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TRIDENT DREDGING STUDY:
THE EFFECTS OF DREDGING AT THE U.S. NAVAL SUBMARINE BASE
AT BANGOR ON OUTMIGRATING JUVENILE CHUM SALMON, ONCORHYNCHUS KETA,
IN HOOD CANAL, WASHINGTON

by

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1.0 SUMMARY

by

Ernest O. Salo and Bruce P. Snyder

- 1.1 Between February and July 1977, approximately 224,000 yd³ of bottom sediments were dredged from Hood Canal with a 10-yd³ clam-shovel dredge which removed two layers of sediment, recent alluvium (overburden) and glacial till, for construction of a gravity drydock at the U.S. Naval Submarine Base, Bangor, Washington.
- 1.2 The sediment load of the plume created by the dredging was limited, by the Washington Department of Fisheries (WDF), to no more than 30 mg/liter over ambient. The levels were monitored weekly and daily by WDF and U.S. Navy Department of Ecology (USNDE), respectively.
- 1.3 As part of the cooperative monitoring program, the Fisheries Research Institute monitored the impact of dredging using juvenile chum salmon (Oncorhynchus keta) as test animals in static, flow-through and field bioassays. The University of Washington R/V KUMTUKS was moored 500 m north of the dredge site and was used for the static and flow-through bioassays as well as the base of field operations.
 - 1.3.1 The field bioassays included live-boxes (cages) to measure direct effects; possible avoidance of the dredge plume was determined by beach seine and townet sampling of chum salmon in the dredge area.
 - 1.3.2 All bioassays were monitored for the incidence of diseases before and after each test.
 - 1.3.3 Water quality parameters measured routinely included: DO, temperature, salinity, pH, and total nonfilterable residue (TNFR).
- 1.4 Static Bioassays. Ninety-six hour LC₅₀ values for the static bioassays varied between 15.8 and 54.9 g/liter, three orders of magnitude higher than the range of total nonfilterable residue (TNFR) values found near the dredging operations (approximately 4-94 mg/liter).
 - 1.4.1 These data suggest that any direct effects suffered by chum salmon migrating through the dredging area were negligible.

- 1.4.2 The juvenile chum salmon were more tolerant of overburden (mean particle diameter = 0.044 mm) than of glacial till (mean particle diameter = 0.064 mm).
 - 1.4.2.1 Differences in dissolved metal concentrations accounted in whole or in part for the differences in tolerance of the salmon to the two types of sediment.
 - 1.4.2.2 A positive correlation existed between fish size and tolerance.
 - 1.4.2.3 No significant difference in blood plasma glucose concentration was shown to exist between test fish subjected to 150-200 mg/liter glacial till and controls.
- 1.5 Flow-through Bioassay. The flow-through bioassay was designed to simulate dredge-area conditions by pumping sea-water continuously for 96 hr periods from the area to determine the effect of the suspended sediments on juvenile chum salmon.
 - 1.5.1 Each bioassay monitored fish mortality, suspended sediment levels, water temperature, D.O., pH, and salinities. A concurrent live-box bioassay (see 1.6, below) monitored these variables in the field.
 - 1.5.2 Results indicated no lethal effect from suspended sediment levels that averaged 10 mg/liter, with a maximum of 37 mg/liter.
 - 1.5.2.1 An increase in mortalities, experienced from mid-May on, was associated with increasing water temperatures, disease epizootics, and handling stresses.
- 1.6 Live-box Bioassays. Live-box bioassays were conducted within the closest perimeter possible to the dredge.
 - 1.6.1 Water quality was monitored once daily at all test and control live-box sites while plume sediment levels were monitored at peak flow of each daylight ebb and flood tide.
 - 1.6.2 Suspended sediment levels averaged 9.4 mg/liter for the study with a range of 4.0 to 94.0 mg/liter. Mortalities were <2% from January to mid-May 1977; increasing mortalities thereafter were associated with decreasing condition of the fish and an onset of disease.

- 1.6.2.1 Salinities ranged from 24 to 32 ppt, pH from 7.7 to 8.4, D.O. from 7 to 14 ppt and water temperatures from 7 to 15°C.
- 1.7 Avoidance-behavior Bioassays. Observations in the field and tests in the laboratory measured the avoidance response of juvenile chum salmon to suspended sediments.
 - 1.7.1 Field surveys were conducted using 37 m beach seines (nearshore) and 5 and 10 min townet (offshore) hauls in and around the dredging plume.
 - 1.7.2 In both the field and the laboratory, any avoidance by the fish appeared to be caused by the concentration of the sediments and not by any contaminants that might be associated with the sediments.
 - 1.7.2.1 Beach seine and 10 min townet data indicated no fish avoidance; however, 5 min townet data indicated fish may have avoided the plume.
 - 1.7.2.2 In the 5-min townet transects, fish abundance was correlated with tide height, except when the ebb tide was accompanied by an increase in TNFR levels from 2.0 to 9.8 mg/liter above ambient. This was interpreted as avoidance.
 - 1.7.2.3 Fish avoiding the plume appeared to disperse during daylight and accumulate on the edge of the plume after dark.
 - 1.7.3 Laboratory investigations of avoidance tested fish from the Big Beef Creek spawning channel against overburden while fish caught near the site were used in the tests with glacial till.
 - 1.7.3.1 No significant response was detected with overburden sediments ranging from 25.6 to 262.0 mg/liter.
 - 1.7.3.2 There was an increased frequency of avoidance to glacial till as the concentrations increased from 35 to 190 mg/liter.
 - 1.7.3.2.1 Based on the laboratory tests, a conservative threshold avoidance concentration of glacial till for test fish was determined to be 182 mg/liter.

1.8 Disease Monitoring. Incidence of disease, especially Vibrio, was monitored in the test chum populations before and after all bioassays. The local chum salmon populations were tested weekly as they migrated through the dredge area.

1.8.1 Dredging did not increase the incidence of disease as <2% of the chums caught in the dredging area had detectable diseases.

1.8.2 Chums held in net pens for testing had few disease problems from February to April; however, from May through June the mortalities increased until a 100% mortality from Vibrio was experienced even in isolated pens with low densities.

1.8.2.1 Vibriosis can be an important limiting factor in handling or confining chum salmon when water temperatures exceed 12°C.

2.0 DISCUSSION AND CONCLUSIONS

by

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

- 2.1 Dredging started in February 1977, with background studies starting in mid-January. Manpower and facilities included 7 project leaders, 11 research aids, and the R/V KUMTUKS, with an operational crew of 3. The project was short-term and labor intensive with 24 persons involved during the peak of the chum migration when over 4,100 man-hr/month were logged. Nine support vessels were used to sample in the field. An effort of this magnitude was necessary to coordinate field observations and laboratory tests; both are necessary to define the influence of low-level sediments. Additional reports will describe the effects of piers, with and without security lighting, on the migrations of juvenile chum salmon. A five-year study on the influences of the Bangor facilities on the outmigration of juvenile chum and pink salmon from Hood Canal has also been completed. A substantial part of the effort involved in the latter studies was integrated with the monitoring of the dredging.
- 2.2 Sediments suspended by the use of a 10-yd³ clam-shell dredge formed a plume which was difficult to discern from either ground level or from the sea surface, but was clearly evident from the air. The sediments settled relatively fast and seldom did the total nonfilterable residue (TNFR) levels exceed 30 mg/liter along the shoreline. Strong tides made definition of the plume difficult. Also, dredging was not continuous.
- 2.3 Dredging was initially projected for a 4-5 month period from late January through May, thus missing the peak of the salmon outmigration in late May-early June. However, the extremely hard glacial till slowed the operations even though 16-hr dredging days were utilized. Dredging was completed on July 24, 1977.
- 2.4 Problems were encountered in obtaining appropriate test fish during the six-month period. Initially, local or wild stocks of chum salmon (i.e., from Hood Canal) were not available in sufficient quantities so hatchery fish were obtained from Big Beef Creek on Hood Canal. Later, spawning channel fish from Big Beef Creek (i.e., those resulting from natural spawning) were used as the hatchery fish were too large. Toward the end of the season, disease epizootics affected all stocks, including the hatchery fish, whenever they were handled.
- 2.5 The static bioassays effectively evaluated the tolerance of juvenile chums to suspended sediments.

- 2.6 Flow-through bioassays were considerably more difficult to conduct as the plume was variable in shape and location and often was not in the vicinity of the fixed water intakes. Also, "control" water was difficult to maintain at either clear or ambient levels.
- 2.7 Live-box bioassays effectively subjected the test animals to TNFR concentrations representative of dredge-area conditions.
- 2.8 The laboratory and field avoidance experiments were the most difficult to conduct and a large number of the "data points" were not representative of field conditions in the immediate vicinity of the dredge. Behavior experiments, although necessarily continuous, required numerous, repetitive data points which were difficult to obtain even with the allotted 8-man crew.
- 2.9 Disease monitoring was effective in defining the susceptibility of chums to vibriosis, when the fish were confined or stressed from handling, particularly when water temperatures exceeded 12°C. The low-density isolated pen experiments indicated that chums are extremely sensitive when confined, leading one to speculate on the possible effects of any low-threshold (stress) conditions affecting hatchery stocks when released into the natural environment late in the season.
- 2.10 During the 6-month dredge monitoring program, no lethal effect on migrating juvenile chum salmon was found in the dredging area. Only on a few occasions during long periods of dredging, during maximum flood or ebb tides, were the allowable TNFR levels of 30 mg/liter exceeded 30 m from shore. This is well below the threshold avoidance level of 182 mg/liter established in the laboratory experiments. There was evidence of avoidance in the field at lower levels (2.0 to 9.8 mg/liter above ambient). We conclude that some avoidance of the plume occurred but any negative impact was not discernable.

3.0 INTRODUCTION

by

Robert A. Campbell, Thomas E. Prinslow, and Ernest O. Salo

3.1 BACKGROUND

Approximately 224,000 yd³ of bottom sediments were dredged from Hood Canal for construction of a drydock-refit pier at the U.S. Naval Submarine Base, Bangor, Washington (Fig. 3-1). The dredging period was February to July 1977. The U.S. Army Corps of Engineers (USACE), based on recommendations from the Washington State Department of Fisheries (WDF) included monitoring the impact of dredging as a condition of the construction permit; therefore the U.S. Navy contracted the University of Washington's Fisheries Research Institute (FRI) to research the impact while the WDF supervised the monitoring. Emphasis was placed on juvenile chum salmon (Oncorhynchus keta) because they are an economically important and biologically sensitive species and were present in the area during dredging.

Preliminary investigations began in 1975 with a literature review by Mortensen, Snyder, and Salo (1976). The general effects of suspended sediments on fish and the aquatic environment had been described in the literature; however, no criteria had been established on the concentration of suspended sediments allowable in the habitat of juvenile salmonids. Generally, suspended sediments may impair fish health directly or indirectly. Direct effects include: 1) decreased respiratory efficiency by clogging or damage to gill epithelia (Wallen 1951; Rogers 1969; Sherk et al. 1974); 2) skin abrasion and subsequent exposure of subepithelial tissue to pathogenic organisms (Herbert and Merckens 1961); 3) disruption of osmoregulation, should sediments pack the gut (Sherk et al. 1974); and 4) exposure to potentially harmful contaminants associated with bottom sediments, including decomposition waste products, ionic metals and hydrocarbons (Servizi, Gordon, and Martens 1969; EPA 1973). Indirect effects include: 1) reduction of food sources caused by a decreased euphotic layer (Bartsch 1959; Samsel 1973; Sherk et al. 1974; O'Connor and Sherk 1975); and 2) reduced dissolved oxygen (DO) concentrations resulting from a decreased euphotic layer and increased biological and chemical oxygen demands associated with bottom sediments (May 1973; Sherk 1971).

A study by Shreiner (1977) describes the movement of outmigrating juvenile salmonids through Hood Canal from March to July 1975 and January to July 1976. In those years the majority of fish migrated along the eastern shoreline, passing through the construction site. Generally, the juveniles appeared to remain in the upper 2 m of water and followed the shoreline, staying close to shore during the early

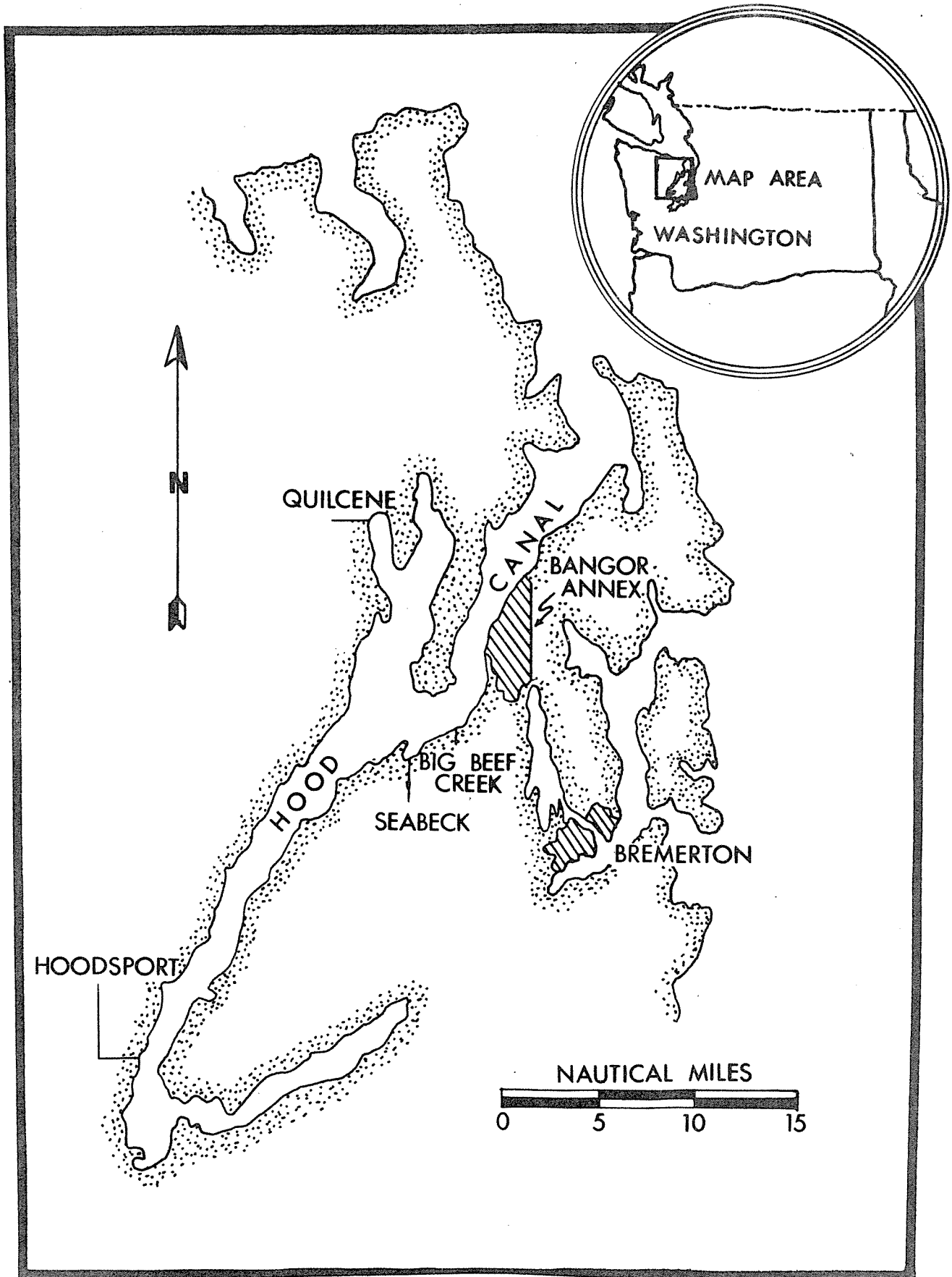


Fig. 3-1. Location of Hood Canal, Bangor Annex, Big Beef Creeks, Quilcene and Hoodsport hatcheries.

months but moving farther from shore by late spring. The peak migration period was between mid-May and mid-June.

Dredging was scheduled to be completed before the peak migration period so the WDF sought to protect the early, nearshore migrants by limiting the sediment load of the water to no more than 30 mg/liter over ambient levels, measured at a depth between 1 and 2 m within a 30-m distance from shore. This level was believed to be a tolerable concentration for the outmigrants; however, the effects of dredging, even limited to these concentrations, were unknown. After conducting a test in October 1976, the U.S. Navy's Department of Ecology (USNDE) concluded that dredging could occur without exceeding the standards that were set.

During May and June 1976, preliminary static and avoidance-behavior bioassays were conducted aboard the University of Washington's R/V KUMTUKS, moored offshore near the proposed construction site (Martin, Salo, and Snyder 1977). The results determined that additional experiments would be necessary for a comprehensive monitoring program. Consequently, a laboratory flow-through bioassay and a field live-box experiment were included in the monitoring of the in situ conditions during the dredging. In 1976, extensive mortality of the juvenile chum salmon being tested was caused by a seasonal outbreak of vibriosis and furunculosis; therefore, monitoring of diseases was also included.

3.2 DESCRIPTION OF MONITORING PROGRAM

A cooperative monitoring program was agreed upon by the U.S. Navy, WDF, and FRI (Fig. 3-2). The USNDE and WDF were responsible for monitoring water quality in the construction area, especially within the 30-m shoreline zone, and both agencies gathered data on sediments and evaluated the impact on shellfish populations. Aerial surveillance was provided by the U.S. Navy to determine the form and extent of the plume formed by the suspended sediments. WDF provided general surveillance of the program.

FRI conducted the laboratory and field experiments on chum salmon including:

- 1) static bioassays to determine the median lethal concentrations (LC₅₀) of suspended sediments for various exposure times;
- 2) flow-through bioassays to assess the exposure of fish to water continuously pumped from the dredge area;
- 3) live-box bioassays to assess the exposure of fish to suspended sediments in the field;
- 4) avoidance-behavior tests conducted in the laboratory and the field to determine if fish would avoid suspended sediments;
- 5) incidence of disease to determine if suspended sediments increased the susceptibility of fish to pathogens.

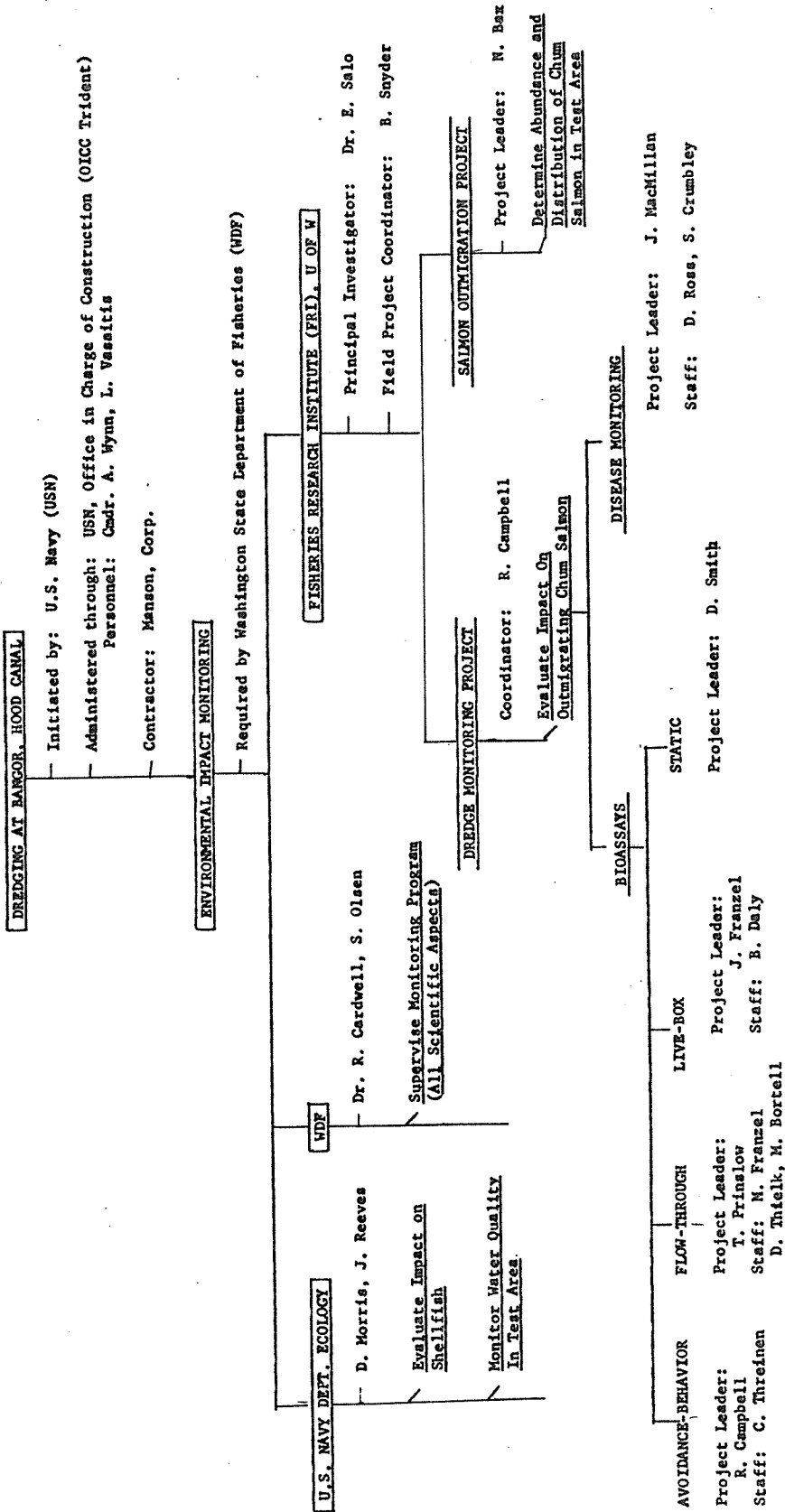


Fig. 3-2. Cooperative scheme for monitoring dredging at Bangor.

Weekly reports were submitted to the U.S. Navy Officer in Charge of Construction (OICC) Trident and to WDF. If experiments had indicated that dredging activity was preventing successful migration of the juvenile chum, action would have been taken to postpone dredging. Monitoring began 1 week prior to the start of dredging and continued for 1 week after completion.

The R/V KUMTUKS served as the field base of operations for 20 persons, 10 of whom were resident scientists, consisting of the basic crew. Others were present at the peak of the season, or were based at the University's Big Beef Creek Research Station located 5 mi south of the field site.

Nine small craft were required to conduct the field surveys. The intensive, 24-hr day monitoring schedule demanded precise logistics and communications.

3.3 OPERATION DESCRIPTION

Dredging began February 11, 1977, with completion scheduled for mid-May 1977; however, technical problems extended the date to July 24, 1977. A 10-yd³ clam-shovel dredge was used to remove two layers of sediment, recent alluvium (overburden) and glacial till, described by Haley and Aldrich (1975) (Plate I). Suspendable sediments forming the dredge plume consisted of fine sands, silt, and clay. The concentration of suspended sediments in the water column depended on the layer dredged, as well as tide, current, and dredging activity. The plume was formed as the clamshell dredge was lifted through the water column and in the process of emptying the spoils onto a scow (Plate II). When a series of scows was filled they were towed away for offsite disposal. Particle size, quantity, location, and date of removal for the two layers appear in Appendix I.

Monitoring began January 31, 1977, and ended July 29, 1977. The laboratory bioassays and disease monitoring were conducted aboard the R/V KUMTUKS (Fig. 3-3) moored adjacent to the dredge site, at the south end of Marginal Wharf. Live-boxes were located in the vicinity of the dredging and at the Small Craft Wharf, Explosives Handling Wharf, and Seabeck. Field avoidance-behavior surveys were conducted near the shoreline of the Bangor Annex area; effort was concentrated near the dredge site (Fig. 3-4 and Plate I).

Control water for the laboratory bioassays and acclimation tank was obtained by pumping ambient water from Hood Canal into four 10,000-liter settling tanks, then into the laboratory via a 5,000-liter tank located on the fantail of the KUMTUKS. Water was pumped directly from the moorage site for water baths (Fig. 3-5 and Plate III).

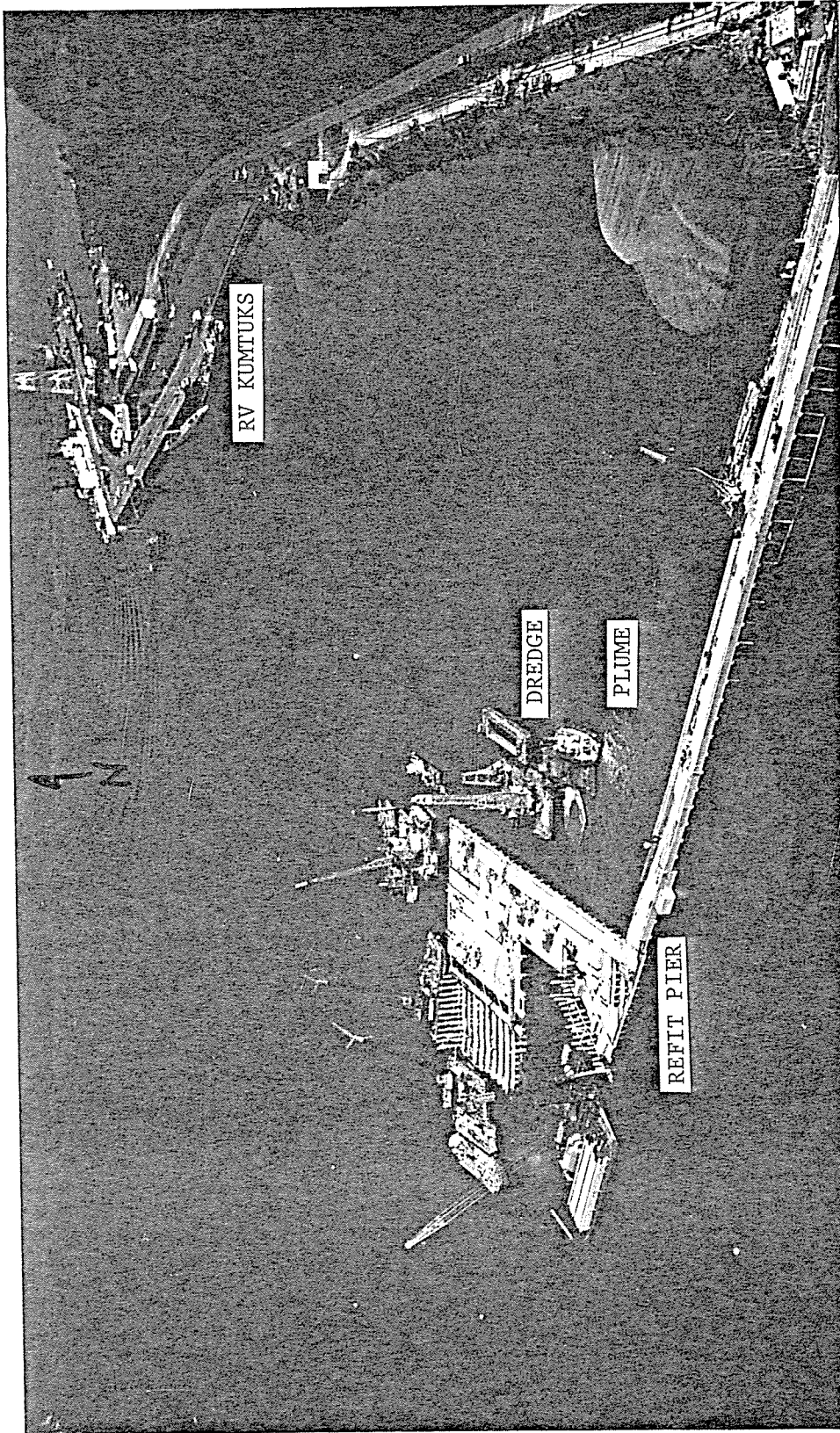


Plate I. Aerial view of dredging site at the Refit Pier, Submarine Base-Bangor. Sediment from pumping of wells (lower right) was not related to dredging.

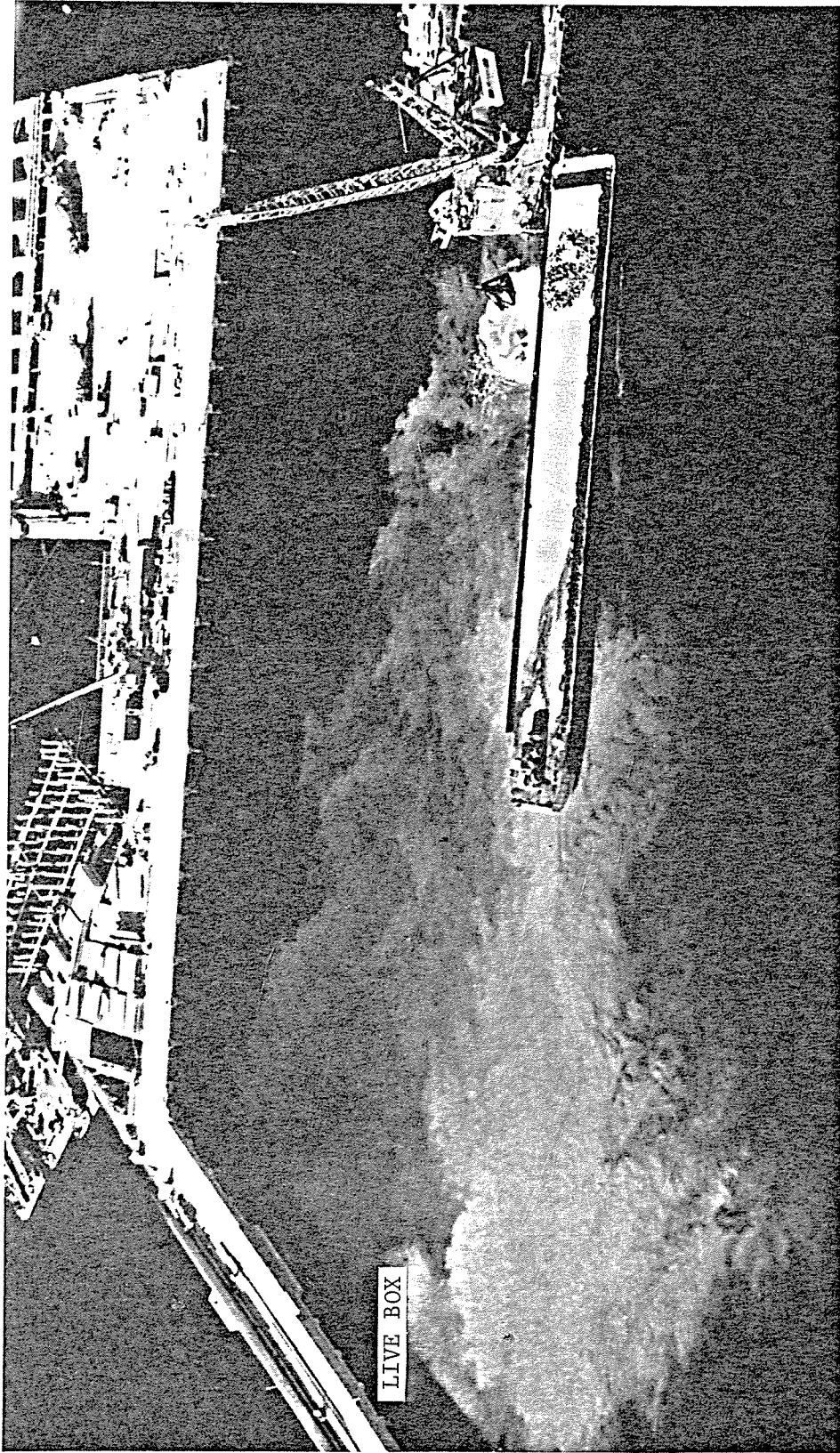


Plate II. Aerial view of dredge, scow, and plume at the Refit Pier, plume enveloping live boxes suspended from trestle.

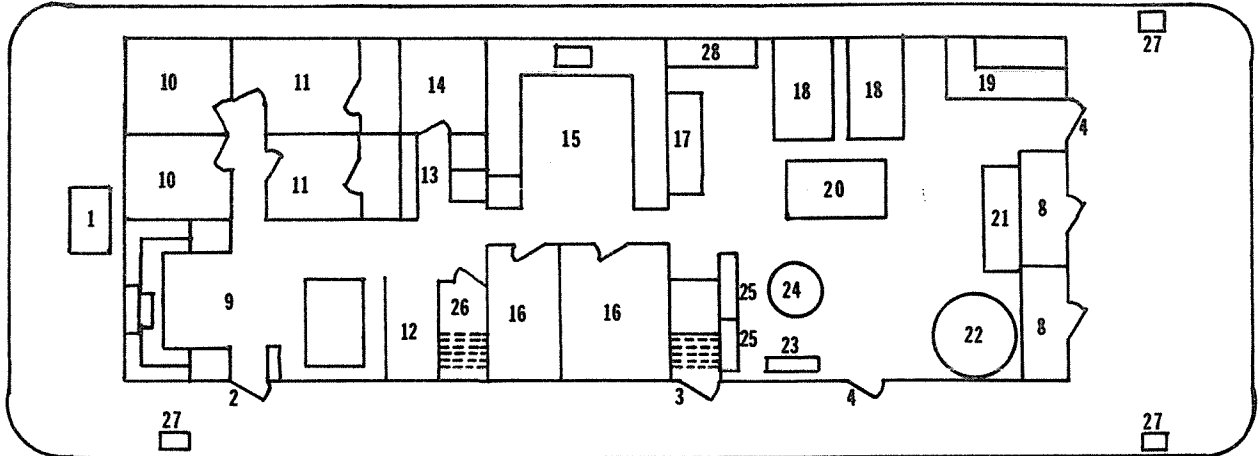


Fig. 3-3. R/V KUMTUKS: a) during operation; b) floor plan.

1. Anchor winch
2. Galley entry
3. Engine room entry
4. Wet lab entry
5. Deck floodlights
6. Ventilators
7. Position of deck crane
8. Storage locker
9. Galley with table, counters, sink
10. Staterooms with washbowl only
11. Staterooms with full head
12. Office and communications
13. Linen storage, washer and dryer
14. Main head
15. Chem lab with refrigerator, hood, counters, sink
16. Instrument rooms
17. Counter space
18. Exercise chamber - respirometer
19. Surgical area, counter, sink
20. Water table (16" deep)
21. Small water tables
22. 6' dia. x 3' deep tank
23. 100 gal recirculating tank
24. 4' dia. x 2 1/2' deep tank
25. 100 gal tanks
26. Stairway down to bunkroom, refrigeration and storage compartments
27. Hatchway to end compartments of hull

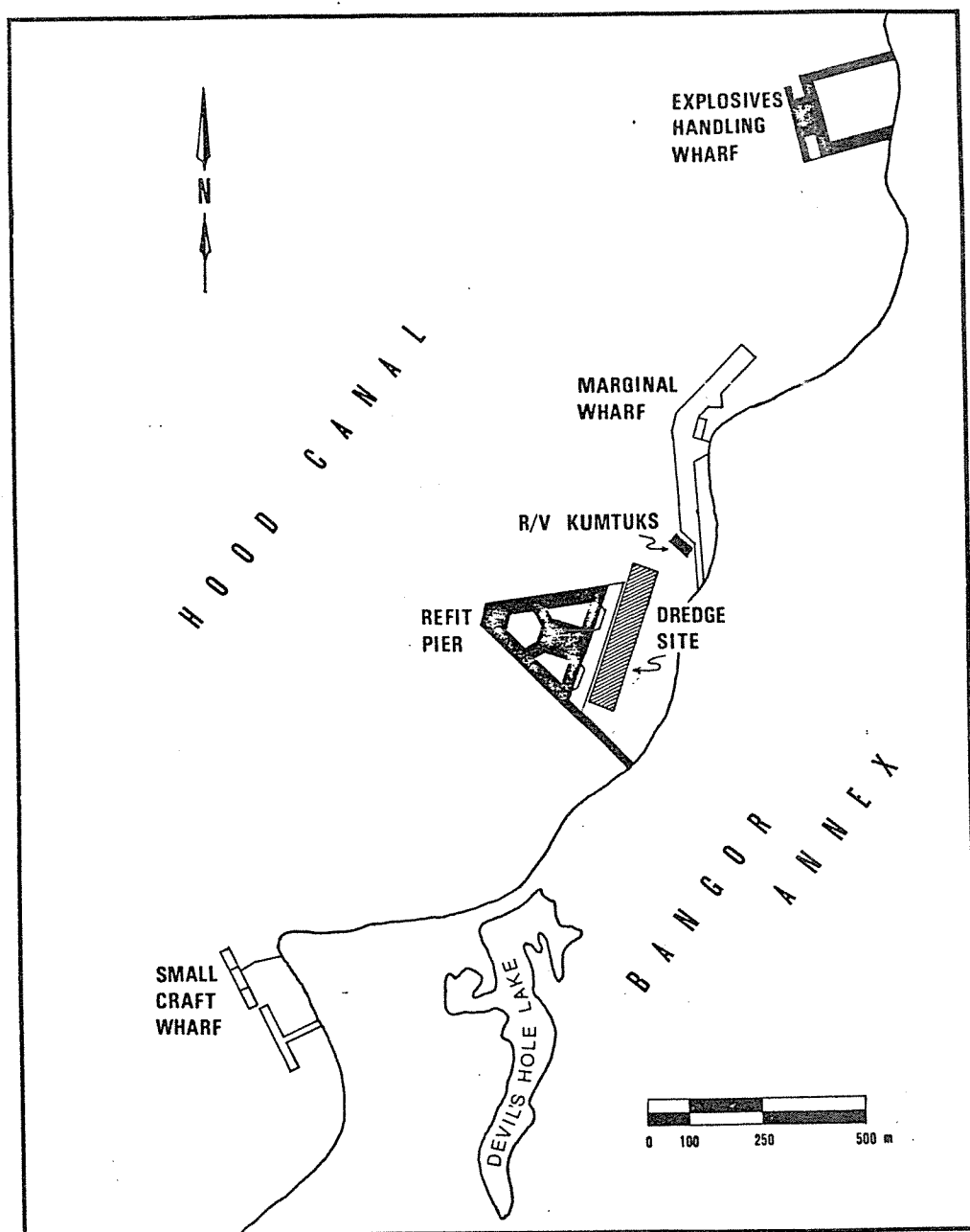


Fig. 3-4. Shoreline at Bangor Annex showing location of Refit Pier, dredge site and R/V KUMTUKS.

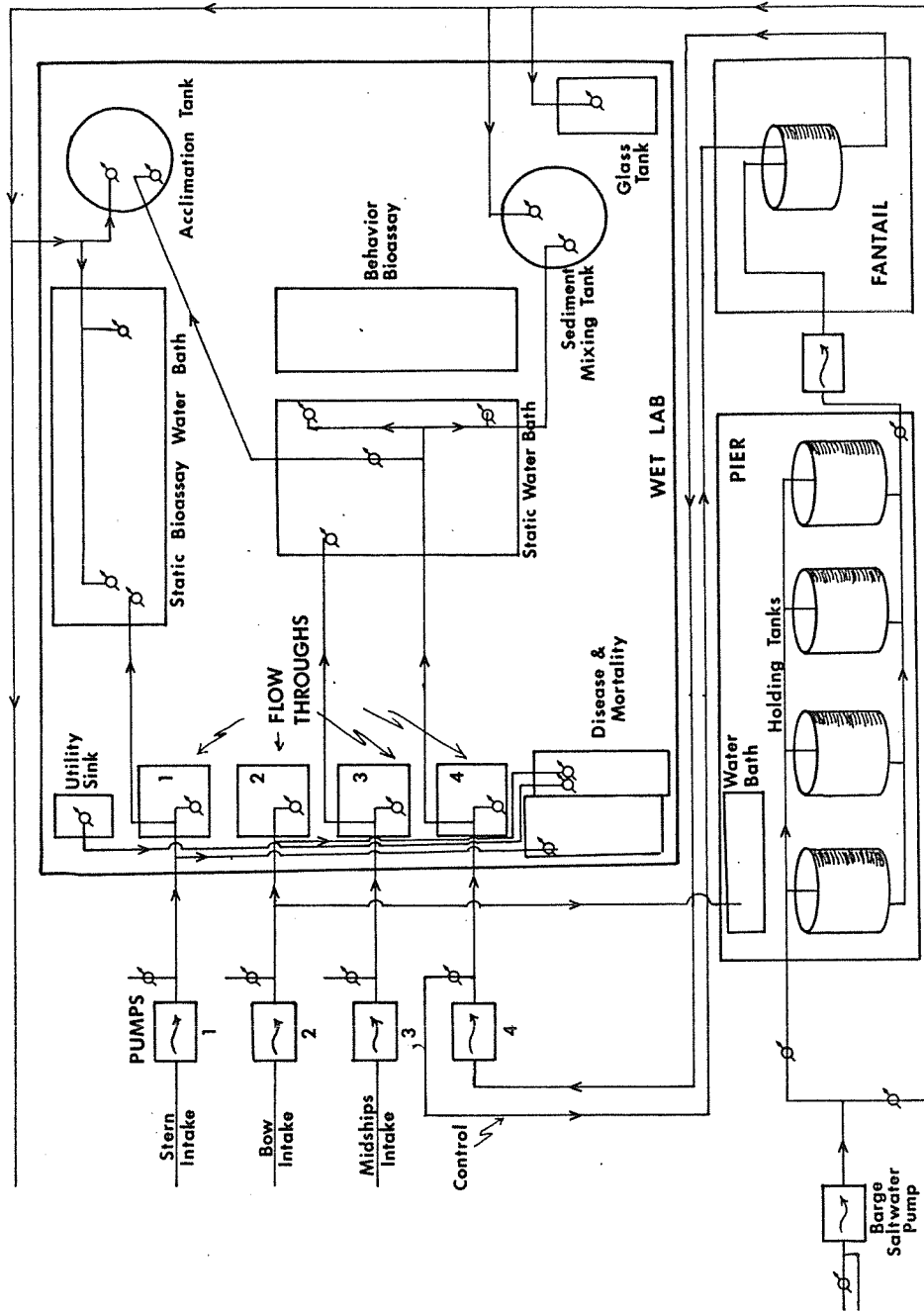


Fig. 3-5. Experimental seawater system.

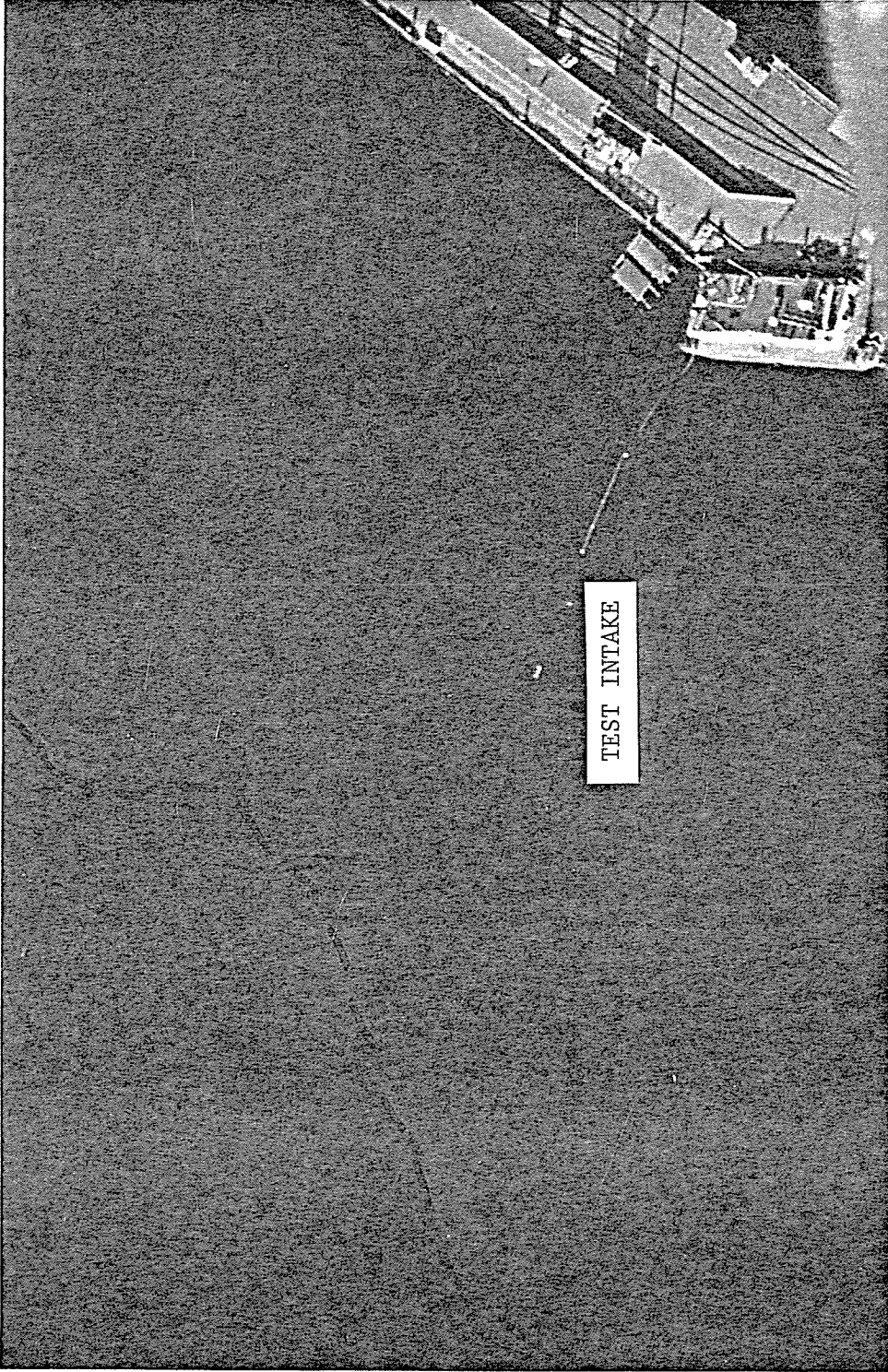


Plate III. Plume enveloping RV KUMTUKS (lower right), showing intake for flow-through bioassays; plume periphery marked by dashed line.

Three sources of test fish were used in the experiments: 1) hatchery; 2) spawning channel; and 3) local. Hatchery fish were obtained from the University of Washington's hatchery at Big Beef Creek, the WDF hatchery at Hoodspoint, Washington, and the U.S. Fish and Wildlife Service's (USFWS) hatchery at Quilcene, Washington (Fig. 3-1). Channel fish were supplied from the spawning channel at Big Beef Creek described by Koski (1975). Local fish were captured in the Bangor Annex area by beach seining and tounetting. The term local fish¹ is used as the fish's origin, either wild or hatchery release, was indiscernible.

Test fish were held in floating pens for approximately 2 weeks prior to experiments (Fig. 3-6). Holding pens were located at the Small Craft Wharf until March 1977 when they were moved to Marginal Wharf (Fig. 3-4). Laboratory test fish were acclimated in a 2,000-liter tank aboard the KUMTUKS for 2 days prior to testing. The tank was enclosed with black polyethylene sheeting and received approximately 10 liters per min of control water and 12 hr of light daily. Fish were not fed during testing or acclimating but were fed Oregon Moist Pellets (OMP) during holding.

