine sampling over the February-to-July season, but Fig. 11 shows that during the period of late March to late April in both 1978 and 1979 beach seine catch at EHW followed the same trend as other sites along the east shore of the submarine base.

RESULTS AND DISCUSSION

Table 2 summarizes test results of the "wharf" and "lights" hypotheses.

H_1: "Wharf Hypothesis"

Results of the Friedman 2-way ANOVA by ranks indicate no significant effect of the EHW (wharf stimulus) on beach seine or townet catch of either chum or pink salmon outmigrants (Table 2). Unfortunately, the submarine berth transect was not sampled during the

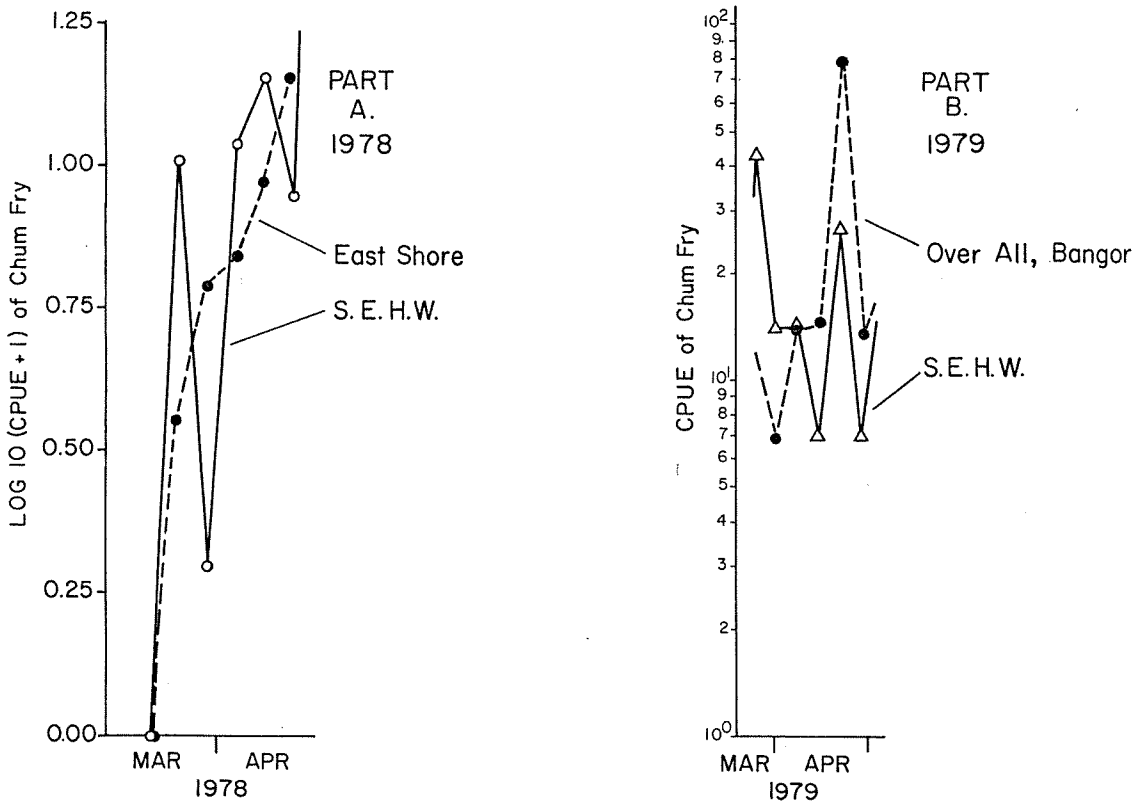

Fig. 11. Trends in beach seine chum catch between March and April 1978 (Part A) and 1979 (Part B).

Table 2. Summary of statistical tests on catch data during lighting test.