Water quality parameters that were monitored routinely during the experiments include: total nonfilterable residue (TNFR); DO; temperature; salinity and pH. Occasional determinations of H₂S and NH₃-H concentrations were made. Dredged sediments were analyzed for total and dissolved heavy metals, total volatile solids, total organic carbon, oil and grease, and particle size distribution. Methods for these analyses are described in the individual sections of this report.

¹In some of the progress reports, weekly reports, and preliminary reports local fish may have been referred to as feral fish, which to some implies wild fish, and to others, feral is used specifically for tame animals which have reverted to a wild condition.

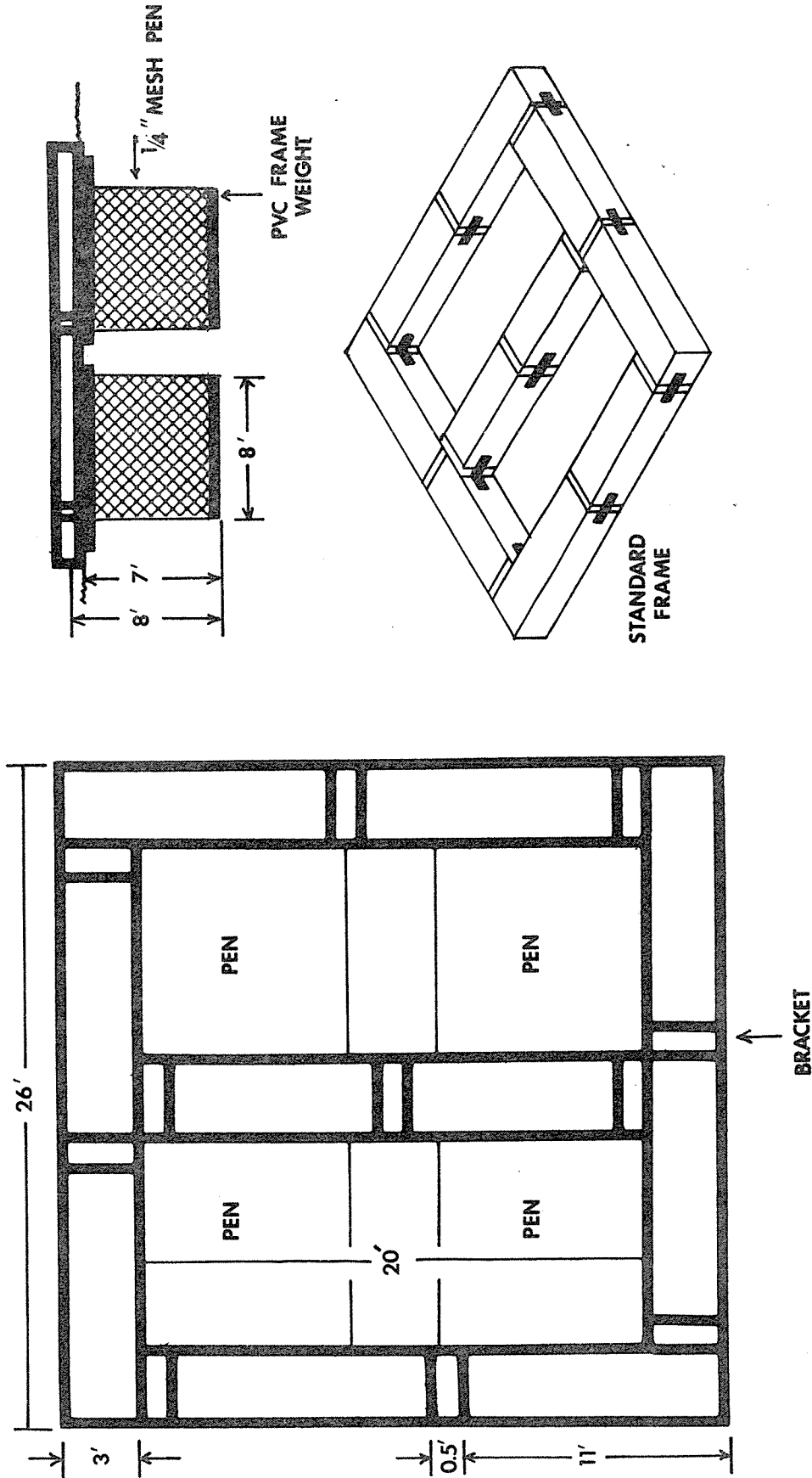


Fig. 3-6. Design of floating pens used to hold test and control fish prior to use in bioassays.

4.0 TOLERANCE OF JUVENILE CHUM SALMON (Oncorhynchus keta) TO SUSPENDED SEDIMENTS (STATIC BIOASSAY)

by
David W. Smith

4.1 INTRODUCTION

This study was undertaken to determine the tolerance of seawater-adapted juvenile chum salmon (Oncorhynchus keta) to suspended sediments. Static bioassays were employed to: 1) obtain median lethal concentrations (LC₅₀ values) and median lethal thresholds; and 2) determine if dredging induced sublethal stress. The cause of death and the relationship between body size and tolerance were also investigated. Similar static bioassays have not been conducted with salmonids in seawater except during a preliminary study to this work (Martin, Salo, and Snyder 1977).

Terms used in a special context are:

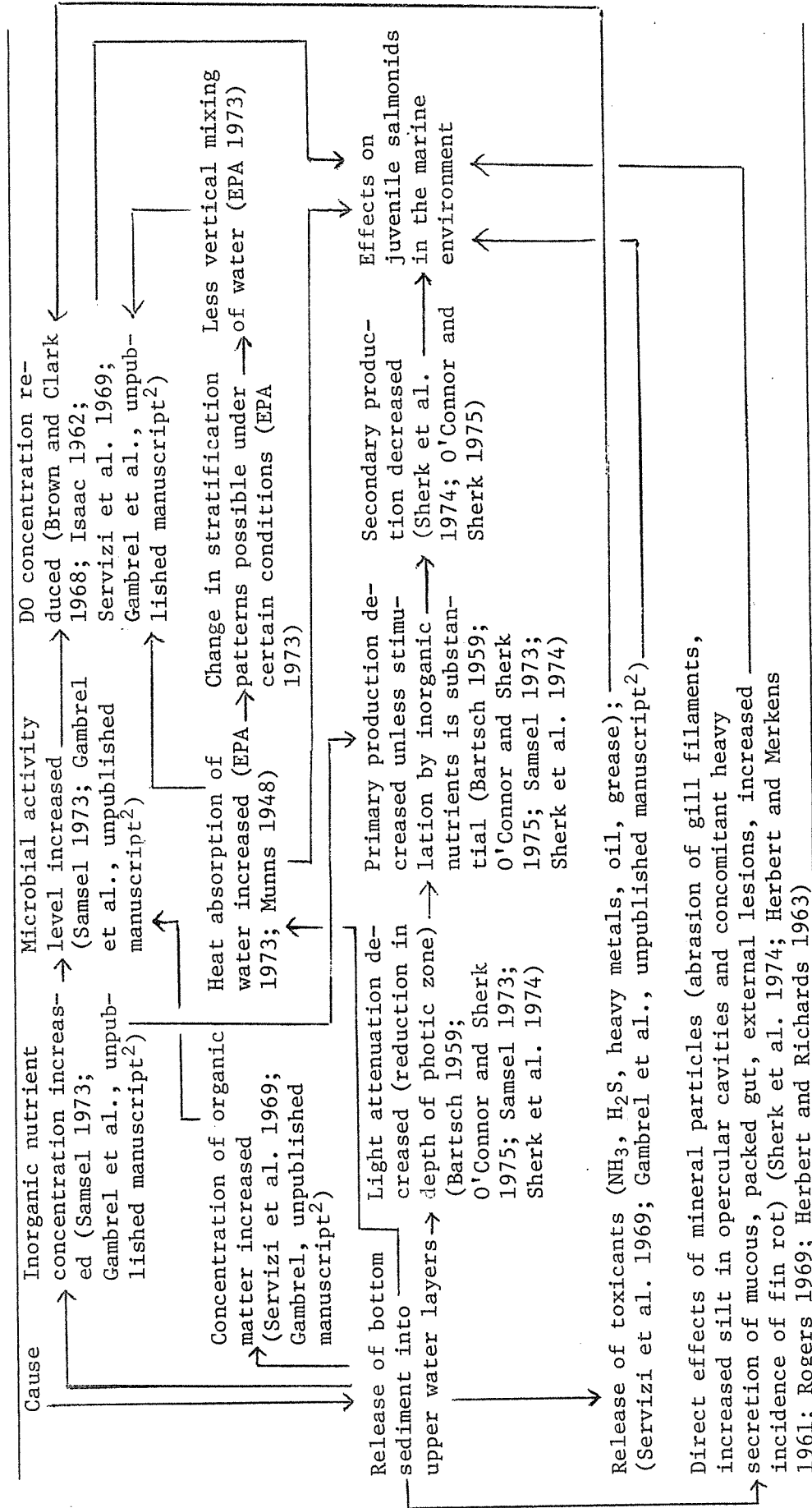
1) Toxicant. Pollutants can usually be categorized according to their effects on fish as chemical (e.g., metals), physical (e.g., mineral particles, radionuclides), or biological (e.g., viruses, bacteria). According to Brown (1973), if the chemical properties of a given pollutant are not specifically and directly related to the manner in which the fish is affected, the pollutant should not be considered a "toxicant." This report will employ such a definition; the term "toxicity" will only be used when referring to the effects of heavy metals, NH₃, H₂S, oil, and grease.

2) Suspended solids. This term pertains primarily to mineral particles, but may include various toxins, organic matter, and microorganisms. "Suspended sediments" will be considered a subset of "suspended solids."

A simplified summary of how juvenile chum salmon may be affected by exposure to suspended sediments is presented in Fig. 4-1. Indirect effects include decreased food supply and DO. Direct effects include abrasion and exposure to increased concentrations of toxins (e.g., heavy metals, NH₃, H₂S, oil, and grease). This report is concerned only with the direct effects of suspended sediments on chum salmon.

4.2 MATERIALS AND METHODS

4.2.1 Acute Bioassays



¹Note: Many of the above effects are based on results from studies conducted in freshwater environments.
²Gambrell, R. P., R. A. Khalid, V. R. Collard, C. N. Reddy, and W. H. Patrick, Jr. The effect of pH and redox potential on heavy metal chemistry in sediment-water systems affecting toxic metal bioavailability. Lab. Flooded Soils and Sediments, Louisiana State Univ., Baton Rouge, La. [Unpublished manuscript]

Fig. 4-1. Simplified cause-effect chart. Impact of suspended solids on juvenile salmonids in the marine¹ environment (assuming no avoidance).

4.2.1.1 General Experimental Design

The study was conducted on a floating laboratory (R/V KUMTUKS) situated close to the dredging activity (Fig. 3-4). Fifteen acute bioassays were conducted between February 10 and June 17, 1977, using two types of bulk sediment (overburden and glacial till) and three sources of fish (Big Beef Creek channel, Hood Canal local, Hoodsport Hatchery, see 3.3). The tests varied from 12 to 488 hr, but most exposures lasted 96 hr. Three tests were run beyond the customary 96-hr period to establish median lethal threshold values (experiments 1, 2, 4). Table 4-1 summarizes the exposure periods, sources of fish, and sediment types used in the bioassays.

Generally, local chum were used whenever possible (experiments 10, 12, and 14), and Big Beef Creek (BBC) channel fish used otherwise, with the exception of experiment 15 which utilized Hoodsport Hatchery stock. During each of the three bioassays conducted with local fish another bioassay was conducted concurrently with channel fish.

During preliminary tests aeration was avoided to minimize detoxification or volatilization of various harmful materials associated with the sediment (e.g., heavy metals, NH_3 , and H_2S).¹ However, seawater with suspended sediment at concentrations required to induce mortality was found to have less than 3 mg/liter DO and could not support fish. Furthermore, when aeration was used long enough to saturate the test water with oxygen and then discontinued, DO levels fell below 4 mg/liter within 4 days (no fish were present). Therefore, continuous aeration was conducted during these bioassays, even though detoxification may have occurred as a result. Two types of harbor sediments used during bioassays conducted by Servizi, Gordon, and Martens (1969) were also shown to exhibit a marked oxygen demand.

The bioassay aquaria (tanks) were situated in water baths (eight in one bath, five in another); aquaria water temperatures within 2.5°C of ambient were maintained. Each water bath was enclosed in black polyethylene sheeting. The natural photoperiod was approximated through the use of automatic timers.

4.2.1.2 Static Bioassay Apparatus

Tests were conducted with a modified version of the apparatus utilized by Martin et al. (1977) (Fig. 4-2). Sixty-liter nontoxic Brute-resin food storage containers were used as aquaria. To retain solids in suspension, water was pumped continuously from the bottom of

¹According to Sprague (1973), depletion of D.O. by fish in static bioassays should not occur as long as loading remains below 3 g fish/day/liter.

Table 4-1. Description of acute bioassay experiments.

Exp. #	Purpose	Duration (hr)	When conducted	Type of sediment used	Source of test fish	Comments
1	LC ₅₀ determinations	488	2/10-3/2	Overburden	Big Beef Creek channel	Only 488-hr LC ₅₀ value determined
2	"	240	3/7-3/17	"	"	
3	"	16	3/29-3/30	Glacial till	"	Only 8- and 16-hr LC ₅₀ values determined
4	"	152	4/1-4/7	"	"	
5	"	96	4/11-4/15	"	"	No LC ₅₀ values determined (including range too low)
6	"	"	4/18-4/22	"	"	
7	"	"	4/25-4/29	"	"	
8	"	"	5/2-5/6	"	"	
9	"	"	5/9-5/13	"	"	
10	"	"	5/9-5/13	"	Hood Canal (in the general vicinity of Devil's Hole) (local)	
11	"	"	5/16-5/20	"	Big Beef Creek channel	

Table 4-1. Description of acute bioassay experiments--continued.

Exp. #	Purpose	Duration (hr)	When conducted	Type of sediment used	Source of test fish	Comments
12	"	"	5/16-5/20	"	Hood Canal (in the general vicinity of Devil's Hole) (local)	
13	"	"	5/23-5/27	"	Big Beef Creek channel	No LC ₅₀ values determined due to disease problem
14	"	"	5/23-5/27	"	Hood Canal (in the general vicinity of Devil's Hole) (local)	
15	"	"	6/13-6/17	"	Hoodsport Hatchery	
16	Sublethal stress assessment	25-27	4/18-4/22	"	Big Beef Creek Hatchery	Pilot study--no data presented
17	"	"	"	"	"	"
18	"	"	"	"	"	"
19	"	"	"	"	"	"

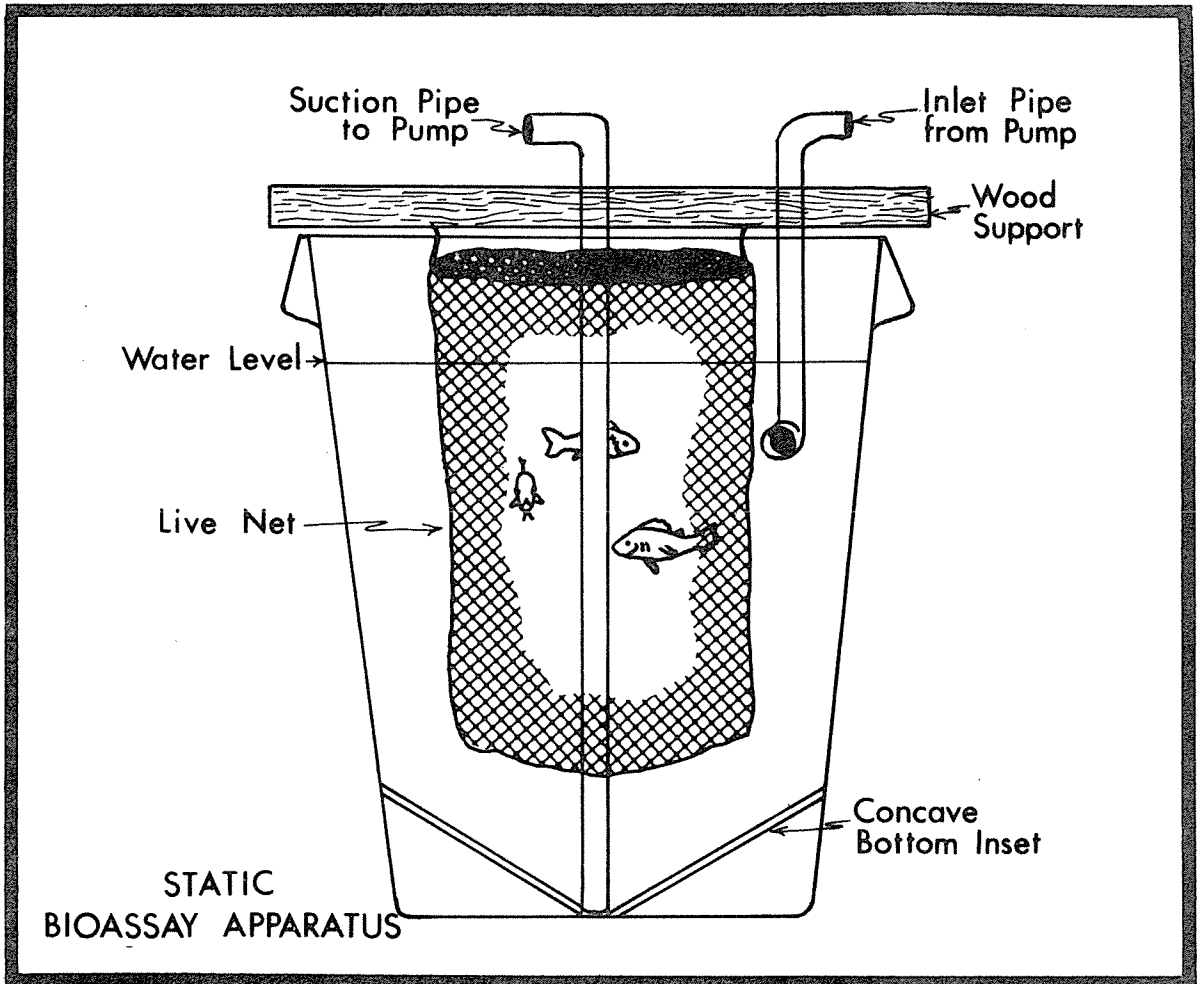


Fig. 4-2. Static bioassay apparatus.

the aquarium to the surface with a Little Giant (TM) submersible pump. Part of the water was diverted back to the bottom of the aquarium to facilitate uplifting of settled sediment. A polyethylene funnel was inserted in the bottom of each container to direct settled solids toward the center. The funnels were sealed to the aquaria with low modulus silicone rubber (Dow Corning 90). Since this material is toxic to fish, it was completely coated with nontoxic aquarium cement. Fish were contained in nets constructed of 0.6-cm mesh Vexar (TM) screen. Nets were suspended in the aquaria from wooden supports.

Initial trials proved the apparatus unable to maintain a constant concentration of sediment in suspension; total nonfilterable residue (TNFR) values would decrease to less than one-tenth of their original value within 96 hr. Manual stirring was conducted every 8 hr. (During weekends stirrings varied up to 12 hr.)

Stirring motions caused control fish to become hyperactive, but the minimal visibility in the test aquaria resulted in only a mild response to stirring from the test specimens. Therefore, stirring of the control water was not conducted.

4.2.1.3 Aquisition, Preparation, Storage, and Characterization of Sediment

Experiments 1 and 2 were conducted with overburden obtained from the dredge site by divers. The mud was sealed in 20-liter polyethylene buckets and stored in a continuous-flow water bath. Since particles larger than 100 μm settled too rapidly to be of practical use, they were separated from smaller particles with a 105- μm wet sieve (Fig. 4-3) and discarded prior to each bioassay.

Experiments 3 through 9 utilized glacial till collected from the scows used for transportation of the dredge spoils. Buckets were filled with sediment-seawater slurries and held in the water bath until all solids had settled. The supernatant was then decanted and the concentrated sediments from all buckets consolidated. These sediments passed through the 105- μm sieve leaving only a trace of sand; sieving was therefore not conducted.

Several factors helped maintain consistent toxic characteristics, particle sizes and shapes among experiments. Overburden sediments were collected from adjacent locations and combined to form two 60-liter stock slurries. Glacial till was collected from scows receiving sediments from similar locations and depths, and then consolidated to form one 60-liter stock supply. The same sediment-water mixtures were used in consecutive experiments unless different concentrations were needed or contamination was suspected. This did not result in NH_3 accumulation (Section 4.2.3).



Fig. 4-3. Wet-sieve apparatus; mesh size = 105 μm .

Particle size distributions were determined by Washington State Department of Fisheries (WDF) using methods suggested by Guy (1969). The University of Washington Quaternary Research Center made electronphotomicrographs of sediments; particle shapes were then classified using the system described by Blatt (1972). The FRI Water Quality Laboratory determined concentrations of total and dissolved heavy metals (Atomic Absorption Spectroscopy), oil and grease (Soxhlet Extraction), total volatile solids (APHA, AWWA, WPCF 1976) and total organic carbon (Perkin-Elmer 240 Elemental Analyzer). Samples used for dissolved heavy metal analysis were first aerated for 1.5 hr at 10°-15°C (to simulate test conditions) and then filtered (0.45- m mesh); the filtrate was acidified and analyzed by Atomic Absorption Spectroscopy.

4.2.1.4 Bioassay Procedure

Generally, bioassays met the criteria recommended by WDF (ASTM 1976). Aeration of test water constituted the only major deviation from this methodology.

Test fish were held in pens (Fig. 3-6) for approximately 2 weeks prior to acclimation in the laboratory.

For each bioassay, one or two controls and five to ten concentrations of suspended sediment in a geometric series were used. The DO concentrations of the seawater-sediment mixtures were raised to at least 7.0 mg/liter. Ten specimens were then added randomly to each aquarium. Mortalities were tabulated every 8 hr; dead fish were removed and examined for disease, abrasion, hemorrhaging, and degree of gut packing. Length-weight data and relative degrees of gut packing and gill silt accumulation were recorded for the survivors. Gill and gut tissues from various fish were preserved in 10% buffered formalin for histological analysis. Preparation of these tissues for microscopic examination included paraffin imbedding, sectioning to 5 μ m and staining with hemotoxylin eosin. Fish suspected of being diseased were frozen and examined by a pathologist.

Lengths and weights of fish used in experiments 1-19 were taken prior to their use.

Temperature, pH, and DO concentrations of bioassay water were monitored 4 days per week; salinity was measured once weekly. Instrumentation and calibration techniques are described in Appendix II.

Analysis of NH₃ were conducted according to the schedule shown in Fig. 4-4 using the colorimetric method (APHA et al. 1976). Data warranted discontinuing the analyses by the sixth experiment.

Hydrogen sulfide analyses were not conducted due to inadequate facilities and insufficient time. However, following preliminary

aeration (prior to introduction of fish), the odor of H₂S was never detected. Since the human olfactory threshold (0.01-0.10 µg/liter; APHA et al. 1976) is less than the accepted tolerance limit of salmonids (2 µg/liter; EPA 1973), the test fish were probably not affected by the chemical.

TNFR values were determined for each tank gravimetrically (APHA et al. 1976) at 0, 0.25, 0.5, 1, 2, 4, and 8 hr after stirring. A new set of values was determined each time a different concentration regime was expected. The average concentrations to which fish were exposed were determined in the following manner:

- 1) A curve was drawn depicting TNFR versus time between two consecutive stirrings (8-hr period) (see Smith 1978).
- 2) The weight of the graph paper encompassed by the curve was determined with an analytical balance (weight "2").
- 3) A smaller square piece of paper with a given known area (area "3," units = concentration · time) was also weighed (weight "3").
- 4) Values obtained in steps 2 and 3 were used in the following equation to determine average exposure concentration:

$$\text{Average TNFR} = (\text{Y-intercept}) + \frac{(\text{wt. "2"}) \cdot (\text{area "3"})}{(\text{wt. "3"}) \cdot (\text{time elapsed between stirrings}) \text{ (usually 8 hr)}}$$

When different stirring schedules were employed in the same experiment (weekend schedules for experiments 1, 2, and 4 involved some 10-hr and 12-hr periods), average concentrations were determined for each unique time interval; these values were then appropriately weighted to yield a "grand average" exposure concentration.

TNFR versus time curves appear in Smith (1978).

Since most fish in tanks with acute or subacute concentrations of suspended sediments were seen or felt swimming within 5 cm of the surface, all TNFR, temperature, pH, DO, salinity, and NH₃ monitoring were conducted on water from that depth.

4.2.2 Sublethal Bioassays

4.2.2.1 Background

Of the many indicators of environmental stress in fish which have been investigated, blood plasma glucose has proven to be one of the most sensitive and reliable (Silbergeld, unpublished manuscript).²

²Silbergeld, E. K. Blood glucose: a sensitive indicator of environmental stress in fish. Stroud Water Res. Ctr., Acad. Nat. Sci., Philadelphia, Avondale, PA. [Unpublished manuscript.]

Concentrations were shown to increase by 133% when Johnny darters (Etheostoma nigrum Rafinesque) were exposed to dieldrin at 0.25 of their 96-hr LC₅₀ for 5 days (Silbergeld, unpublished manuscript)³, and by as much as 300 percent when coho salmon (Oncorhynchus kisutch) were exposed to pulpmill effluents at 0.8 of their 96-hr LC₅₀ for 4 days (McLeay and Brown 1975). In addition, Sherk et al. (1974) showed that rates of liver glycogen utilization were significantly higher among hogchokers (Trinectes maculatus) exposed to 1.28 g/liter fuller's earth (sublethal concentration) than among controls. Since more glucose is released into the bloodstream as greater quantities of liver glycogen are broken down, these authors have indirectly shown that exposure to sublethal concentrations of suspended solids may elevate blood glucose concentrations.

4.2.2.2 Procedure

To measure sublethal stress in the present study, blood plasma glucose levels were determined after exposure to suspended glacial till at concentrations slightly greater than the maximum TNFR recorded at the dredge site (94 mg/liter). Chum salmon from Big Beef Creek Hatchery were used as test specimens, since fish from other available sources were not large enough to deliver sufficient quantities of blood. Four experiments were conducted using four test tanks and three control tanks. Each tank held 12 fish. The bioassay apparatus was identical to that described in Section 4.2.1.2.

The bioassay procedure was patterned after McLeay and Brown (1975). Fish were saltwater-adjusted in holding pens and acclimated in the laboratory (Section 4.2.1.4). Test aquaria were supplied with 2 g/liter glacial till; the sediment was then allowed to settle to a concentration of approximately 300 mg/liter, at which time 12 fish were added randomly to each aquarium. Fish were sacrificed after a 25- to 27-hr exposure period (final concentrations = 150-220 mg/liter). This experimental design allowed for the maintenance of a relatively constant TNFR regime; however, particle size distributions were not comparable to those in the acute bioassays. All aquaria were gently aerated and the same sediment-water slurries were used for each experiment.

Water samples were siphoned from tanks for TNFR analysis at a 5-cm depth. A logarithmic time schedule similar to that used for TNFR sampling in acute bioassays (Section 4.2.1.4) was employed. All other water quality parameters were monitored shortly after blood sampling to minimize undesired stress.

³Ibid.

4.2.2.3 Blood Sampling

Blood sampling was conducted as discussed in Wedemeyer and Yasutake (1977). Fish were netted in groups of four to eight and immediately placed in an MS-222 solution strong enough to immobilize within 1 min. Fish were quickly rinsed off in distilled water and blotted dry. Caudal peduncles were then severed and blood was collected in 50- μ l microcapillary tubes, two to four fish per tube. Pooled samples were centrifuged and plasma was immediately stored at -20°C .

4.2.2.4 Glucose Analysis

After 2 months at -20°C , plasma samples were thawed and glucose concentrations determined by the micromethod of Mattenheimer (1971).

4.2.3 Data Analyses

The BMD 03S computer program (Dixon 1970) was used to obtain LC_{50} values and conduct Chi-square goodness-of-fit tests on the probit- \log_{10} concentration curves. Ninety-five percent confidence intervals were determined using the method outlined by Litchfield and Wilcoxon (1949). Gut and gill silt accumulation data and length-weight data were analyzed by means of programs BMD 3R4V (combined regression and covariance), BMD 02R (stepwise multiple regression) (Dixon 1970), and Bartlett's test (Dixon and Massey 1969).

Blood plasma glucose concentrations of the control and test groups used in the sublethal study were compared using a nested ANOVA design. Program BMD 08V (Dixon 1970) was employed for this purpose.

4.3 RESULTS AND DISCUSSION

4.3.1 Mortality Data

Cumulative mortality data were not included from tanks where: 1) fish were proven to have been infected with a pathogen; 2) contamination of the water had occurred; or 3) cannibalism was evident.

A selection of percent survival versus \log_{10} TNFR curves is presented in Smith (1978). Tolerance curves (LC_{50} versus exposure time) are displayed in Figs. 4-5 and 4-6, and LC_{50} values $\pm 95\%$ C.I.'s on Table 4-2.

4.3.1.1 Effects of Dredging on Survival

Ninety-six-hour LC_{50} values varied between 15.8 and 54.9 g/liter, three orders of magnitude higher than the range of TNFR values found to

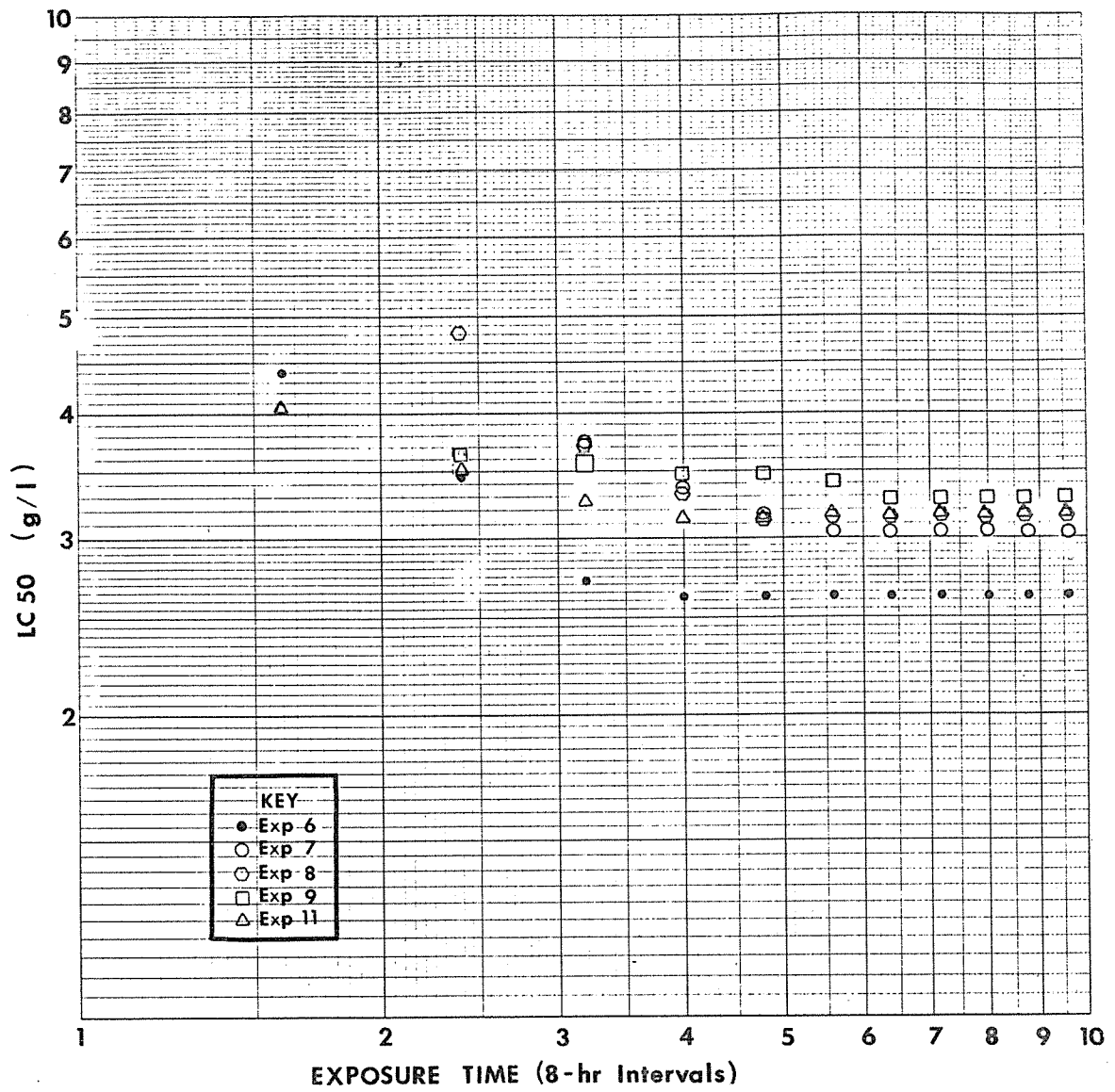


Fig. 4-5. LC_{50} vs. exposure time: experiments 6, 7, 8, 9, 11.

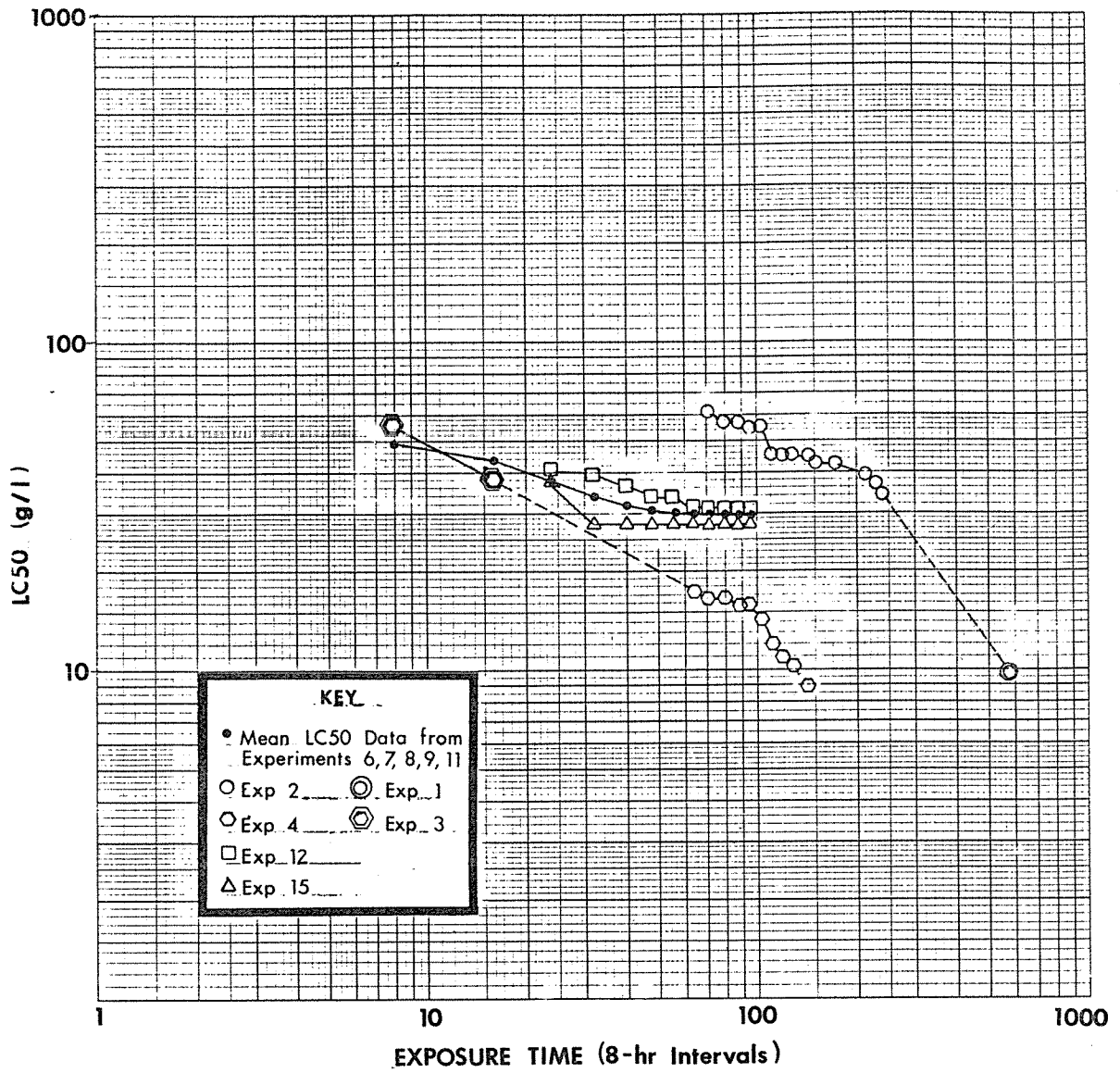


Fig. 4-6. LC_{50} vs. exposure time: experiments 1-4, 6-9, 11, 12, 15.

Table 4-2. LC₅₀ values (upper numbers) with 95 percent confidence intervals (lower numbers) (g/liter).

Exp. no.	Exposure period (hr)					
	0-8	8-16	16-24	24-32	32-40	40-48
1						
2						
3	55.867	39.442*				
	33.859-92.115	2.500-622.243				
4						
6		43.967	34.524	27.836	27.201	26.362
		11.999-161.118	23.526-50.636	10.512-73.712	11.281-65.593	9.514-73.052
7				37.376	33.623	31.471
				11.021-126.765	24.638-45.877	13.150-75.317
8			48.376	37.432	33.439	31.606
			19.652-119.086	8.197-170.939	7.972-140.258	6.290-158.806
9			36.528	35.796	34.982	34.982
			32.797-40.680	24.396-52.526	19.598-61.664	19.598-61.664
11	48.884	40.051*	35.121	32.508	31.661	31.661
	16.603-143.925	2.540-631.094	24.901-49.538	16.080-65.718	11.869-85.049	11.869-85.049
12			40.319	39.483	36.598	33.948
			21.733-74.801	19.335-80.627	9.329-142.809	5.071-227.288
15			36.915	27.871	27.871	27.871
			22.690-60.057	12.450-62.392	12.450-62.392	12.450-62.392

Exp. 6-11

mean: 48.884 43.967 38.257 33.982 32.060 31.089
 16.603-143.925 11.999-161.118 24.789-59.042 13.008-88.772 13.897-73.963 11.298-85.548

Values with an asterisk beside them not included.

*The data did not significantly fit the probit-log₁₀ concluding model ($\alpha = .05$) (X^2 goodness of fit test proved the null hypothesis invalid).

Table 4-2. LC₅₀ values (upper numbers) with 95 percent confidence intervals (lower numbers) (g/liter)--cont.

Exp. No.	Exposure period (hr)					
	48-56	56-64	64-72	72-80	80-88	88-96
1						
2		61.177	57.213	54.929		
	15.966-234.417	13.807-237.070	13.807-237.070	20.120-149.956		
3						
4		17.341	16.757	15.806		
	9.745-30.846	8.053-34.871	7.300-34.211	7.300-34.211		
6		26.362	26.362	26.362		
	9.514-73.052	9.514-73.052	9.514-73.052	9.514-73.052		
7		30.513	30.513	30.513		
	17.810-52.278	17.810-52.278	17.810-52.278	17.810-52.278		
8		31.606	31.606	31.606		
	6.290-158.806	6.290-158.806	6.290-158.806	6.290-158.806		
9		34.338	32.950	32.950		
	13.881-84.943	10.427-104.120	10.427-104.120	10.427-104.120		
11		31.661	31.661	31.661		
	11.869-85.049	11.869-85.049	11.869-85.049	11.869-85.049		
12		33.948	31.204	31.204		
	5.071-227.288	5.183-187.855	5.183-187.855	5.183-187.855		
15		27.871	27.871	27.871		
	12.450-62.392	12.450-62.392	12.450-62.392	12.450-62.392		
Exp. 6-11						
mean:	30.811	30.530	30.530	30.530	30.530	30.530
	11.187-84.861	10.555-88.310	10.555-88.310	10.555-88.310	10.555-88.310	10.555-88.310

Table 4-2. LC₅₀ values (upper numbers) with 95 percent confidence intervals (lower numbers) (g/liter)--cont.

Exp. no.	Exposure period (hr)					
	96-104	104-112	112-120	120-128	128-144	144-152
1						
2	54.929 20.120-149.956	45.648 20.059-103.870	45.648 20.059-103.870	45.648 20.059-103.870	45.648 20.059-103.870	42.779 22.269-82.168
3						
4	14.248 7.156-28.370	12.013 8.959-16.108	10.809 6.635-17.609	10.425 5.228-20.276	8.816 5.133-15.142	
6						
7						
8						
9						
11						
12						
15						

exist in Hood Canal near dredging operations (approximately 4-96 mg/liter). These data strongly suggest that direct effects suffered by chum salmon migrating through the dredging area were negligible.

4.3.1.2 Tolerance of Big Beef Creek Channel Fish to Glacial Till and Overburden

Big Beef Creek channel fish were substantially more tolerant of overburden than of glacial till (Fig. 4-6). Several factors which may affect tolerance were examined to account for this difference, including:

- 1) sediment particle characteristics;
 - a) size distribution;
 - b) angularity;
- 2) inorganic toxins;
 - a) heavy metals;
 - (1) soluble;
 - (2) insoluble;
 - b) decomposition products;
 - (1) H₂S;
 - (2) NH₃;
- 3) organic toxins;
 - a) petrochemicals;
 - (1) oil and grease.

4.3.1.2.1 Particle size distributions. Particle size distributions of the two sediment types are presented in Fig. 4-7 and Appendix I. Median particle diameters were 0.044 mm and 0.064 mm for overburden and glacial till, respectively. Sediment samples used in the determination of size distributions were obtained from bioassay aquaria shortly after hand mixing. Therefore, the actual median particle size to which the fish were exposed was less than that determined (Fig. 4-7). However, notice in Fig. 4-7 that if larger particles were allowed to settle out of the water column, the disparity between median particle size of the two sediment types would increase. It is therefore quite evident that throughout the bioassays, glacial till consisted of a noticeably higher percentage of particles in the large size categories than did the less harmful overburden. This relationship between tolerance and particle size has also been shown to exist among various species of fish exposed to commercial solids (Rogers 1969). Larger particles appear to pass through gill filaments less easily, clog guts more readily, and probably require greater rates of mucous production to be sloughed out of the opercular cavities. Insufficient gill and gut silt accumulation data were obtained to test these hypotheses.

4.3.1.2.2 Particle angularity. Particle angularity has also been shown to affect the tolerance of fish to suspended solids (Rogers 1969); however electronphotomicrographs of the two sediment types used in this study (Figs. 4-8 through 4-11) reveal no marked differences in

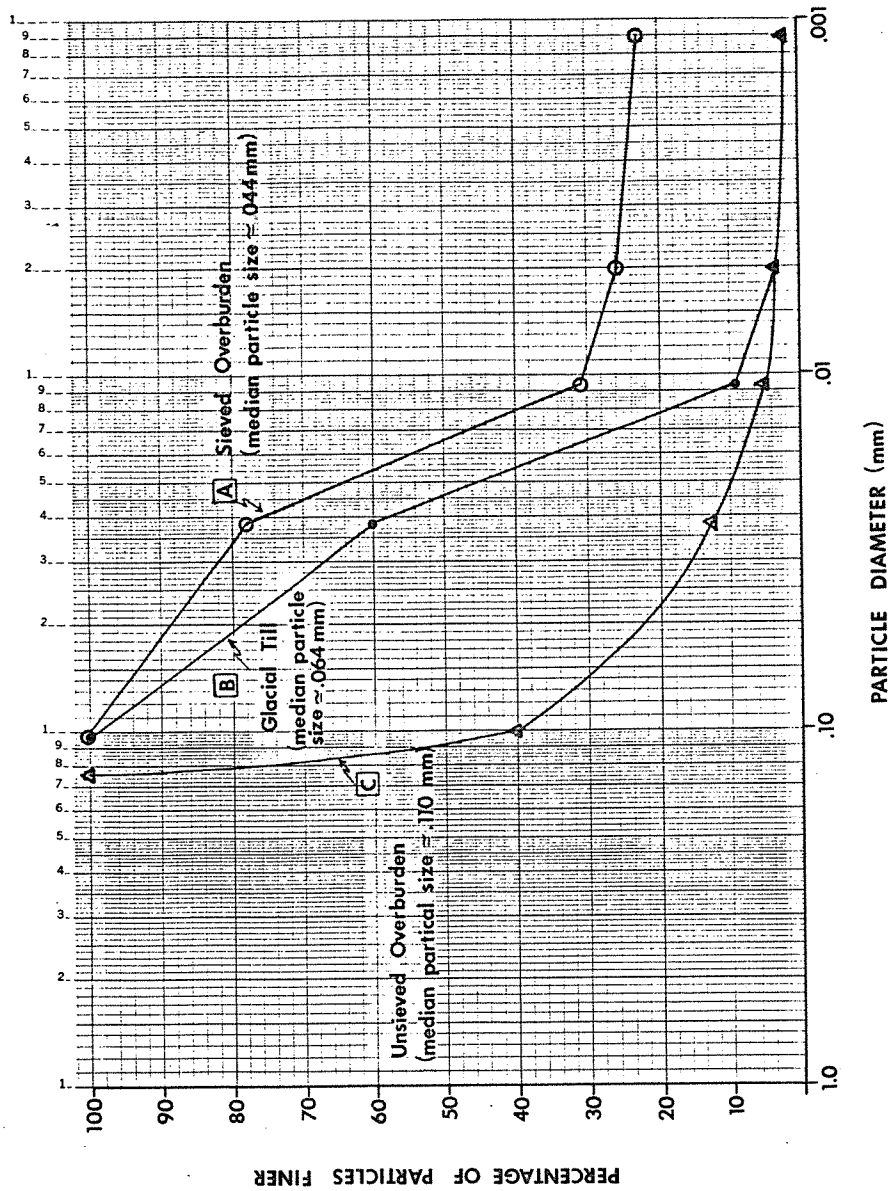


Fig. 4-7. Particle size distributions of unsieved overburden, sieved overburden, and glacial till.



Fig. 4-8. Electronphotomicrograph of mineral particles: overburden (400X).

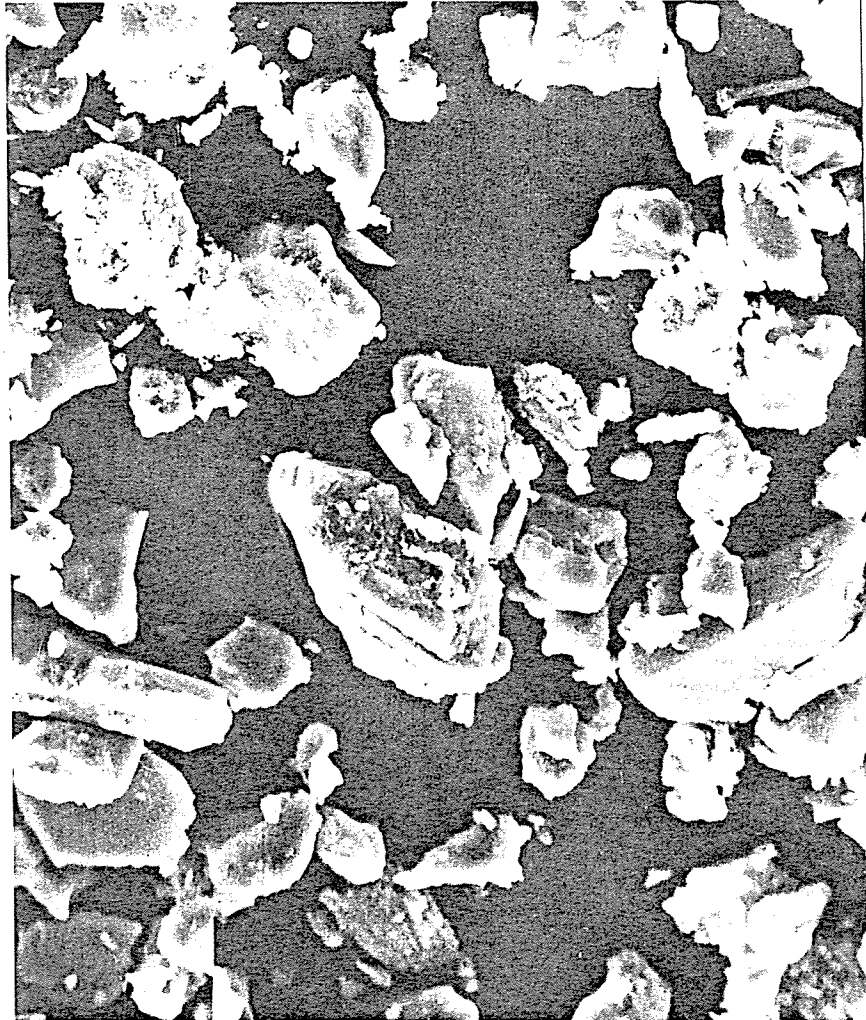


Fig. 4-9. Electronphotomicrograph of mineral particles: glacial till (400X).



Fig. 4-10. Electronphotomicrograph of mineral particles: overburden (1200X).



Fig. 4-11. Electronphotomicrograph of mineral particles: glacial till (1200X).

shape between particles belonging to the different sediment types. Based on a particle "roundness" scale developed by Blatt (1972) particle shapes in this study would be considered "subangular" to "angular."

4.3.1.2.3 Inorganic compounds.

1) General. A third characteristic of the sediment which must be considered is the inorganic chemical toxicity. Results pertaining to H_2S and NH_3 are discussed in Sections 4.2.1.4 and 4.3.3, respectively. The concentrations of various heavy metals in representative samples of overburden and glacial till are presented in Table 4-3. The large differences between dissolved and total concentrations are primarily due to adsorption of metals by the inert particulate matter (Doudoroff 1957). Also presented in the table are ranges of concentrations found to exert acute effects on salmonids in the marine environment. An application factor of 0.05 was used to estimate maximum levels which exert no sublethal effects.

2) Heavy metals--Bioavailability and toxicity. The contribution of soluble forms to heavy metal toxicity has been documented (Sprague 1964). However, the contribution of insoluble forms is uncertain (Mount 1966); thus, two alternatives are presented for discussion: insoluble forms contribute a) insignificantly; or b) significantly, to heavy metal toxicity.

a) Alternative 1: Insoluble forms contribute insignificantly. The synergistic effect(s) of dissolved "copper + zinc" on the fish may have been highly significant; the dissolved concentration of these metals in glacial till was within the applicable 24-hr LC_{50} range (Table 4-3). However, a substantial portion of the metals in soluble form was probably bound to organic complexing agents and calcium salts. Schmidt and Wildung (1975) found that the bulk of Cu^{+2} added to seawater became complexed with amino acids and polypeptide chains. In such a molecular state, the metal is rendered far less toxic (United Kingdom Ministry of Technology 1969; Lewis, Whitfield, and Ramnarine 1972). In addition, it is well known that copper and zinc toxicity are inversely related to water hardness (Mount 1966; Pickering and Henderson 1966). The "copper + zinc" LC_{50} data presented in Table 4-3 were obtained from studies which tested the tolerance of juvenile Atlantic salmon (Salmo salar) to a 3:1 ratio of zinc to copper in fresh, soft water (hardness = 20 mg/liter $CaCO_3$). Hardness was lower than in the seawater used in this study's bioassays; dissolved organic matter concentrations were probably also lower. Thus, estimations of metal toxicity based on comparisons with the relevant bioassay literature are most likely too high.

When comparing the two sediment types, one finds that the concentration of dissolved "copper + zinc" in overburden was one-half

Table 4-3. Total and dissolved heavy metal concentrations in overburden and glacial till.

Toxin	Data obtained in this study: concentration of toxin at 30 g/liter suspended sediment		Range of concentrations found to exert acute effects on salmonids in marine environment ¹			
	Overburden	Glacial till	24-hr	48-hr	96-hr	Other
Copper (Cu)	.545	.175	.042	.15-2.0	.008-.10	1.9
Cadmium (Cd)	.044	< .073 ³	< .006 ³	30	7-day: .008-.01 7-day: .45	.000012-.000015
Chromium (Cr) (hexavalent)	.753	< .025 ³	< .073 ³	69	3.45	
Lead (Pb)	< 1.25 ³	< 3.65 ³	< 2.92 ³	.41	.34-3	1
Manganese (Mn)	4.98	.338	.161	1,400	70	
Nickel (Ni)	.913	.030	.058	25-170	1.25-8.5	
Zinc (Zn)	1.72	.016	.042	2-6	.6-4.6	.1-.3
Copper + zinc	2.27	.035	.084	Zn-Cu ratio in water = 1.5, LC ₅₀ = .034 ppm	3-85	.15-4.25
				Cu and Zn	.0017 ppm	.03-.23
					Cu and Zn	.002-.10 ppm Zn
						.04-2.00 ppm Zn

¹Where insufficient data are available for salmonids in seawater, data from freshwater studies are substituted. Data taken from EPA 1973.

²Based on data assimilated in EPA (1973). An application factor of .0015 was used for cadmium (Eaton 1974).

³Below limits of detection.

of that in glacial till. This may account at least partially for the difference in tolerance.

b) Alternative 2: Insoluble forms of metals contribute significantly. Alternative 2 must take into account the following information:

(1) Sherk et al. (1974) noted that, "in the stomach, entrapped particles are exposed to approximately the same conditions used in stripping sorbed materials from particulate matter for chemical analysis. Thus, potentially toxic materials such as heavy metal ions . . . may be freed and made available to the organisms." Since gut packing was routinely observed among bioassay survivors in this study, it appears that a small portion of the heavy metal toxicity could be attributed to the insoluble fraction.

(2) the total "copper + zinc" concentration in overburden was slightly greater than the upper limit of the applicable 24-hr LC₅₀ range (Table 4-3). In addition, total cadmium concentrations were within the 7-day LC₅₀ range (overburden). If the sorbed metals contributed substantially to the bioavailable fraction, one would expect exposure of fish to 30 g/liter overburden to produce greater than 50% mortality in 24 hr solely on account of metal toxicity. The actual overburden tolerance data show that less than 50% mortality occurred at 30 g/liter, and this includes stress imparted by inert solids. Thus, observed and expected toxicities seem disparate, lending support to Alternative 1.

(3) Overburden had consistently higher total metal concentrations than glacial till. This is opposite to the relationship found when only the dissolved fraction was considered and does not coincide with the LC₅₀ data of this study, thus lending further support to Alternative 1.

c) Conclusions. Based on the considerations made under Alternatives 1 and 2, one could conclude that the toxicity of metals in insoluble forms is at best only weakly significant. Given this premise, one can suggest that differences in dissolved metal concentrations accounted in whole or in part for the differences in tolerance of the salmon to the two types of sediment. However, since it is not known what concentrations of dissolved organic matter existed in bioassay water, one cannot be certain of the absolute role which metals played in causing mortalities.

The difference in dissolved metal concentrations between the two sediment types was not related to the total quantity of metals but evidently to the sorptive characteristics of the particles. Although the overburden possessed a greater concentration of total metals, the concentration of dissolved metals was highest in the glacial till, indicating a much greater propensity of the latter sediment type to

release sorbed metals into solution (mean dissolved-total ratio = 0.032 for overburden, mean dissolved-total ratio = 0.165 for glacial till).

3) Mode of toxic effect. Copper, zinc, and suspended solids stress fish similarly by inducing respiratory stress through interference with gas exchange across the gills (Burton, Jones, and Cairns 1972; Doudoroff 1957).

4.3.1.2.4 Organic toxins. Oil-grease concentrations were 12 mg/liter in overburden and 2 mg/liter in glacial till. These values refer to oil-in-water dispersions (OWD) rather than the water-soluble fraction, since stock slurries were vigorously mixed prior to removal of samples for analysis. They are three to four orders of magnitude lower than concentrations of crude and fuel oils (OWD) shown to produce 50% mortality among various fish in 24 hr (Cyprinodon variegatus, Medidia beryllina, Fundulus simulus) (Anderson et al. 1974). Therefore, it appears that no direct harmful effects due to oil-grease were prevalent.

It was originally postulated that differences in tolerance to the two sediment types may have been due to differences in the ratios of inorganic to organic matter (indicated by percentage organic carbon). For example, if organic matter accounts for a greater fraction of one type of sediment than another, fish may be more tolerant of that sediment. In the present study, however, relative amounts of organic matter were similar in glacial till and overburden:

	<u>Total volatile solids</u>	<u>Total organic carbon</u>
Overburden	8.07 %	0.99 %
Glacial till	10.50 %	0.88 %

4.3.1.3 Estimation of Median Lethal Thresholds

Tolerance curves for experiments 2 and 4 (long-term) did not culminate in a plateau (Fig. 4-6); in fact, the shape of the curves is convex rather than concave. On the other hand, in short-term (96-hr) experiments rates of decline in LC₅₀ values decreased steadily, reaching zero at or before 64 hr. These data therefore suggest that:

1) After a 96-hr exposure period, food deprivation becomes a significant stressor, resulting in increased mortality. (The effect of starvation in experiment 1 was highly significant since cannibalism was witnessed in one tank.)

2) Without food deprivation, 100- to 240-hr LC₅₀ values from experiments 2 and 4 may have remained at the same level as the 96-hr values.

3) Ninety-six-hour LC₅₀ values are probably the best estimates of median lethal thresholds in this study.

4) Static bioassays should be limited to approximately 96 hr, even in moderately cold water (Sprague [1973] prescribes a 2-week limit). (Note: It should be mentioned that no data-supported rationale can be given for the abnormally low tolerance of fish to suspended sediment in experiment 4 [96-hr LC₅₀ = 15.8 g/liter]).

4.3.1.4 Tolerance of Big Beef Creek Channel Fish Compared with Tolerance of Local Fish

During two experiments using local fish (10 and 14), too few deaths occurred after 96 hr to enable LC₅₀ values to be ascertained; yet in bioassays where Big Beef Creek fish were subjected to the same experimental conditions (experiments 6-9, 11), 96-hr LC₅₀ values consistently fell well within the range of concentrations to which the local fish were exposed. Two factors appear potentially responsible for this difference in tolerance:

1) Genetic difference. Inherent fitness may have been a significant cause of the tolerance difference, but could not be quantified in this study.

2) Size difference. Local fish were substantially larger than Big Beef Creek fish (Fig. 4-12); this size difference appears related to the ability of the fish to pass silt through their gills and guts. Covariance analyses showed local survivors of 96-hr bioassays to have had significantly less silt in their opercular cavities, esophagi and stomachs than Big Beef Creek 96-hr survivors ($p < 0.05$). It seems highly plausible that the larger size of the interfilament spaces and gut cavities of local fish enabled them to pass silt through their gills and alimentary canals more easily than Big Beef Creek fish. Also, since oxygen demand/unit body weight decreases with increased body size among fish, larger individuals may tolerate more respiratory interference than smaller individuals (Sherk et al. 1974). Further support of an inverse size-tolerance relationship is provided by the length-weight data discussed in Section 4.3.2, and by studies conducted with white perch (Morone americana) exposed to fuller's earth (Sherk et al. 1974).

The results of experiment 12 at this point seem contradictory, for while the tolerance of these local fish was only slightly higher than that of the Big Beef Creek 96-hr test specimens (Fig. 4-6), their size was substantially greater (Fig. 4-12). However, it is possible that various factors were operating to mask a size-related effect (e.g., disease, origin of local fish, feeding habits in the holding pens).

4.3.1.5 Effect of Water Temperature on Tolerance

Tolerance curves from experiments 6-9 and 11 (96-hr bioassays using Big Beef Creek fish) were remarkably similar (Fig. 4-5) in spite of the fact that the mean water temperature of the five experiments ranged from 11.1° to 13.4°C. In addition, the mean water temperatures

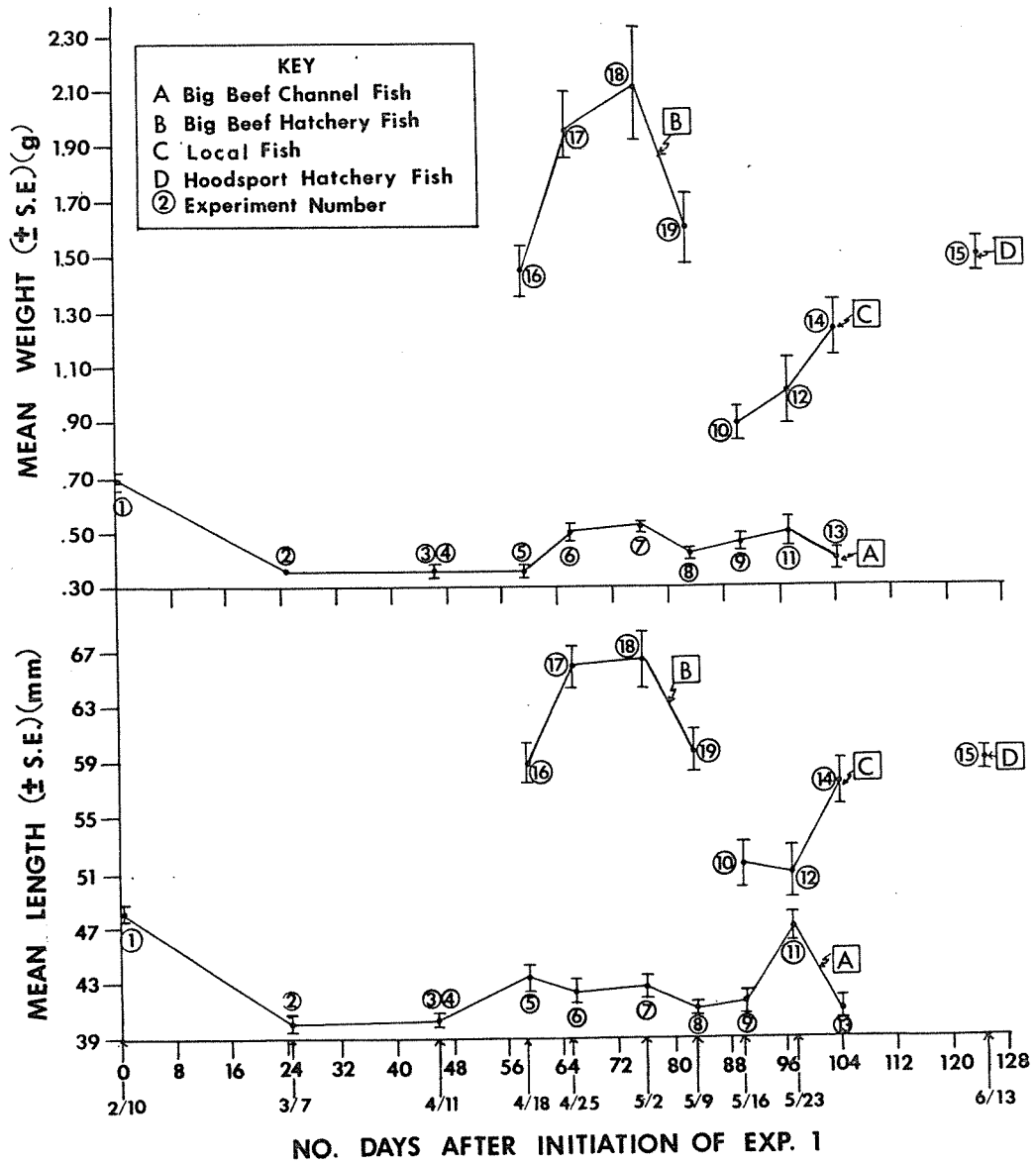


Fig. 4-12. Mean (\pm S.E.) initial lengths and weights of fish vs. time, means connected for clarity; "initial" pertains to size of fish belonging to populations from which samples were drawn for use in experiments 1-19 (data obtained the first day of each bioassay).

of experiment 15 (Hoodsport Hatchery fish) was 15.7°C, while the tolerance curve was found to be nearly identical to the consolidated curve for experiments 6-9 and 11 (Fig. 4-6). These data run contrary to those presented by Rogers (1969), who showed that the tolerance of fourspine stickleback (Apeltes quadaeus) to Kingston silt (glacial rock flour) decreased eighteenfold as the experimental water temperature increased from 9.25°C to 15°C. A temperature effect on tolerance may have been masked in this study by a size-related effect. Data discussed in Section 4.3.1.4 suggest that a positive correlation exists between size and tolerance, and show that fish used in experiment 15 were substantially larger than those used in experiments 6-9 and 11 (Fig. 4-13). Stock differences (Hoodsport versus Big Beef Creek) may also have acted to mask an effect due to temperature.

4.3.1.6 Incidence of Disease

Several fish in three test aquaria from two of the long-term experiments exhibited tail rot. A species of Pseudomonas bacterium was determined responsible. No fish from control aquaria showed signs of bacterial problems, and thus one can conclude that long-term exposure to suspended sediment may increase the potential for external infection to develop. Abrasion of the body epithelium would most likely be the mode of effect. An abnormally high incidence of fin rot has also been observed among rainbow trout (Salmo gairdnerii) exposed to 90-810 mg/liter suspended solids for 28 weeks (Herbert and Merkens 1961). Sherk et al. (1974) observed abraded body epithelia among various species exposed to sublethal concentrations of fuller's earth.

The only other disease problem encountered was during experiment 13 (Big Beef Creek fish; 96-hr bioassay using glacial till). Within 32 hr, 20% of the control fish had died, thus invalidating the determination of LC₅₀ values. Thirty percent of control fish were dead within 56 hr. Fish exposed to suspended sediment died more rapidly than controls. A comparison of tolerance between sick and healthy Big Beef Creek fish (experiment 13 versus experiments 6-9 and 11) was not possible due to the excessive control mortalities. Costia, a protozoan which infects the gills, was observed on test fish.

4.3.1.7 Cause of Death

It is well recognized that fish exposed to heavy concentrations of suspended solids suffer from hypoxia (Sherk et al. 1974; Rogers 1969). Evidence supportive of this issue include:

- 1) Hematological compensation for reduced gas exchange across the gill surface has been shown to occur among several species of fish exposed to sublethal concentrations of fuller's earth (increased hematocrit, hemoglobin concentration, and erythrocyte numbers [Sherk et al. 1974]).

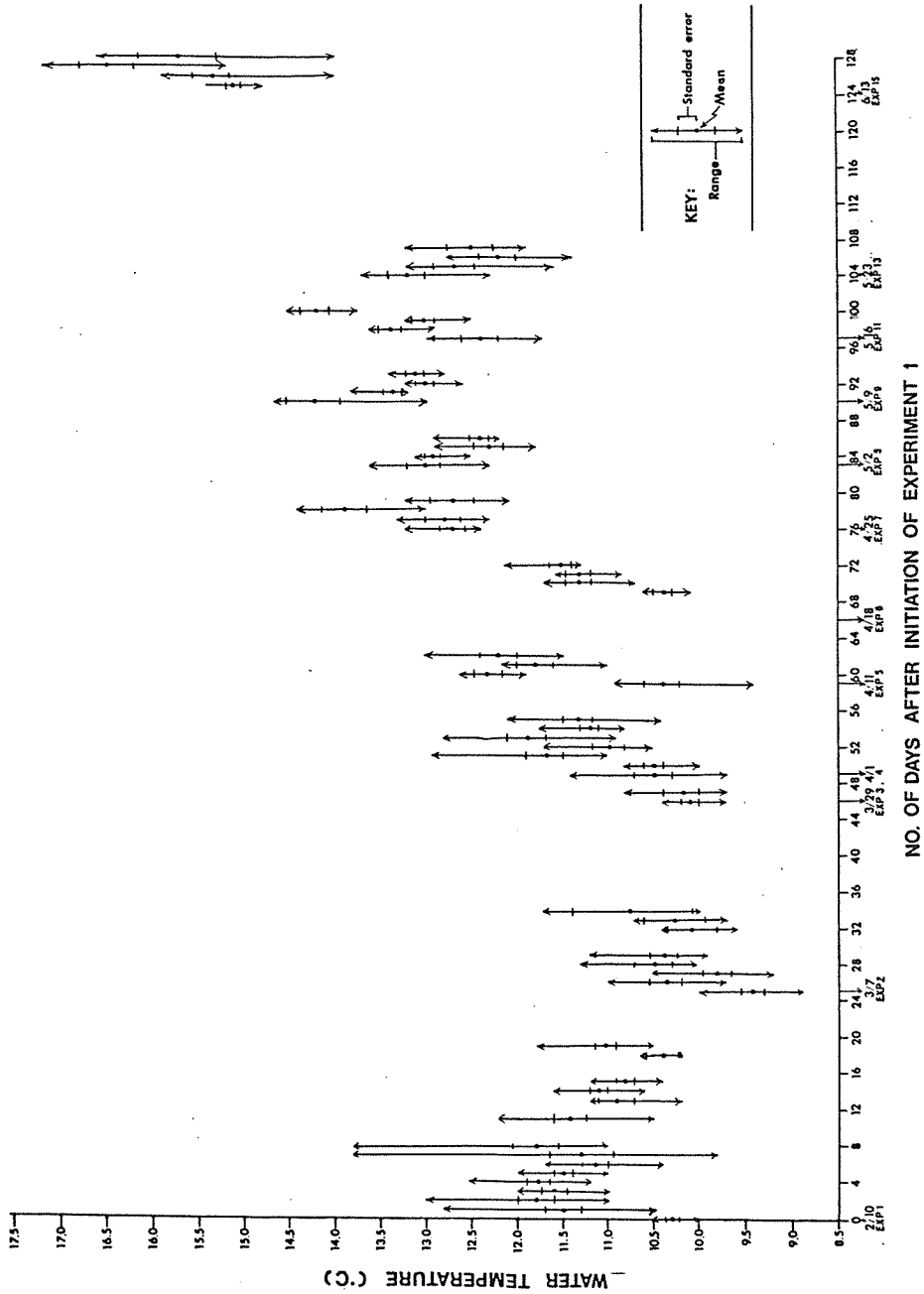


Fig. 4-13. Mean (\pm S.E.), maximum, and minimum tank water temperatures vs. time: experiments 1-9, 11, 13 (Big Beef Creek channel fish) and experiment 15 (Hoodsport hatchery fish).

2) Rogers (1969) showed that supplemental oxygenation of bioassay water increased the tolerance of several species of fish to a variety of types of sediment.

3) Steelhead trout (Salmo gairdnerii) exposed to a polluted section of stream (coal washings) exhibited a higher rate of opercular movement than did control fish (Pautzke 1937).

4) A direct positive relationship was shown to exist between DO and the tolerance of shiner perch (Cymatogaster aggregata) and striped bass (Morone saxatilis) to suspended bentonite solids (Peddicord and McFarland 1975).

5) Exposure to suspensions of fuller's earth or Patuxent River sediments was shown to reduce oxygen consumption among white perch (Morone americana) and striped bass (M. saxatilis) swimming at sustained speeds in a respirometer (Sherk et al. 1974).

6) Behavioral reactions to high concentrations of suspended solids and to low DO are identical (Rogers 1969; Wallen 1951).

7) Sherk et al. (1974) showed that species with very low oxygen requirements were highly tolerant of suspended solids.

Three mechanisms by which suspended solids may reduce gas exchange across the gills have been proposed:

1) Clumps of silt engulfed by mucus retard or deflect water passing over the gill filaments. Mucus secreted into the opercular cavity entraps particulate matter, thereby preventing it from making direct contact with gill tissue. The excess mucus may, however, reduce respiratory efficiency by retarding or deflecting water passing over the gills (Sherk 1971; Wallen 1951). Large "islands" of silt surrounded by mucus were routinely observed in this study. Pautzke (1937) and Rogers (1969) made similar observations. Sherk et al. (1974) found more mucus goblet cells per unit area on the gills of white perch (M. americana) exposed to sublethal concentrations of fuller's earth than on gills of control specimens.

2) Reduction in the gill surface area available for gas exchange through coating of filaments. If the rate of mucus production cannot keep up with the rate of silt accumulation, gill coating and/or cellular damage may ensue. Filament coating was observed in 24% of the fish examined in this study (bioassay survivors); these fish usually appeared moribund and were less energetic when handled than the other survivors. Similar observations were made by Wallen (1951). One may therefore hypothesize that swimming speed and gill coating are inversely related: the energy required for active metabolism would become less available as prolonged exposure reduced respiratory efficiency. The organism would therefore be eventually compelled to decrease its activity.

3) Damage to gill filaments (abrasive action). This mechanism has not received full support; some studies have shown specific cellular and supracellular gill damage to have occurred (Sherk et al.

1974; Herbert and Merkens 1961; Report to the Water Pollution Research Board 1960), while others have found none (Wallen 1951; Rogers 1960; Ritchie 1970). The discrepancy may be the result of differences in the types of particles used in these studies (especially with regard to angularity). Results from gill section examinations of various fish which survived bioassays in this study concur with Wallen's and Rogers' findings (no cellular or supracellular disruption).

The mechanisms described above may also decrease excretory efficiency (Wallen 1951) and thereby increase concentrations of metabolic wastes in the blood streams. However, the degree to which acute or chronic levels of suspended solids may exert such an effect has not been studied. Possible effects on osmoregulation are also unknown.

Little information is available regarding gut packing in fish exposed to heavy concentrations of suspended solids. Sherk et al. (1974) observed severe packing, and implied that the phenomenon may be a significant factor contributing to death. Covariance tests conducted during the present study vaguely suggest that gut packing hinders survival (analyses presented in Smith [1978]). They indicate: 1) no significant difference exists between dead local fish and dead Big Beef Creek channel fish with respect to degree of gut packing; whereas 2) significant differences do exist between local and Big Beef Creek survivors. If gut silt packing exerted no deleterious effect, one would expect dead local fish to show a lesser degree of silt packing than dead Big Beef Creek fish (i.e., the same relationship which exists between local and Big Beef Creek survivors). This does not appear to be the case; thus, one might conclude that a certain "median threshold" of gut silt accumulation exists, common to all fish used in this research.

Gut packing could conceivably exert adverse effects on seawater-dwelling salmonids by: 1) damaging the cells responsible for osmoregulation; and/or 2) significantly restricting the rate of water transport through the gut, thereby causing osmoregulatory problems to develop. Histological examination of the inner gut walls of control and test fish revealed no significant damage attributable to gut packing; thus, the latter mode of effect would appear most plausible.

4.3.2 Changes in Length and Weight

For experiments 1 and 2 a moderately high positive correlation was found to exist between the TNFR of bioassay water and the ratio of final weight (survivors) to "initial" weight⁵ ($r^2 = 0.458$). TNFR and the final-initial length ratio were also found to be positively correlated to a substantial degree ($r^2 = 0.498$). This appears

⁵Refers to the average population size.

contradictory to the mortality data, for it implies that fish exposed to higher concentrations of suspended sediment suffer less from starvation. However, Herbert and Richards (1963) obtained similar results: rainbow trout (Salmo gairdnerii) which survived 200 mg/liter wood fiber for 40 weeks had a greater average weight than control fish. The authors suggested that this phenomenon may have been due to survivors of the suspended fibers having abnormally high inherent growth rates. Also, selective death of the smaller fish could account for the size increase. Data presented in Smith (1978) support these hypotheses: a high inverse correlation was obtained between the number of survivors in each aquaria and their mean final-initial weight ratios ($r = -0.930$, $r^2 = 0.865$). Identical correlation coefficients were obtained when length was substituted for weight. The size selectivity hypothesis is further supported by information provided in Section 4.3.1.4.

Unexpected differences in growth rate between test and control fish have also been found following sublethal bioassays (no deaths) (McLeay and Brown 1974). In such cases the above rationale is inapplicable.

4.3.3 Water Quality

Table 4-4 presents mean (\pm S.E.), maximum and minimum water quality values for each experiment. DO usually remained above 7 mg/liter. The range of pH values was within limits conducive to optimum health of salmonids (6-9) (EPA 1973). Equipment problems resulted in unreliable salinity determinations during experiments 1-3; thus, values obtained from these experiments are not presented in Table 4-4. Salinity varied from 27.0 to 31.0 ppt during experiments 4-19. Figures 4-13 through 4-15 portray mean daily temperatures (\pm S.E.) and intertank temperature ranges as a function of time. Note that the range in temperature between tanks was generally less than 2°C.

NH₃ concentrations were found to increase with higher suspended sediment concentrations but decrease over time (except experiment 2, day 2) (Fig. 4-4). Evidently, rates of volatilization exceeded rates of buildup from metabolic wastes. The volatilization of NH₃ originally in the stock seawater-sediment mixture occurred as an unavoidable consequence of pumping and aeration. The maximum concentration which exerts no sublethal effects among salmonids has been reported to be between 5 and 20 µg/liter (EPA 1973; Wedemeyer and Yasutake 1977). NH₃ concentrations measured in this study ranged from < 1 to 28 µg/liter; thus, one cannot discount the possibility of impact.

4.3.4 Behavior

Most fish in tanks with > 5 g/liter suspended sediment always swam within 5 cm of the water surface. Presumably, they were avoiding the higher concentrations at lower depths. A similar avoidance response

Table 4-4. Summary of water quality data: mean (\pm S.E.), minimum, and maximum values of each experiment (1-19).

Exp. no.	Temperature ($^{\circ}$ C)		Dissolved oxygen (mg/liter)		pH		Salinity (ppt)	
	Mean (\pm S.E.)	Min. Max.	Mean (\pm S.E.)	Min. Max.	Mean (\pm S.E.)	Min. Max.	Mean (\pm S.E.)	Min. Max.
1	11.1 \pm 0.06	9.4 13.8	8.7 \pm 0.03	7.4 9.3	7.79 \pm 0.009	7.52 7.95		
2	10.2 \pm 0.08	8.9 11.7	8.4 \pm 0.07	7.0 9.6	7.61 \pm 0.020	7.31 7.93		
3	10.1 \pm 0.07	9.7 10.8	9.1 \pm 0.07	8.7 9.7	7.86 \pm 0.025	7.71 8.00		
4	11.2 \pm 0.09	9.7 12.9	8.8 \pm 0.05	8.0 9.3	7.88 \pm 0.008	7.76 7.99	28.0 \pm 0.00	28.8 28.0
5	11.7 \pm 0.19	9.4 12.8	8.5 \pm 0.08	7.6 9.0	7.89 \pm 0.050	7.66 8.05	28.1 \pm 0.08	28.0 28.5
6	11.1 \pm 0.11	10.1 12.1	8.6 \pm 0.09	7.6 9.5	7.78 \pm 0.023	7.68 8.20	29.3 \pm 0.21	28.5 30.0
7	13.0 \pm 0.15	11.8 14.4	8.7 \pm 0.12	7.9 9.9	7.78 \pm 0.022	7.68 8.12	29.6 \pm 0.19	29.0 30.0
8	12.6 \pm 0.09	11.8 13.6	8.8 \pm 0.12	7.5 9.8	7.76 \pm 0.012	7.63 7.86	29.8 \pm 0.28	29.0 31.0
9	13.4 \pm 0.12	12.6 14.6	8.3 \pm 0.06	7.4 8.8	7.79 \pm 0.015	7.66 8.05	27.5 \pm 0.22	27.0 28.0
10	12.8 \pm 0.12	11.4 14.1	8.5 \pm 0.11	7.8 9.6	7.82 \pm 0.014	7.73 8.12	28.0 \pm 0.00	28.0 28.0
11	13.3 \pm 0.17	11.7 14.5	8.4 \pm 0.12	7.4 9.3	7.79 \pm 0.013	7.72 7.85	28.5 \pm 0.27	28.0 29.5
12	13.1 \pm 0.16	11.5 14.4	8.3 \pm 0.10	7.2 9.1	7.79 \pm 0.006	7.74 7.84	28.2 \pm 0.20	28.0 29.0
13	12.7 \pm 0.13	11.4 13.7	8.8 \pm 0.10	7.9 9.9	7.82 \pm 0.022	7.50 8.04	29.5 \pm 0.56	28.0 31.0
14	12.4 \pm 0.08	11.0 12.9	9.1 \pm 0.11	8.1 10.4	7.81 \pm 0.011	7.72 7.94	28.9 \pm 0.34	28.0 30.0
15	15.7 \pm 0.17	14.0 17.2	8.4 \pm 0.06	7.8 9.2	7.88 \pm 0.025	7.69 8.15	29.4 \pm 0.48	28.0 31.0
16	10.3 \pm 0.24	9.4 11.4	8.3 \pm 0.11	7.5 8.7	7.99 \pm 0.027	7.85 8.11	28.2 \pm 0.15	28.0 29.0
17	11.4 \pm 0.11	10.4 12.0	8.7 \pm 0.15	7.8 9.7	7.88 \pm 0.023	7.74 8.00	28.2 \pm 0.15	28.0 29.0
18	12.9 \pm 0.10	12.0 13.3	8.0 \pm 0.12	7.0 8.7	7.79 \pm 0.019	7.63 7.87	28.9 \pm 0.13	28.5 29.5
19	12.8 \pm 0.10	12.1 13.2	8.0 \pm 0.16	6.6 8.8	7.81 \pm 0.267	7.66 7.91	28.4 \pm 0.20	28.0 29.5

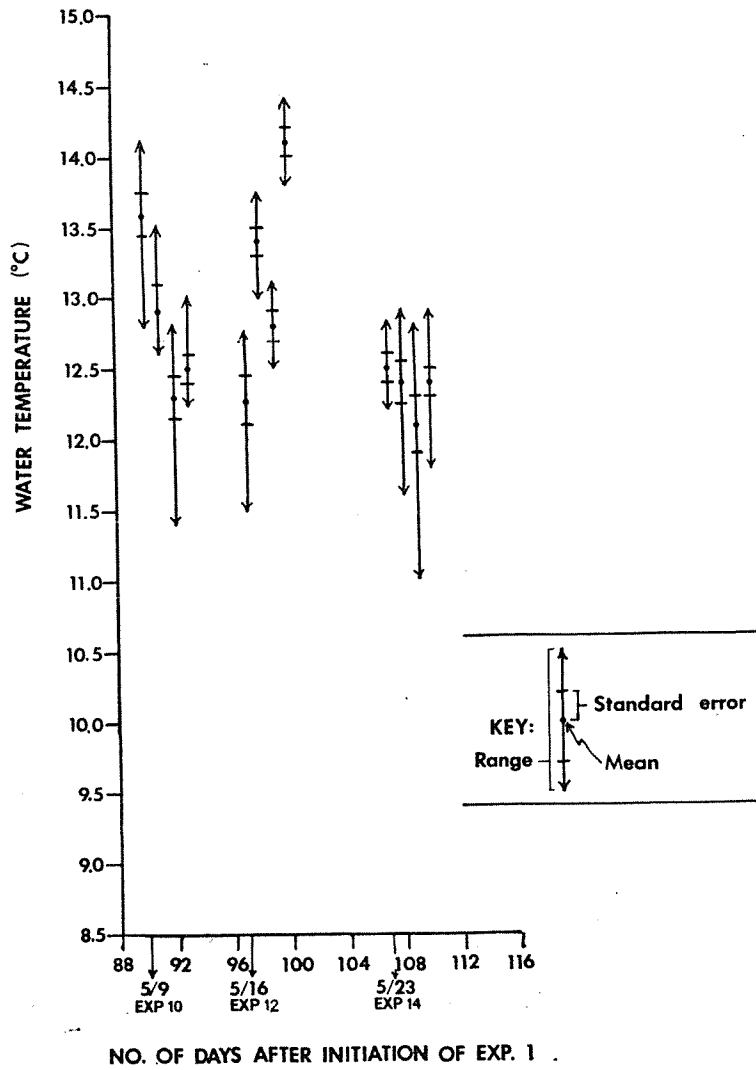


Fig. 4-14. Mean (\pm S.E.), maximum, and minimum tank water temperatures vs. time: experiments 10, 12, 14 (local fish).

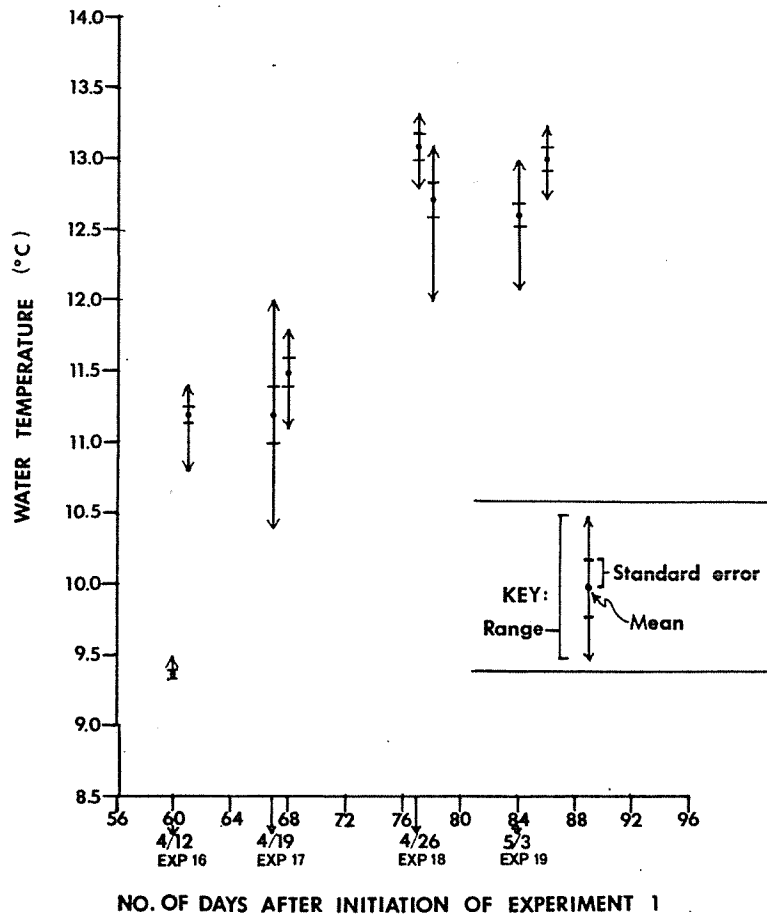


Fig. 4-15. Mean (\pm S.E.), maximum, and minimum tank water temperatures vs. time: experiments 16, 17, 18, 19, (Big Beef Creek hatchery fish).

was observed by Ingle, Ceurvels, and Leinecker (1955) when fish of three different species were placed in tanks containing high concentrations of Mobile Bay sediment. In contrast, control fish used in the present study usually remained in a cluster near the bottom of their aquaria during the day and moved closer to the surface at night.

Fish on the verge of death would exhibit typical reactions to respiratory stress, including: 1) gulping of air; 2) loss of equilibrium; and 3) floating on side with occasional attempts to swim. Identical observations were made by Rogers (1969) and Wallen (1951); the former author witnessed such behavior among fish exposed to aerated water containing suspended solids, and also among fish residing in vacuum-degassed water.

It should be noted that fish commonly utilize a coughing reflex to help clear the gills of particulate matter (Sherk et al. 1974). Due to limited visibility, comparisons of coughing rates between test and control fish were not possible.

4.3.5 Blood Plasma Glucose Analyses

Pertinent data are summarized in Table 4-5. The mean control glucose concentration (60.3 mg percent) was very close to that shown for juvenile coho salmon (Oncorhynchus kisutch) by McLeay and Brown (1974) (61.3 mg percent). Standard deviations were also similar (10.5 mg percent in McLeay and Brown, 12.5 mg percent in this study).

The mean test value (62.2 ± 15.2) was only slightly higher than the mean control level (Table 4-5). A nested ANOVA test showed that effects due to suspended sediment, position of aquarium in water bath (tank no. ⁶), experiment conducted, order in which fish were removed from aquaria (group no. ⁷), and amount of time fish were kept in MS-222 prior to sampling (pooled sample no. ⁸) had no significant effects on blood plasma glucose levels.

The absence of any effect due to suspended sediment is understandable since concentrations used were only 0.01 of the mean 96-hr LC₅₀. However, effects may have been shown if the exposure period had been either significantly shorter or longer: contradictory data are provided by McLeay and Brown (1975) and McLeay (1977) regarding the relationship between length of time exposed to a pollutant and the development of a maximum hyperglycemic response. Further research is needed to resolve these contradictions.

⁶Refers to Table 4-5, and Smith (1978; Appendix D).

⁷Ibid.

⁸Ibid.

Table 4-5. Summary of blood plasma glucose data.

Exp. no.	Tank no.	Average TNFR of water in tank (mg/liter)	Control data (no sediment added to tank)		Test data (glacial till added to tanks)	
			mean glucose concentrations (mg %)		mean glucose concentrations (mg %)	
			Tank means	Experiment means	Tank means	Experiment means
17	1	~ 10	56.3			
	2	194			52.2	
	3	198			57.5	
	4	~ 10	50.0	59.3		59.2
	5	205			63.3	
	6	194			63.8	
	7	~ 10	71.5			
18	1	~ 10	54.3			
	3	185			50.0	
	4	~ 10	72.2	59.6		54.3
	5	205			54.4	
	6	180			58.4	
	7	~ 10	52.3			
	7	~ 10	75.2			
19	1	~ 10	75.2			
	2	214			70.6	
	3	190			76.5	
	4	~ 10	61.2	62.0		73.0
	5	190			66.2	
	6	205			78.6	
	7	~ 10	49.7			
			Grand mean (\pm S.D.): 60.3 \pm 12.5		Grand mean (\pm S.D.): 62.2 \pm 15.2	

4.3.6 Conclusions

The most important results of this research are: 1) juvenile chum salmon are highly tolerant to suspended sediments; and consequently, 2) the direct effects of the dredging in Hood Canal were negligible.

4.3.6.1 High Tolerance to Suspended Sediments

Estuarine fishes have been classified according to their tolerance of suspended sediments (Sherk et al. 1974):

- 1) Tolerant: 24-hr LC₁₀ > 10 g/liter;
- 2) Sensitive: 24-hr LC₁₀ < 10 > 1.0 g/liter;
- 3) Highly sensitive: 24-hr LC₁₀ < 1.0 g/liter.

It appears from this study that chum salmon in seawater fall into the "tolerant" category. All 24-hr LC₅₀ values determined were between 34.5 and 48.4 g/liter.

Only during mudflows have TNFR values in estuaries reached the 10- to 100-g/liter range (May 1973; Masch and Espey 1967). However, it should be noted that certain aspects of the experimental design of this study may have resulted in overestimations or underestimations of the actual tolerance of a chum salmon to various TNFR levels in Hood Canal:

Factors which may have resulted in an overestimation of tolerance

- 1) selecting the fittest; fish which died during transfers to pens and acclimating tanks were probably the weakest members of their population;
- 2) aeration of bioassay water;
- 3) fluctuating concentration regime;
- 4) no predator-related stress was prevalent.

Factors which may have resulted in an underestimation of tolerance

- 1) stress imparted during handling, stirring, and mortality observations;
- 2) starvation (primarily with respect to long-term experiments);
- 3) fluctuating concentration regime;
- 4) lighting, photoperiod, and temperature only approximated natural conditions;
- 5) the spread and/or contraction of disease may have been promoted by: a) recirculation of water in the bioassay aquaria; b) high fish density in the holding pens, acclimation tank, and bioassay aquaria; c) all potential stressors listed above (1, 2, 3, and 4).

4.3.6.2 Direct Effects of Dredging Negligible

Concentrations of glacial till representative of maximum levels found in the dredge area (approximately 100 mg/liter) had no significant sublethal effect after 24 hr, or lethal effect after 96 hr.

4.4 SUMMARY

1) Acute static bioassays were employed to determine the tolerance of seawater-adapted juvenile chum salmon (Oncorhynchus keta) to the direct effects of suspended sediments. Sublethal bioassays were also conducted, using blood plasma glucose concentration as an indicator of stress.

2) The experiments were conducted on a floating laboratory situated close to dredging activity at Bangor, Washington (Hood Canal). In addition to yielding general tolerance data, they provided specific information regarding the extent to which juvenile chum migrating through the Bangor area may have been affected by dredged sediments. A modified version of the experimental apparatus utilized by Martin et al. (1977) was employed.

3) Ninety-six-hr LC₅₀ values ranged between 15.8 and 54.9 g/liter, and were probably the best estimates of median lethal thresholds. No significant difference in blood plasma glucose concentration was shown to exist between test and control fish subjected to 150-200 mg/liter glacial till. These data suggest that dredging activity had negligible direct effects on the outmigrating salmon.

4) Silt accumulation in opercular cavities and gill coating were observed, but no cellular damage was evident. Sediments may have contained toxic concentrations of copper-zinc, depending on unmonitored factors controlling bioavailability. Low tolerance was associated with small body size, large particle size, and a high concentration of dissolved heavy metals. An effect of water temperature on tolerance was not observed.

5) Several fish exposed to suspended overburden for 10-20 days exhibited tail rot.

6) Three mechanisms by which suspended sediments may reduce gas exchange across the gills were discussed: a) physical damage through abrasion; b) reduction in effective surface area through coating; and c) reduction in waterflow over the lamellae through the formation of silt mucus aggregations in the opercular cavities.

7) Behavioral reactions to high concentrations of suspended sediments were identical to those which have been exhibited by fish suffering from hypoxia.

8) Data from this study suggest that acute toxicity tests should be limited in duration to ~ 96 hr. Apparently, starvation-related stress can be significant thereafter.

4.5 ACKNOWLEDGMENTS

I would like to extend my sincere appreciation to Dr. Ernest O. Salo and Bruce P. Snyder for their guidance and strong support in this study.

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Special thanks go to Tom Prinslow, Bob Campbell, Dr. Richard Cardwell, Sharleen Olsen, and Dennis DiJulio for their helpful advice and constructive criticism.