Hypothesis	Test	Group	Run		Result	
			Day Catch			
H_1: no difference in catch between unlighted wharf and control ("wharf hypothesis")	Friedman 2-way ANOVA by ranks	BS	chum		p≃.3	SEHW,C,DH,
			pink		p≃.3	MW "
		TN	chum,	EHW in	-[1]	NA
			,	EHW out	.5<p<.9	2,5,4,3,6
			pink,	EHW in	-[1]	NA
			,	EHW out	p≃.2	2,5,4,3,6
			Night Catch			
H_2: no difference in catch ratios between lighted wharf/control and unlighted wharf/control ("lights hypothesis")	Mann-Whitney rank sum comparison using ratio of EHW catch to other site or transect	BS	chum		p=.05	SEHW-DH
			pink		p=.10	SEHW-DH
		TN	chum,	EHW in	-[1]	1-5
			,	EHW out	.028<p<.057	2-5
			pink,	EHW in	-[1]	1-5
			,	EHW out	.057<p<.114	2-5

H_o: catch at EHW and other sites equal.

[1] insufficient data to perform test.

daytime in March, so the effect of this area of the unlighted wharf could not be tested. Table 3 shows, however, that the catch-per-unit of effort (CPUE = number of fish caught per beach seine set or townet transect) in the submarine berth by townet during the 3 sampling days in April exceeded the largest townet CPUE at any other transect during that period, suggesting attraction of the outmigrating salmon to the submarine berth. The difference in CPUEs was even more dramatic considering that the berth transect was only 2 min in duration compared with 10 min of the other tows (2 min = time to tow from one end of the berth to the other).

H_2: "Lights Hypothesis"

Results of the Mann-Whitney rank sum comparisons of catch ratios indicate a significant effect ($p \leq .1$) of EHW security lights on beach seine and townet catches of chum and pink outmigrants (Table 2). While insufficient sampling of the submarine berth transect during nighttime in March precluded testing the effect of this area, the two 2-min tows completed captured more chum and pink salmon than in any other tows in the Bangor area (Table 3 and Plate II), and suggested a significant effect of lighting in the submarine berth. Light intensities just below the water's surface registered 206 lux in the berth compared with 0-15 lux elsewhere below the wharf (Table 4), suggesting that the salmon were attracted to the lights.

Table 3. 1978 townet catch data for marked chums, unmarked chums and pink salmon in the sub-base, Bangor area, during lighting tests, 3/27-31 and 4/26-28/ 78.

Sample Period: March 27-30, Day.

Transect[1]	SPECIES CAUGHT											
	Marked Chum				Unmarked Chum				Pink			
EHW in												
EHW out		6	0	0		11	0	3		12	0	12
CARL-SP	3	0	0	1	8	23	0	8	46	44	0	10
SP-RP	0	0	0	5	0	11	0	46	0	1	0	48
RP-MW	3	1	0	3	10	0	0	203	43	14	2	149
EHW-FLOR	0	0	0	3	17	11	2	6	12	5	4	6
FLOR-MSF	0	1	0	0	0	4	0	1	0	5	0	1

Sample Period: March 27-30, Night.

Transect	Marked Chum				Unmarked Chum				Pink			
EHW in			9	0			26	14			203	63
EHW out	0	0	0	1	0	0	1	2	1	4	2	8
CARL-SP	0	0	1		0	11	2		1	27	3	
SP-RP	0	0	0		0	2	0		0	0	1	
RP-MW	0		1		2		3		7		4	
EHW-FLOR	0	0	1		0	4	10		0	6	11	
FLOR-MSF	0	0	0	0	0	1	2	1	1	0	6	7

Sample Period: April 26-28, Day.

Transect	Unmarked Chum			Pink		
EHW in	118	152	0	25	68	0
EHW out	11	17	0	1	3	0
SP-RP	69	1	0	23	0	1
RP-MW	13	3	4	11	1	9
MW-EHW	6	78	19	2	14	10
EHW-FLOR	0	29	27	0	0	3

Sample Period: April 26-28, Night.

Transect	Unmarked Chum			Pink		
EHW in	0	9		0	3	
EHW out	0	8	0	1	6	2
SP-RP	3	14	7	0	5	1
RP-MW	5	53	13	1	29	6
MW-EHW	11	48	3	1	13	0
EHW-FLOR	1	4	4	1	5	3

[1] see Fig. 3 for location.