5.0 FLOW-THROUGH BIOASSAY

by

Thomas E. Prinslow

5.1 INTRODUCTION

Dredging increases suspended sediment levels in the water column, and the effects on fish depend on sediment concentration and exposure time (Mortenson, Salo, and Snyder 1976). Since migrating chum, Oncorhynchus keta, pass through the dredge area in a few days (Schreiner 1977), the flow-through bioassay was designed to simulate dredge-area conditions. A concurrent live-box bioassay (Section 6.0) monitored mortality of chum exposed to suspended sediments in the field.

5.2 MATERIALS AND METHODS

Twenty-six weekly bioassays were conducted on the R/V KUMTUKS between January 31, 1977, and July 29, 1977, including 1 week before and after dredging. The bioassays followed the dredging schedule, beginning Monday morning and running continuously for 96 hr. The experimental design criteria were based on Sprague (1973).

5.2.1 Apparatus

Test water was pumped from three intakes positioned at a 1- to 2-m depth approximately 25, 50, and 100 m from the shoreline, and 175 m north of the dredge site (Fig. 5-1). These positions were chosen to monitor the zone through which chum salmon migrate (Schreiner 1977). Intakes could not be located closer to the dredge (< 175 m) without obstructing boat traffic. Control water was pumped from 5 m offshore to a 45,000-liter settling tank system (Fig. 3-4). Test or control water was supplied to four raceway tanks in the laboratory. Each tank consisted of a 90-liter head trough supplying three replicate 60-liter raceway troughs (Fig. 5-2) at 50 liters/hr/trough. Opaque sheeting surrounded the tank area to minimize laboratory disturbance. Fluorescent lighting was provided on a 12-hr cycle.

Between bioassays, pump lines, test and acclimation chambers were disinfected with a commercial chlorine/iodine solution and flushed for 2 days before reuse.

5.2.2 Test Procedure

Bioassay fish of three types--hatchery, channel, and local--came from six sources: Big Beef Creek Hatchery and spawning channel,

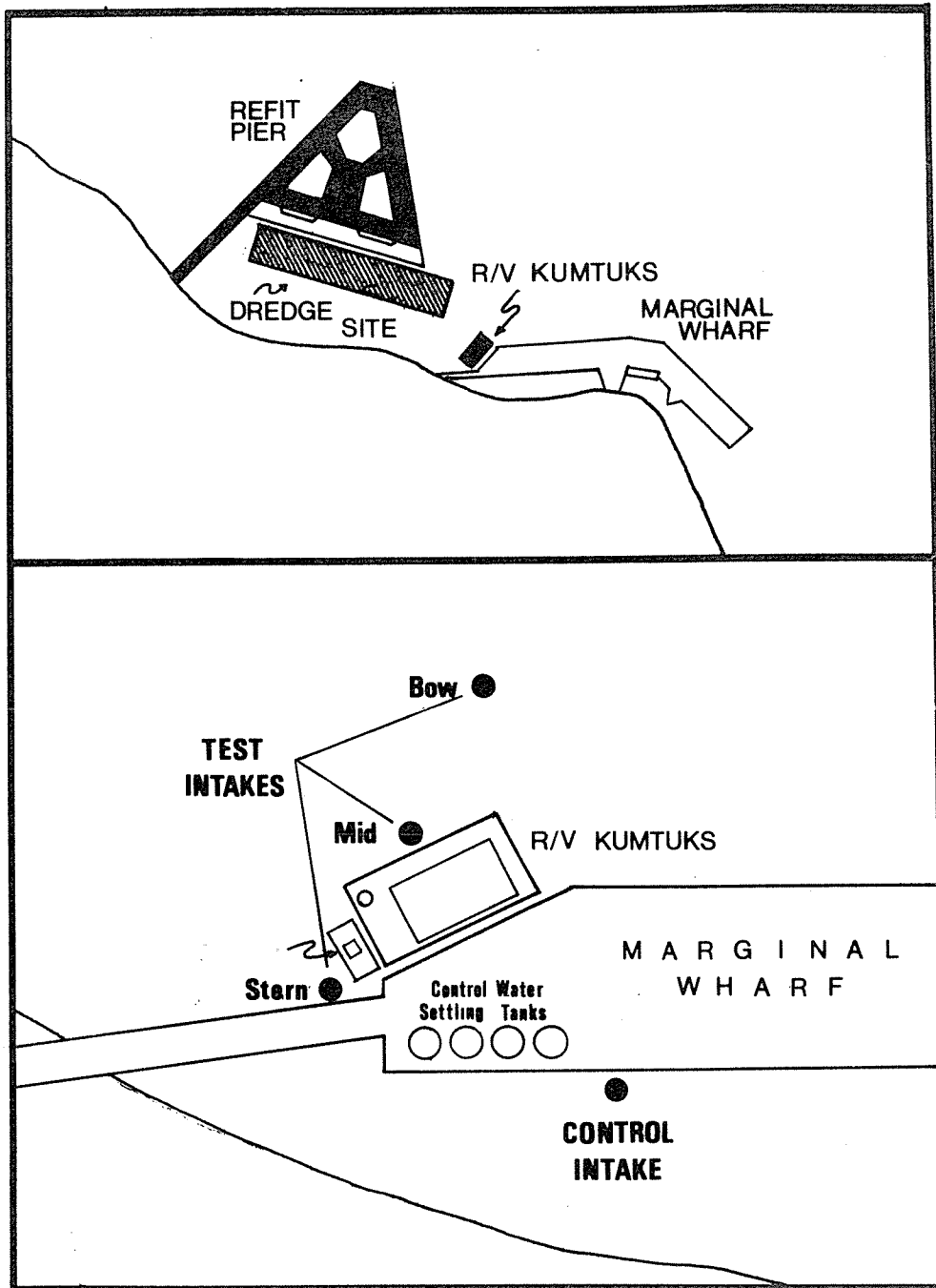


Fig. 5-1. Location of test and control intakes.

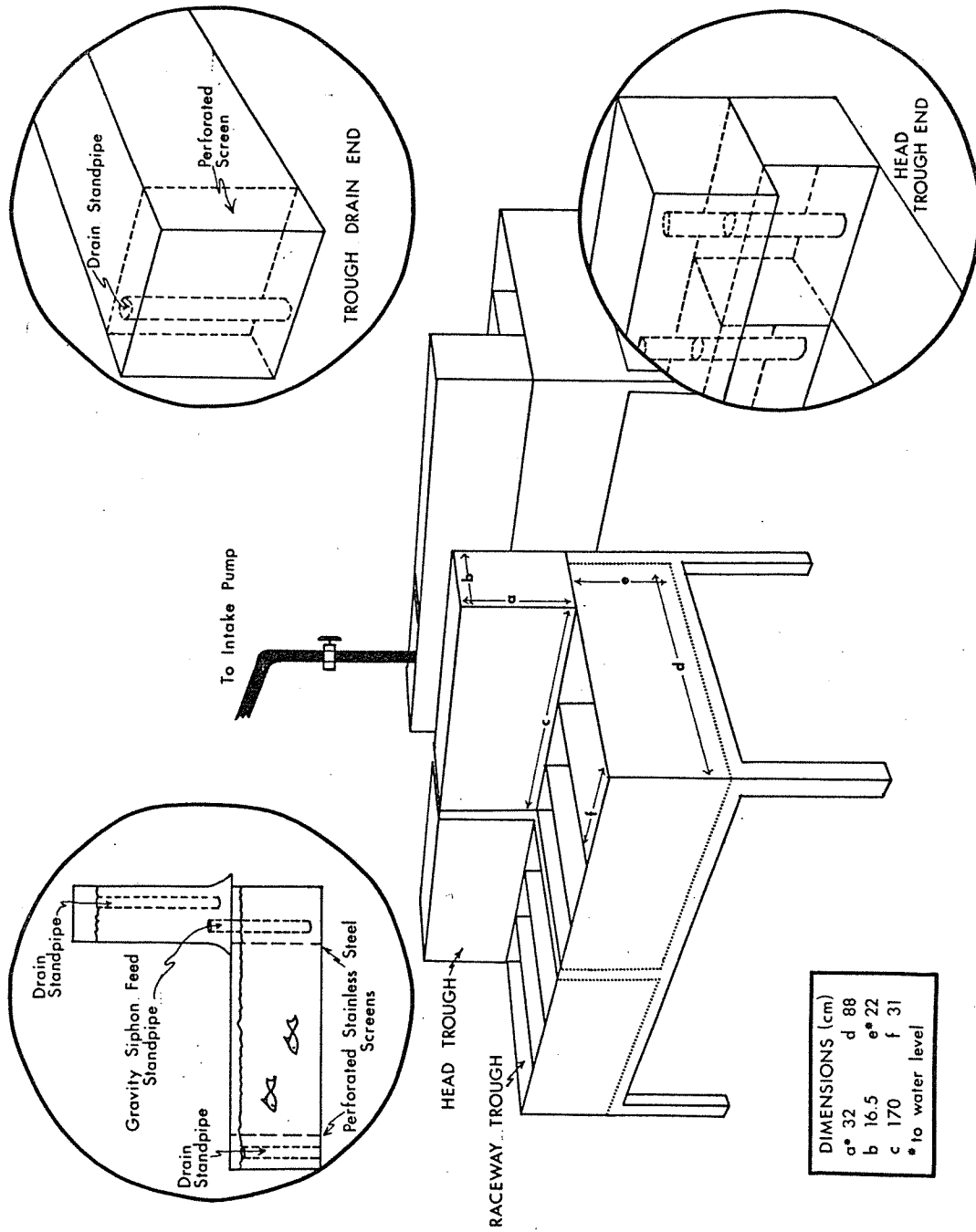


Fig. 5-2. Experimental tank system.

Hoodsport and Quilcene hatcheries, and local fish from beach seine and tordnet sampling from Hood Canal near Bangor. Of the 26 bioassays, hatcheries provided fish for nine, spawning channel for 12, and local for five (Table 5-1). Although local fish were preferred for bioassays, handling stress mortalities and limited availability resulted in predominant use of channel and hatchery fish. Test fish were held in net pens near the barge and fed daily for 1 to 2 weeks prior to testing. A 2-day acclimation period aboard the KUMTUKS preceded the bioassay. The 2,000-liter acclimation tank received a flow of control water at about the same exchange rate used in the bioassay raceways; isolation and lighting duplicated test conditions.

For each bioassay 120 fish were netted at random from the acclimating tank and distributed to the test troughs (10 per trough). Fish were then monitored for changes in condition. At the end of the bioassay, all fish were netted from the troughs and inspected for signs of disease or stress (Table 5-2). Twenty test and 10 control fish were selected at random and retained for disease analysis (Gillespie et al. 1974, and Section 8.0). Additionally, from each of the three test and one control treatments, five fish were removed and checked for the presence of sediment in the gills and gut. Fork lengths and blotted wet weights of these 20 fish provided population data (Table 5-1).

5.2.3 Water Quality

The following parameters were monitored at 4-hr intervals: suspended sediment concentration as total nonfilterable residue (TNFR), DO, pH, temperature, and salinity. Methods used appear in Table 5-3.

5.3 RESULTS AND DISCUSSION

5.3.1 Water Quality

Water quality parameters (temperature, DO, pH, salinity) followed seasonal patterns (Figs. 5-3 through 5-6). Dissolved oxygen remained above 7 mg/liter throughout the study. Salinity ranged 28 to 32 ppt, and pH, 7.8 to 8.3. Temperature was the only variable to which the fish obviously responded. Weekly mean test temperatures did not differ significantly from control during the 26 bioassays (Fig. 5-3). A warming trend starting in April (bioassay 10) raised temperatures from a February-to-April average of 8°C to 11°C-12°C by mid-May (bioassay 16). By mid-June (bioassay 20) average temperatures reached a maximum of 14°C-15°C, with no substantial change through July (bioassay 26). Upper ranges did increase, however, to a maximum of 18°C (bioassay 26). The April-May phase of the warming trend was accompanied by an increase in diseases and mortality (see below, Section 5.3.3).

Suspended sediment concentration (TNFR) fluctuated considerably during the bioassay series (Fig. 5-7). Variable dredging activity and area currents continuously changed the location and sediment load of

Table 5-1. Summary fish population data: source, length and weight.

Assay No.	Dates	Source ¹	Fork length (cm)		Wet weight (g)		Condition index	
			\bar{x}	R	\bar{x}	R	\bar{x}	R
1	1/31-2/4	BBC H	4.3	4.2-4.9	.57	.41-.70	.611	.505-.709
2	2/7-2/11	BBC H	4.8	4.5-5.2	.75	.55-.98	.656	.579-.706
3	2/14-2/18	BBC H	4.4	3.9-4.9	.55	.34-.75	.634	.563-.689
4	2/21-2/25	BBC H	4.7	4.0-5.2	.66	.39-.99	.640	.595-.704
5	2/28-3/4	BBC C	4.1	3.9-4.2	.40	.31-.45	.597	.508-.641
6	3/7-3/11	BBC C	4.1	3.8-4.3	.40	.31-.46	.574	.526-.621
7	3/14-3/18	BBC C	4.0	3.8-5.1	.40	.30-.86	.604	.556-.667
8	3/21-3/25	BBC C	4.1	3.6-4.2	.40	.27-.72	.598	.510-.770
9	3/28-4/1	BS L	4.2	3.8-4.4	.44	.36-.52	.605	.505-.672
10	4/4-4/8	BBC C	4.2	3.9-4.6	.46	.37-.62	.622	.567-.696
11	4/11-4/15	BBC C	4.3	3.8-5.0	.57	.37-.89	.694	.578-.783
12	4/18-4/22	BBC C	4.5	4.0-5.6	.67	.47-1.30	.727	.682-.844
13	4/25-4/29	BBC C	4.1	3.7-4.4	.53	.35-.62	.730	.667-.842
14	5/2-5/6	BBC C	4.2	3.9-4.7	.52	.40-.76	.714	.607-.984
15	5/9-5/13	BBC C	4.1	3.8-4.8	.47	.31-.74	.658	.500-.814
16	5/16-5/20	BBC C	4.2	3.7-5.1	.50	.30-.96	.659	.563-.744
17	5/23-5/27	BBC C	4.2	3.7-5.2	.47	.28-.91	.600	.510-.751
18	5/30-6/3	HDT H	5.4	4.8-5.9	1.09	.81-1.40	.693	.637-.778
19	6/6-6/10	BS L	6.4	4.7-8.8	2.06	.64-4.82	.664	.501-.765
20	6/13-6/17	BS L	6.3	4.2-8.2	2.11	.55-3.98	.692	.588-.759
21	6/20-6/24	HDT H	6.1	5.7-7.0	1.67	1.34-2.51	.726	.663-.815

Table 5-1. Summary fish population data: source, length and weight - continued.

Assay No.	Dates	Source ¹	Fork length (cm)		Wet weight (g)		Condition index	
			\bar{x}	R	\bar{x}	R	\bar{x}	R
22 ²	6/27-7/1	QLC H	6.1	4.8-6.8	1.73	.88-2.40	.767	.688-.866
23	7/3-7/7	QLC H	6.1	4.7-7.6	1.77	.69-3.38	.734	.665-.801
24 ²	7/11-7/15	HDT H	4.7	3.9-5.4	.70	.40-1.24	.670	.503-.787
25 ²	7/18-7/22	TN L	7.9	6.6-9.3	4.20	2.94-6.24	.840	.711-1.047
26	7/25-7/29	TN L	10.0	9.3-10.7	8.01	6.16-9.97	.805	.696-.968

¹BBC H: Big Beef Creek Hatchery, BBC C: Big Beef Creek channel, HDT H: Hoodsport Hatchery, QLC H: Quilcene Hatchery, BS L: beach seine, local, TN L: townet, local.

²Data based on the first 20 mortalities (no live fish remained for postassay examination).

Table 5-2. Symptoms of disease and stress in flow-through test fish.

Category	Symptom
Abnormal behavior/stress	Loss of equilibrium
	Listlessness
Disease	Lesion
	Hemorrhage
	Frayed/eroded fin
	Discoloration
	Scale loss
Moribund	Loss of locomotory ability
Dead	Cessation of respiration

Table 5-3. Water quality parameters, measurement methods, accuracy of measurements, and instruments used in flow-through bioassays. (Note: footnotes refer to Standard Methods for the Examination of Water and Wastewater, 14th ed., American Public Health Association, American Water Works Association, Water Pollution Control Federation 1976.)

Parameter	Method	Accuracy (recorded to nearest __)	Instrument
Suspended sediment ¹	As TNFR (total nonfilterable residue)	0.1 mg/liter	--
Dissolved oxygen ²	Winkler, azide modification	0.1 mg/liter	--
pH	Portable meter	0.1 units	Coleman portable pH meter, Model 37A
Temperature	Handheld thermometer	0.1° C	--
Salinity	Handheld refractometer	1 ppt	American Optical Goldberg temperature-compensated refractometer, Model 10419
"	Portable meter	1 ppt	Beckman electrodel inductor salinometer

¹Section 208D. "Total Nonfilterable Residue Dried at 103°-105° C," p. 94.

²Section 1122B. "Azide Modification," pp. 443-447.

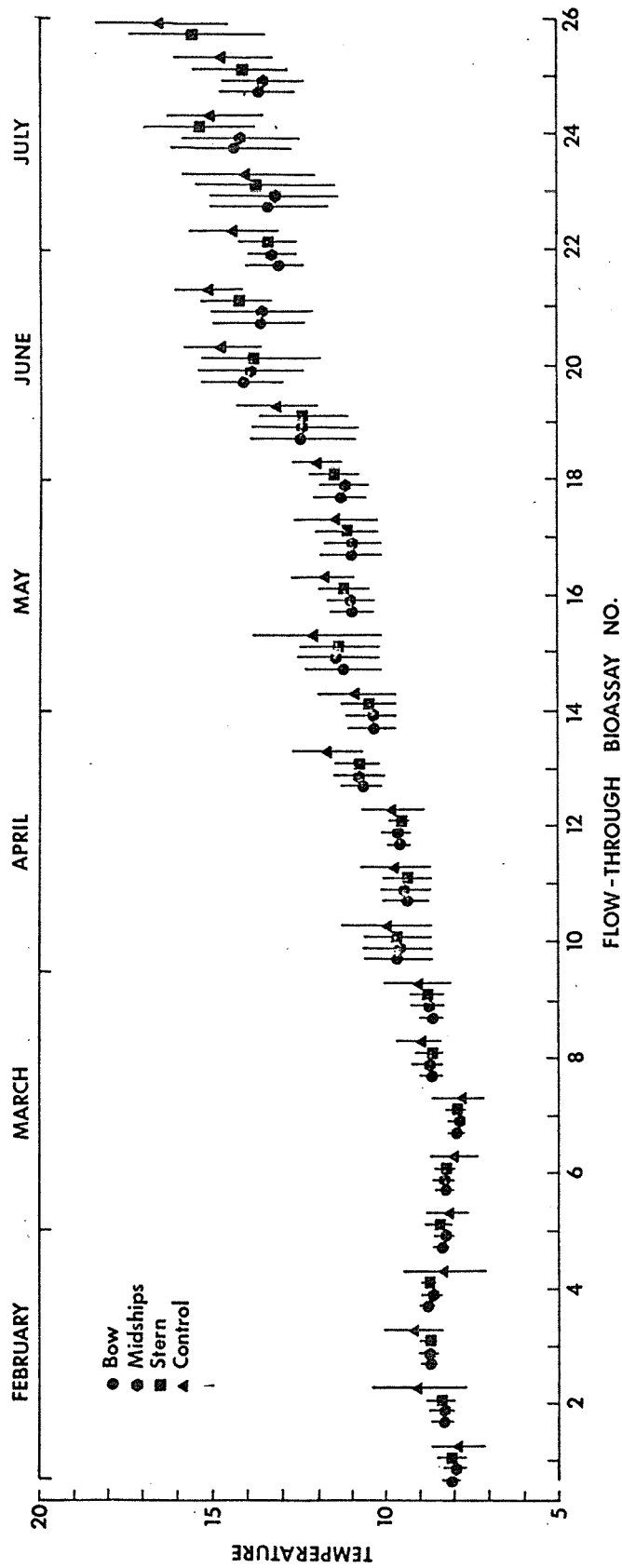


Fig. 5-3. Temperature: weekly means and ranges (denoted by vertical line through symbol: ϕ).

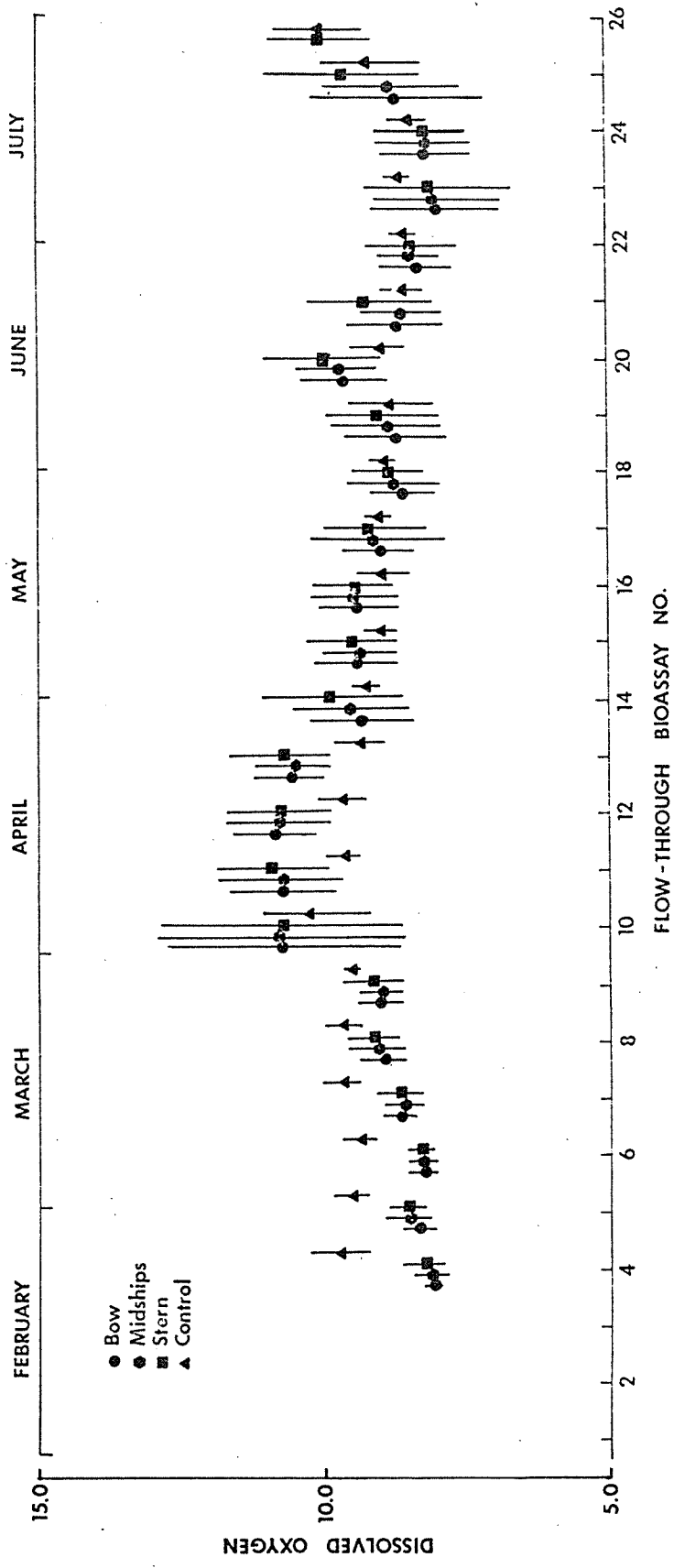


Fig. 5-4. Dissolved oxygen: weekly means and ranges (denoted by vertical line through symbol: ϕ).

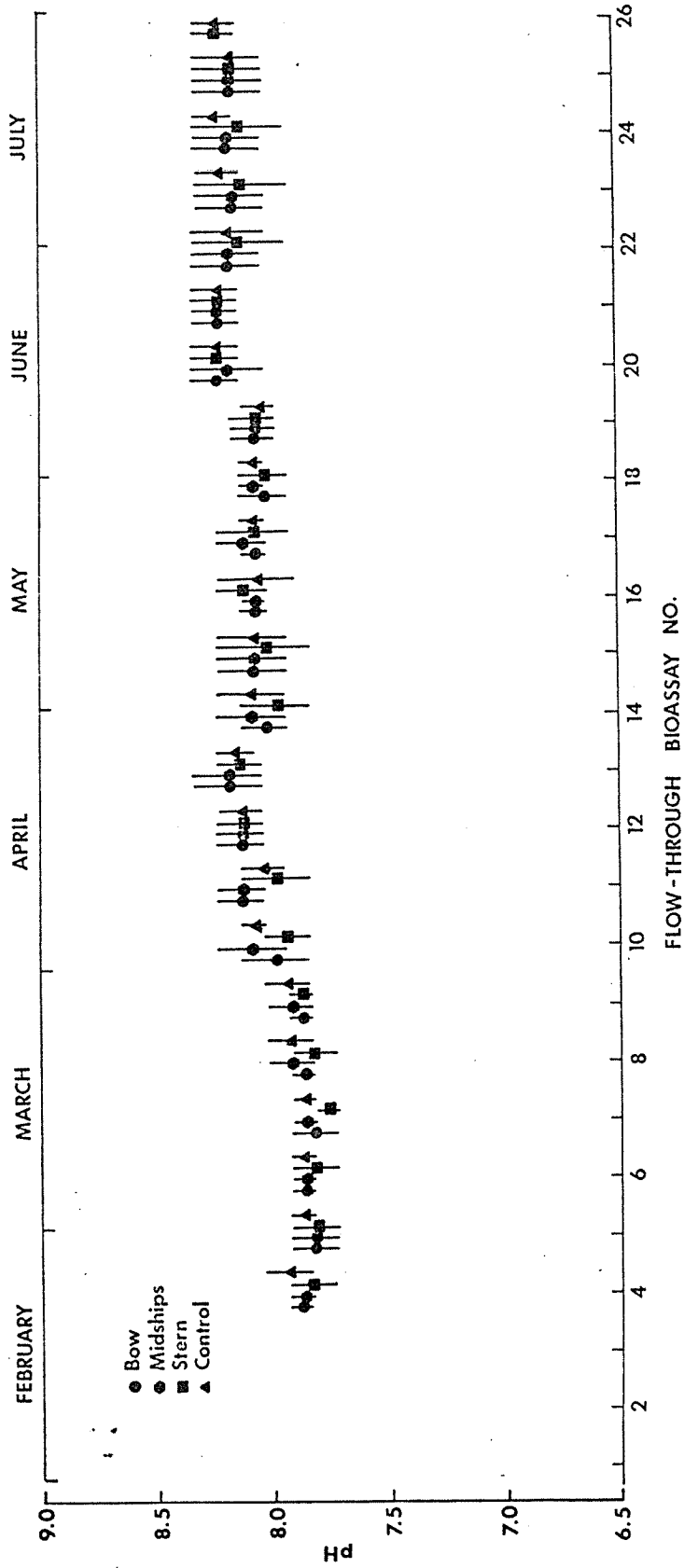


Fig. 5-5. pH: weekly means and ranges (denoted by vertical line through symbol: ϕ).

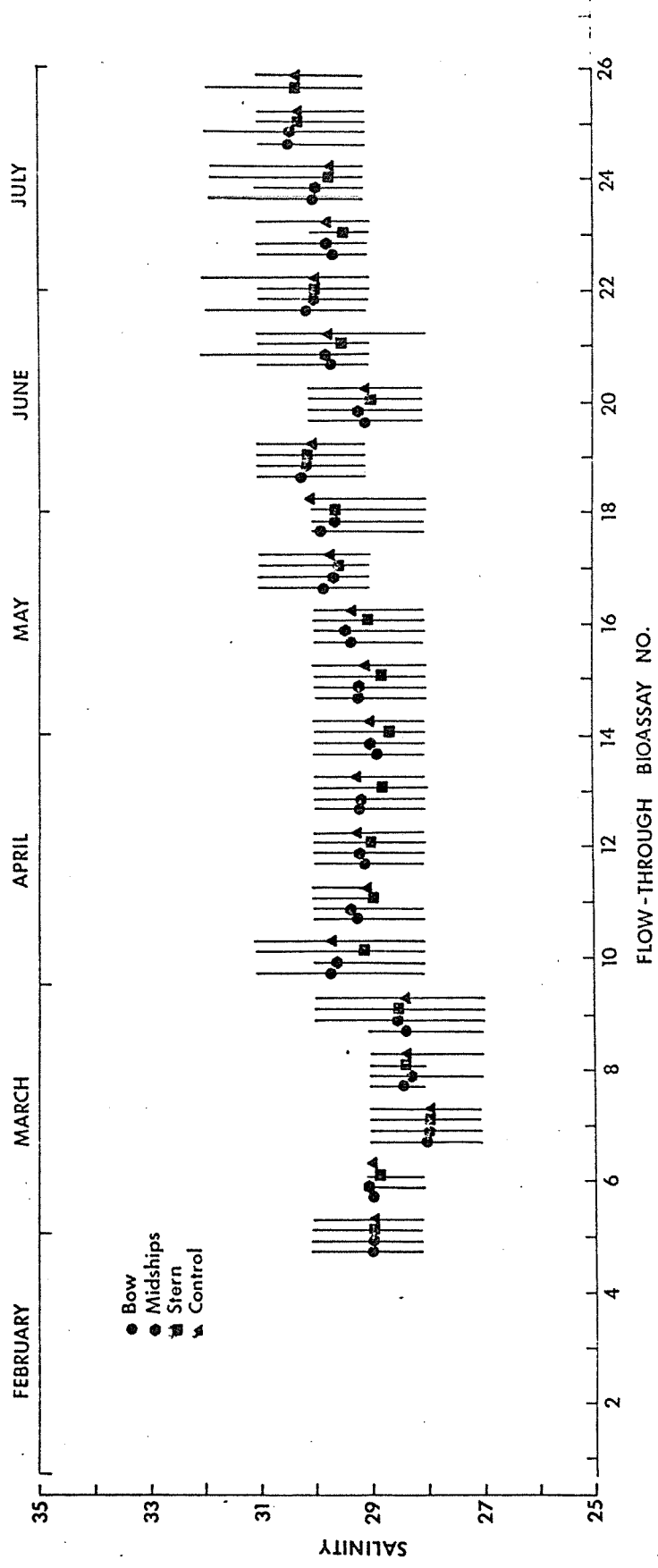


Fig. 5-6. Salinity: weekly means and ranges (denoted by vertical line through symbol: ϕ).

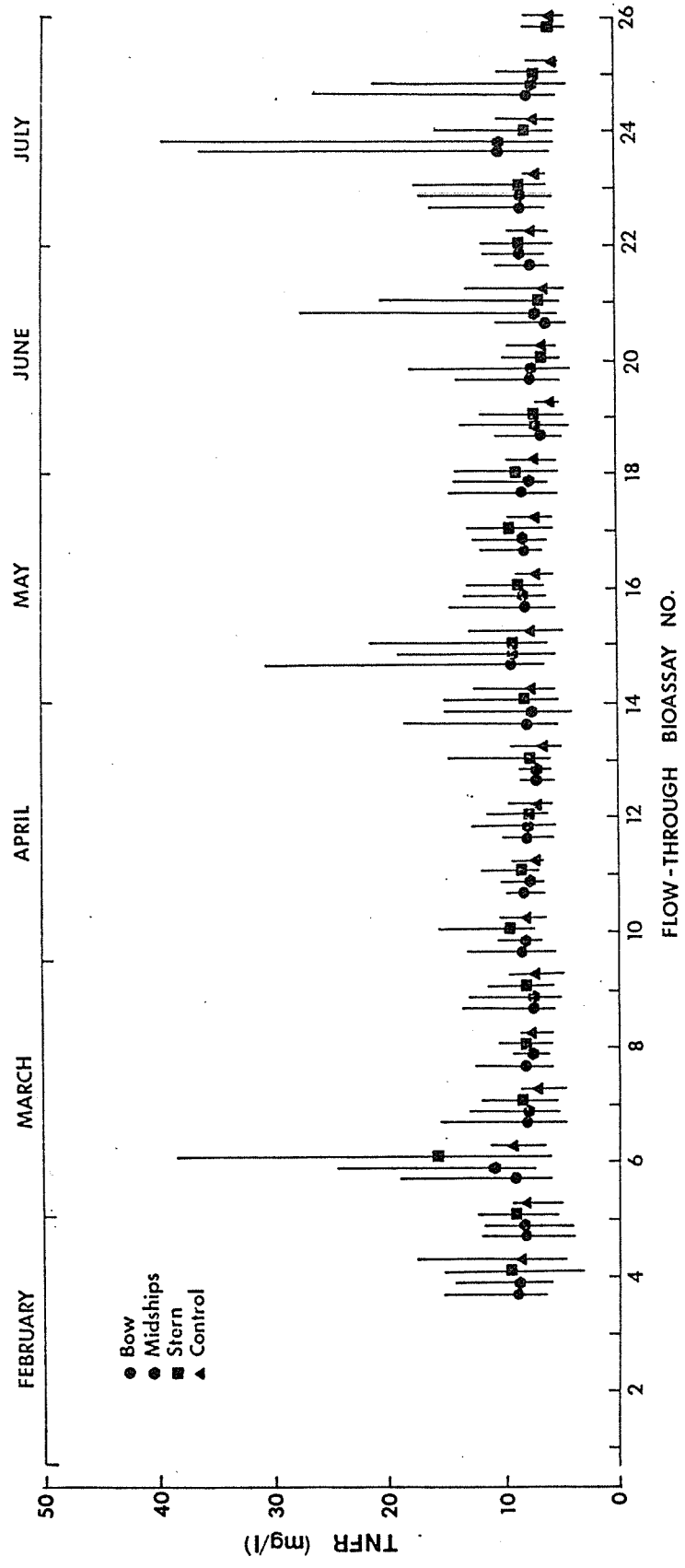


Fig. 5-7. TNFR: weekly means and ranges (denoted by vertical line through symbol: ϕ).

the plume. In four bioassays (6, 15, 21, and 24) TNFR varied among intakes by as much as 30 mg/liter (Fig. 5-7). Despite this variation, average TNFRs were stable: in only four of the 69 total "test sample weeks" (23¹ bioassays x three treatments per bioassay) did the weekly mean exceed 10 mg/liter, and then to a maximum of only 16 mg/liter (bioassay 6). Thus, TNFRs seldom exceeded background levels by more than 5 mg/liter.

5.3.2 Fish

Length and weight of test fish remained fairly uniform during the first 17 bioassays, ranging from 3.6 to 5.6 cm (average, 4.3 cm), and 0.27 to 1.30 g (average, 0.52 g), respectively (Table 5-1). Big Beef Creek channel and hatchery provided fish for 16 of these bioassays. During the remaining 10 bioassays, local and hatchery stock averaged 6.6 cm fork length and 2.59 g wet weight, reflecting seasonal growth.

From bioassay 16 onward, increases in disease and mortality forced departure from holding and acclimating procedures. Holding and acclimating periods were reduced from 2 weeks to 2 days or hours depending on fish health and availability. Exceptions are listed in Table 5-4.

5.3.3 Mortality Factors

The 26 bioassays are divided into two groups based on mortality. From bioassay 1 through 15, mortality averaged only 0.2% per assay, while from bioassay 16 to 25² (roughly mid-May onward) mortalities averaged 28% per bioassay (Table 5-5).

5.3.3.1 Disease

Two indices were used to monitor disease: external symptoms (Table 5-2) and incidence of Vibrio. As mortality rose from an average per bioassay of 0.2% to 28% (bioassays 1-15 versus 16-25), external symptoms increased from an average 3% to over 39% (Table 5-6). Concurrently, incidence of Vibrio rose from 1%³ to an average 18-19% and correlated closely with mortality (Table 5-7).

Stress factors such as handling or transport may increase the severity of a Vibrio disease outbreak (Wood 1968, page 29). For

¹Note: Data from bioassays 1 through 3 not included due to differences in sample volumes.

²Data from bioassay 26 excluded due to small sample size.

³First confirmed Vibrio in mid-May (bioassay 16).

Table 5-4. Exceptions to normal¹ holding/acclimating procedure.

Assay no.	Holding period (days)	Acclimating period (days)	Comments
18	15	-- ²	--
20	--	--	Acclimated with Hoodsport Hatchery fish
21	35	--	Held adjacent to sick Quilcene Hatchery fish
22	3	--	Acclimated with Hoodsport Hatchery fish; both groups diseased
23	2	--	--
24	2	--	Acclimated with diseased Quilcene Hatchery fish
25	0	0	Townet direct to flow-through
26	0	0	Townet direct to flow-through

¹Normal: 1- to 2-week holding, 2-day acclimating.

²Normal: indicates normal procedure.

Table 5-5. Mortality (96-hr, cumulative percent) in flow-through bioassays.

Assay no.	Mortality (percent) Test			Control
	Bow	Mid	Stern	
1 through 6	0	0	0	0
7	0	0	0	3
8	0	0	0	3
9	0	0	0	3
10	0	0	3	0
11 through 15	0	0	0	0
16	0	0	13	10
17	20	20	27	40
18	0	0	0	0
19	0	0	3	0
20	0	3	0	0
21	0	10	3	3
22	100	100	100	100
23	3	7	0	23
24	100	100	100	100
25	13	20	53	50

Table 5-6. Incidence of external disease symptoms--lesion, hemorrhage, frayed/eroded fin, discoloration, scale loss--among fish examined at assay completion.

Assay no.	Symptom incidence (percent)
1 through 9	0
10	25
11	15
12	0
13	10
14	0
15	0
16	16
17	5
18	8
19	20
20	16
21	30
22	90
23	25
24	80
25	56
26	86

Table 5-7. Comparison of *Vibrio* incidence with mortality.

Assay no.	Initial	During	Final Test	Control	Confirmed ¹ isolates (percent)	Mortality (pooled cumulative percent)
16	na	--	20/1	--	5	6
17	60/0	22/1 ²	20/0 ²	na	2	27
18	60/0	0/0	20/0	10/0 ²	0	0
19	139/0	3/0	20/0	10/0	0	1
20	--	0/0	20/0	10/0	0	1
21	12 ⁴	3/	na ³			4
22	na ³	5/	na ³			100
23	60/0	3/1	20/0	10/0	3	8
24	60/0	3/1	27/27	10/10	95	100
25	60/0	<u>1/1</u>	<u>18/4</u>	<u>4/2</u>	30	34
	TOTAL	32/4	165/32	54/12		
	Confirmed <i>Vibrio</i>	12%	19%	22%		

¹Of total fish streaked during and at completion of assay.

²Number of fish streaked/number of confirmed *Vibrio anguillarum* isolates.

³Samples destroyed by equipment tampering.

⁴No record of number of fish streaked.

example, bioassay 21 was the only bioassay where Vibrio was confirmed in test fish prior to use in the bioassay. Yet, mortality averaged only 4% although final examination of the survivors did disclose 65% with hemorrhaging of the eye--symptomatic of Vibrio (Wood 1968). However, from this same population live-box mortalities averaged 56% after 4 days, suggesting some extraneous influences in the live-box study.

5.3.3.2 Sediment

Sediment did not appear to affect survival. In fact, incidence of substantial mortality (above 10% per bioassay) occurred during periods of low (below 10 mg/liter) TNFR (Fig. 5-7), e.g., bioassays 16, 17, and 22. Conversely, bioassays with high TNFR (above 10 mg/liter) had low mortality, e.g., 6, 15, 21, and 23. Although sediment concentration in the 24th bioassay reached a maximum of 37 mg/liter--the highest recorded in the flow-through during the 26 bioassays--test and control mortalities were equal. This suggests that mortality factors, including disease, were not related to sediment concentration. Also, only one of the 375 test fish examined had traces of sediment in the gills, and at no time was there evidence of sediment clogging or packing as described in O'Connor, Neumann, and Sherk (1976).

While ranges reflected maximum TNFRs to which test fish were exposed, these maxima were sporadic and transitory--averaged TNFRs remained about 10 mg/liter. Flow-through bioassays indicate that exposure to these maxima did not affect mortality.

The static bioassay (Section 4.0) found a minimum LC₅₀ value at 96 hr of 15.6 g/liter--1,500 times greater than the average flow-through TNFR. Working with coho fry, O. kisutch, in a similar bioassay, LeGore and DesVoigne (1973) found no effect of sediment at concentrations up to 28.8 g/liter. Even TNFR samples taken directly from the plume (live-box study, Section 6.0) approximated only 100 mg/liter. Thus, had fish been exposed continuously to the plume, it is still unlikely that dredging would have affected mortality. Apparently, factors other than sediment influenced flow-through survival.

5.3.3.3 Temperature

The sudden onset of mortality (27% in bioassay 17, May 23-27) did coincide with increasing water temperature (Fig. 5-3). However, mortality did not increase with temperature alone, but varied with source of fish, holding and acclimating procedures and exposure to groups of diseased fish. In other words, elevated temperatures were necessary for disease, but were not the sole variable responsible for epidemics.

5.3.3.4 Procedures and Handling

Varying holding and acclimating procedures resulted in differences in frequency of handling and recovery time between handlings. During the "disease" phase (bioassays 16-26), transfer to either holding pens or acclimating tanks produced apparent handling stress losses within the first 24 hr. Mortalities then dropped off and either remained at zero or rose again after several days, depending on the particular test group. Elimination of holding and acclimating in bioassays 25 and 26 improved initial survival: losses after 24 hr of 13% and 40%, respectively, were less than those of bioassays 22 and 24--91% and 59%, respectively.

5.3.3.5 Contamination

Contamination from other fish stocks may also have affected survival. In bioassay 23, Quilcene Hatchery fish kept isolated during acclimation lost only 8%, while in the previous bioassay, fish from the same source lost 100% (Table 5-5)--apparently from exposure to diseased Hoodspout stock during acclimation.

5.3.3.6 Overview

Conflicting results make pinpointing causes of mortality difficult. Certainly, sediment levels in the dredge area had no lethal effects. Elevated temperatures (above 12°C) contributed, but were not the sole source as bioassays 19 and 20 had less than 1% mortality despite average temperatures of 12° to 14°C. Exposure to disease during testing, handling stress, and general initial health of the fish which may have been a function of source--whether hatchery or local,-- may be factors but formed no consistent pattern throughout the bioassay series.

5.4 SUMMARY

1) A series of 96-hr flow-through bioassays testing the effects of suspended sediment from dredging on outmigrating juvenile chum salmon, Oncorhynchus keta, in Hood Canal, Washington, was conducted between January 31 and July 29, 1977.

2) Flow-through bioassays were conducted on a floating laboratory moored at the dredge site; parallel live-box bioassays (Section 6.0) were conducted concurrently in the field.

3) Bioassays monitored fish mortality, suspended sediment, temperature, DO, pH, and salinity.

4) Suspended sediment averaged about 10 mg/liter, with sporadic transitory increases up to 37 mg/liter. Temperatures followed a seasonal increase from an average 8°C in February to 15°C in July. Dissolved oxygen levels remained above saturation (> 7 mg/liter)

throughout the study. Salinity ranged from 28 to 32 ppt, and pH, 7.8 to 8.3.

5) Increased mortality, from less than 1% to an average of 11%, was associated with increased temperature (above 11° to 12°C from mid-May onward) and the occurrence of vibriosis.

6) Sediment concentrations in the flow-through bioassay had no lethal effect on the chum. Mortality was associated with a combination of disease and handling stresses, although cause and effect relationships were not firmly established.

5.5 ACKNOWLEDGMENTS

Consistent operation of the flow-through bioassay would not have been possible without the reliable assistance of Mark Franzel, Dave Thielk, and Mike Bortell.

6.0 LIVE-BOX BIOASSAY

conducted by

James Franzel and Brad Daly

and compiled by

Thomas E. Prinslow

6.1 INTRODUCTION

The live-box bioassay provided seminatural open water tests of the effects of suspended sediments from dredging on juvenile chum salmon (Oncorhynchus keta).

6.2 MATERIALS AND METHODS

Twenty-four weekly bioassays were conducted in the Bangor Annex area of Hood Canal (Fig. 3-1) from January 31 to July 17, 1977. The bioassays followed the dredging schedule, beginning Monday morning and running continuously for 7 days. The experimental design was based on Finn (1975).

6.2.1 Design

The four test sites were within an area 100 m north and south of the dredging to allow for tidal shift of the sediment plume. Three control sites were located beyond the maximum range of the plume (Fig. 6-1). Test sites had two replicate live-boxes, control sites had three, so that similar numbers of fish were exposed to test (160 fish at 20/box) and control (180 fish at 20/box) conditions. A fourth control site was not available sufficiently close to the dredge area to permit daily observation.

6.2.2 Apparatus

Live-boxes were 30.5- x 45.7-cm fiberglass pipe, 6 mm thick, covered on each end with nylon netting (3-mm mesh) (Fig. 6-2). The boxes were secured at each site by a system of buoys and anchors (Figs. 6-2 and 6-3).

6.2.3 Test Procedure

Most of the fish were from the Big Beef Creek spawning channel and hatchery. Some were from the Washington State Department of Fisheries (WDF) Hood Canal Hatchery (Hoodsport), some from U.S. Fish and Wildlife Service (USFWS) Quilcene Hatchery, and some "local fish" were seined at

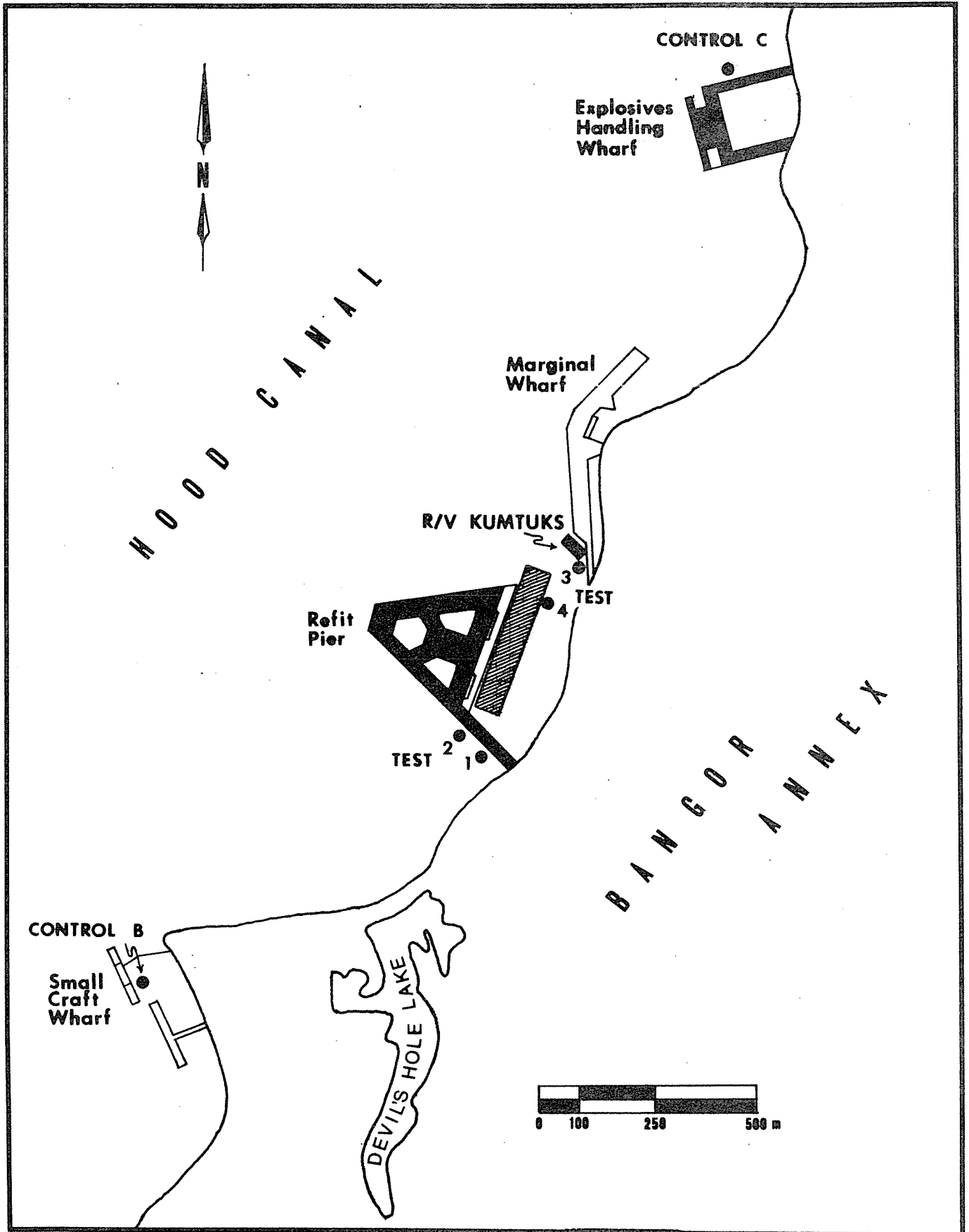


Fig. 6-1. Location of live-box test and control sites.

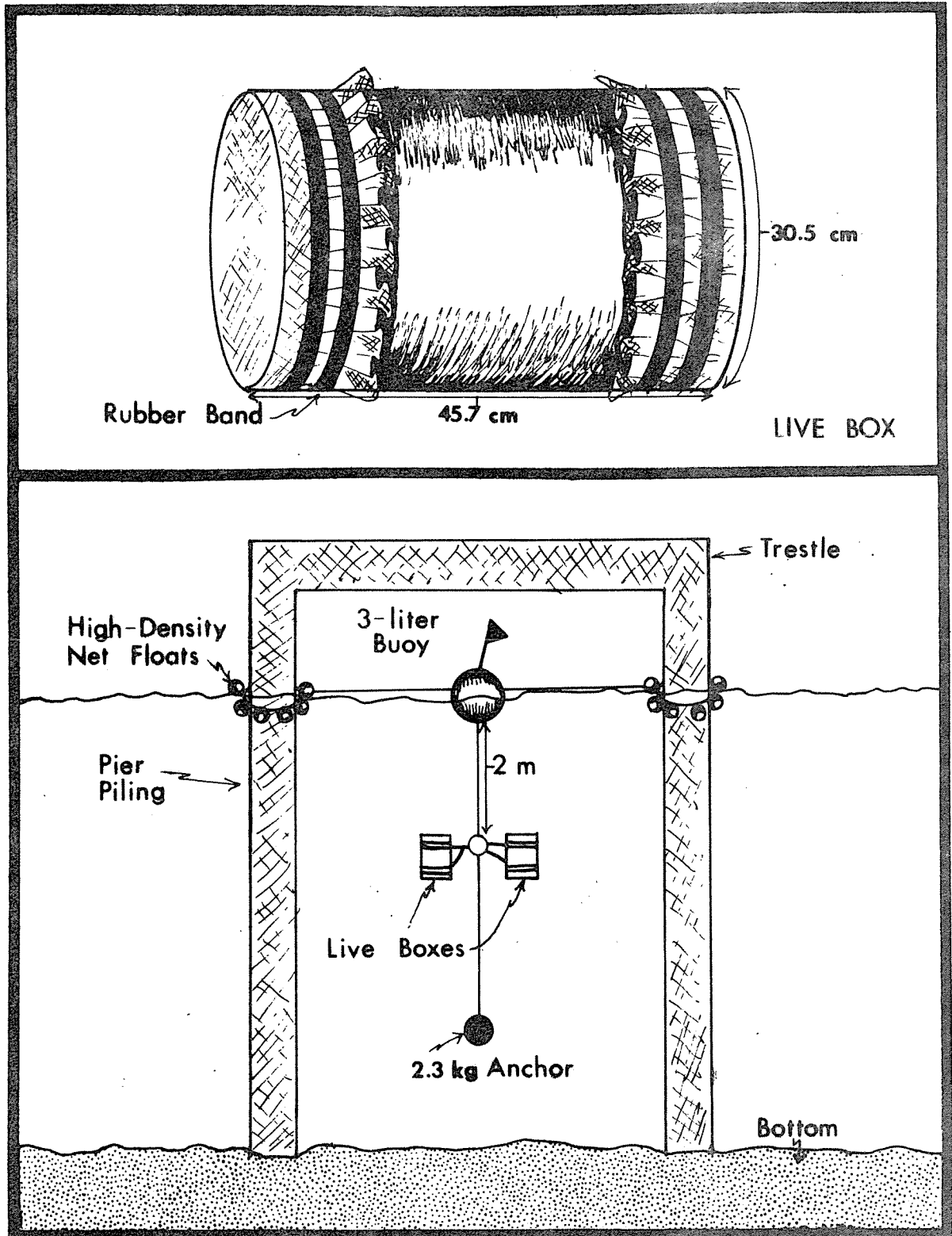


Fig. 6-2. Live-box diagram and pier-trestle mooring system.

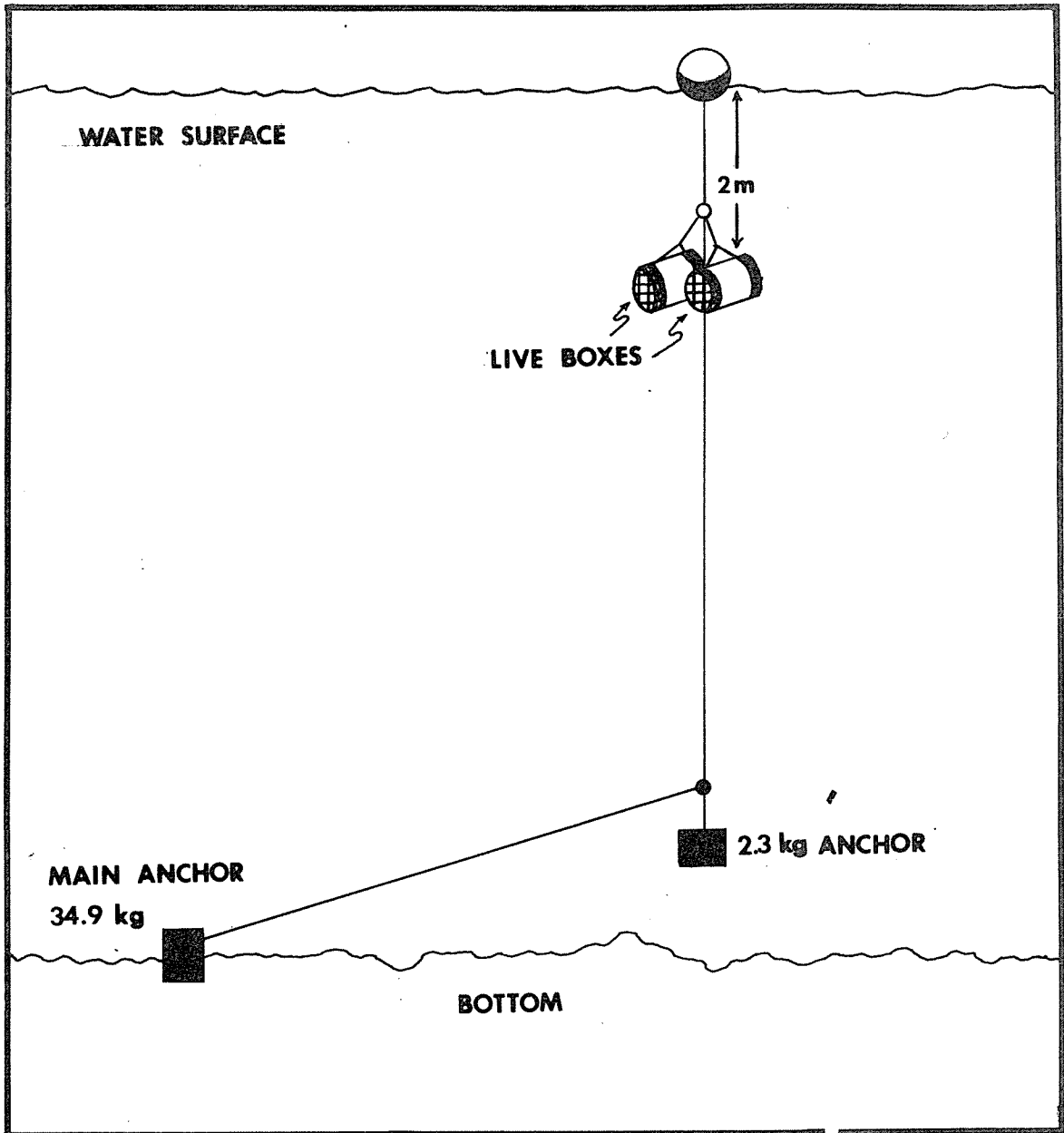


Fig. 6-3. Open-water mooring system.

the Bangor Annex. Fish were held in pens for approximately 2 weeks before each bioassay to adjust to saltwater conditions.

Groups of 20 fish were transferred from the holding pens to 20-liter plastic buckets for transport to live-boxes (one bucket/box). To minimize stress, fish used in the Bangor Annex area were transported in two trips, each supplying boxes at two test sites and one control. The most distant site (control A, Seabeck Harbor) was supplied by a third trip. Handling time was about 1 hr per trip.

A subsample of 30 fish was narcotized in MS-222, measured (nearest 1 mm fork length), weighed (nearest 1 mg blotted wet weight), and examined for any external signs of disease.

Boxes were raised to the surface daily and inspected for mortalities which were removed for post-mortem analysis. At the end of the bioassay period, survivors were examined for signs of disease, then released. Boxes were scrubbed with abrasive pads and the nets were washed in detergent, soaked in Clorox, and sun-dried.

In anticipation of a disease outbreak, the following changes were initiated in early May: 1) any fish which, during daily live-box inspection, exhibited abnormal swimming behavior was removed for disease analysis; 2) at the start of each bioassay, a sample of 60 fish was removed from the holding pen for disease analysis; 3) following the bioassay, 30 fish (15 test and 15 control) were retained for disease analysis.

6.2.4 Water Quality Monitoring

Water samples were taken daily at all sites in the Bangor Annex area at a depth of 2 m with a 1.5-liter PVC Van Dorn bottle and temperatures were measured with a thermometer inserted into the bottle. Salinity was measured in the field with a Martek TDC metering instrument calibrated with the silver nitrate titration procedure. After March, salinity was measured in the laboratory with a portable Goldberg refractometer (model 10419). Dissolved oxygen was measured in the field with a portable YSI DO meter (model 54) calibrated daily using the sodium azide modification of the Winkler method with a chloride correction factor. A Coleman (model 37) or an Orion specific ion meter (model 407) was used for pH determination.

Total nonfilterable residue (TNFR) was measured once or twice daily (usually mid-ebb- and mid-flood tide) following the procedure outlined in APHA, AWWA, and WPCF (1976).

6.3 RESULTS AND DISCUSSION

6.3.1 Water Quality

From January to July temperatures ranged from 6°-18°C (Fig. 6-4); pH, 7.7-8.4 (Fig. 6-5); DO, 7-13 mg/liter (Fig. 6-6); and salinity, 24-32 ppt (Fig. 6-7). Temperature, pH, and DO were consistently higher at control sites while the salinity was usually slightly lower.

Daily TNFR samples at test sites (Table 6-1) ranged from 4-94 mg/liter, exceeding the WDF guideline (Section 3.0) of 30 mg/liter above ambient (approximately 5 mg/liter) in five bioassays: 6, 12, 13, 18, and 24. Weekly means did not exceed 23 mg/liter and they averaged 9.4 mg/liter for the 24 bioassays. Daily control values ranged from 4-16 mg/liter; weekly means ranged 5-11 mg/liter, averaging 7.3 mg/liter for the 24 bioassays (Table 6-2).

6.3.2 Mortality

The effect of dredging on chum was evaluated principally in terms of mortality rates of the test animals. Mortality rates did not differ significantly between test and control during the 24 bioassays (Tables 6-3 and 6-4); however, sediment levels did ($p < .001$). Mortality rates did differ significantly ($p < .001$) among bioassays (Fig. 6-8). Apparently, factors other than sediment accounted for this variability. These factors include: 1) handling associated with transport; 2) daily observation of live-boxes; 3) the variable sources of test fish; 4) initial general health; and 5) the onset of diseases.

6.3.2.1 Handling Stress

Procedures involved handling of bioassay fish during initial transport of fish and at the daily inspection of live-boxes. Transport stress was evaluated in terms of initial 24-hr mortality rates; daily inspection stress was evaluated in terms of weekly mortality.

Fish were transported to test and control sites in three trips. The same sequence of sites was supplied in each bioassay. For example, trip 1 supplied test site 1 first, and control site B third. Trip 2 supplied test site 4 first, and control site C third. Fish supplied to sites B and C were always handled for a longer interval than those to test sites 1 and 4. However, 24-hr mortality rates at the third site supplied in trips 1 and 2 (controls B and C) did not differ significantly from the first sites (tests 1 and 4), averaging 3-4% during the 24 bioassays (Table 6-5). (The 24-hr mortality data at control site A were only collected in 12 of the 24 bioassays and are not included in this analysis.)

Daily inspection procedures differed between test and control only with respect to the number of boxes handled daily at each site (3 at

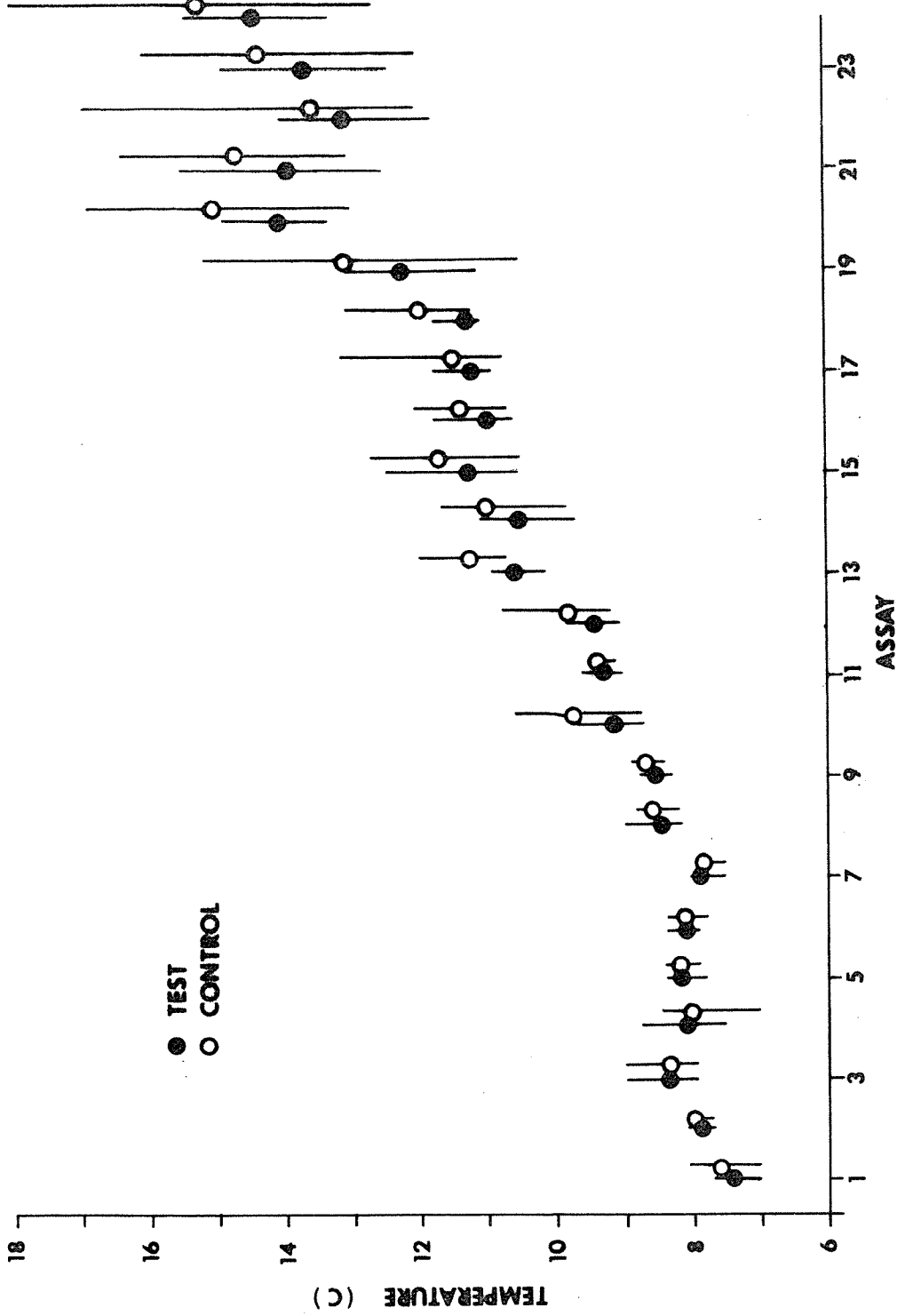


Fig. 6-4. Temperature: symbols (ϕ) denote weekly mean and range of pooled test or control samples.

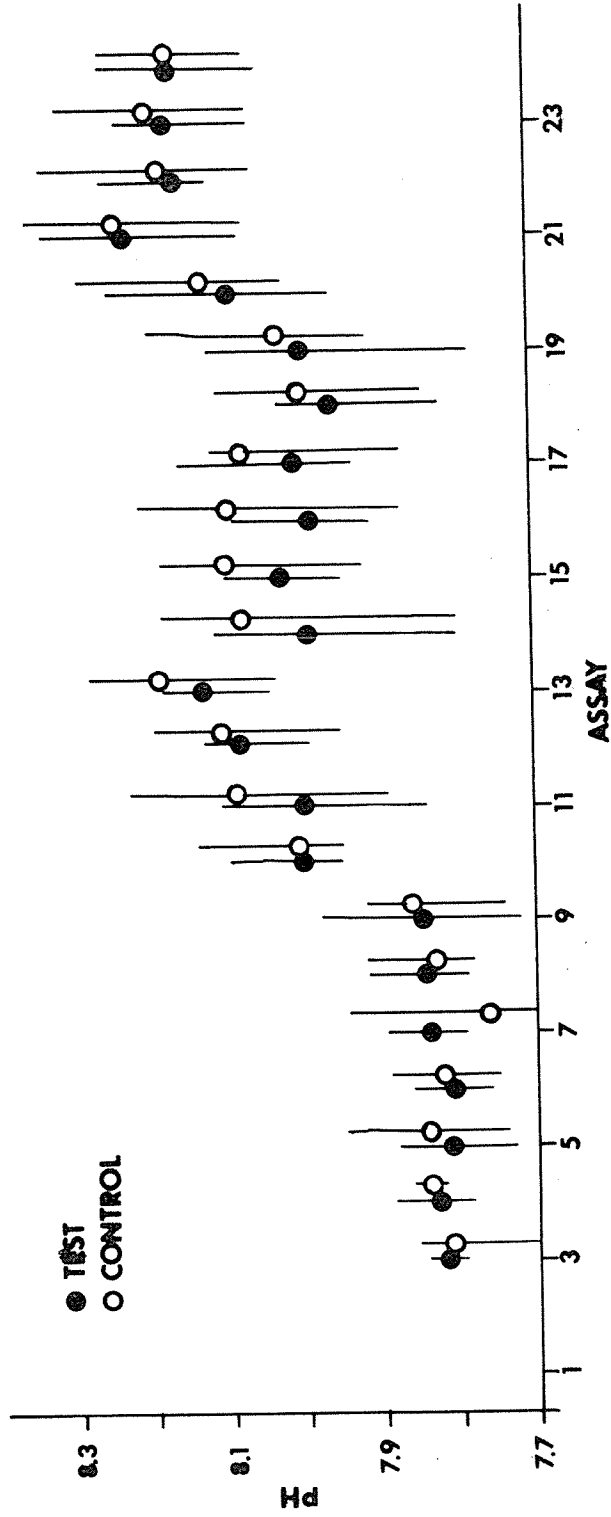


Fig. 6-5. pH: symbols (●) denote weekly mean and range of pooled test or control samples.

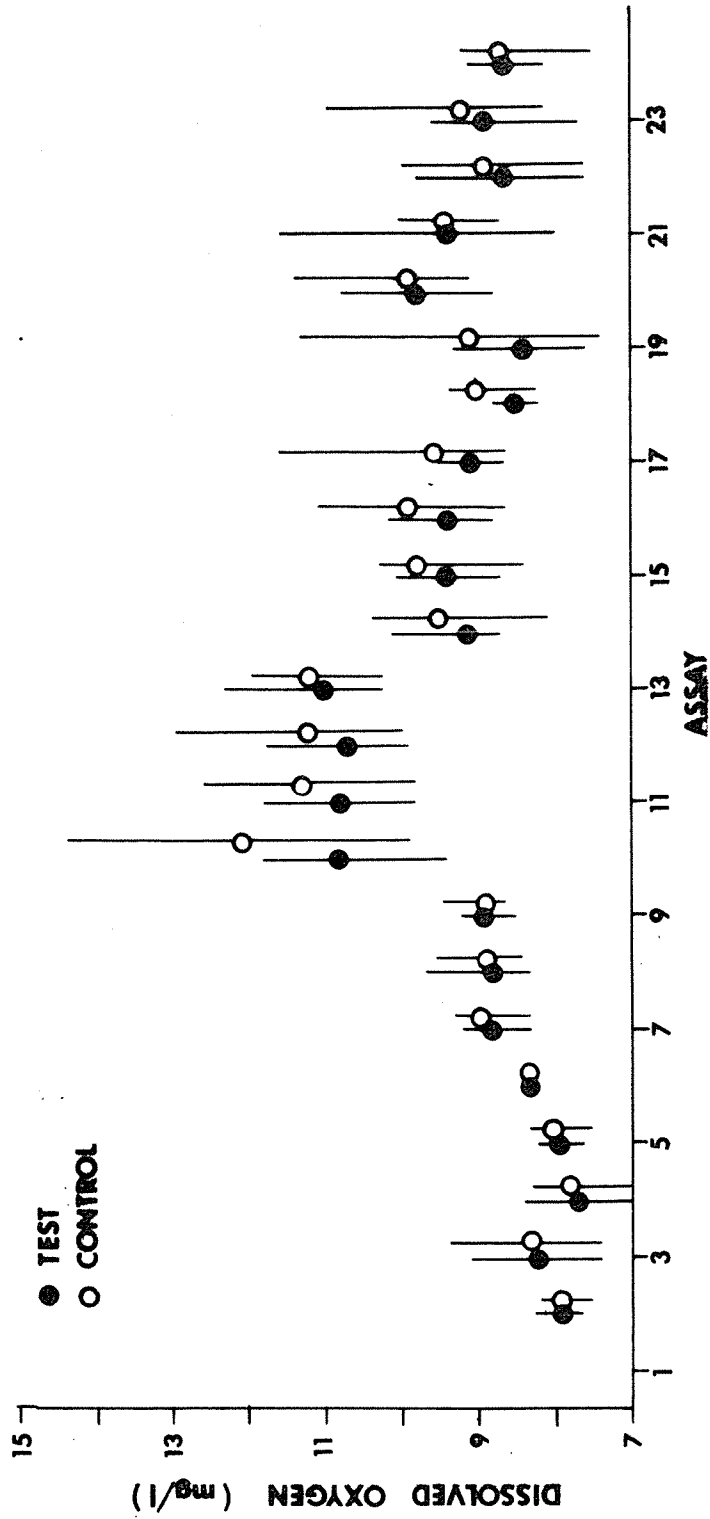


Fig. 6-6. Dissolved oxygen: symbols (ϕ) denote weekly mean and range of pooled test or control samples.

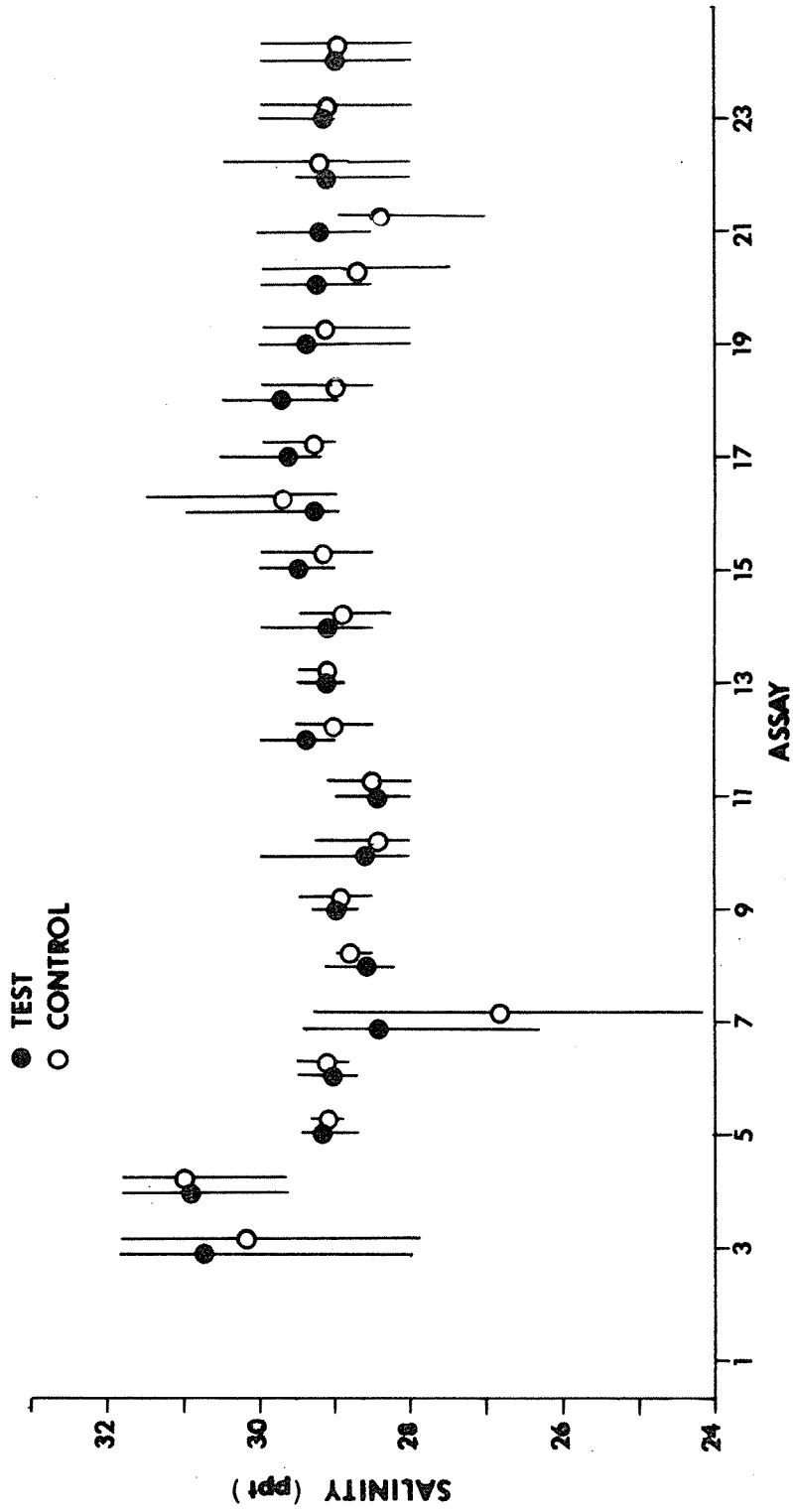


Fig. 6-7. Salinity: symbols (●) denote weekly mean and range of pooled test or control samples.

Table 6-1. TNFR: Weekly mean and range (mg/liter) at live-box test sites.

Site	1			2			3			4			Pooled ¹
	Min	Max	Av	Min	Max	Av	Min	Max	Av	Min	Max	Av	
Assay	-	-	-	-	-	-	-	-	-	-	-	-	-
1	-	-	-	6.5	9.2	7.4	-	-	-	7.0	9.4	8.0	7.7
2	-	-	-	5.4	14.6	9.7	5.9	17.2	9.1	5.9	10.3	8.0	8.9
3	6.7	13.3	8.8	6.2	23.0	10.4	5.2	9.5	7.4	4.9	9.2	7.8	8.5
4	5.9	16.1	8.5	5.3	9.5	7.2	4.3	21.9	8.7	3.6	10.6	6.9	8.0
5	6.7	13.5	9.2	5.5	16.4	9.6	6.4	15.7	9.2	6.2	60.1	18.4	12.0
6	5.4	27.6	10.9	4.3	10.4	7.4	3.7	12.0	6.6	4.3	8.4	6.5	6.7
7	4.1	9.7	6.3	2.7	11.1	6.1	4.8	9.5	6.0	4.3	8.3	5.6	6.0
8	4.6	8.4	6.5	5.8	20.3	8.5	5.6	20.2	8.4	5.0	12.2	7.1	8.0
9	5.7	11.6	7.9	6.7	13.4	9.8	8.0	11.5	9.6	7.0	10.4	8.8	9.9
10	7.0	16.4	11.3	7.5	17.1	10.1	7.1	10.9	8.3	7.2	9.2	7.9	8.9
11	7.6	11.5	9.1	8.2	48.6	20.3	5.3	12.8	8.8	6.2	27.7	11.0	12.5
12	7.1	13.5	9.7	5.8	93.6	19.2	6.6	18.3	9.1	6.1	11.2	8.3	12.2
13	6.2	45.1	12.3	6.9	10.9	9.0	7.7	23.7	11.0	6.5	22.4	10.5	10.4
14	7.0	24.0	11.1	6.7	12.9	9.2	5.8	12.4	8.3	7.7	10.6	9.0	9.2
15	8.0	15.8	10.1	6.9	9.2	8.3	6.4	8.6	7.7	6.5	9.2	8.0	8.8
16	6.7	11.3	8.8	8.0	15.5	10.0	7.5	9.9	8.6	6.8	10.4	8.2	8.9
17	6.6	10.9	8.7	6.5	82.1	22.9	7.0	8.6	7.8	6.8	8.0	7.4	11.7
18	6.1	16.1	8.6	6.7	18.5	9.2	6.6	21.3	8.9	6.0	14.5	9.5	9.1
19	6.1	13.6	8.5	5.5	12.6	8.3	6.1	26.0	11.0	5.7	12.4	8.6	9.1
20	6.1	10.7	8.3	6.9	14.1	8.6	6.7	8.6	7.6	6.8	10.4	8.2	8.2
21	5.5	10.7	8.3	6.0	23.7	12.5	7.0	32.5	12.6	6.8	14.5	10.2	11.1
22	6.4	13.3	9.0	4.6	7.9	6.7	5.1	17.4	10.0	6.9	30.2	11.7	9.2
23	6.4	15.6	8.3	5.0	25.4	9.3	6.4	19.6	11.5	6.5	38.2	13.4	12.0
24	6.1	51.2	13.8										

¹Values are means of the average TNFR's from the four test sites.

Table 6-2. TNFR: Weekly mean and range (mg/liter) at live-box control sites.

Site	A			B			C			Pooled ¹
	Min	Max	Av	Min	Max	Av	Min	Max	Av	
Assay										
1	-	-	-	-	-	-	-	-	-	-
2	-	-	8.0 ²	5.9	8.5	7.5	6.9	8.2	7.3	7.6
3	-	-	9.0	4.9	9.3	7.3	5.5	10.5	8.0	8.1
4	-	-	-	5.7	15.5	9.5	6.0	7.6	6.8	8.1
5	-	-	-	4.4	10.6	6.8	5.5	12.5	6.9	6.8
6	-	-	8.4	5.0	10.4	7.0	5.0	8.6	7.2	7.5
7	-	-	5.7	3.8	8.7	6.7	4.6	12.0	6.9	6.4
8	-	-	4.4	4.5	6.7	5.1	4.7	7.7	5.7	5.1
9	-	-	4.5	5.0	8.1	6.6	5.0	8.2	6.2	5.8
10	-	-	10.4	8.0	10.0	8.8	7.4	10.5	8.7	9.3
11	9.8	13.6	11.2	5.3	10.8	8.1	6.8	8.5	7.6	9.0
12	5.0	11.5	8.2	5.6	10.5	8.3	4.7	9.9	7.9	8.1
13	5.2	6.9	6.1	6.2	8.6	7.2	5.0	9.2	7.0	6.8
14	6.3	7.4	6.9	7.1	11.1	9.1	6.2	9.4	7.6	7.9
15	7.6	10.0	8.8	6.9	9.7	8.2	7.1	8.9	8.0	8.3
16	7.4	8.0	7.7	5.6	8.9	7.2	6.4	8.5	7.4	7.4
17	6.9	7.6	7.2	6.4	9.2	7.3	6.4	9.1	7.8	7.4
18	5.5	6.0	5.8	5.8	16.1	9.1	5.4	7.6	6.4	7.1
19	5.1	8.4	6.7	5.8	8.2	6.7	5.7	8.1	6.6	6.7
20	5.2	7.6	6.2	5.8	9.1	7.2	5.3	8.5	6.5	6.6
21	6.1	8.0	7.1	5.3	9.4	7.0	5.7	8.8	6.9	7.0
22	5.1	7.1	6.4	6.5	10.1	7.7	6.1	9.1	7.6	7.2
23	5.2	7.1	6.2	5.8	8.3	6.9	5.4	8.7	6.9	6.7
24	5.3	8.0	8.3	5.9	9.2	7.1	5.8	10.7	7.0	7.5

¹Values are means of the average TNFR's from the three control sites.

²Assays 2-10 based on one sample per assay.

Table 6-3. Weekly mortality rates (cum percent) at live-box test sites.¹

Site	1			2			3			4			
	Box	1	2	Av	3	4	Av	5	6	Av	7	8	Av
Assay													
1	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	
2	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	
3	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	
4	0	0	0.0	10	15	12.5	0	0	0.0	0	5	2.5	
5	0	0	0.0	0	5	2.5	5	0	2.5	0	0	0.0	
6 ³													
7	5	5	5.0	5	5	5.0	5	5	5.0	5	15	10.0	
8	0	5	2.5	0	0	0.0	5	0	2.5	5	5	5.0	
9	5	0	2.5	5	0	2.5	0	0	0.0	0	0	0.0	
10	0	0	0.0	0	5	2.5	0	0	0.0	0	0	0.0	
11	5	0	2.5	0	0	0.0	0	0	0.0	0	0	0.0	
12	10	5	7.5	5	0	2.5	0	0	0.0	0	0	0.0	
13	10	0	5.0	0	5	2.5	0	0	0.0	0	0	0.0	
14	0	0	0.0	5	0	2.5	0	0	0.0	5	0	2.5	
15	5	20	12.5	15	5	10.0	5	10	7.5	5	10	7.5	
16	20	10	15.0	15	0	7.5	15	35	25.0	70 ²	60	65.0	
17	75	55	65.0	60	50	55.0	45	90	67.5	90	70	80.0	
18	0	0	0.0	5	5	5.0	10	10	10.0	0	0	0.0	
19	15	5	10.0	25	30	27.5	20	25	22.5	5	15	10.0	
20	10	10	10.0	5	0	2.5	15	10	12.5	0	10	5.0	
21	60	60	60.0	80	75	77.5	90	100	95.0	60	85	72.5	
22	100	85	92.5	95	95	95.0	100	95	97.5	90	100	95.0	
23	25	55	40.0	30	30	30.0	75	15	45.0	48 ³	15	31.5	
24	70	55	62.5	60	10	35.0	50	45	47.5	45	30	37.5	

¹20 fish per box initially and tested for 7 days
(i.e. the fish were replaced every 7 days).

²Fish escaped.

³Exposed to chlorine during holding.

⁴23 fish initially.

Table 6-4. Weekly mortality rates (cum percent) at live-box control sites.¹

Site Box	A				B				C			
	A	B	C	Av	D	E	F	Av	G	H	I	Av
Assay												
1	5	0	0	1.7	0	0	0	0.0	5	5	0	3.3
2	0	0	0	0.0	0	0	0	0.0	0	0	0	0.0
3	0	0	0	0.0	0	0	0	0.0	20	10	0	10.0
4	0	5	0	1.7	5.0	0	0	1.7	5	0	5	3.3
5	10	10	5	8.3	0	10	0	3.3	0	5	0	1.7
6 ²												
7	0	0	5	1.7	0	0	0	0.0	5	0	0	1.7
8	5	5	0	3.3	5	10	0	5.0	0	20	5	8.3
9	15	- ³	- ³	15.0	5	5	5	5.0	0	0	0	0.0
10	5	0	0	1.7	5	0	0	1.7	- ⁴	- ⁴	- ⁴	-
11	5	0	0	1.7	0	0	5	1.7	0	0	5	1.7
12	10	5	0	5.0	0	0	5	1.7	0	0	0	0.0
13	0	0	0	0.0	0	0	0	0.0	5	0	5	3.3
14	0	0	0	0.0	0	0	5	1.7	5	0	0	1.7
15	10	5	10	8.3	10	10	15	11.7	5	5	5	5.0
16	15	15	5	11.7	20	25	20	21.7	15	25	25	21.7
17 ⁵	25	30	25	26.6	55	65	70	63.3	65	80	75	73.3
18	5 ³	0 ³	0 ³	1.7	0	0	5	1.7	5	5	5	5.0
19	- ³	- ³	- ³	-	5	0	30	11.7	- ⁴	- ⁴	- ⁴	-
20	5	0	10	5.0	10	5	10	8.3	10	15	20	15.0
21	100	95	100	98.3	75	95	85	85.0	70	55	70	65.0
22	100	95	100	98.3	100	90	95	95.0	95	95	95	95.0
23	95	100	95	96.7	95	45	75	71.7	75	5	40	40.0
24	100	75	100	91.7	55	50	95	66.7	65	35	30	43.3

¹20 fish per box initially, and tested for 7 days (i.e., the fish were replaced every 7 days).

²Exposed to chlorine during holding.

³Fish not accounted for.

⁴Station disturbed, fish lost.

⁵Moribund included as mortalities except for 7th day moribund.

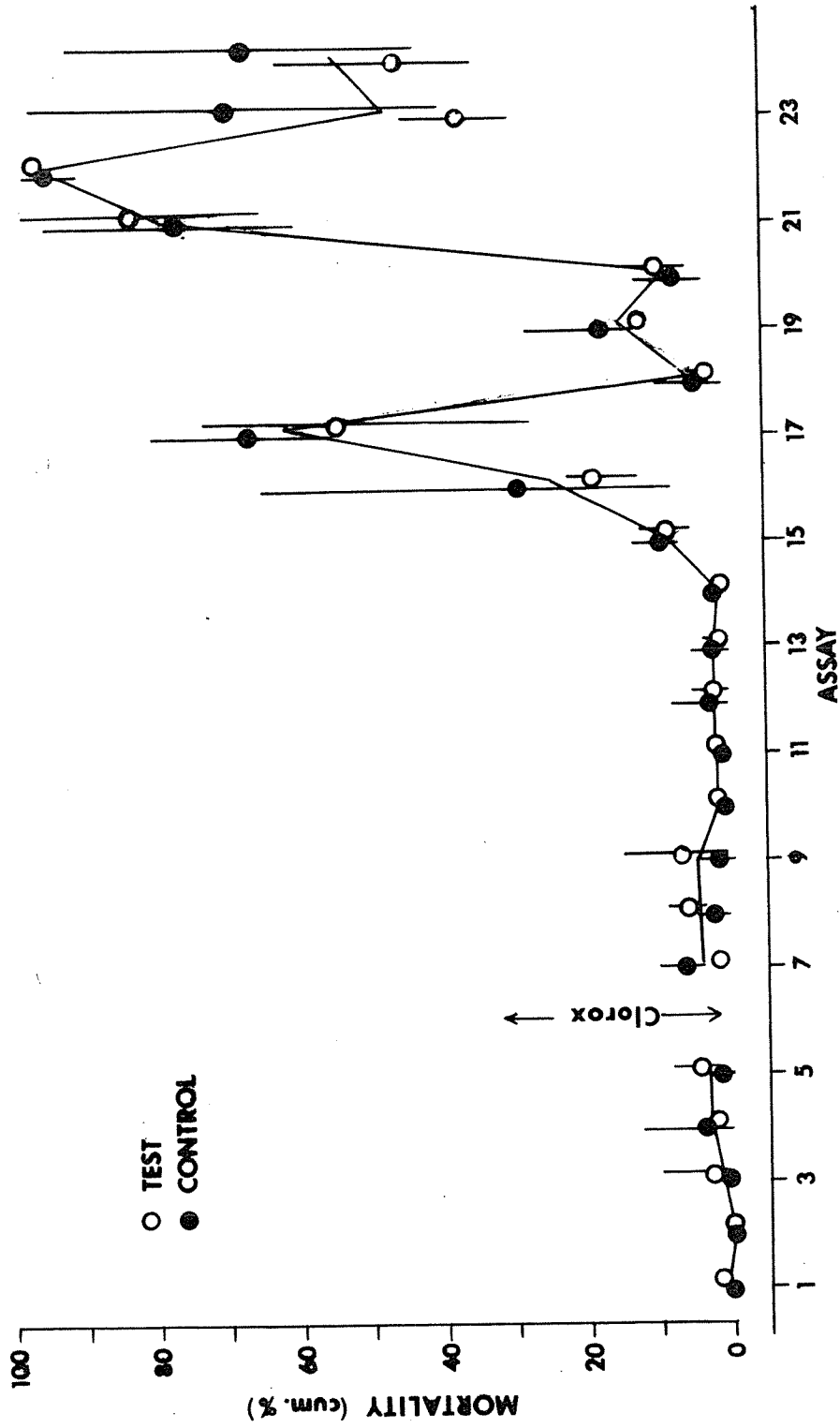


Fig. 6-8. Mortality (7-day): symbols (ϕ) denote weekly mean and range of pooled test or control sample; lines connect pooled test plus control values.

Table 6-5. Comparison of transport time/loading order and 24-hr mortality at live-box stations.

Loading sequence		First	Second	Third
1	Site	1	2	B
	Mortality ²	3.3	2.8	2.8
2	Site	4	3	C
	Mortality	3.8	2.5	2.5
3	Site		A ³	
	Mortality		(9.0) ⁴	

¹Duration approximately one hr.

²24-hr average over assays 1-24, as percent of initial fish loaded.

³Only stationed loaded; transport time approximately 3/4 hr.

⁴Based on only 12 assays (1, 7-9, 17-24).

controls and 2 at test sites) and the time interval during which fish at each site were disturbed. Any cumulative effect of this handling time difference would be expressed in weekly mortality rates. These rates did not differ significantly between test and controls (Fig. 6-8).

The inspection procedure--raising the boxes to the surface, removing the netting and observing the fish--may have affected survival, but was identical at all sites and could not be quantified.

6.3.2.2 Fish Source--Initial Health

With the exception of bioassay 9, test fish used in bioassays 1-14 came from Big Beef Creek Hatchery and spawning channel. Mean fork length ranged from 41 to 52 mm and mean weight ranged from 0.38 to 0.83 g. Local fish used in bioassay 9 averaged 42 mm length and 0.42 g weight (Table 6-6).

Fish health was measured by the external signs of disease and by condition factor ($\text{weight}/[\text{length}]^3$). While no fish from bioassays 1 through 14 showed disease signs, condition factor did vary (Fig. 6-9) from a mean of 0.569 (bioassay 7) to 0.710 (bioassay 12). Condition factor variability did not affect mortality during this period--mortality rates averaged only 2% per bioassay among test and control sites combined ("pooled")--but became important in subsequent bioassays.

6.3.2.3 Disease

In bioassay 15 (May 9-15) mortality rose to 9% among pooled sites (Fig. 6-8). This sudden change was associated with decreasing condition factor (Fig. 6-9). Mortality continued to increase, averaging 24% in bioassay 16 and 62% in bioassay 17, as the condition factor of Big Beef Creek channel test fish declined from a mean of 0.710 (bioassay 12) to a mean of 0.609 (bioassay 17). Test fish in bioassays 16 and 17 also had eroded caudal fins and discoloration of skin, the first incidence of disease signs. Mortality decreased sharply to 3% when Hoodspout Hatchery fish were tested in the following bioassay (18). These fish had an average condition factor of 0.682 (length = 54 mm, weight = 1.09 g) (Fig. 6-9) and they showed no external abnormalities. While these data suggest an inverse relationship between condition factor and mortality, the correlation was not statistically significant ($r = 0.69$, $p > .05$; Sokal and Rohlf 1969).

In bioassays 19 and 20 local fish losses measured 16 and 8%, respectively. This mortality increase was associated with the onset of vibriosis in live-box fish. In the next four bioassays (21-24), Vibrio anguillarum were isolated from fish in each bioassay in rough

Table 6-6. Live-box bioassay dates: Fish source, length, and weight.

Assay	Date	Fish source ¹	Length (mm)		Weight (g)	
			Mean	Range	Mean	Range
1	1/31-2/6	BBCH	45.0	40-48		
2	2/7-2/13	BBCH	47.4	40-51		
3	2/14-2/20	BBCH	51.8	48-59		
4	2/21-2/27	BBCH	47.15	41-54	0.720	
5	2/28-3/6	BBCH	49.55	45-54	0.832	
6	3/7-3/13	BBCC	41.77	39-45	0.432	}2
7	3/14-3/20	BBCC	40.95	37-48	0.391	
8	3/21-3/27	BBCC	40.72	37-46	0.385	
9	3/28-4/3	Local	41.55	37.5-49	0.423	0.310-0.708
10	4/4-4/10	BBCC	42.66	37.5-49	0.481	0.287-0.740
11	4/11-4/17	BBCC	43.73	39-49.5	0.574	0.342-0.889
12	4/18-4/24	BBCC	46.53	39-57	0.746	0.354-1.398
13	4/25-5/1	BBCC	42.97	40-47.5	0.546	0.421-0.747
14	5/2-5/8	BBCC	42.28	36-46	0.497	0.215-0.647
15	5/9-5/15	BBCC	40.68	36.5-51	0.425	0.238-0.817
16	5/16-5/22	BBCC	44.05	38-65.5	0.582	0.324-2.020
17	5/23-5/29	BBCC	42.44	38-58	0.485	0.305-1.230
18	5/30-6/5	Hoodsport Hatch.	54.17	46-59.5	1.085	0.696-1.403
19	6/6-6/12	Local	71.36	49-88	2.660	0.729-5.075
20	6/13-6/19	Local	70.55	44.5-89	2.697	0.560-5.199
21	6/20-6/26	Hoodsport Hatch.	62.58	58-68.5	1.786	1.412-2.256
22	6/27-7/3	Quilcene R. Hatch	62.74	51.5-71.5	1.818	0.956-2.650
23	7/4-7/10	Quilcene R. Hatch.	62.01	53-71	1.688	0.969-2.742
24	7/11-7/17	Hoodsport Hatch.	47.97	34.5-56	0.840	0.297-1.254

¹BBCH: Big Beef Creek hatchery.