Table 4. Underwater light intensities in the EHW area during "normal" lighting (see text); readings taken at night, low tide; distance from top of trestle to water surface, 5 1/2 m.

Station[a]	Intensity (lux) Depth (m) 0	2	6	10
1	(no water)[b]			
2	(no water)			
3	8			
4	0			
5	13	3	1	
6	19			
7	8			
8	139	71	27	10
9	0			
10	3			
11	206	94	28	9
Mid-berth	197			
12	14			
13	10			
14	1	1	0	
15	5			
Distance north of N. Trestle 5 m	5			
Distance north of N. Trestle 13 m	3			
Distance north of N. Trestle 20 m	0			
16	8			
17	9	5	2	
18	15			
19	8			
20	10			

[a]Visual observation stations depicted in Fig. 4.

[b]Tide out when measured.

Visual Observations - Lights On Phase, March 1978

During sweep search observations, a total of 572 juvenile salmonids, 124 small non-salmonids, and 39 potential predators[1] was counted (Table 5). Juvenile salmonids concentrated in three zones (see Fig. 4): 1) the nearshore end of the south trestle, stations 1 and 2 (53% of total 572 fish): 2) the west offshore arm of EHW, stations 11-14 (23% of total); and 3) the northwest corner of the main wharf, stations 11-14 (23% of the total). The majority (72%) of small non-salmonids was also observed at stations 10-14. Most of the potential predators (54%) were observed in the submarine berth area, stations 7-12; none was observed at stations 1 and 2 where juvenile salmonids occurred most frequently. A large school (approximately 1,000) of pile perch, Rhacochilus vacca, was observed nightly between stations 8 and 9 (berth area); however, they are not considered normal predators of juvenile salmonids (Hart 1973).

All of the area below the wharf was illuminated with the exception of stations 4 and 9 (Fig. 4 and Table 4). Only 2% of the juvenile salmonids were observed at stations 4 and 9 while 12% were observed at stations 7 and 12, which had surface intensities of 8-14 lux and were considered transition zones between the intensely-lit submarine berth area (139-206 lux, at surface) and the dark berth entrance.

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[1]e.g., chinook salmon, cutthroat trout, dogfish.

Table 5. Fish observed in sweep search observations at 20 stations around EHW from 3/27 to 3/31/78.

Type of fish observed:	Juvenile salmonids (<5 cm)									Non-salmonids (<5 cm)									"Predators" (>5 cm)									Position totals		
Round:	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9	Salmonids	Non-salmonids	Predators
Position[a]																														
1						200																						200	0	0
2				75					30					1														105	1	0
3		10		8	1			1	15								1											35	1	0
4						1										1	1										1	1	2	1
5			1	8	2	22								1			10						1					33	11	1
6		1		20							1	3			2		1	1				1						21	8	1
7				17	1							5		1						1	1							18	6	2
8																							3	2				0	0	5
9					8				1							1		1		1		b		b		b		9	2	1
10															1	20												0	21	0
11			75												1						10				1			75	1	11
12						50				15	3	1		1			4			1		1						50	24	2
13	3		1	2					1			2				1		1										7	4	0
14		1		1	1			5	5		2		25	1	11													13	39	0
15																			1				5					0	0	6
16				1																								0	0	0
17				1				2												2					4			3	0	6
18													1										1			1		0	1	2
19		1											1						1									1	1	1
20						1				1				1														1	2	0
Round totals: Juvenile salmonids:										3	13	77	132	13	273	1	8	52										572	124	39
Non-salmonids:										16	6	11	27	6	15	23	17	3												
Predators:										2	5	11	2	9	2	5	2	1												
										21	24	99	161	28	290	29	26	55												
Current/tide at start										Ebb	Ebb	Ebb	Flood slack	Ebb	Flood slack	Ebb	Ebb	Flood slack												

[a] Visual observation stations depicted in Fig. 4.

[b] Perch.

Visual Observations - Lights Off Phase, April 1978

During the 3-night test period, only seven juvenile salmonids, eight non-salmonids, and two potential predators were observed in six observation rounds (Table 6). Four of the seven juvenile salmonids (59%) were observed along the south trestle; 57% of the juvenile salmonids counted during March were observed in this area. The two potential predators were observed at the entrance to the submarine berth area (Table 6), the area of greatest predator concentration in March (Table 5).