BBCC: Big Beef Creek local.

²Group weights.

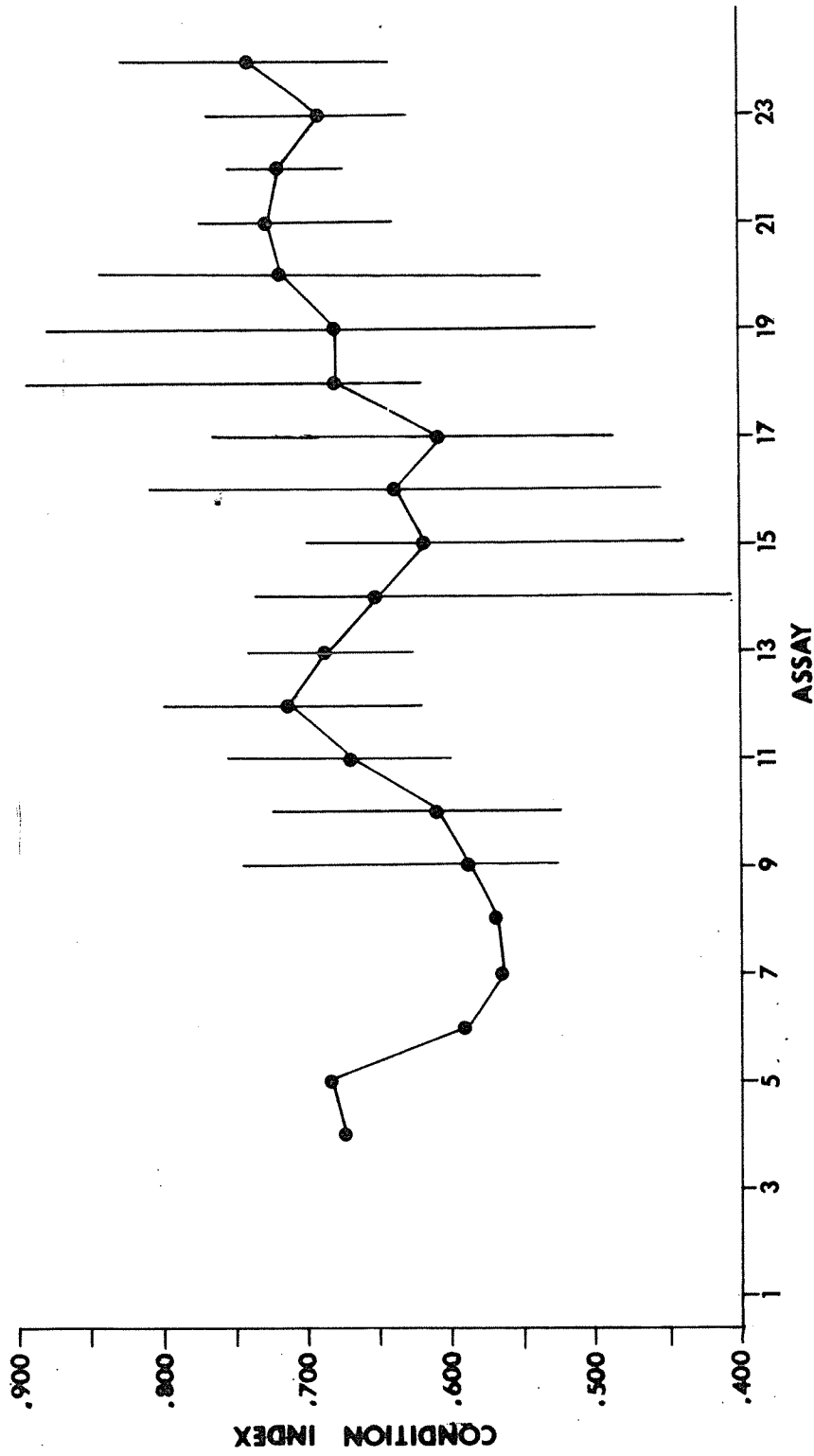


Fig. 6-9. Condition index (W/L³) of test fish: symbols (φ) denote weekly mean and range; means connected for clarity; assays 1-4: data not taken; 4-8: based on group weight, mean length; 9-24: mean weight and length.

proportion¹ to bioassay mortality (Table 6-7). As mortality rose to 79% in bioassay 21 and 96% in bioassay 22, Vibrio were confirmed in 100% (21) and 92% (22) of fish examined. Mortality dropped to 51% (23) and 55% (24) as confirmed Vibrio decreased to 16% and 38%, respectively.

Similar proportions of Vibrio detected in test (49%) and control (58%) fish sampled during this period (Table 6-7) suggest that factors affecting disease were not related to suspended sediments.

6.3.3 Conclusions

Dredging did not affect mortality of test fish. Decline in condition factor and increase in disease were associated with rising mortality, but correlations were not statistically significant. Handling did not measurably contribute to mortality.

6.4 SUMMARY

1) A series of 24 7-day live-box bioassays was conducted between January 31 and July 17, 1977, to determine the effects of suspended sediments from dredging on juvenile chum salmon (Oncorhynchus keta) migrating in Hood Canal, Washington.

2) Live-boxes were located at test sites in areas affected by the dredge plume and at control sites in areas isolated from the dredge plume.

3) Water temperature, DO, salinity, pH, and TNFR were measured daily at a 2-m depth at all stations. Mean temperature increased from 7°C in January to 15°C in July. Dissolved oxygen levels (7-14 mg/liter) remained at or above saturation. Salinities varied between 24 and 32 ppt and pH varied from 7.7 to 8.4. Suspended sediment (TNFR) concentrations at test stations (average, 9.4 mg/liter; range, 4 to 94 mg/liter) consistently ($p < .001$) exceeded control (average, 7.3 mg/liter; range, 4-16 mg/liter).

4) Mortalities at test stations did not differ significantly from control. TNFR did differ significantly ($p < .001$), but did not affect mortality. From January 31 to May 8, 1977 (bioassays 1-14), mortality averaged 2% per bioassay. Mortality began increasing with bioassay 15 (May 9-15, 1977) and was apparently associated with decreasing condition factor of test fish. In the remaining bioassays (May 16 to July 17, 1977) mortality rates correlated with incidence of Vibrio in test fish.

¹Not statistically significant ($r = 0.91$, $p > .05$; Sokal and Rohlf 1969).

Table 6-7. Comparison of *Vibrio* incidence with live-box mortality.

Assay	Initial	Final ¹		Confirmed <i>Vibrio</i> isolates (percent)	Mortality ² (percent)
		Test	Control		
19			1/1 ³	100	16.3
20 ⁴					8.3
21	12 ⁵	15/15	15/15	100	79.0
22		18/16	7/7	92	95.5
23		21/3	23/4	16	50.7
24		21/3	31/17	38	54.9
	Total	75/37	77/44		
	Confirmed <i>Vibrio</i>	49%	58%		

¹Includes fish sampled during assay.

²Pooled test and control.

³Number of fish streaked/number confirmed *Vibrio anguillarum* isolates.

⁴Samples destroyed by incubator tampering.

⁵No record of number of fish streaked.

6.5 ACKNOWLEDGMENTS

Special thanks are extended to Charles Threinen and Joseph Bentley for their valuable assistance with this study.

7.0 AVOIDANCE-BEHAVIOR BIOASSAY

by
Robert A. Campbell

7.1 INTRODUCTION

Turbidity is a stimulus capable of inducing changes in behavior in fish. Avoidance of suspended sediments may be caused by physical irritation to sensory and respiratory organs. The degree of irritation is dependent on sediment concentration, particle size, shape, and hardness. Indirectly, displacement and suspension of bottom sediments may increase levels of ionic metals and decomposition waste products in the water column. Prolonged turbidity may decrease the euphotic layer, resulting in reduced primary productivity and decreased DO concentrations.

The purpose of this study was to evaluate avoidance-behavior of outmigrating juvenile chum salmon (Oncorhynchus keta) encountering dredge-created suspended sediments in laboratory and field situations. Laboratory bioassays were conducted to define the concentration of suspended sediments that induces threshold avoidance. Field surveys were conducted in the area affected by dredging turbidity to assess in situ avoidance.

7.2 LITERATURE REVIEW

Previous field observations on avoidance were generally made on adult fish, whereas juveniles or small species were used in laboratory tests. Except for experiments reported by Martin, Salo, and Snyder (1977), applicable avoidance studies have not been conducted with juvenile chum salmon.

7.2.1 Field

Field observations of adult salmonids passing through high concentrations of suspended sediments have been cited (Gibson 1933; Ward 1938; Smith and Saunders 1958);¹ however, when given a choice, adult chinook salmon selected clear water for migration (Sumner and Smith 1939).² Migration through a fish ladder by barbel (Barbus fluviatilis) decreased with increased turbidity (Hofbauer 1962).³ Moore (1932)⁴ observed immediate avoidance by minnows to a turbid

¹Cited in European Inland Fish. Advis. Comm. (1965).

²Cited in European Inland Fish. Advis. Comm. (1965).

³Cited in European Inland Fish. Advis. Comm. (1965).

⁴Cited in European Inland Fish. Advis. Comm. (1965).

stream section. Disrupted migration in a copper-zinc polluted river was cited by Sprague, Elson, and Saunders (1965). Collins (1952) determined that migrating anadromous fish would avoid waters with reduced DO concentrations.

7.2.2 Laboratory

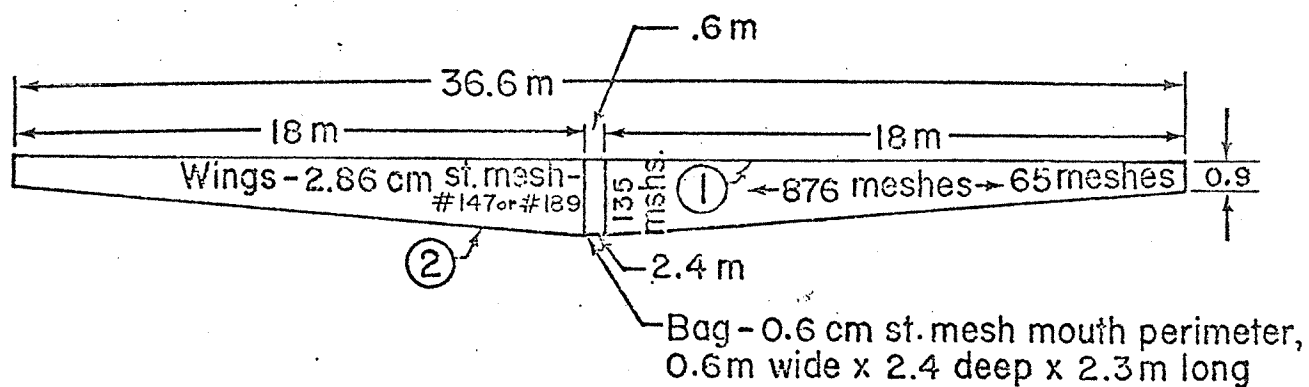
Pertinent laboratory experiments on avoidance of suspended sediments have been reported by Martin et al. (1977) for juvenile chum salmon and by Mizunuma (in Ishio 1965) for "ko-ayo" (Plecoglossus altivelis). Sprague et al. (1965) researched avoidance by juvenile Atlantic salmon (Salmo salar) to ionic forms of copper and zinc. Reactions to ammonia and hydrogen sulfide have been discussed by Ishio (1965) for minnows (Moroco steindachneri), carp (Cyprinus carpio), goldfish (Carassius auratus), bitterling (Acheilognathus limbata), and dace (Tribolodon hakonensis). Avoidance by juvenile chinook and coho salmon (Oncorhynchus tshawytscha, O. kisutch) to low DO concentrations was established by Whitmore, Warren, and Doudoroff (1960).

7.3 MATERIALS AND METHODS

7.3.1 Field

Weekly field surveys were conducted from March 16 to July 20, 1977. Generally, three tides were surveyed per day, starting 1 hr after slack tide. The dredge area was sampled during each survey with simultaneous beach seine (Fig. 7-1) sets and townet (Fig. 7-2) transects for catch-per-unit-of-effort (CPUE). The CPUE is defined as the number of chum salmon caught during a single beach seine set or townet transect and is distinct for the three capture techniques: 1) beach seine; 2) 10-min townet transect; and 3) 5-min townet transect. Nearshore CPUE and water quality data were obtained at six beach seine sites between Carlson and Floral points. Offshore areas between Carlson and Floral points were sampled by means of a series of 10-min transects conducted parallel to the shoreline. The offshore areas immediately north (Marginal Wharf area) and south (Devil's Hole area) of the dredge site were both sampled with three consecutive 5-min townet transects (Fig. 7-3). Townet transects were conducted in the direction of tidal flow; i.e., north to south during flood, south to north during ebb. To provide simultaneous nearshore data, beach seining was initiated at Floral Point during flood tide and Carlson Point during ebb tide. Methods of deployment for the townet and beach seine were described by Schreiner (1977).

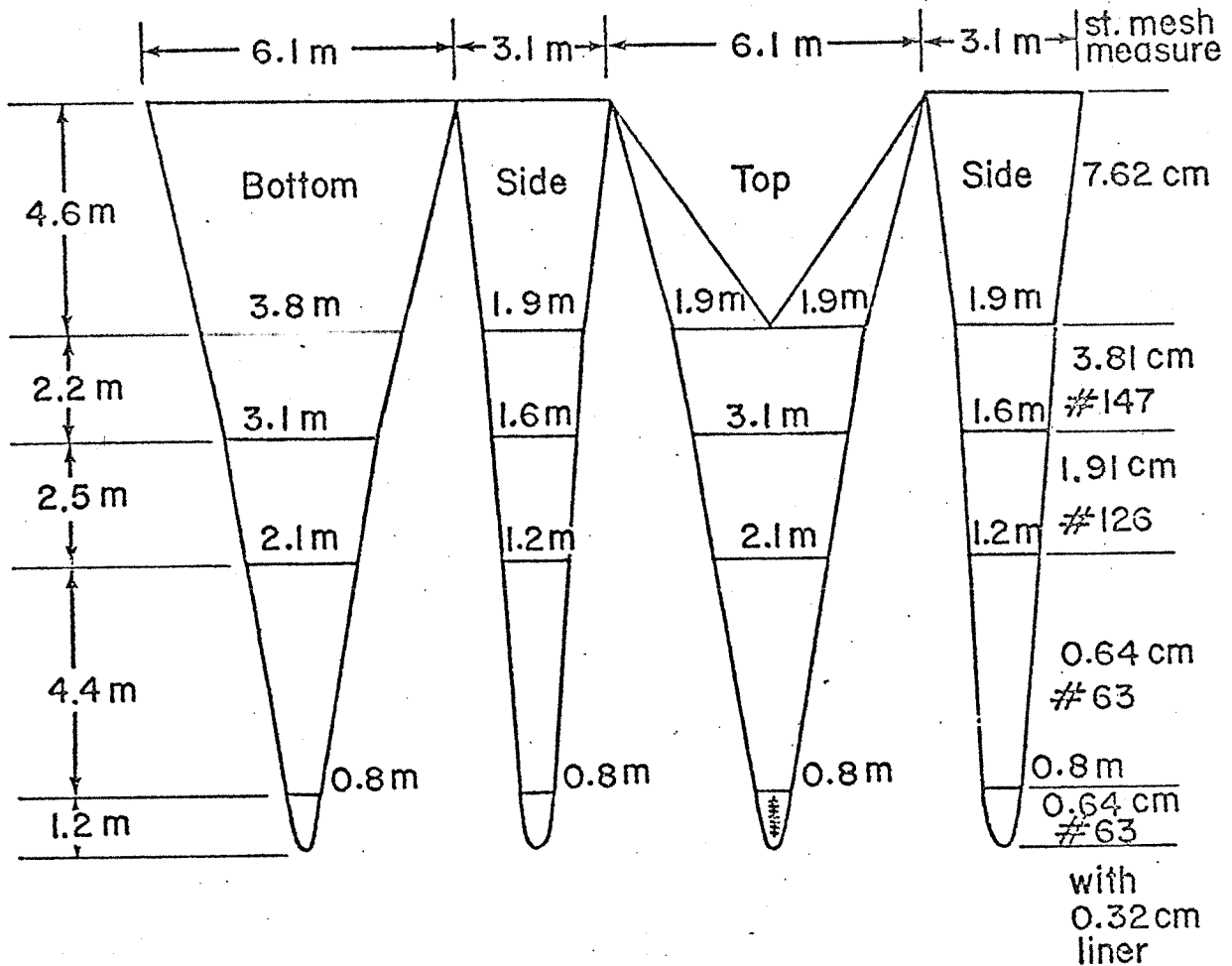
The CPUE in test and control situations was defined as the CPUE in the presence or absence of the plume (as described in Section 3.3). The CPUE for a station was determined in the absence of the plume and then compared to the catch when the plume was present. Samples were then classified as test or control, depending on the presence or



- ① 3.8 cm x 6.4 cm float every 6th hanging; convert to floating seine with seven 12.7 x 27.9 cm "T" floats.
- ② 113.4 g lead every 2nd hanging.

Fig. 7-1. Beach seine utilized during near-shore field avoidance surveys.

Surface Trawl - 6.1 m x 3.1 m mouth
15 m long



All seams are of 3.81 cm and smaller mesh reinforced with heavy 2.54 cm nylon tape including center lines of bottom and top panels; rib-lines of 0.95 cm diameter polypropylene on four corner seams full length. Mouth of net is double twine and hung on 0.35 cm polypropylene single braid with mimbles at each corner. A 0.9 m nylon coil zipper is in the cod end and on liner in the top panel. Six 4-oz leads are spaced evenly along the foot line. 5.08 cm rings are sewn on top panel at 1.91 cm - 0.64 cm seam.

Fig. 7-2. Surface townet used during offshore field avoidance surveys.

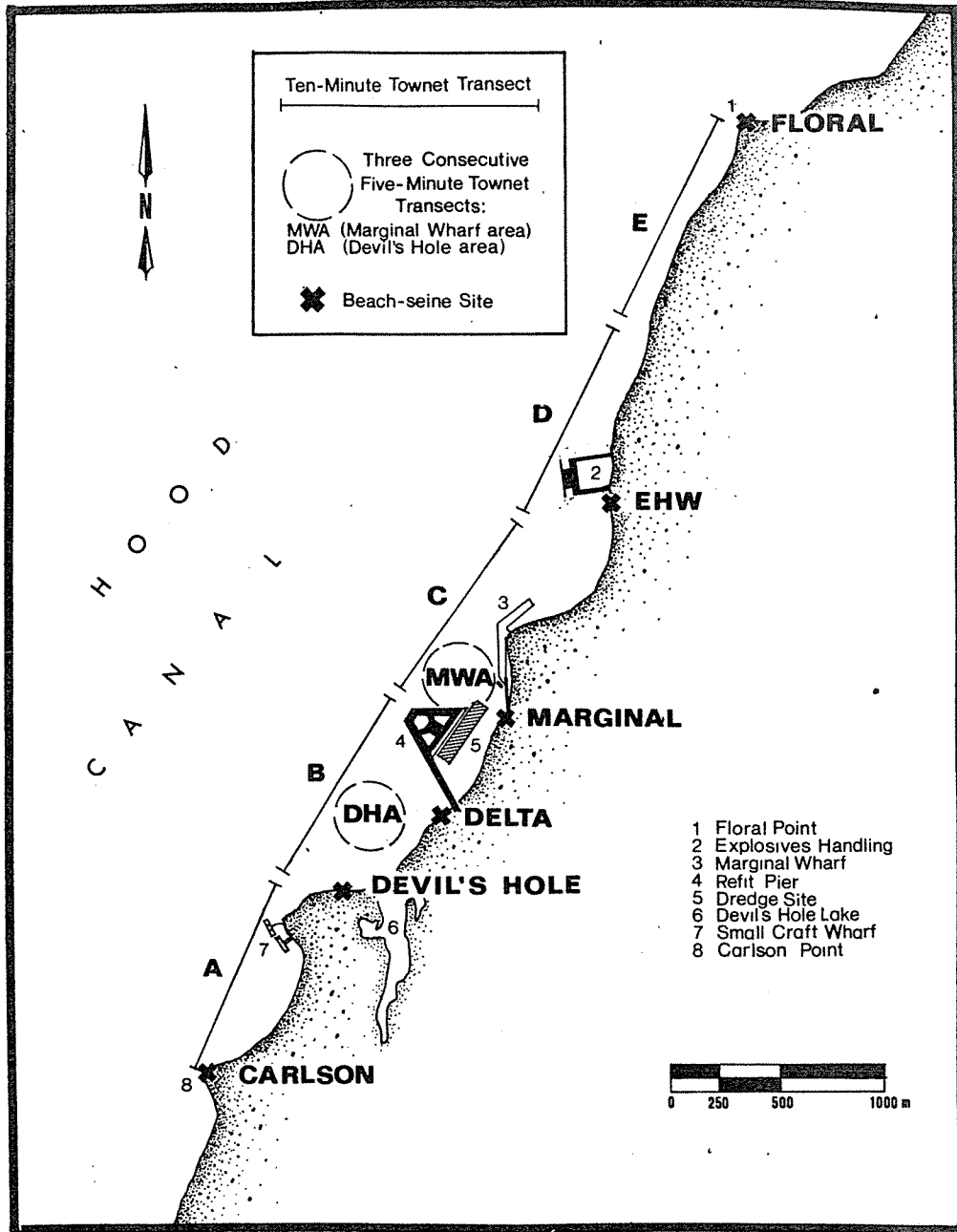


Fig. 7-3. Location of beach-seine sites and townet transects during field avoidance surveys.

absence of the plume. A Martek (TM) transmissometer verified the location of the plume offshore; the transmissometer probe was towed approximately 1 m below surface from the bow of the townet boat R/V TENAS. Verification of the plume at beach seine sites also depended on offshore transmissometer readings since the nearshore total nonfilterable residue (TNFR) samples could not distinguish dredging turbidity from beach erosion and runoff turbidity. For example, a nearshore sample was classified as test if offshore transmissometer readings indicated the plume extended toward the beach seine site.

7.3.1.1 Fish

Chum salmon from each townet transect and beach seine set were sorted from other species caught (see Schreiner 1977), counted (CPUE), and a maximum of 100 were placed in plastic jars filled with ambient water, labeled, and stored on ice until measured. Individual fork lengths were recorded to the nearest mm, generally within 24 hr of capture.

CPUE regression analysis was computed using BMD 02R computer program (Dixon 1970).

7.3.1.2 Environmental Variables

Parameters recorded during townet operations were: 1) temperature; 2) salinity; 3) conductivity; 4) TNFR; and 5) percent transmission. Temperature, salinity, and conductivity were measured at the end of each transect from a 1-2 m depth, by a KAHL SICO Model RS5-3 salinometer. Water was sampled with a Van Dorn bottle from 1-2 m below surface, approximately halfway along the transect for TNFR determination. TNFR samples were taken for all 5-min transects and one of the 10-min transects. Percent transmission values were recorded from the Martek transmissometer every 30 sec for the duration of each transect. These values were used to determine the percent of time spent in the plume.

Parameters measured at each beach seine site, 10-15 m from shore at a 1-1.5 m depth, were: 1) temperature; 2) DO; and 3) TNFR. Temperature and DO were measured with a YSI Model 54 oxygen meter.

Tide height was determined from a tide-graph calendar.

7.3.2 Laboratory

7.3.2.1 Apparatus

The test chamber (Figs. 7-4 and 7-5) was the same as that described by Martin et al. 1977, except nylon screens (0.6-cm mesh) were placed 46 cm from each end of the chamber to reduce rheotaxis and illumination was by two 40-W Dura-Test Vita-Lites (TM). Continuous

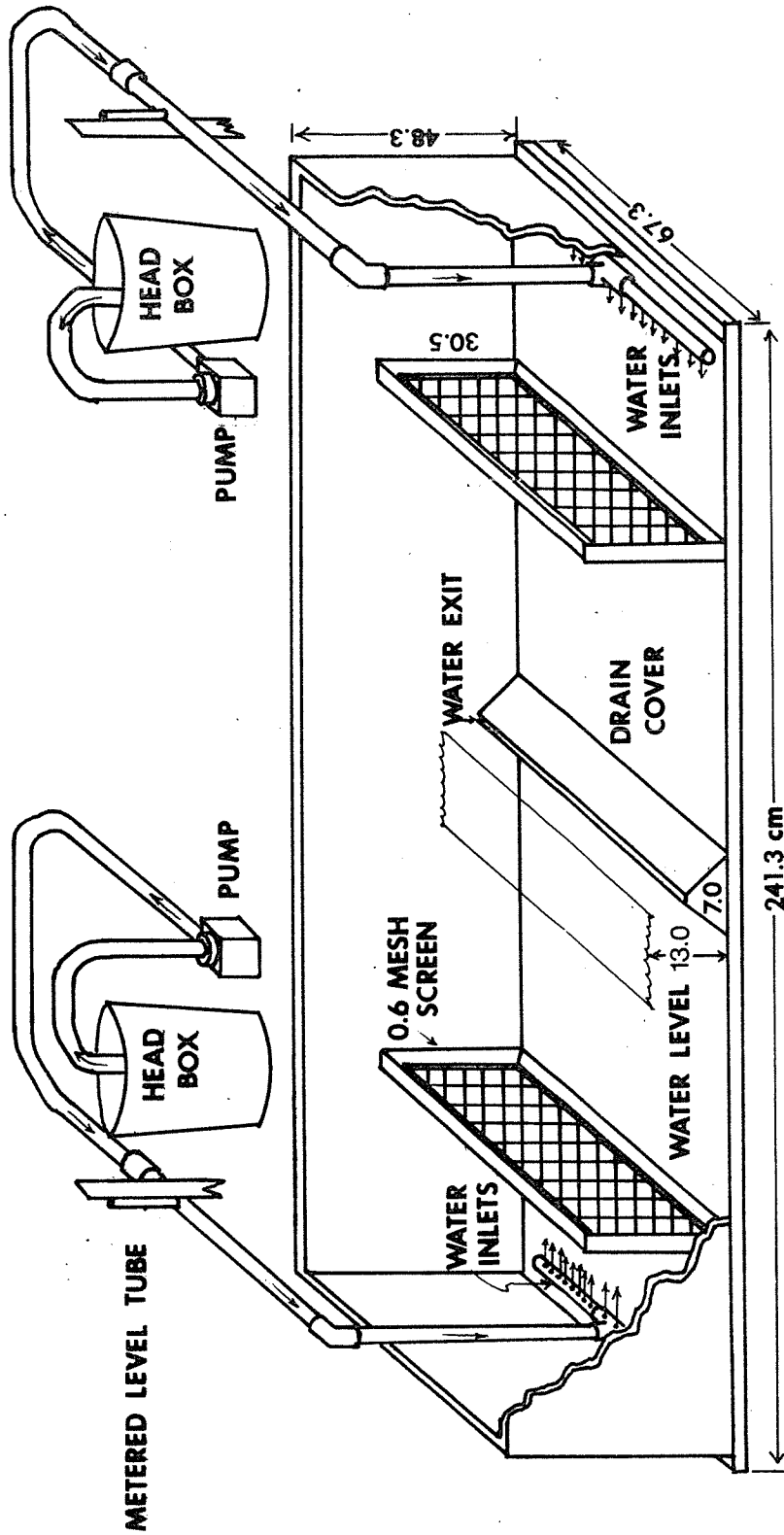


Fig. 7-4. Test chamber used during laboratory avoidance-behavior experiments. Water was delivered from head boxes to each end of the test chamber and exited through the center drain cover.

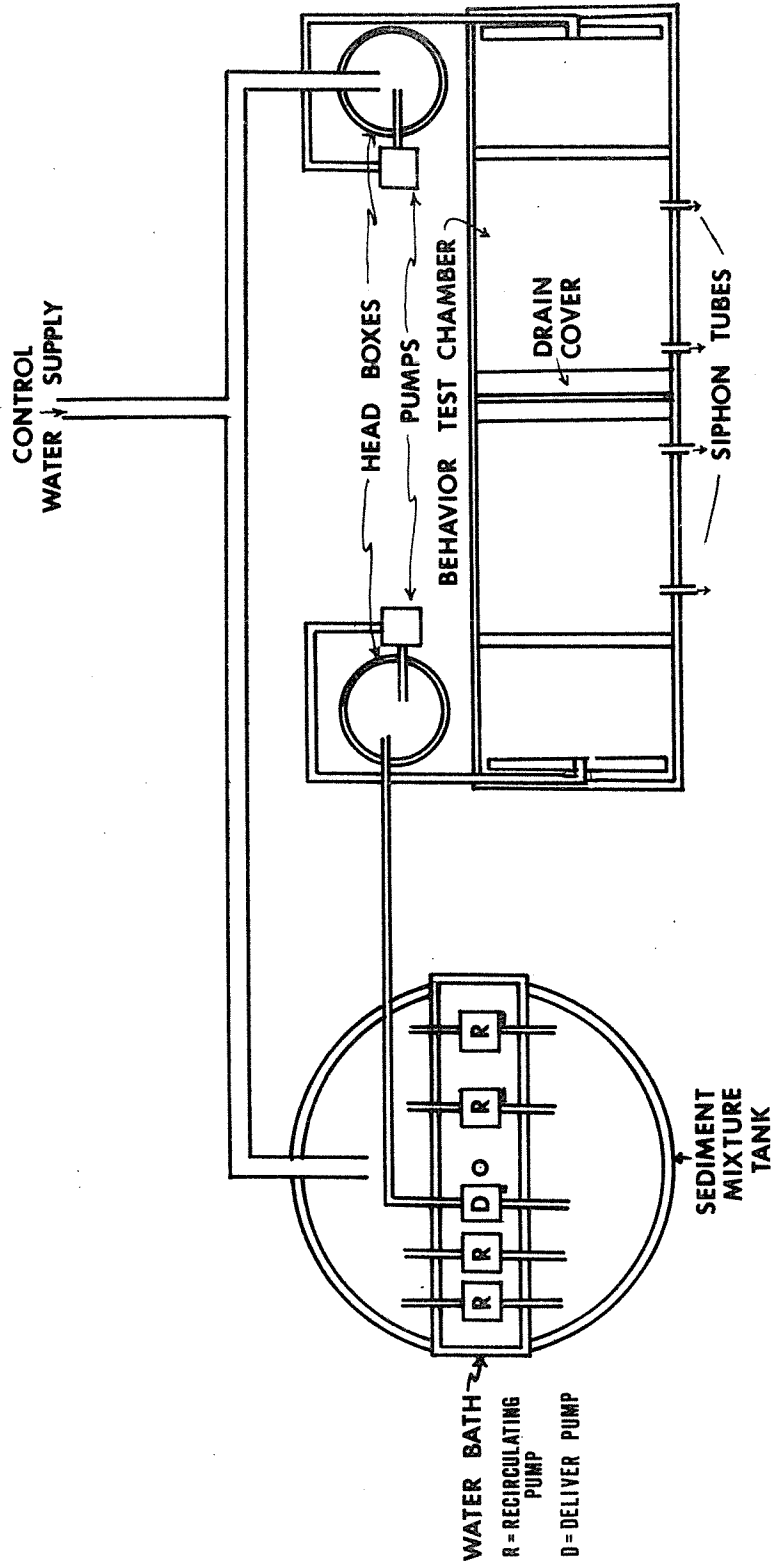


Fig. 7-5. Schematic plumbing diagram for laboratory avoidance-behavior experiments showing control water supply, sediment-mixture tank, and test chamber.

supplies of control water were delivered to both ends of the test chamber from head boxes and discharged through the center drain. Flow rates, regulated by metered level tubes (Fig. 7-6), were equal during any one test but varied from 11.7-13.4 liters/min among tests. A constant water depth (13 cm) was maintained in the test chamber by adjusting the size of the drain openings (Fig. 7-7) and test fish moved freely over the drain cover (7 cm high). When sediments were added to the water in the sediment mixture tank (Figs. 7-5 and 7-8), the test chamber offered fish a choice between clear and turbid water.

7.3.2.2 Procedure

- 1) Ten laboratory-acclimated fish were placed in the test chamber, containing clear water in both halves, and allowed 10-60 min to become accustomed to the chamber. Fish were considered accustomed to the surroundings when they exhibited exploratory behavior, i.e., consistently moving about the chamber as a school.
- 2) Fish were observed for a 15-min period and the number of fish present in one-half of the chamber (side B) was recorded every 10 sec.
- 3) A predetermined amount of sediment was added to the sediment mixture tank and its supply of control water was shut off. A minimum of 6 min was necessary to replace clear with turbid water in one-half of the test chamber (side A); meanwhile, the other half (side B) was still receiving a continuous supply of control water. Once replacement was complete, siphoning tubes were activated for TNFR samples.
- 4) Fish were observed for another 15-min period, and the number of fish present in the clear water half (side B) was recorded at 10 sec intervals.

The percent of time spent in side B was calculated by converting the sum of fish recorded to a percentage of 900 (90 observations x 10 fish). Chi-square analysis of control and test observations determined the significance of avoidance or preference. After a series of tests was made for several sediment concentrations, the net percentage of significant avoidance was calculated as the number of tests showing significant avoidance minus the number of tests showing significant preference, divided by the total number of tests at that concentration and multiplied by 100.

7.3.2.3 Sediments

Bottom sediments were collected directly from the dredge area, wet-sieved through a 105- μ m screen, sealed in 20-liter plastic buckets and stored in an ambient temperature water bath. Two types of sediment were used: 1) overburden, collected by divers; and 2) glacial till, collected directly from scows being filled with sediments dredged below the overburden layer. The concentrations of H₂S, NH₃, and ionic metals associated with the sediments were analyzed (methods described in Section 4.0) to determine if these chemicals might influence avoidance.

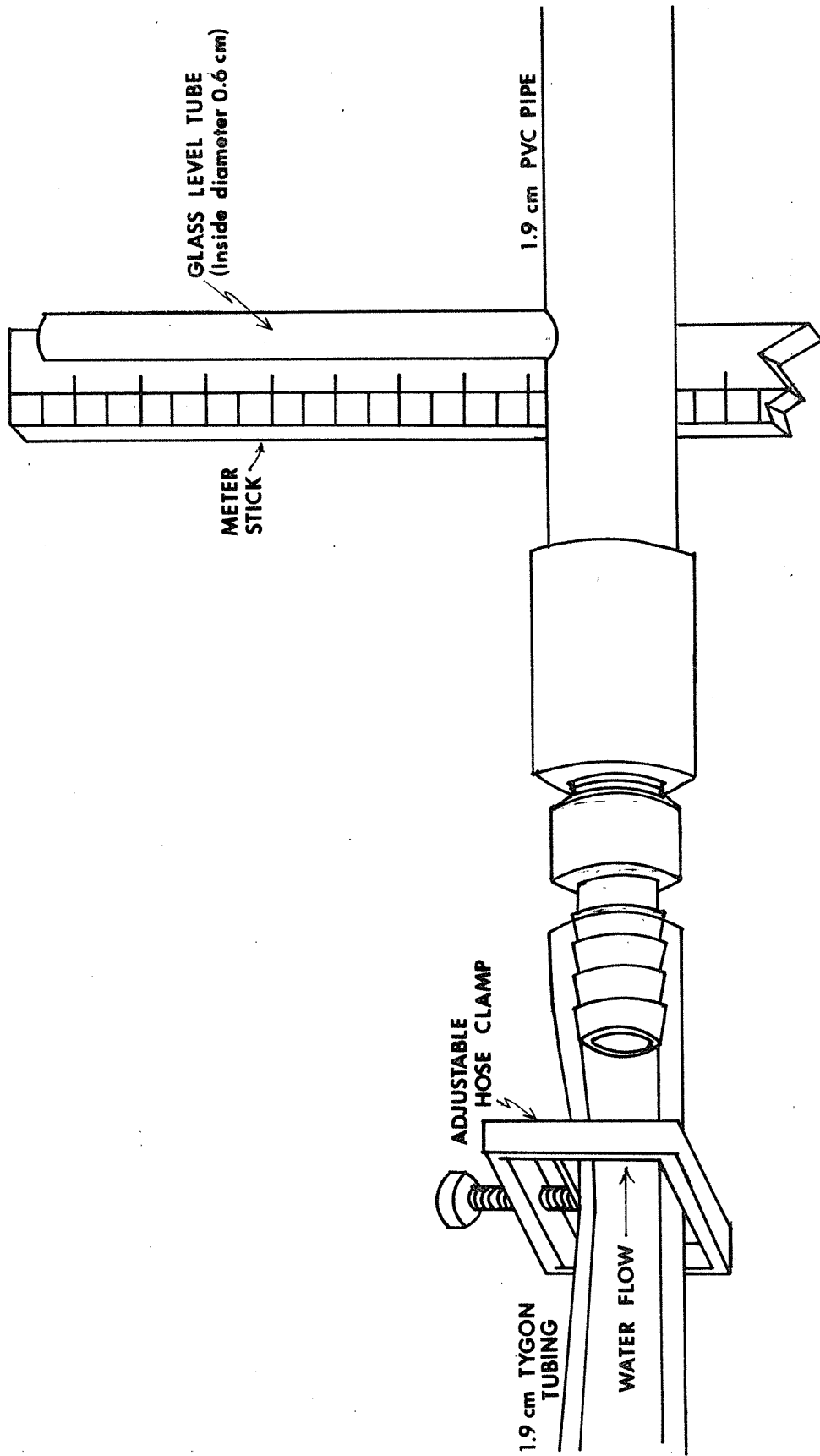


Fig. 7-6. Metered level tubes used to deliver equal flows of water from the head boxes to the test chamber.

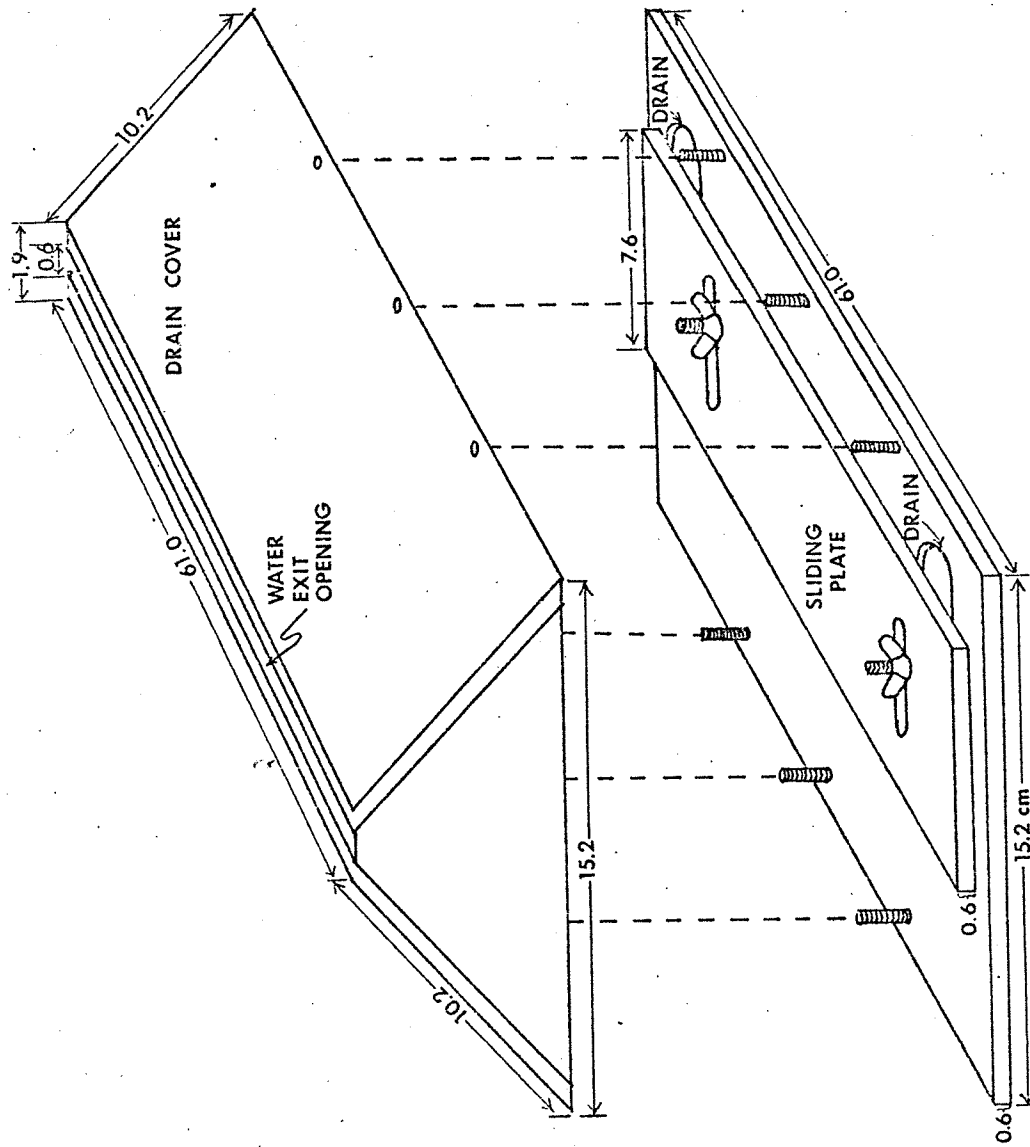


Fig. 7-7. The adjustable drain system used in the test chamber. The drain cover was open at the apex and separated the two halves of water in the test chamber; the draining rate was adjusted by sliding the plate over the drain openings.

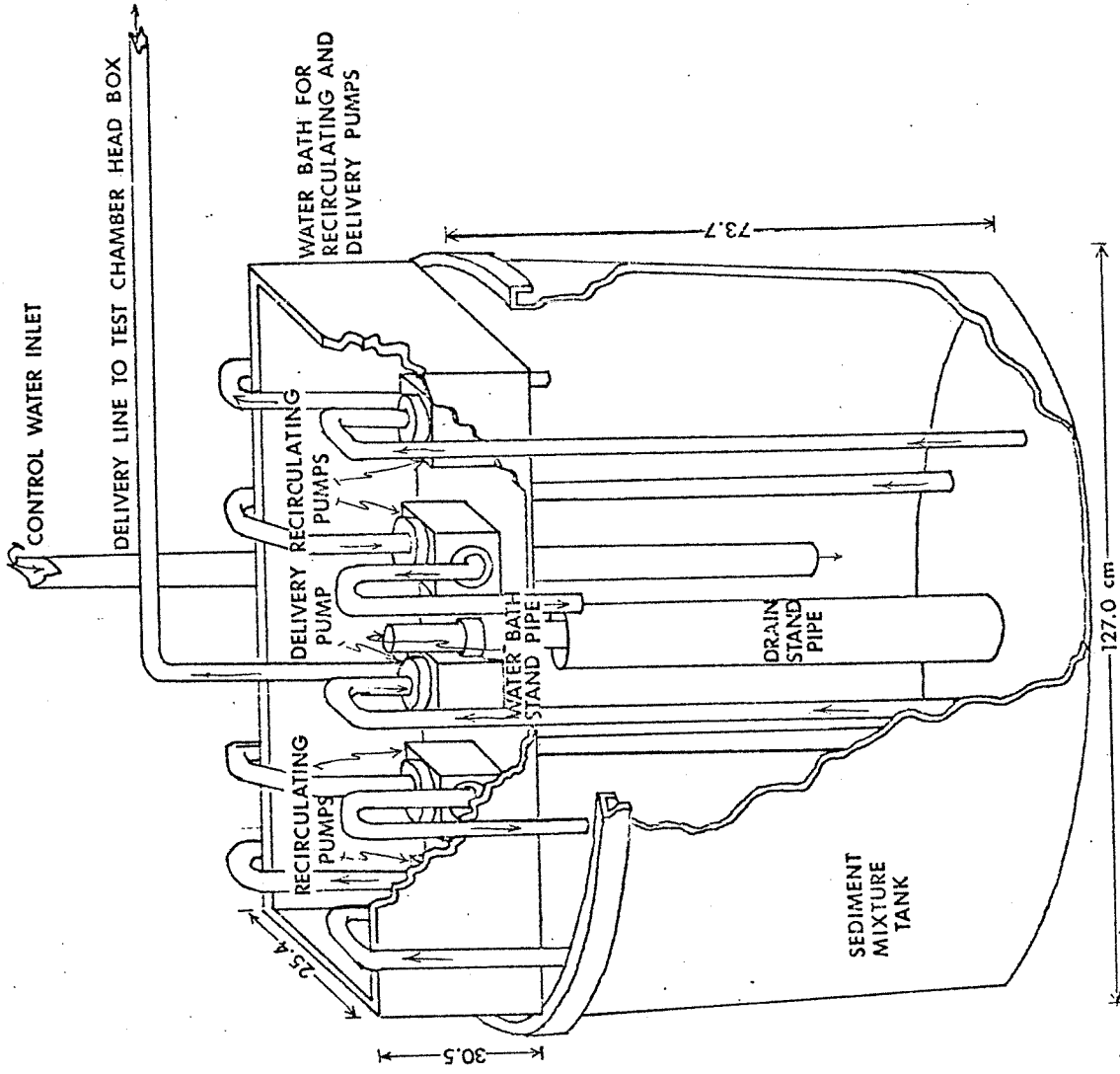


Fig. 7-8. Sediment-mixture tank for laboratory avoidance-behavior experiments. Sediment was added to control water in the mixture tank; recirculating pumps were used to maintain the sediments in suspension and the delivery pump supplied water to one of the test chamber's head boxes.

7.3.2.4 Water Quality

Water quality parameters, except TNFR, were sampled from turbid and control water at the completion of each test. Temperature was taken with a hand-held thermometer. Salinity and conductivity were recorded with a calibrated KAHLSCO Model RS5-3 salinometer. DO was monitored by a YSI Model 54 oxygen meter, calibrated by the azide corrected Winkler method (APHA, AWWA, and WPCF 1976). Four TNFR samples were siphoned during each test from 7 cm below surface. Siphoning tubes were located along the wall of the test chamber at 14 and 62 cm from center (Fig. 7-5).

7.3.2.5 Test Fish

Two sources of fish were used: 1) Big Beef Creek spawning channel; and 2) local. Fish were held in floating pens for 5-12 days and fed Oregon Moist Pellets daily, then acclimated unfed in the laboratory for 2 days prior to testing. Immediately after each test, fish were anesthetized with MS-222 for length and weight determination. Fork length was recorded to the nearest mm; wet weight, blotted dry, was determined using a Mettler 1200 top-loading balance, accurate to 0.01 g.

7.4 RESULTS AND DISCUSSION

7.4.1 Field

7.4.1.1 Plume Description

Aerial surveillance during overburden dredging showed turbidity extending south past Carlson Point, approximately 1.5 km from the dredge site (flood slack tide); north past Explosives Handling Wharf (EHW), approximately 1.1 km from the dredge site (ebb slack tide); and west approximately 0.5 km. However, during dredging of the glacial till the plume was less extensive. The composition of this layer caused frequent cessations of dredging and the plume was rarely observed as far south as Carlson Point or north to EHW. During June, the peak period of chum migration (Table 7-1), the plume was generally contained between Marginal Wharf and the Small Craft Wharf. In this period the settling of sediments resulted in a rapidly decreasing turbidity with distance from the dredge.

During field surveys of avoidance TNFR samples taken offshore in the plume ranged from 7.0 to 30.5 mg/liter; control values ranged from 5.4 to 16.9 mg/liter (Table 7-2). During the first week of May and the fourth week of June, no TNFR samples were taken. During the 19 weeks of sampling, the plume was present in only 7 of them.

Table 7-1. Weekly mean chum salmon CPUE for separate capture techniques.

Date	Month	Week number	CPUE - weekly mean		
			Beach seine	Townet	
			10 min	5 min	
March		3	46.9	4.4	6.3
		4	3.5	7.6	0.2
		5	31.7	7.7	0.9
April		1	32.3	6.1	0.7
		2	18.5	2.3	0.7
		3	2.3	41.2	2.0
		4	206.4	49.9	27.4
May		1	39.8	21.5	3.5
		2	45.1	2.1	3.7
		3	47.8	0.2	0.4
		4	121.5	28.8	7.7
June		1	82.4	64.1	68.8
		2	97.2	181.5	34.6
		3	93.7	195.0	28.6
		4	-	-	-
		5	44.6	73.1	32.8
July		1	26.5	30.3	11.7
		2	2.3	27.7	7.9
		3	9.8	3.2	1.4

Table 7-2. Weekly range of control and plume TNFR values taken offshore during 5-min townet transects.

Month	Date		TNFR - weekly range (mg/liter)	
	Week number		Control	Plume
March	3		6.3-9.4	b
	4		6.5-10.5	b
	5		6.9-13.0	12.3-12.5
April	1		9.3-16.9	b
	2		7.8-13.4	b
	3		8.7-13.7	b
	4		6.3-9.4	9.2
May	1		a	a
	2		6.8-12.9	b
	3		8.3-14.4	b
	4		7.4-12.0	12.1-19.4
June	1		5.4-9.7	9.2-13.8
	2		5.7-10.0	7.9-11.7
	3		6.8-10.4	11.1-15.5
	4		a	a
	5		7.0-9.6	7.0-30.5
July	1		6.5-10.4	b
	2		6.0-9.4	b
	3		6.0-13.1	b

^a no sample taken.

^b no transects in plume.

Other water quality variables associated with suspended sediments that may induce avoidance include reduced DO and increased concentrations of NH_3 , H_2S , and ionic metals. However, data recorded during the Live-box Study (Section 6.0) showed no relationship between DO values ranging from 7.6 to 10.0 mg/liter and TNFR samples ranging from 6.0 to 82.1 mg/liter (Table 7-3). The concentration of NH_3 , H_2S , and ionic metals present at a TNFR value of 30.5 mg/liter was below laboratory threshold avoidance levels for salmon parr (Sprague et al. 1965) or maximum concentrations for marine waters (Table 7-4) recommended by EPA (1976).

7.4.1.2 Seasonal Trends

Chum salmon CPUE and fork length, water temperature, DO, salinity and conductivity data were investigated for seasonal trends. Weekly beach seine, 5-min, and 10-min townet transect data are presented in Tables 7-5, 7-6, and 7-7, respectively. There were two peaks in CPUE (Fig. 7-9): one comprised primarily of beach seine fish occurred at the end of April; and the second extended from late May to early July, and was comprised primarily of fish caught during 10-min townet transects. Apparently, there was an offshore progression during the season. The chum populations sampled increased in size (Fig. 7-10), with the monthly mean length being 3.8 cm (range: 3.2 to 7.1 cm) in March and 7.0 cm (range: 4.8 to 11.0 cm) in July. This was a combination of chums sampled offshore and nearshore. Offshore chums were generally larger than nearshore chums; in July means were 6.5 cm (range: 3.1 to 12.4 cm) for 5-min townet groups and 5.2 cm (range: 3.1 to 10.2 cm), for 10-min townet groups, respectively. Temperature showed a seasonal warming trend (Fig. 7-11); mean monthly temperatures were 8.2°C (range: 7.6° to 9.6°C) in March and 13.7°C (range: 11.5° to 17.0°C) in July for combined offshore and nearshore temperatures. Offshore temperatures averaged less than nearshore; seasonal means were 10.7°C (range: 8.1° to 15.0°C) and 11.6°C (range: 7.9° to 17.0°C), respectively. DO, salinity, and conductivity showed no apparent seasonal trends; values ranged from 7.2 to 15.6 mg/liter, 27.7 to 31.6 ppt, and 29.7 to 34.3 mmhos/cm, respectively.

7.4.1.3 Determination of Avoidance of Chum Salmon

7.4.1.3.1 Beach Seine. Beach seine sites differed in the presence or absence of: piers, construction activity, dredging turbidity, "holes" or relatively deep protected areas, and freshwater influx including runoff turbidity. These variables prevent direct comparison of CPUE among the separate sites. Also, Devil's Hole, Delta, and Marginal were directly exposed to dredging turbidity, while Carlson, EHW, and Floral were not. Therefore, the beach sites were analyzed individually and only those stations exposed to the plume could be used in determining avoidance. Finally, the period from late April to mid-June was selected for analysis since it represented the period when beach seine CPUE was the most consistent.

Table 7-3. Comparison of DO and TNFR levels at Refit Pier live-box station 2 from May 23 to July 8, 1977.

Date	<u>(mg/liter)</u>	<u>TNFR</u> <u>(mg/liter)</u>	Date	<u>D.O.</u> <u>(mg/liter)</u>	<u>TNFR</u> <u>(mg/liter)</u>
May 23	9.4	8.5	June 17	8.8	6.3
24	9.5	10.8	18	8.5	8.6
25	9.0	8.9	20	9.1	14.1
26	9.1	8.4	21	10.2	10.2
27	8.6	8.0	22	9.7	7.8
31	8.3	6.5	23	9.3	7.4
June 1	8.5	9.5	24	8.0	7.3
2	8.6	82.1	25	8.7	8.0
6	8.2	6.7	27	8.7	7.4
7	8.0	6.4	28	9.8	6.1
8	7.6	6.3	29	8.5	6.0
9	9.2	7.6	30	8.2	9.7
10	8.6	6.2	July 1	8.0	15.9
11	8.7	7.3	4	9.0	6.5
13	9.9	7.6	5	8.4	6.7
14	9.8	7.3	6	8.9	7.9
15	9.5	12.0	7	9.1	7.5
16	10.2	12.6	8	9.6	7.6

Table 7-4. Comparison of concentrations of sediment contaminants present at 30.5 mg/liter (highest field avoidance survey TNFR recorded) and D.O. with established threshold avoidance concentrations or recommended criteria.

Parameter	Concentration at TNFR=30.5 mg/liter sediment type		Laboratory ² threshold avoidance level for salmon parr (Sprague et al. 1965) (mg/liter)		LC50 x 0.01 (application factor) for salmonids in marine waters (EPA, 1973) (mg/liter)	
	Overburden (mg/liter)	Glacial flour (mg/liter)	1965 (mg/liter)	24 hr	48 hr	96 hr
<u>Ionic metals</u>						
Cadmium	$<2.0 \times 10^{-6}$	$<6.0 \times 10^{-6}$		3.0×10^{-1}		
Chromium ¹	$<2.5 \times 10^{-5}$	$<7.3 \times 10^{-5}$				6.9×10^{-1}
Copper	1.9×10^{-5}	4.2×10^{-5}	2.4×10^{-3}		3.4×10^{-3}	
Lead	$<1.0 \times 10^{-3}$	$<2.9 \times 10^{-3}$				1.4×10^1
Manganese	3.4×10^{-4}	1.6×10^{-4}			2.5×10^{-1}	
Nickel	3.0×10^{-5}	5.8×10^{-5}	5.4×10^{-2}			
Zinc	1.6×10^{-5}	2.6×10^{-4}	1.3×10^{-2}			
Zinc and copper	3.5×10^{-5}	8.4×10^{-5}				
<u>Decomposition</u>						
Waste Products (maximum recorded)						Recommended maximum concentration for salmonids (EPA 1973)
Total sulfide	$<4.0 \times 10^{-2}$	NA			2.0×10^{-3}	3
Total ammonia	1.4×10^{-2}	NA			2.0×10^{-2}	
Dissolved oxygen (minimum recorded)			4.5	Whitmore et al. 1960		
		7.7				

¹Hexavalent.

²Field threshold estimated to be higher than laboratory (Sprague et al. 1965).

³Criteria for freshwater aquatic life.

Table 7-5. Seasonal beach-seine data for chum salmon based on weekly values.

Date		CPUE	Fork length (cm)		Temperature (°C)		DO (mg/liter)	
Month	Week number	\bar{X}	\bar{X}	Range	\bar{X}	Range	\bar{X}	Range
March	3	62.6	3.6	3.2-4.2	-	-	9.4	8.7-9.7
	4	3.5	4.0	3.9-4.1	8.2	7.9-8.4	8.5	7.7-9.5
	5	30.5	4.0	3.3-6.9	8.9	8.3-9.6	9.5	9.3-9.9
April	1	32.3	3.7	3.1-6.6	9.3	8.7-10.4	9.8	9.8-10.8
	2	18.5	4.1	3.2-4.9	9.5	9.3-9.7	9.7	9.7-10.0
	3	6.2	4.0	3.1-6.0	-	-	-	-
	4	206.4	4.0	3.7-6.0	-	-	-	-
May	1	41.4	4.8	3.4-6.9	-	-	-	-
	2	47.8	5.5	3.3-8.9	10.9	10.5-11.7	8.6	8.3-9.0
	3	52.2	5.2	3.6-9.4	12.0	10.5-13.0	9.5	8.7-10.2
	4	116.1	6.2	3.5-9.0	11.8	11.0-13.2	9.3	8.4-9.9
June	1	87.2	6.1	3.2-8.7	11.7	10.5-13.0	9.7	8.4-12.6
	2	97.2	6.8	3.7-9.0	12.0	11.0-13.2	-	-
	3	102.3	6.6	4.8-9.8	-	-	-	-
	4	-	-	-	-	-	-	-
	5	47.2	6.5	3.8-10.2	13.7	13.0-15.0	-	-
July	1	31.7	6.7	5.0-9.9	14.6	12.5-16.5	10.3	8.6-15.2
	2	2.6	6.5	5.6-7.7	14.2	13.0-14.5	8.2	7.2-9.0
	3	9.8	7.2	5.2-9.6	14.5	11.5-17.0	10.9	8.4-15.6

Table 7-6. Seasonal data for 5-min tow net transects for chum salmon based on weekly values.

Date		CPUE	Fork length (cm)		Temperature (°C)		Salinity (ppt)		Conductivity (mmhos/cm)	
Month	week number	\bar{X}	\bar{X}	Range	\bar{X}	Range	\bar{X}	Range	\bar{X}	Range
March	3	9.5	3.9	3.3-5.2	8.1	-	29.2	29.0-29.5	30.7	30.5-30.8
	4	0.2	-	-	7.6	7.6-7.7	28.8	28.6-29.1	30.7	30.3-30.8
	5	3.1	-	-	8.4	8.2-8.7	30.7	29.8-31.6	32.5	21.9-33.3
April	1	2.0	-	-	8.7	8.4-9.4	-	-	-	-
	2	2.0	-	-	9.5	9.0-9.9	28.7	28.6-28.7	30.1	30.0-30.3
	3	7.0	4.1	3.6-6.2	8.8	8.6-9.1	29.1	29.0-29.2	31.7	30.0-32.0
	4	82.2	4.3	3.2-10.5	10.1	9.6-10.6	29.0	28.5-29.6	31.5	29.8-31.8
May	1	33.2	4.9	3.5-7.4	9.4	9.1-10.2	29.2	29.1-29.5	31.8	31.7-31.8
	2	11.0	6.4	4.4-9.6	-	-	-	-	-	-
	3	31.0	7.4	6.0-9.0	11.6	10.5-12.6	28.8	28.4-29.2	32.7	32.3-33.0
	4	23.0	6.8	5.1-10.6	10.7	10.6-11.1	29.1	28.5-29.5	32.4	32.0-32.8
June	1	206.5	6.8	4.7-10.0	11.1	10.5-11.8	29.1	28.8-29.6	32.3	32.1-32.6
	2	104.0	7.1	4.7-12.0	12.0	11.0-12.5	30.4	29.6-30.7	32.3	31.6-32.6
	3	86.0	6.7	4.3-10.2	14.5	13.9-15.7	29.2	28.8-29.5	33.2	33.0-33.5
	4	-	-	-	-	-	-	-	-	-
	5	102.6	7.6	5.4-12.4	12.2	11.7-12.9	29.6	29.4-29.8	33.1	32.7-33.4
July	1	35.1	6.5	4.8-11.0	13.7	12.3-14.8	29.2	28.8-29.6	33.6	33.1-34.2
	2	23.7	7.0	5.8-8.8	13.2	12.8-14.5	29.5	29.2-29.7	33.6	33.1-34.3
	3	8.0	8.5	7.2-10.6	13.1	12.9-13.5	28.8	28.5-28.9	32.7	32.5-33.1

Table 7-7. Seasonal data for 10-min tow-net transects based on weekly values.

Date	Week number	CPUE		Fork length (cm)		Temperature (°C)		Salinity (ppt)		Conductivity (mmhos/cm)	
		\bar{X}	Range	\bar{X}	Range	\bar{X}	Range	\bar{X}	Range	\bar{X}	Range
March	3	4.4	3.2-4.1	8.1	8.1-8.2	29.1	29.1-29.3	30.7	30.6-30.9		
	4	7.6	3.4-4.0	7.6	-	28.9	28.7-28.9	30.6	30.5-30.6		
	5	7.7	3.4-7.1	8.4	8.1-8.8	30.6	30.1-31.3	32.4	32.0-32.6		
April	1	6.5	3.5-7.3	8.6	8.2-9.1	-	-	-	-		
	2	2.3	3.8-7.2	9.3	9.0-9.7	28.5	27.7-29.3	30.0	29.7-30.3		
	3	38.3	3.2-7.6	8.7	8.7-8.8	29.2	29.1-29.3	31.8	31.5-32.1		
	4	51.8	3.1-9.8	10.1	9.6-10.4	29.1	28.8-29.4	30.8	29.8-31.8		
May	1	13.8	3.5-10.3	9.6	9.0-10.1	29.4	29.2-29.5	31.7	31.6-31.8		
	2	2.3	5.0-9.5	-	-	-	-	-	-		
	3	0.2	-	11.8	11.3-12.7	28.9	28.4-29.2	32.7	32.3-33.2		
	4	29.4	3.5-9.0	10.7	10.4-11.1	29.1	28.7-29.8	32.4	32.2-32.6		
June	1	64.1	5.4-11.9	10.9	10.3-11.6	29.1	28.6-29.4	32.3	32.1-32.4		
	2	181.4	4.2-10.5	11.8	10.9-12.5	30.2	29.9-30.6	32.3	31.9-32.5		
	3	194.9	3.8-10.8	14.9	14.3-15.0	28.5	28.7-29.7	33.2	32.7-33.4		
	4	-	-	-	-	-	-	-	-		
	5	70.1	5.2-12.2	12.4	11.8-12.9	29.6	29.0-29.8	33.2	32.6-33.7		
July	1	29.9	5.0-10.7	13.9	12.9-14.5	29.0	28.5-29.5	33.6	32.5-34.1		
	2	27.6	6.0-9.8	13.0	12.3-13.7	29.5	29.2-29.8	33.4	33.0-33.7		
	3	1.7	7.4-9.0	12.9	12.6-13.2	28.9	28.5-29.3	32.3	31.9-32.5		

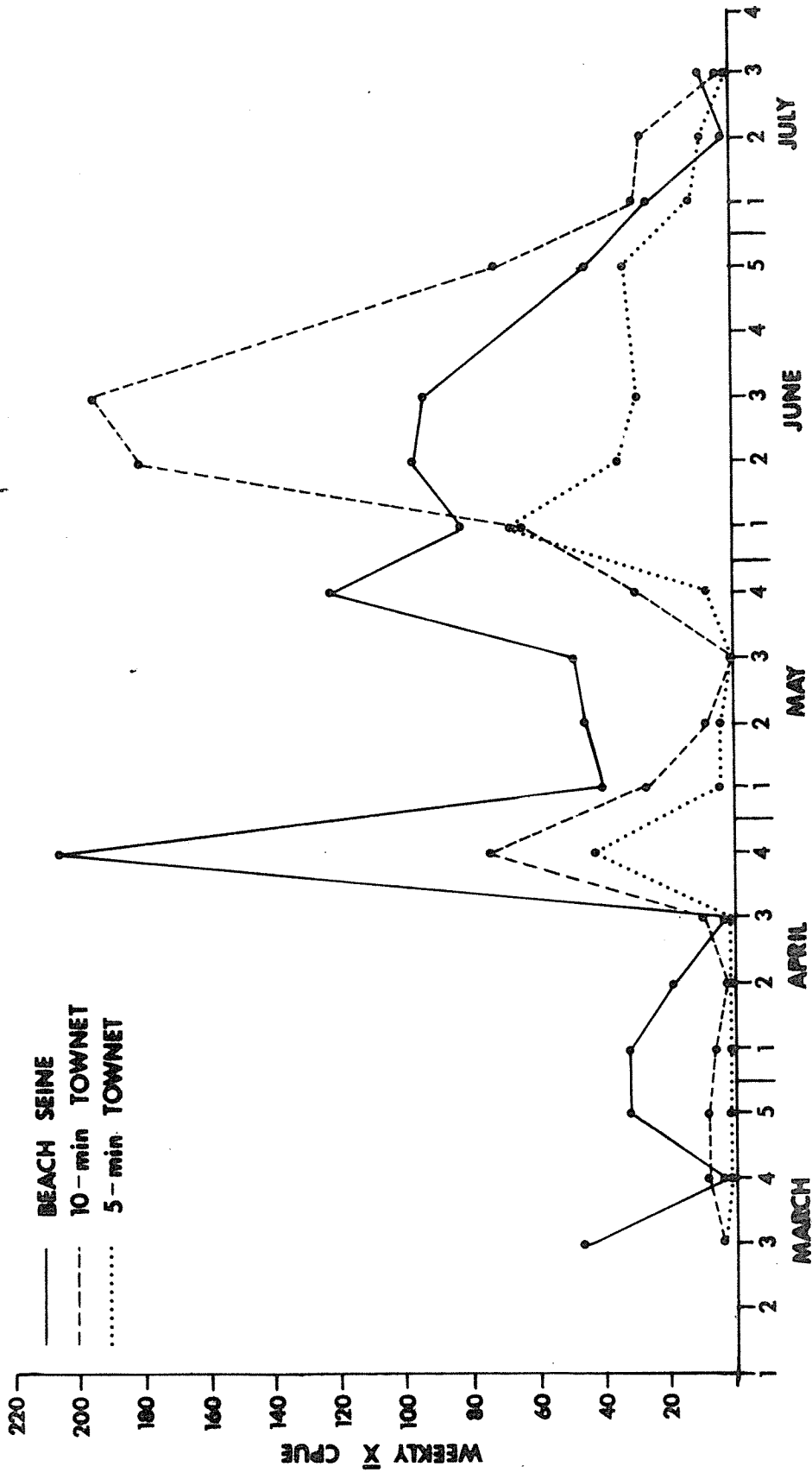


Fig. 7-9. Weekly mean CPUE showing peak periods for beach seine, 10-min tow net and 5-min tow net transects during the March 16 to July 20, 1977 field avoidance surveys.

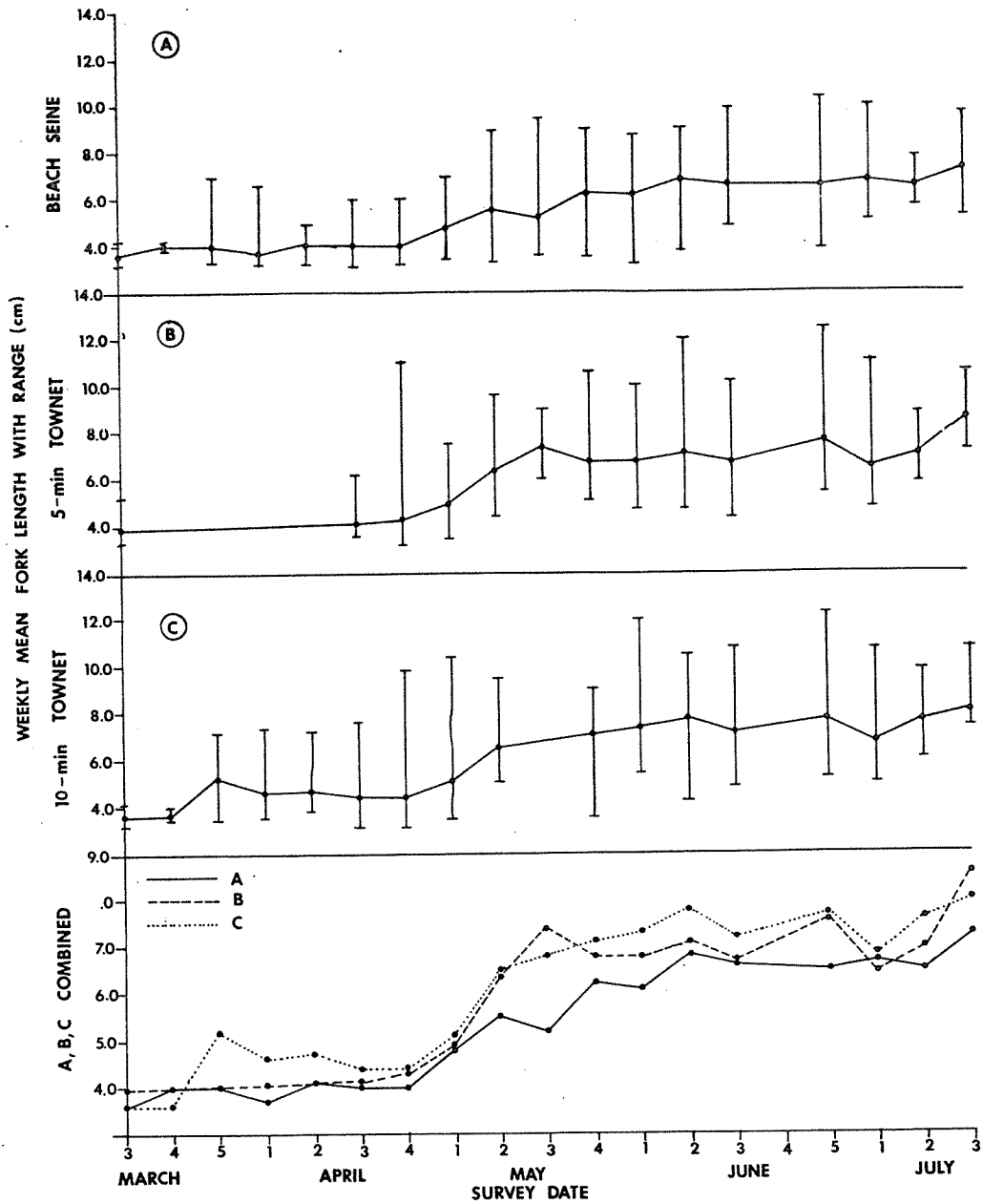


Fig. 7-10. Weekly mean fork lengths with ranges during the March 16 to July 20, 1977 field avoidance surveys for a) beach seine, b) 5-min townet, c) 10-min townet transects, and d) comparison of mean fork lengths for the three capture techniques.

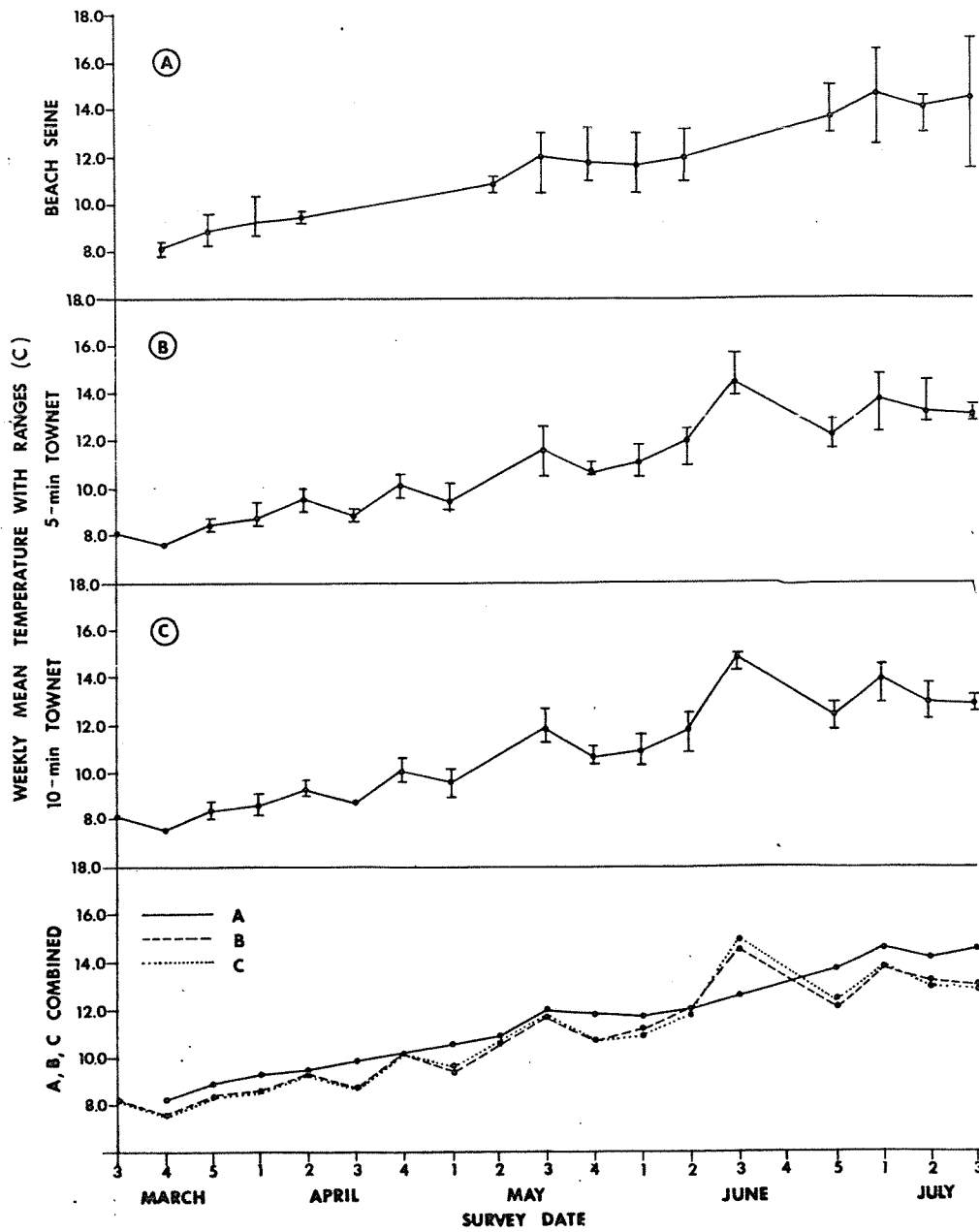


Fig. 7-11. Weekly mean temperatures and ranges recorded during the March 16 to July 20, 1977 field avoidance surveys for a) beach seine, b) 5-min townet, c) 10-min townet transects, and d) comparison of mean temperatures for the three capture techniques.

7.4.1.3.1.1 Devil's Hole. Most fish from Devil's Hole (92.6%) were caught between late April and mid-June (Fig. 7-12). The dredging plume was in the area three times during this period (Table 7-8); however, test TNFR values (8.7 to 26.4 mg/liter) were within the range of control values (6.9 to 30.0 mg/liter). Therefore, it was not possible to distinguish between dredge-created and naturally-occurring turbidity. Irrespective of the source of turbidity, an equal number of sets was made when TNFR values were less than and greater than 10.0 mg/liter. Mean CPUE was 113.4 (range: 0-400) at the lower sediment concentrations and 55.9 (range: 0-254) at concentrations greater than 10.0 mg/liter. This suggests that fewer chum salmon were present when TNFR values increased; however, both groups had catches of zero, which implies that factors other than turbidity may have been affecting the presence and abundance of chum salmon. Mathematical inspection of tide height and direction, time of day, and available temperature and DO data indicated no consistent relationship with CPUE.

7.4.1.3.1.2 Delta. Slightly more chum salmon (53.6%) were caught at Delta during the peak period than at other times (Fig. 7-13). The plume was in the area three times during this period (Table 7-9), but test TNFR values (11.2 to 19.7 mg/liter) were not appreciably different from control (8.2 to 16.3 mg/liter). The mean CPUE (3.3; range: 0 to 22) of nine sets made at TNFR concentrations less than 12.0 mg/liter was less than the mean CPUE (42.0; range: 0 to 150) of seven sets made at TNFR concentrations greater than 12.0 mg/liter. Again, there was no apparent relationship between CPUE and environmental variables, including TNFR.

7.4.1.3.1.3 Marginal. The majority of fish caught at Marginal (73.9%) also occurred between late April and mid-June (Fig. 7-14). Dredging turbidity was in the area four times during this period (Table 7-10). Again, test TNFR values (8.7-13.0 mg/liter) were not distinguishable from control (7.6-16.9 mg/liter). Nine sets at TNFR concentrations less than 12.0 mg/liter averaged 24.3 CPUE (range: 0-80); ten sets at TNFR levels greater than 12.0 mg/liter averaged 71.8 CPUE (range: 0-400). Again, no discernible trends were found after inspection of the data.

Based on the data gathered at beach seine stations, there were no consistent results indicating avoidance of either dredge-created or naturally-occurring suspended sediments.

7.4.1.3.2 Ten-minute townet transects. The late May to early July peak period was selected for determination of avoidance. During this period, the plume did not extend into the offshore areas covered by the 10-min transects. However, transects B and C (Fig. 7-3) were designated as test sites, since they were adjacent to the plume when it was located during subsequent 5-min transects closer to shore, and transects A, D, and E were designated control sites. The plume was

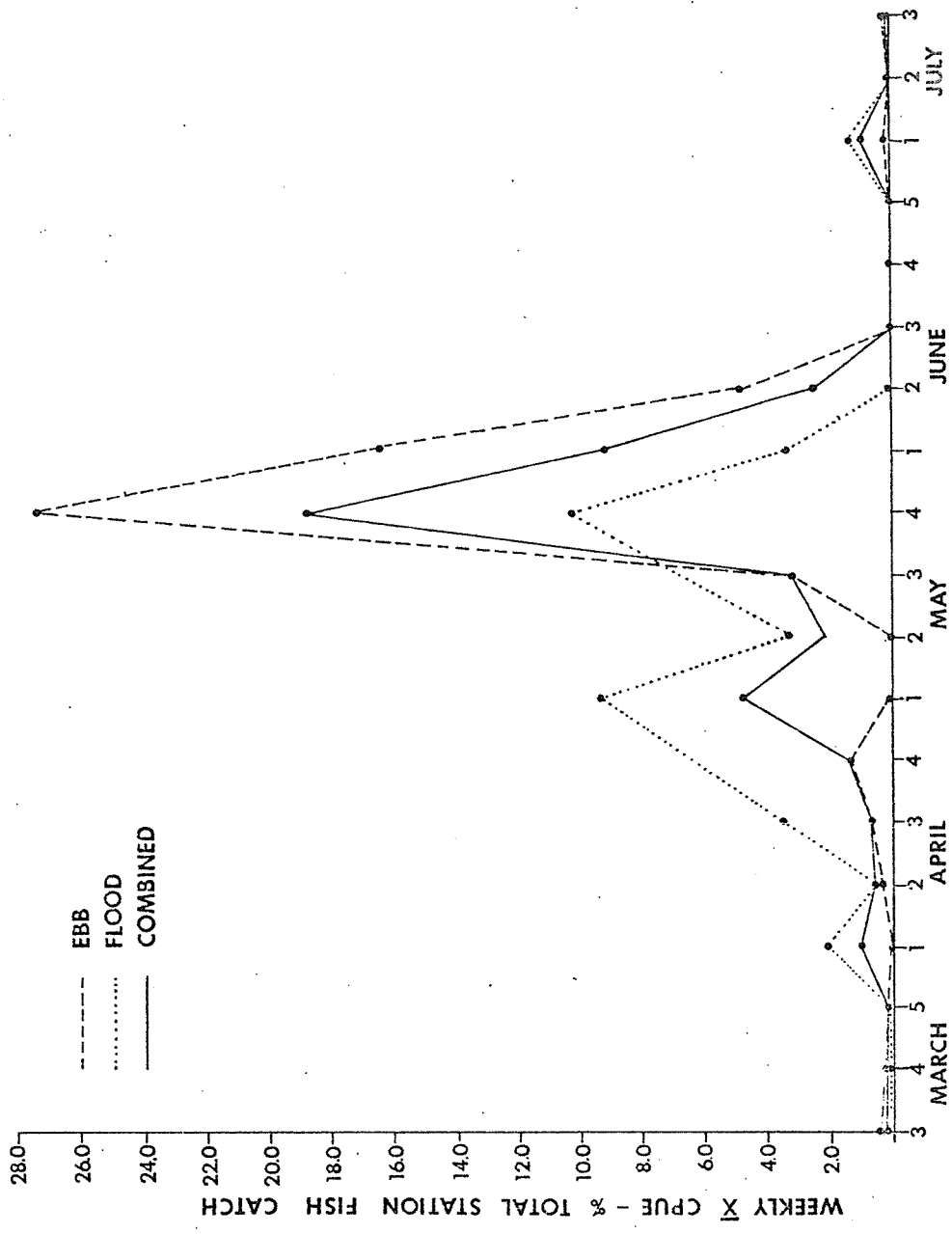


Fig. 7-12. Weekly mean CPUE for Devil's Hole beach-seine site, expressed as a percentage of the total chum salmon caught at the site between March 16 and July 20, 1977, showing peak periods for ebb and flood tide data separately and combined.

Table 7-8. Devil's Hole beach-seine site data for chum salmon collected during peak period.

Date ^a	CPUE	% TOT STA CPUE	Fork length (cm)		Temperature (°C)	DO (mg/liter)	TNFR (mg/liter)	Tide		Plume/no plume (P/NP)	Time
			\bar{X}	Range				Height (ft)	Ebb/flood (E/F)		
April 28A	21	1.4	4.0	3.4-5.3	-	-	8.8	7.0	E	NP	1141
May 4A	1	0.1	-	-	-	-	12.0	4.0	E	P	0920
4B	254	17.4	4.3	3.4-5.6	-	-	26.4	1.0	F	P	1440
5A	2	0.1	-	-	-	-	12.5	6.5	E	NP	0852
5B	22	1.5	4.1	3.6-4.8	-	-	30.0	1.0	F	NP	1538
11A	0	0	-	-	11.0	8.3	21.0	7.0	F	NP	1100
11B	0	0	-	-	-	-	8.7	6.0	E	NP	1525
13B	97	6.6	4.5	3.1-6.3	-	-	11.7	4.5	F	NP	1200
18C	45	3.1	5.3	4.1-9.4	11.8	8.7	9.4	9.5	E	NP	2130
25B	400	27.4	5.5	3.8-8.1	13.2	9.9	8.4	5.5	E	NP	1245
25C	150	10.3	5.7	3.8-7.8	12.0	9.6	9.3	10.5	F	NP	2230
June 1B	50	3.4	-	-	13.0	12.6	7.5	6.5	F	NP	1530
1C	240	16.4	6.4	3.7-8.6	11.0	10.6	8.7	9.0	E	P	2135
9B	71	4.9	6.2	3.8-9.0	-	-	16.5	6.5	E	NP	1500
9C	1	0.1	-	-	11.5	-	6.9	7.5	F	NP	2130
15B	0	0	-	-	-	-	16.1	2.5	F	NP	1345

^a "A,B,C" refer to time of day of sampling: "A", morning (0600-1200 h); "B", afternoon (1200-1800 h); "C", evening (1800-2400 h).

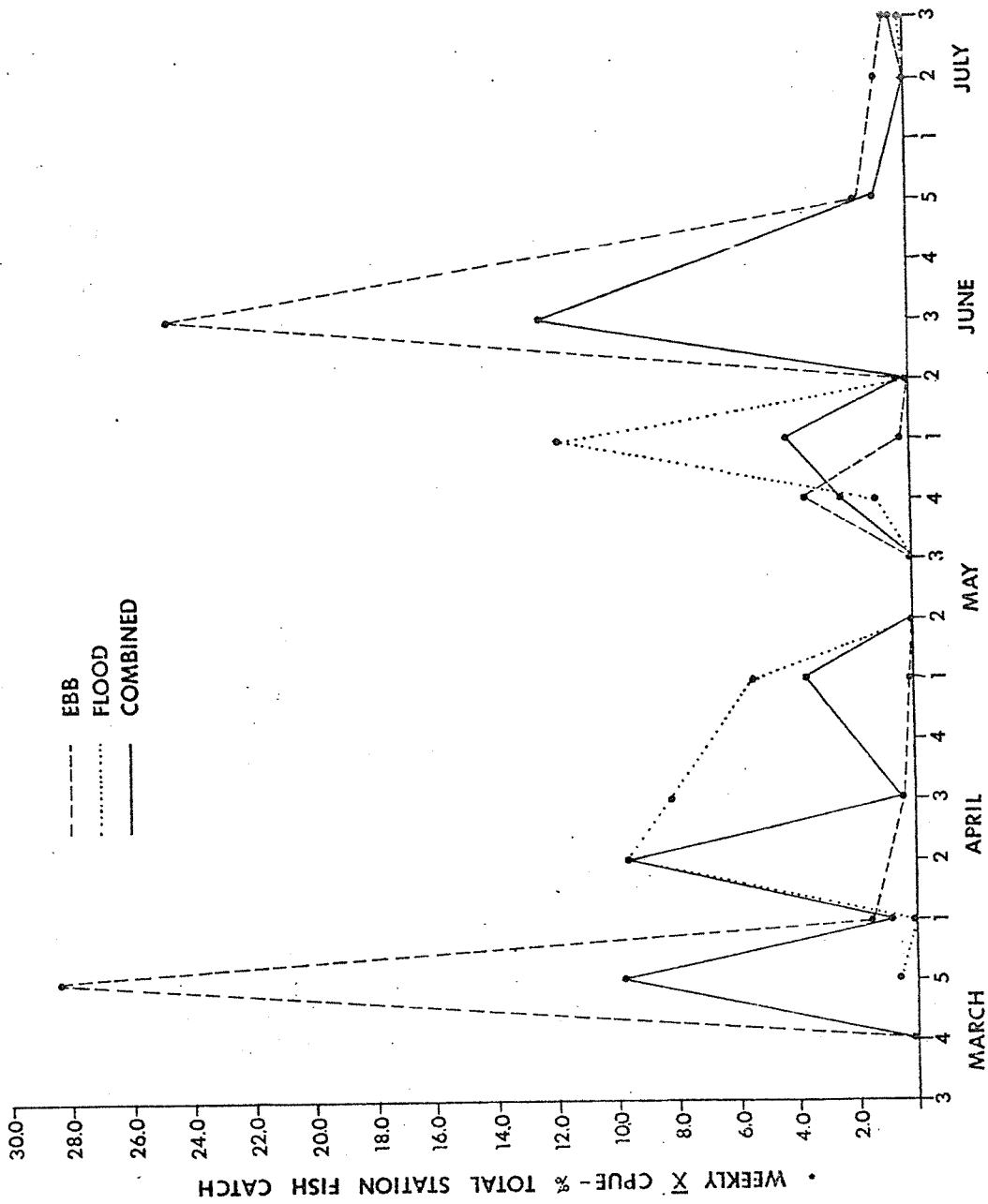


Fig. 7-13. Weekly mean CPUE for Delta beach-seine site, expressed as a percentage of the total chum salmon caught at the site between March 16 and July 20, 1977, showing peak periods for ebb and flood tide data separately and combined.

Table 7-9. Delta beach-seine site data for chum salmon collected during peak period.

Date ^a	CPUE	% TOT STA CPUE	Fork length (cm)		Temperature (°C)	DO (mg/liter)	TNFR (mg/liter)	Tide		Plume/no plume (P/NP)	Time
			X	Range				Height (ft)	Ebb/flood (E/F)		
April 28A	-	-	-	-	-	-	-	-	-	-	-
May 4A	-	-	-	-	-	-	-	-	-	-	-
4B	0	0	-	-	-	19.7	4.5	F	P	1550	
5A	0	0	-	-	-	11.4	4.0	E	NP	0955	
5B	67	11.1	5.0	3.5-6.6	-	15.4	1.0	F	NP	1521	
11A	0	0	-	-	11.4	9.9	7.0	F	NP	1100	
11B	-	-	-	-	-	-	-	-	-	-	
13B	0	0	-	-	-	11.3	4.5	F	NP	1147	
18B	0	0	-	-	13.0	11.2	3.0	F	NP	1440	
18C	0	0	-	-	11.8	11.4	9.5	E	NP	2130	
25B	22	3.6	7.0	6.4-8.4	13.0	8.2	5.5	E	NP	1310	
25C	8	1.3	6.8	6.2-8.0	11.2	8.6	10.0	F	NP	2205	
June 1A	4	0.7	-	-	11.5	13.3	-2.5	E	P	1035	
1B	72	11.9	5.3	3.8-6.7	12.5	14.5	5.0	F	NP	1510	
1C	1	0.2	-	-	11.0	11.2	8.0	E	P	2150	
9B	0	0	-	-	13.2	16.3	6.5	E	NP	1510	
9C	0	0	-	-	11.5	8.5	7.0	F	NP	2115	
15B	0	0	-	-	-	10.2	2.0	F	NP	1320	
15C	150	24.8	8.1	6.2-9.8	-	12.4	7.0	E	NP	2245	

^a "A,B,C" refer to time of day of sampling: "A", morning (0600-1200 h); "B", afternoon (1200-1800 h); "C", (1800-2400 h).

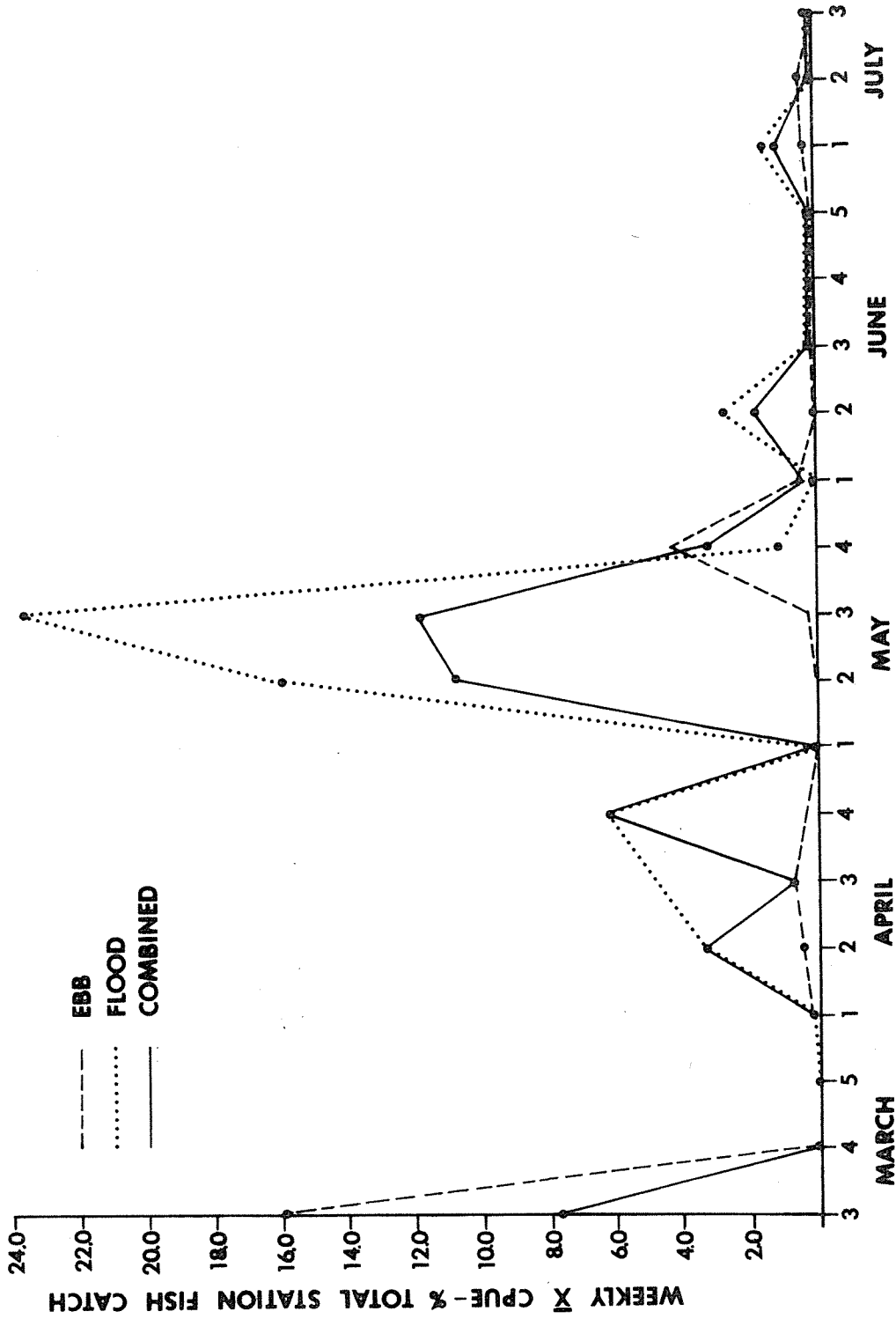


Fig. 7-14. Weekly mean CPUE for Marginal beach-seine site, expressed as a percentage of total chum salmon caught at the site between March 16 and July 20, 1977, showing peak periods for ebb and flood tide data separately and combined.

Table 7-10. Marginal beach-seine site data for chum salmon collected during peak period.