Total salmon catch (combined beach seine and townet) during April exceeded that during March by 55% on a per sample basis (2360 fish/72 samples vs. 2956/58) (combined data from Tables 3 and 7), yet only 2.8 fish/round were observed in the unlighted EHW area compared to 81.7 fish/round during the lighted March observations. Clearly at night EHW lights attracted significantly more fish than the wharf itself.

The degree of light intensity determines whether fish respond positively or negatively: low levels attract, high levels repulse (Salo 1976). While juvenile salmonids were observed only once during March within the intensely-lit submarine berth area (75 fish, round 3, station 11), concurrent townetting through the area caught 315 pinks and chums in two 2-min tows. Since the townet fishes at greater depth than visible from the wharf, and since light intensity diminishes with depth, apparently many young salmon were present in the berth area but at a lower level of illumination than that at the surface.

Table 6. Fish observed in sweep search observations at 20 stations around EHW from 4/25 to 4/28/78.

Type of fish observed:	Juvenile salmonids (<10 cm)						Non-salmonids (<10 cm)						Predators (>10 cm)						Position totals		
Round:	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	Salmonids	Non-salmonids	Predators
Position[a]																					
1	2								1										2	1	0
2			1						1	1									1	2	
3	1																		1		
4																					
5																					
6																					
7										1			1							1	1
8										1										1	
9																					
10																					
11						2													2		
12															1						1
13							1					1								2	
14										1										1	
15																					
16																					
17																					
18																					
19						1													1		
20																					
			Juvenile salmonids:				3	0	1	0	0	3							7	8	2
Round totals:			Non-salmonids:				1		2	4		1									
			Predators:				1		1												
							5		4	4		4									
	Current/tide at start						Flood slack	Ebb	Flood slack	Ebb	Flood slack	Ebb									

[a] Visual observation stations depicted in Fig. 4.

Table 7. 1978 beach seine catch data for marked chums, unmarked chums and pinks in the sub base, Bangor area, during lighting tests, 3/27-31 and 4/26-28/ 78.

Sample Period: March 27-30, Day.

Site[1]	SPECIES CAUGHT															
	Marked Chum				Unmarked Chum				Pink							
S. EHW	0	0	0	1	0	0	0	19	0	0	5	24				
CARL	0	0	0	0	0	0	0	1	0	0	0	0				
DH	0	0	1	0	121	5	12	9	201	3	26	4				
MW	0	0	1	0	3	1	5	1	7	0	23	0				

Sample Period: March 27-31, Night.

Site	Marked Chum					Unmarked Chum					Pink					
S. EHW	2	3	3	2	5	33	23	22	67	30	48	27	102	53	80	
CARL		3	0				10	0				46	1			
DH	2	0	0			12	2	15			13	1	0			
MW		0	0				5	3				3	8			

Sample Period: April 26-28, Day.

Site	Unmarked Chum			Pink		
S. EHW	0	68	0	0	23	0
CARL	0	0	1102	0	0	305
DH	181	24	81	21	1	8
MW	7	0	0	0	0	0

Sample Period: April 26-28, Night

Site	Unmarked Chum			Pink		
S. EHW	4	4	16	0	3	1
CARL	12	9	7	7	2	4
DH	18	12	45	0	2	2
MW	3		5	0		1

[1] see Fig. 3 for location.

The light intensity within the berth area at 2, 6, and 10 m depths was 94, 28, and 9 lux, respectively (Table 4). Surface intensity in the south trestle area where the majority of fish was observed was 7-10 lux. The townet fishes from the surface to 3 m deep, or an intensity range of about 50-200 lux.

During the tests lighting conditions at the wharf were set to duplicate normal operating procedure for security inspections (Knudtzon, personal communication). Additional high intensity lamps at the EHW, which would be illuminated during vessel loading procedures, significantly increased light intensity (Table 8). Surface intensities in the berth area and along the trestles more than doubled. This increase would probably alter fish concentrations determined by the March study. Most potential predators were observed in the berth area and this was probably a response to greater concentrations of prey, including salmonids. Increased light intensity along the trestles might increase prey and predator concentrations there as well, with subsequent impact on outmigrant populations.

Mark-Recapture Experiment

During the 5 days[2] following their release, the CPUE of marked chums peaked in the area south of EHW (nearest the release point) on day 1 (CPUE = 2.5), peaked in the area north of EHW (farthest from the

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[2]Here "day" refers to the 24-hr period covering both day and night.

Table 8. Underwater light intensities in the EHW area during "maximum" lighting (see text)[a]; readings taken at night, low tide; distance from top of trestle to water surface, 5 1/2 m.

Station[b]	Intensity (lux) Depth (m) 0	2	6	10
1	(no water)[c]			
2	(no water)			
3	18	9	2	1
4	0			
5	22			
6	63	24	8	3
7	32			
8	349	202	67	23
9	11			
10	5			
11	337	172	63	24
Mid-berth	420			
12	22			
13	14			
14	5	2	1	
15	15			
Distance north of N. Trestle 5 m	9			
Distance north of N. Trestle 13 m	4			
Distance north of N. Trestle 20 m	2			
16	5			
17	11			
18	66			
19	10			
20	10			

[a] lamps additional to those used for security lighting are: 24 400-W and 21 1,000-W metal halide, and 16 1,500-W quartz lamps in the berth area, and 12 250-W sodium vapor, 25 400-W high pressure sodium, and 12 500-W incandescent lamps on the trestles (Figs. 7 through 10).

[b] visual observation stations depicted in Fig. 4.

[c] tide out when measured.

release point) on day 3 (CPUE = 2.2), but peaked at EHW on day 5 (CPUE = 3.7) (Table 9). Although these data indicate delay of migration caused by attraction to EHW, we consider this a tentative conclusion since marked fish often do not behave as a group (Whitmus and Olsen 1979).

CONCLUSIONS

Apparently during the lights-off phase offshore salmonids were attracted only to the submarine berth area, and only during the day. In comparison with the other test sites, this area was shaded by a box-like steel enclosure above the submarine berth (Plate I shows this enclosure partially completed). Evidently, the juvenile salmon sought the shelter provided by the shaded berth area. At night with security lights off darkness provided protection, so the fish were no longer attracted to the enclosed area. Similarly, outmigrating salmon school for protection during the day, but disperse at night (Schreiner 1977). At night with security lights on the salmon were attracted to the EHW, the lights evidently reversing the normal dispersal behavior.

Table 9. Daily catch of marked chum in test (EHW) and control (south and north of EHW) area, 3/27 to 3/31/78.

Sample area	Date	Days after release	Beach seine			Townet			Total		
			n[a]	Catch	CPUE[b]	n	Catch	CPUE	n	Catch	CPUE
EHW	3/27	1	3	4	1.3	3	0	0.0	6	4	0.7
	28	2	3	6	2.0	4	6	1.5	7	12	1.7
	29	3	4	3	0.8	6	10	1.7	10	13	1.3
	30	4	4	9	2.3	7	4	0.6	11	13	1.2
	3/31	5	2	6	3.0	1	5	5.0	3	11	3.7
South	3/27	1	9	3	0.3	18	64	3.6	27	67	2.5
	28	2	13	4	0.3	17	7	0.4	30	11	0.4
of	29	3	9	10	1.1	14	6	0.4	23	16	0.7
	30	4	5	0	0.0	9	26	2.9	14	26	1.9
EHW	3/31	5		na			na			na	
North	3/27	1	2	0	0.0	9	1	0.1	11	1	0.1
	28	2	5	1	0.2	5	0	0.0	10	1	0.1
of	29	3	3	3	1.0	6	17	2.8	9	20	2.2
	30	4	6	1	0.2	9	25	2.8	15	26	1.7
EHW	3/31	5	5	0	0.0	8	0	0.0	13	0	0.0

[a] n = No. of samples .
[b] CPUE = catch ÷ n.

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ERRATA

Pages 16 and 17, Figs. 9 and 10:

Spot Lamps are "150 W," not "100 W," as shown in key.