Date ^a	GPUE	% TOTAL STA GPUE	Fork length (cm)		Temperature (°C)	DO (mg/liter)	TNFR (mg/liter)	Tide		Plume/no plume (P/NP)	Time
			\bar{X}	Range				Height (ft)	Ebb/flood (E/F)		
April 28A	80	6.3	3.7	3.2- 4.5	-	-	8.8	6.5	E	NP	1119
May 4A	0	0	-	-	-	-	12.0	3.5	E	NP	0937
4B	0	0	-	-	-	-	14.1	0.0	F	NP	1410
5A	1	0.1	-	-	-	-	14.1	5.0	E	NP	0934
5B	1	0.1	-	-	-	-	16.9	-1.0	F	NP	1441
11A	0	0	-	-	10.5	8.4	13.0	7.0	F	NP	1025
11B	0	0	-	-	-	-	12.5	5.0	E	NP	1615
13B	400	31.6	6.1	3.8- 8.7	-	-	14.4	3.5	F	NP	1120
18B	300	23.7	5.1	3.6-8.2	13.0	9.8	13.6	1.5	F	NP	1410
18C	2	0.2	-	-	11.8	9.0	8.0	10.0	E	NP	2200
25B	55	4.3	5.8	3.8- 7.8	12.0	8.8	8.0	5.0	E	NP	1330
25C	27	2.1	6.6	5.3- 8.2	11.0	8.4	9.9	9.5	F	P	2140
June 1A	0	0	-	-	12.0	10.5	11.7	-2.5	E	NP	1050
1B	0	0	-	-	12.0	9.4	13.0	5.0	F	P	1455
1C	16	1.3	6.1	4.9- 8.1	10.5	8.4	13.8	8.0	E	NP	2205
9B	0	0	-	-	13.0	-	8.7	6.5	E	P	1525
9C	48	3.4	7.0	5.4- 8.6	11.5	-	7.6	8.0	F	NP	2050
15B	4	0.3	-	-	-	-	10.6	1.5	F	P	1310
15C	3	0.2	-	-	-	-	8.6	7.5	E	NP	2230

^a "A,B,C" refer to time of day of sampling: "A", morning (0600-1200 h); "B", afternoon (1200-1800 h); "C", evening (1800-2400 h).

present (in the 5-min townet area) during the surveys listed in Table 7-11, part B, which were considered test conditions, whereas those surveys listed in Table 7-11, part A, were considered control conditions since the plume was absent closer to shore (in 5-min townet area). Hypothetically, the abundance of chum salmon caught at test sites during test conditions might show variations that did not occur during control conditions or at control sites. Since no such variations were apparent (Table 7-11), there was no indication that the plume caused variation in the abundance of chum salmon present in the areas adjacent to the plume. Furthermore, variation of chum salmon abundance during successive transects (i.e., A thru E) appeared to be independent of water quality, which showed no significant variation between test and control sites per survey (Table 7-12). There was no indication of avoidance based on the data collected during the 10-min townet transects.

7.4.1.3.3 Five-minute townet transects. Abundance of chum salmon is expressed four ways in the succeeding discussion:

1) CPUE defines the number of chum salmon caught during a single 5-min transect;

2) $CPUE_3$ applies to total number of chum salmon caught during the series of three 5-min transects made in a given area, either the Marginal Wharf Area (MWA) or the Devil's Hole Area (DHA);

3) Percent total station CPUE (PERCENT TOT STA CPUE) describes $CPUE_3$ as a percentage of the season's total $CPUE_3$ at either the MWA or DHA station;

4) Percent total survey townet CPUE (PERCENT TOT SURV TN CPUE) describes $CPUE_3$ as a percentage of total chum salmon captured per survey in the townet, both 10- and 5-min transects combined. Weekly mean $CPUE_3$ peaked the first week in June and was associated with a month-long period of high catches (Fig. 7-15); 64.4% were caught in the MWA and 35.6% in the DHA (Table 7-13).

7.4.1.3.3.1 Marginal Wharf Area

7.4.1.3.3.1.1 Ebb. Seven surveys were conducted in the MWA, during ebb tide, between June 1 and July 7 (Table 7-14). The plume was present during one survey (9B June) and had a TNFR concentration (11.7 mg/liter) significantly greater ($p < 0.05$) than control (5.4 to 9.7 mg/liter). During the plume survey ($CPUE_3 = 27$ fish), two of the three transects were made completely in the plume (Plate IV); the third spent 60% of the transect time in the plume and had the highest CPUE (18 fish). Whether or not chum salmon were in the plume cannot be determined; however, the decreased CPUE associated with increased time spent in the plume does suggest avoidance of the plume.

Tide height was inversely correlated with PERCENT TOT SURV TN CPUE, except when the plume was present (Fig. 7-16). Linear regression analysis, based on control values, showed a significant trend ($p < 0.05$; $r^2 = 0.9134$); however, when the plume survey datum was

Table 7-11. Comparison of fish catch per transect, expressed as a percentage of total chum salmon caught during all 10-min transects per survey for A. Control and B. Plume.

Date	% Total 10-min TN survey chum				
	A	B	C	D	E
A. 9B June	86.5	7.4	0.5	4.7	0.9
9C	44.4	42.1	9.0	3.5	1.0
29C	1.5	1.5	4.5	13.4	79.1
7A July	3.0	17.5	48.8	20.5	10.2
7B	17.5	0	0	46.0	36.5
7C	5.5	1.6	20.3	36.7	4.9
\bar{x}	26.4	11.7	13.8	20.8	21.3
Range	1.5-86.5	0-42.1	0-48.8	3.5-46.0	0.9-79.1
B. 1A June	75.4	20.5	3.3	0.7	0
1B	84.7	6.4	7.8	1.1	0
1C	6.7	1.8	39.4	42.9	9.2
15B	15.8	7.2	29.7	46.3	0.9
15C	61.3	16.3	5.4	5.9	11.2
29A	69.4	1.1	7.0	0.2	22.3
29B	1.8	2.8	3.7	30.3	61.4
\bar{x}	45.0	8.0	13.8	18.2	15.0
Range	1.8-84.7	1.1-20.5	3.3-39.4	0.2-46.3	0-61.4

Table 7-12. Water quality parameters for 10-min townet transects during peak capture period showing general homogeneity of individual surveys.

Date ^a	Water quality parameter	Transect					Range
		A	B	C	D	E	
May 25B	Temp (°C)	10.6	11.1	10.6	10.7	10.5	10.5-11.1
	Salinity (ppt)	29.1	28.9	28.9	29.8	29.4	28.9-29.8
	Cond (mmhos/cm)	32.3	32.6	32.2	32.6	32.4	32.2-32.6
25C	Temp (°C)	10.7	10.4	10.5	10.5	10.8	10.4-10.8
	Salinity (ppt)	28.7	29.0	29.0	29.1	28.9	28.7-29.1
	Cond (mmhos/cm)	32.5	32.2	32.4	32.4	32.3	32.2-32.5
June 1A	Temp (°C)	10.6	10.6	10.8	11.2	11.1	10.6-11.2
	Salinity (ppt)	29.1	29.1	29.1	28.8	28.8	28.8-29.1
	Cond (mmhos/cm)	32.1	32.2	32.1	32.2	32.2	32.1-32.2
1B	Temp (°C)	11.5	11.6	10.5	11.0	11.2	10.5-11.6
	Salinity (ppt)	28.7	28.6	29.4	29.0	29.0	28.6-29.4
	Cond (mmhos/cm)	32.3	32.3	32.4	32.3	32.4	32.3-32.4
1C	Temp (°C)	10.6	10.8	11.1	10.3	10.3	10.3-11.1
	Salinity (ppt)	29.4	29.4	29.1	29.1	29.4	29.1-29.4
	Cond (mmhos/cm)	32.2	32.2	32.3	32.3	32.3	32.2-32.3
9B	Temp (°C)	11.8	12.5	12.5	10.9	11.5	10.9-12.5
	Salinity (ppt)	30.6	29.9	29.9	30.4	30.2	29.9-30.6
	Cond (mmhos/cm)	32.4	32.5	32.5	31.9	32.3	31.9-32.5
9C	Temp (°C)	-	-	-	-	-	-
	Salinity (ppt)	-	-	-	-	-	-
	Cond (mmhos/cm)	-	-	-	-	-	-
15B	Temp (°C)	15.3	-	14.8	15.2	14.9	14.8-15.3
	Salinity (ppt)	28.7	29.7	29.0	28.8	29.0	28.7-29.7
	Cond (mmhos/cm)	33.2	32.7	33.2	33.4	33.1	32.7-33.4
15C	Temp (°C)	15.0	14.9	14.9	15.0	14.9	14.9-15.0
	Salinity (ppt)	28.8	29.1	29.0	28.8	28.9	28.8-29.1
	Cond (mmhos/cm)	33.3	33.2	33.2	33.3	33.3	33.2-33.3
29A	Temp (°C)	12.2	11.8	11.9	12.5	12.7	11.8-12.7
	Salinity (ppt)	29.6	29.0	29.6	29.6	29.4	29.0-29.6
	Cond (mmhos/cm)	33.0	32.6	32.8	33.2	33.3	32.6-33.3
29B	Temp (°C)	12.6	12.6	12.8	12.9	12.5	12.5-12.9
	Salinity (ppt)	29.7	29.0	29.6	29.7	29.5	29.0-29.7
	Cond (mmhos/cm)	33.3	33.2	33.6	33.7	33.2	33.2-33.7
29C	Temp (°C)	12.6	12.1	12.6	12.2	12.1	12.1-12.6
	Salinity (ppt)	29.7	29.8	29.7	29.8	29.8	29.7-29.8
	Cond (mmhos/cm)	33.3	33.0	33.4	33.1	33.3	33.0-33.1
July 7A	Temp (°C)	14.3	14.2	14.1	14.0	13.9	13.9-14.3
	Salinity (ppt)	28.8	28.8	28.9	29.0	28.9	28.8-29.0
	Cond (mmhos/cm)	33.5	33.5	33.5	33.4	33.4	33.4-33.5
7B	Temp (°C)	14.4	14.4	14.4	14.5	14.1	14.1-14.5
	Salinity (ppt)	28.9	29.0	28.9	29.0	29.2	28.9-29.2
	Cond (mmhos/cm)	33.6	33.8	33.9	34.1	33.9	33.6-34.1
7C	Temp (°C)	13.7	12.9	13.0	13.2	13.1	12.9-13.7
	Salinity (ppt)	29.1	28.5	29.4	29.5	29.5	28.5-29.5
	Cond (mmhos/cm)	33.7	32.5	33.4	33.7	33.6	32.5-33.7

^a "A,B,C" refer to time of day of sampling: "A", morning (0600-1200 h); "B", afternoon (1200-1800 h); "C", evening (1800-2400 h).

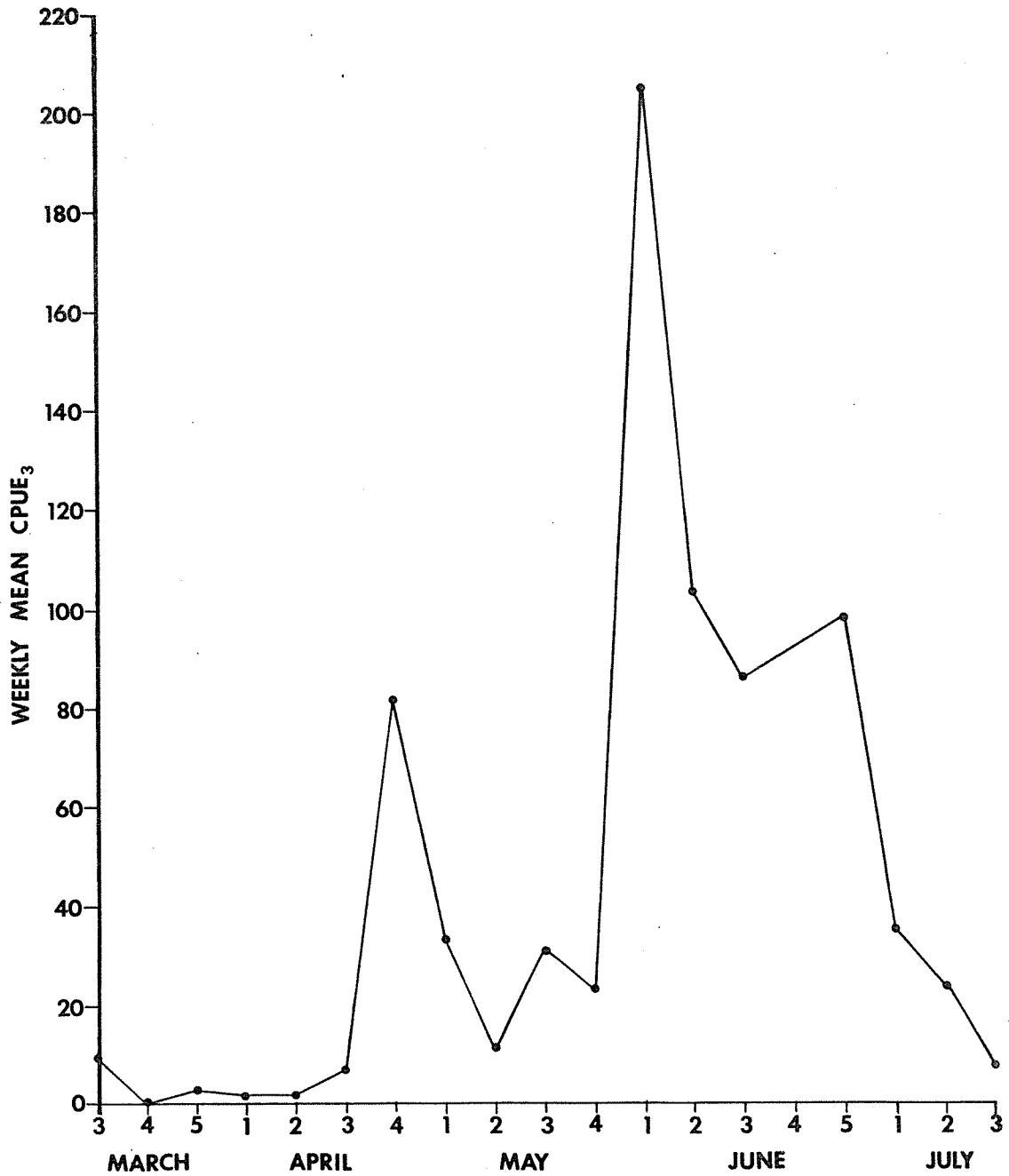


Fig. 7-15. Weekly mean CPUE₃ for 5-min townet transects conducted between March 16 and July 20, 1977, showing the early June to early July peak period.

Table 7-13. Comparison of weekly chum salmon CPUE₃ for 5-min townet transects in Devil's Hole and Marginal Wharf areas.

Date	Week number	Weekly total CPUE ₃		Total	Number of surveys
		Devil's Hole Area	Marginal Wharf area		
March	3	38	0	38	2
	4	1	0	1	1
	5	9	10	19	3
April	1	6	2	8	2
	2	0	4	4	1
	3	9	19	28	2
	4	18	311	329	2
May	1	292	40	332	5
	2	0	66	66	3
	3	0	124	124	2
	4	26	66	92	2
June	1	355	884	1239	3
	2	327	89	416	2
	3	156	188	344	2
	4	-	-	-	-
	5	49	542	591	3
July	1	93	117	210	3
	2	22	73	95	2
	3	11	21	32	2
Sums		1,412	2,556	3,968	
% TOT 5 mt		35.6%	64.4%		

Table 7-14. Data gathered during ebb tide surveys in the Marginal Wharf area during the June 1 to July 7, 1977 peak period of juvenile chum salmon migration.

Date	Transect number	CPUE	% TOT SURV TN CPUE	Fork length X̄ Range	Temperature C X̄	Salinity ppt X̄	Cond mmhos/cm X̄	TNFR mg/liter X̄	Tide Height (ft)	Time (hr)	% Plume
1A	3	0		-	10.9	29.1	32.2	5.4		1106	0
	4	425		6.6 4.9-8.1	10.8	29.2	32.1	6.2		1111	0
	5	406		7.0 5.0-8.8	10.9	29.0	32.2	6.6		1120	0
	Total	831	60.8	6.8 4.9-8.8	10.9	29.1	32.2	6.0	-2.5		
1C	3	0		-	10.5	29.5	32.3	8.1		2325	0
	4	0		-	10.5	29.5	32.3	9.1		2331	0
	5	19		7.4 5.6-8.8	10.5	29.6	32.3	8.2		2337	0
	Total	19	5.0	7.4 5.6-8.8	10.5	29.5	32.3	8.5	6.5		
9B ¹	3	18		6.3 5.9-7.0	12.3	30.7	32.5	8.6		1608	60
	4	7		7.6 5.5-11.0	11.6	30.7	32.3	11.72		1614	100
	5	2		-	11.0	30.7	32.1	7.9		1630	100
	Total	27	1.6	6.7 5.5-11.1	11.6	30.7	32.3	9.4	4.5		
15C	3	35		7.2 5.7-10.2	14.2	29.5	33.1	9.7		2345	0
	4	15		7.3 5.8-9.0	13.9	29.5	33.0	8.1		2351	0
	5	11		-	14.3	29.2	33.1	6.8		2359	0
	Total	61	3.4	7.2 5.7-10.2	14.1	29.4	33.1	8.2	7.0		
29A	3			-	12.2	29.5	32.8	9.6		1108	0
	4	236		7.1 5.4-9.3	12.3	29.5	33.0	7.5		1114	0
	5	203		8.0 6.5-9.5	12.5	29.4	33.1	7.0		1121	0
	Total	439	44.7	7.5 5.4-9.5	12.3	29.5	33.0	8.0	-2.5		
29C	3	6		7.6 6.4-8.2	12.2	29.8	33.2	9.2		2139	0
	4	1		-	12.1	29.8	33.1	7.9		2146	0
	5	7		9.7 7.4-12.4	11.9	29.8	33.0	8.2		2152	0
	Total	14	11.4	8.7	12.1	29.8	33.1	8.4	7.5		
7B	3	4		-	14.1	29.2	33.9	8.5		1501	0
	4	3		-	14.1	29.3	33.9	7.3		1507	0
	5	35		6.6 4.8-9.3	14.0	29.3	33.8	7.7		1513	0
	Total	42	24.6	6.6 4.8-9.3	14.1	29.3	33.9	7.8	4.5		

¹Plume present.

²Plume present with TNFR value significantly greater than control.

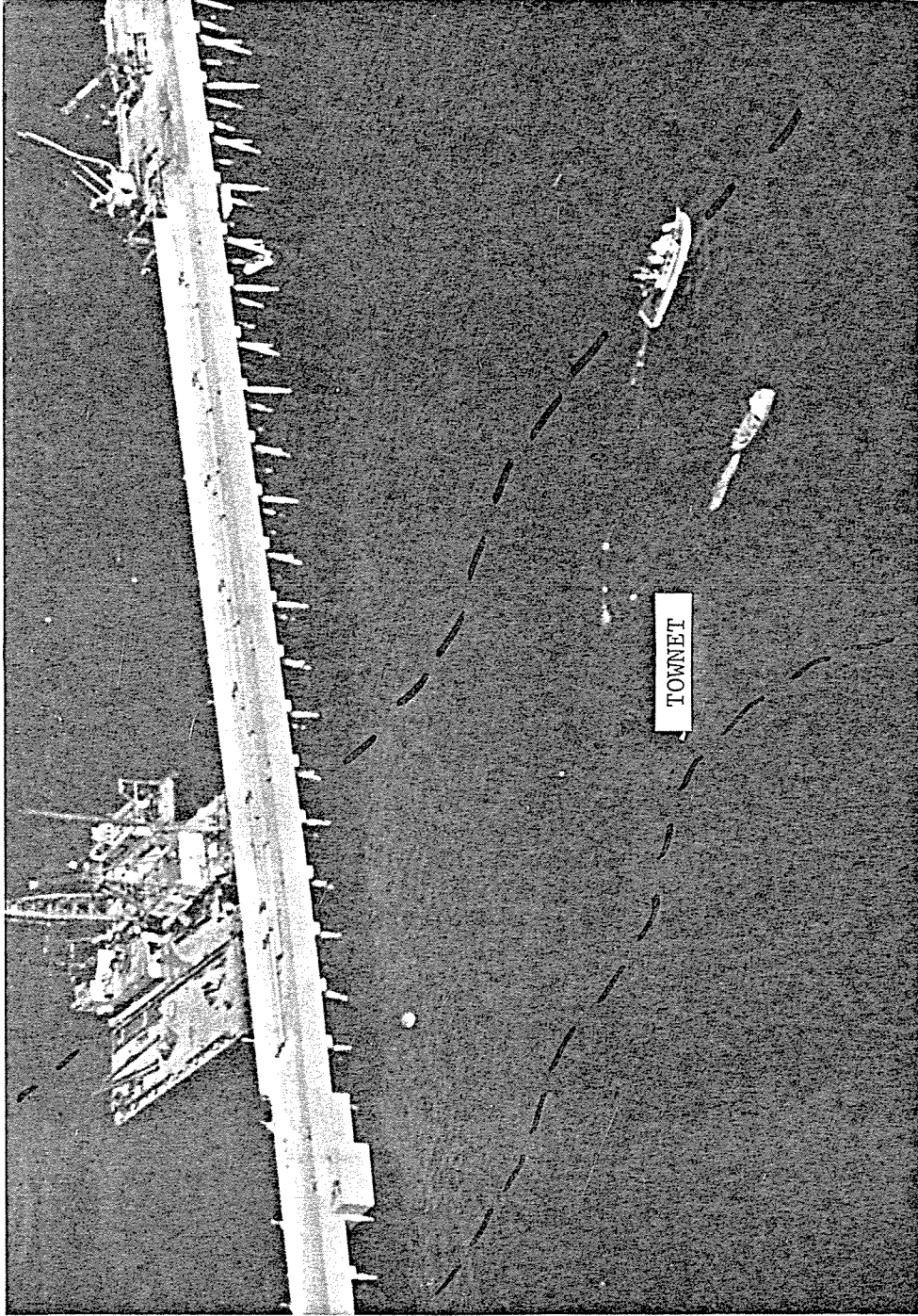


Plate IV. Townetting through the plume (periphery marked with dashed lines).

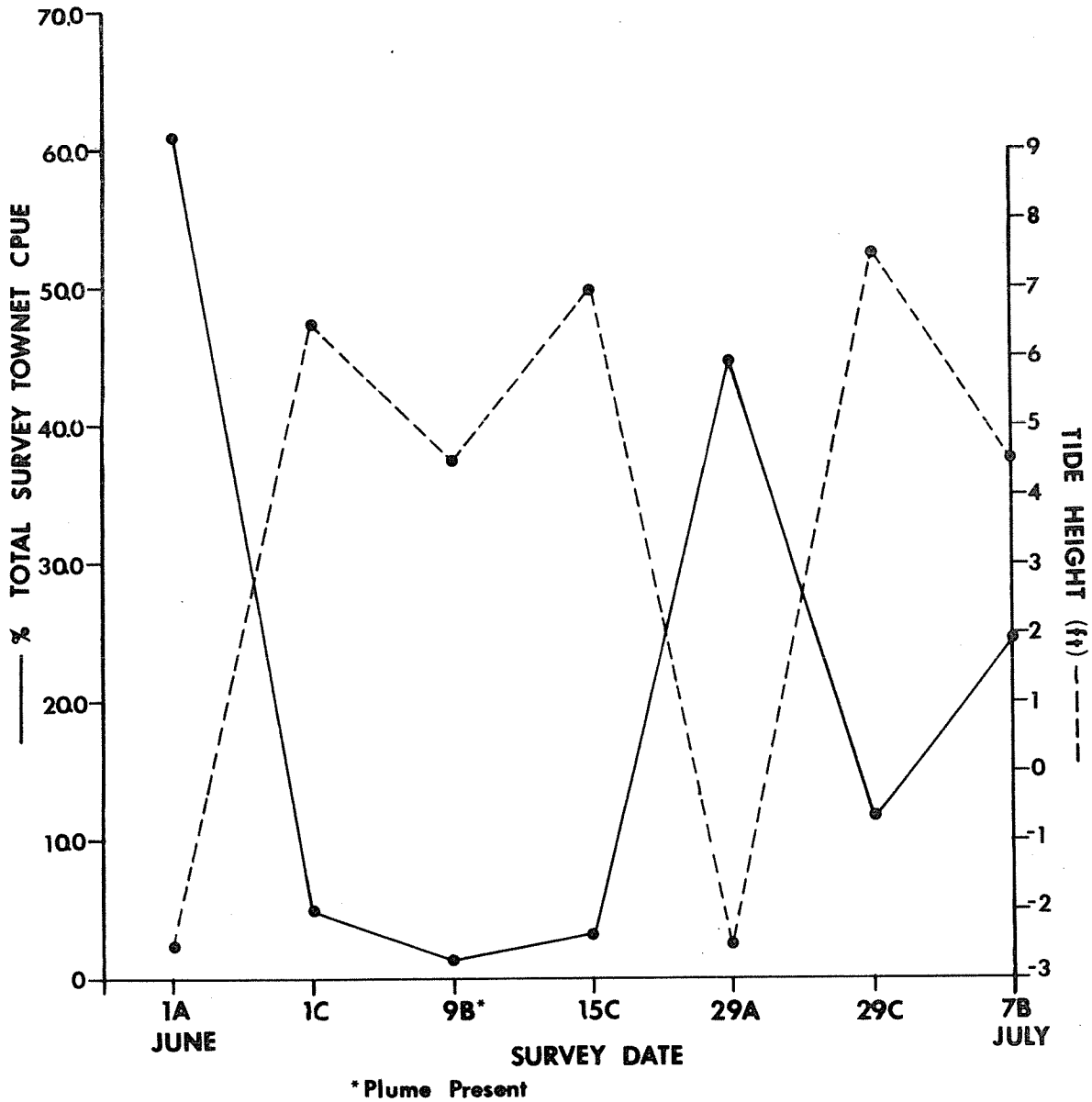


Fig. 7-16. The abundance of chum salmon, when expressed as percent Total Survey Townnet CPUE, was inversely correlated with tide height in the Marginal Wharf area during ebb tide. Figure shows that fewer than expected fish were present during the 9B June survey, which was the only time the plume was present in the Marginal Wharf area during ebb tide between June 1 and July 7, 1977.

included on the graph, the point deviated significantly ($p < 0.05$) from the predicted line (Fig. 7-17). Since fewer than predicted fish were present during the plume survey, fish were determined to avoid the plume when it increased the TNFR concentration of the water between 2.0 and 6.3 mg/liter above control.

The use of PERCENT TOT SURV TN CPUE is not totally acceptable, since it is based on a combination of two capture techniques; however, the apparent relationship suggests that the number of chum salmon caught in the MWA was a function of the overall abundance of chum salmon in the Bangor Annex area. The correlation of PERCENT TOT SURV TN CPUE with tide height during ebb tide possibly indicates a preferred zone for migration as related to distance from shore and/or depth of water.

7.4.1.3.3.1.2 Flood. Table 7-15 presents the data collected during six flood tide surveys conducted in the MWA between June 1 and July 7. Three surveys (1B, 15B, and 29B June) were conducted when the plume was present, only one of which (1B June) had a TNFR sample (13.8 mg/liter) significantly greater than control (6.6 to 10.9 mg/liter). Two of the three transects made during the 1B June survey were partially in the plume; the third transect was made completely in the plume and had the lowest CPUE, suggesting avoidance of the plume.

There was no apparent influence of tide height, or other environmental variables, on the abundance of chum salmon during flood tide.

7.4.1.3.3.2 Devil's Hole Area

7.4.1.3.3.2.1 Ebb. Seven surveys were conducted in the DHA between June 1 and July 7, four surveys during plume, and three during control conditions (Table 7-16). Two of the four plume surveys (15C and 29A June) had TNFR values (15.5 and 30.5 mg/liter, respectively) significantly greater than control (5.7 to 10.0 mg/liter). During the 15C June survey ($CPUE_3 = 154$ fish), two of the transects were made outside of the plume; the third transect spent 50% of the time in the plume ($CPUE = 50$ fish). Again, whether or not the fish were in the plume cannot be determined. During the 29A June survey ($CPUE_3 =$ one fish), two transects were conducted completely in the plume and the third spent 20% of the transect time in the plume. The low $CPUE_3$ may have been caused by the high TNFR concentration of the plume (30.5 mg/liter).

Tide height was inversely correlated with PERCENT TOT STA CPUE (Fig. 7-18A) except during the 15C and 29A June surveys (Fig. 7-18B). Considerably more fish were present during the 15C June survey than expected, which may have resulted if chum salmon were avoiding the plume and consequently were accumulating in the plume periphery. TNFR concentrations of the water within the plume were between 5.5 and

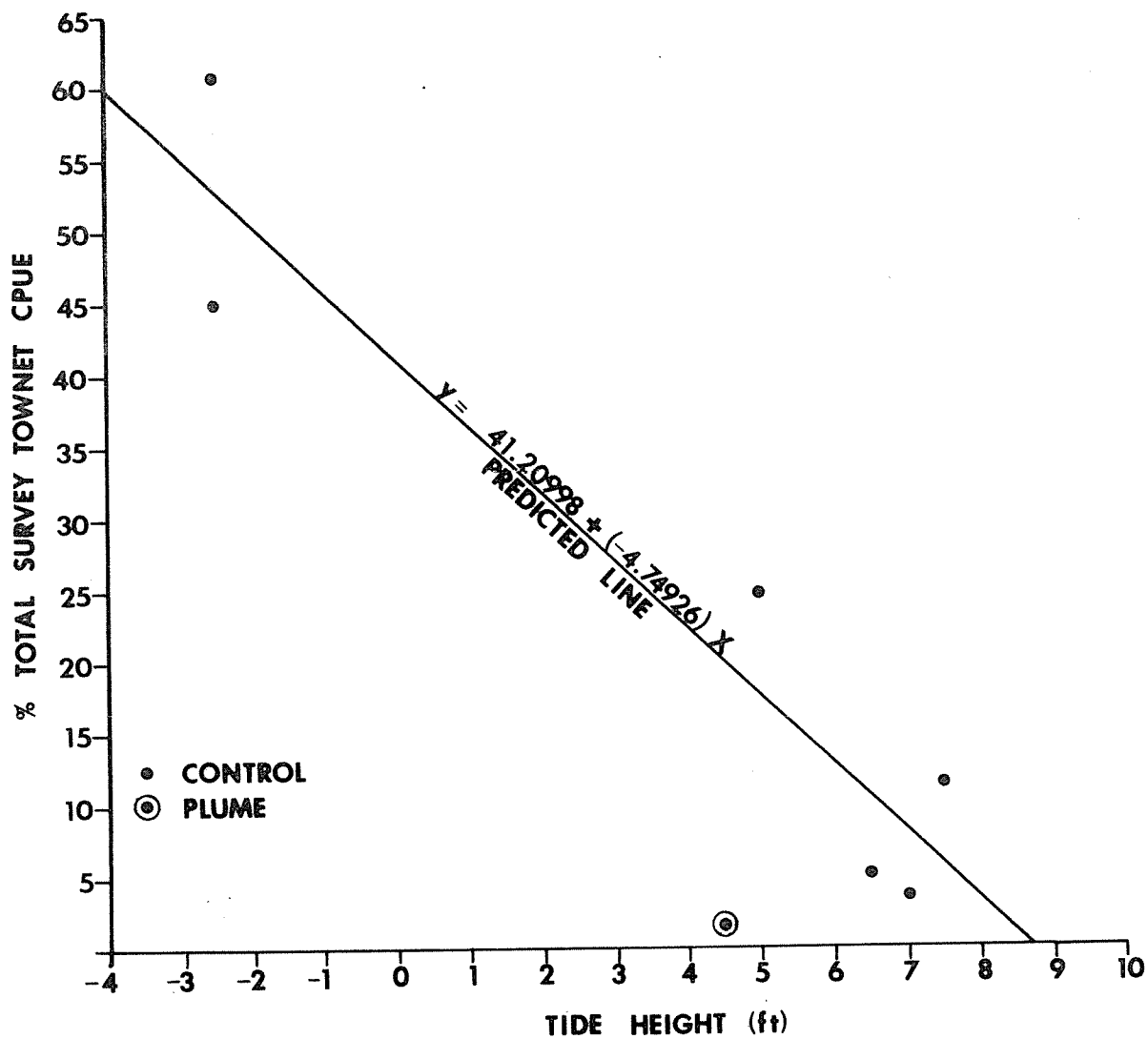


Fig. 7-17. Linear regression of tide height and Percent Total Survey Townnet CPUE for 5-min townet transects in the Marginal Wharf area during ebb tide. The plume survey data was not included in determining the predicted line.

Table 7-15. Marginal Wharf area flood tide data collected between June 1 and July 7, 1977.

Date	Transect number	CPUE	% TOT SURV TN CPUE	Fork length		Temperature °C	Salinity ppt	Cond mmhos/cm	TNFR mg/liter	Tide height (ft)	% Time (hr) plume
				\bar{X}	Range						
1B ¹	3	23		6.7	5.3-7.8	11.7	28.8	32.6	10.1	1618	80
	4	7		6.6	5.1-8.2	11.5	28.8	32.5	10.8	1625	40
	5	4		-	-	11.8	28.9	32.4	13.82	1632	100
		(CPUE ₃) 34	7.5	6.7	5.1-8.2	11.7	28.8	32.5		11.6	9.5
Total											
9C	3	5		6.5	5.4-7.6	11.4	-	-	7.0	2141	0
	4	42		9.6	6.6-12.0	11.4	-	-	6.6	2148	0
	5	15		6.9	5.3-8.3	11.7	-	-	6.6	2155	0
		(CPUE ₃) 62	10.7	8.7	5.3-12.0	11.5	-	-		6.7	8.0
Total											
15B ¹	3	0		-	-	15.7	28.8	33.5	9.0	1722	0
	4	119		6.3	5.0-8.5	14.7	29.3	33.4	8.4	1729	40
	5	8		6.1	5.0-7.2	15.0	28.9	33.4	9.1	1735	0
		(CPUE ₃) 127	14.4	6.3	5.0-8.5	15.1	29.0	33.4		8.8	10.5
Total											
29B ¹	3	0		-	-	12.9	29.6	33.5	8.2	1533	50
	4	3		-	-	12.5	29.6	33.3	7.0	1539	30
	5	86		7.7	5.8-9.8	12.7	29.8	33.4	8.1	1545	0
		(CPUE ₃) 89	11.9	7.7	5.8-9.8	12.7	29.7	33.4		9.5	
Total											
7A	3	0		-	-	13.9	29.0	33.7	7.3	1118	0
	4	5		5.6	4.8-5.9	13.9	28.9	33.7	8.5	1129	0
	5	29		6.2	5.3-7.3	13.9	28.9	33.5	8.2	1135	0
		(CPUE ₃) 34	16.2	6.1	4.8-7.3	13.9	28.9	33.6		8.0	8.0
Total											
7C	3	5		-	-	12.4	29.6	33.2	7.2	2100	0
	4	23		6.6	5.5-10.5	12.3	29.6	33.1	10.9	2107	0
	5	13		6.1	5.4-7.1	12.3	29.6	33.2	9.0	2113	0
		(CPUE ₃) 41	13.2	6.4	5.4-10.5	12.3	29.6	33.2		9.0	10.0
Total											

¹Plume present.²Plume present with TNFR value significantly greater than control.

Table 7-16. Devil's Hole area ebb tide data.

Date	Transect number	CPUE	% TOT SURV TN CPUE	Fork length (cm)		Tempera- ture °C	Salinity ppt	Conductivity X mmhos/cm	TNFR mg/liter X	Tide height (ft)	Time (hr)	% plume
				X	Range							
1A ¹	1	80		6.9	5.3-8.9	11.4	29.1	32.4	10.3		1150	70
	2	6		6.9	5.9-7.3	11.3	28.8	32.3	7.4		1156	10
	3	51 (CPUE ₃)		6.4	4.7-8.3	11.4	29.1	32.4	8.9		1204	30
Total		137	9.7	6.7	4.7-8.9	11.4	29.0	32.4	8.9	-2.5		
1C ¹	1	3		-	-	10.6	29.4	32.1	9.7		2257	0
	2	12		7.6	6.5-9.5	10.6	29.3	32.1	9.2		2304	40
	3	64 (CPUE ₃)		7.2	6.1-8.5	10.5	29.3	32.1	8.3		2310	30
Total		79	5.6	7.3	6.1-9.5	10.6	29.3	32.1	9.1	6.5		
9B	1	9		-	-	12.5	29.6	32.7	6.8		1648	0
	2	39		6.7	5.8-7.7	12.0	30.5	32.6	10.0		1654	0
	3	71 (CPUE ₃)		6.8	5.7-8.7	12.0	30.5	32.6	5.7		1701	0
Total		119	8.4	6.8	5.7-8.7	12.2	30.2	32.6	7.5	4.5		
15C	1	11		6.5	4.3-5.1	14.2	29.4	33.1	7.9		2310	0
	2	93		7.0	7.4-8.7	14.2	29.5	33.1	7.9		2316	0
	3	50 (CPUE ₃)		-	-	14.5	29.5	33.1	15.52		2323	50
Total		154	10.9	6.9	4.3-8.7	14.3	29.5	33.1	10.4	7.0		
29A ¹	1	0		-	-	12.0	29.6	33.0	16.92		1029	100
	2	1		-	-	12.2	29.6	32.9	30.52		1036	100
	3	0 (CPUE ₃)		-	-	12.0	29.6	32.9	10.9		1051	20
Total		1	0.1	-	-	12.1	29.6	32.9	19.4	-2.5		
29C	1	4		-	-	11.7	29.7	32.8	7.9		2113	0
	2	12		7.8	7.0-9.0	12.0	29.6	33.0	8.2		2120	0
	3	26 (CPUE ₃)		8.3	6.1-9.4	12.0	29.7	33.0	7.4		2127	0
Total		42	3.0	8.1	6.1-9.4	11.9	29.7	32.9	7.8	7.5		
7B	1	5		6.0	5.6-6.3	14.8	28.9	34.2	6.8		1435	0
	2	36		6.6	5.3-7.8	14.5	29.0	33.9	8.9		1442	0
	3	25 (CPUE ₃)		7.2	5.6-11.0	14.0	29.1	33.9	6.3		1448	0
Total		66	4.7	6.8	5.3-11.0	14.4	29.0	34.0	7.3	4.5		

¹Plume present.²Plume present with TNFR value significantly greater than control.

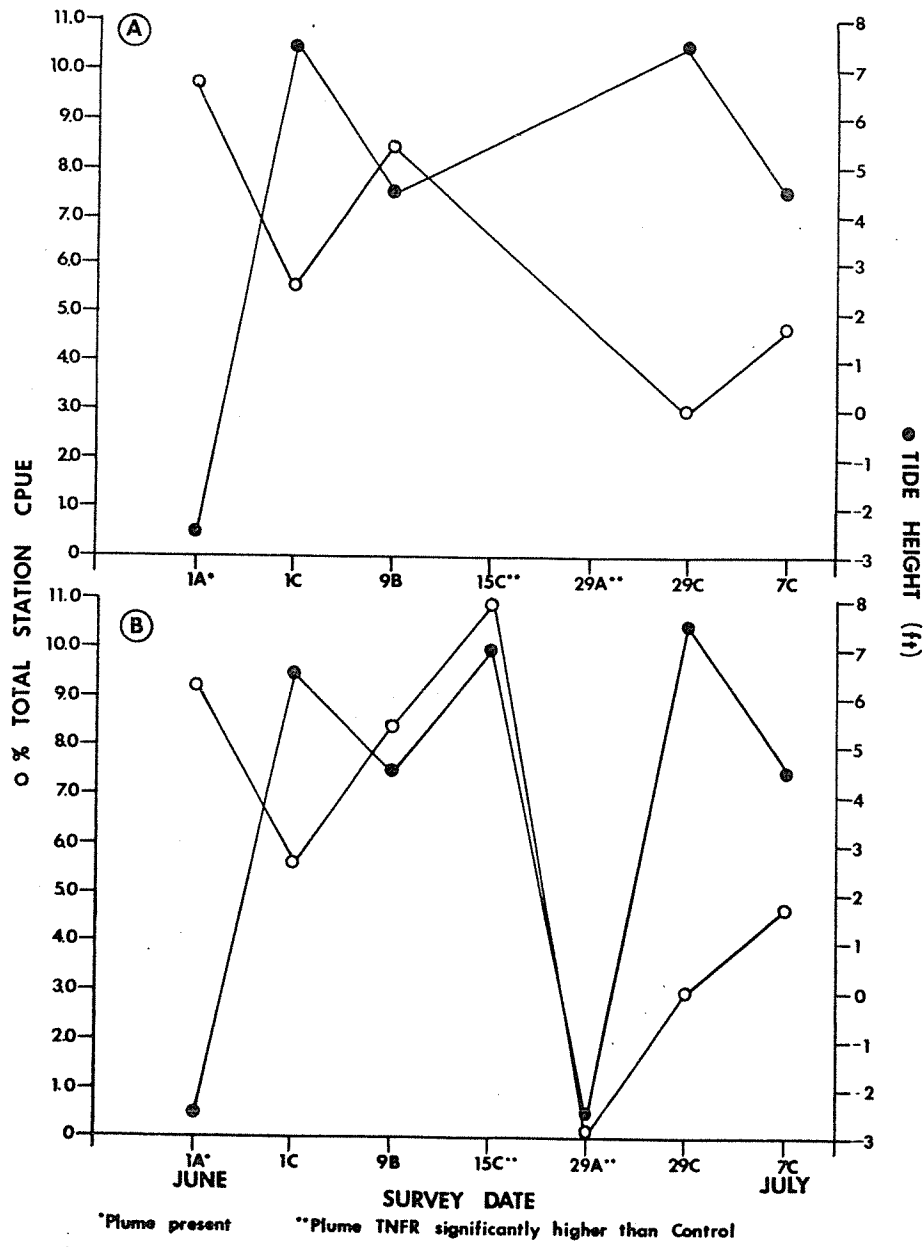


Fig. 7-18. During ebb tide, 5-min townet transects in the Devil's Hole area showed a) an inverse correlation between tide height and Percent Total Station CPUE; however, b) the correlation was disrupted when the plume was present at a TNFR concentration greater than control.

9.8 mg/liter above control. Since this survey was conducted after dark, the juvenile chum salmon may have been more restricted in movements away from the area. During the 29A June survey, significantly fewer fish were present than expected when the TNFR concentration of the plume (30.5 mg/liter) was the highest recorded during the offshore surveys.

7.4.1.3.3.2.2 Flood. Flood tide data collected between June 1 and July 7 are presented in Table 7-17. The plume was present during one (15B June) of the six surveys; however, TNFR values (7.9 to 11.1 mg/liter) were not significantly greater than control (6.5 to 10.0 mg/liter). The single plume survey represented the lowest CPUE₃ (two fish) during the period. However, other data (e.g., % of transect time spent in the plume and environmental variables) did not provide sufficient information to interpret the low CPUE₃ value as indicative of avoidance.

7.4.1.4 Evidence of Avoidance

Based on the inverse correlation between tide height and abundance of chum salmon present in the MWA and the DHA during ebb tide, there is evidence that the chum salmon avoided the plume when the concentration (TNFR) increased between 2.0 and 9.8 mg/liter above control (9B June, 15C and 29A June, DHA). Generally, the data indicated that during dayling juvenile chum salmon abundance decreased with increased TNFR concentrations, since 1) fewer than expected chum salmon were caught during the 9B June survey in the DHA, and 2) avoidance was apparent during the 29A June survey in the DHA when TNFR values were the highest. After dark, the data suggested that chum salmon avoided the plume and accumulated at its periphery (15C June survey). Further suggestions of accumulations at the periphery of the plume were found during the 1B and 9B June surveys in the MWA.

The 1B and 9B June surveys and the 29A June survey in the DHA were the only surveys conducted in which all of the three consecutive 5-min transects were made at least partially in the plume, and at least one of the three transects was conducted entirely in the plume. During the 1B and 9B June surveys in the MWA more chum salmon were caught during the transects during the transects conducted partially in the plume (Tables 7-14 and 7-15). During the 29A June survey in the DHA only one chum salmon was caught--apparently due to the high TNFR concentration of the plume (30.5 mg/liter).

7.4.2 Laboratory

Laboratory tests, conducted between February 2 and May 25, 1977, offered test fish a choice between control and test water. Test water was formed by adding sediment to water pumped directly from the canal during early tests (February 2 to March 16) and to control water during later tests (March 16 to May 15). Since temperature and DO levels

Table 7-17. Devil's Hole area flood tide data.

Date	Transect number	CPUE	% TOT SURV STA CPUE	Fork length (cm)		Temperature °C	Salinity ppt	Conductivity mmhos/cm	TNFR mg/liter	Tide height (ft)	Time (hr)	% plume
				\bar{X}	Range							
1B	1	72		6.8	5.9-10.0	11.3	28.9	32.4	7.9	7.2	1531	0
	2	57		6.9	5.2-8.9	11.2	28.9	32.4	6.7	8.0	1540	0
	3	10		7.3	6.0-8.1	11.3	28.9	32.4	6.9	8.0	1600	0
Total		139 (CPUE ₃)	9.8	6.9	5.2-10.0	11.3	28.9	32.4	7.2	8.0		
9C	1	64		6.9	5.0-8.4	11.5	-	31.6	8.2	8.3	2104	0
	2	31		6.6	4.8-9.5	11.4	-	31.9	8.4	8.0	2110	0
	3	113 (CPUE ₃)		6.9	5.6-8.0	11.6	-	-	8.4	8.0	2125	0
Total		208 (CPUE ₃)	14.7	6.9	4.7-9.5	11.5	-	31.7	8.3	7.0		
15B ¹	1	2		-	-	14.2	29.1	33.0	10.4	9.8	1638	10
	2	0		-	-	14.8	28.8	33.3	7.9	9.5	1644	0
	3	0		-	-	14.8	29.3	33.4	11.1	9.5	1703	60
Total		2	0.1	-	-	14.6	29.1	33.2	9.8	9.5		
29B	1	2		-	-	12.1	29.6	33.0	7.6	8.0	1456	0
	2	3		-	-	12.5	29.7	33.4	7.4	8.0	1502	0
	3	1 (CPUE ₃)		-	-	12.1	29.5	32.7	8.1	8.0	1517	0
Total		6 (CPUE ₃)	0.4	-	-	12.2	29.6	33.0	7.7	8.0		
7A	1	6		6.4	5.6-7.0	14.1	28.9	33.6	8.3	8.0	1034	0
	2	4		-	-	14.2	28.8	33.5	6.5	8.0	1040	0
	3	0		-	-	14.3	28.9	33.6	10.0	8.0	1107	0
Total		10 (CPUE ₃)	0.7	6.4	5.6-7.0	14.2	28.9	33.6	8.3	8.0		
7C	1	13		5.9	5.3-6.9	12.7	29.6	33.2	7.1	8.5	2013	0
	2	4		-	-	12.7	29.4	33.2	7.9	8.5	2019	0
	3	0		-	-	12.6	29.5	33.2	7.0	8.5	2037	0
Total		17 (CPUE ₃)	1.2	5.9	5.3-6.9	12.7	29.5	33.2	7.3	8.5		

¹Plume present.

varied between control and canal water, TNFR was not the only water quality variable between control and test water during the early tests. Consequently, results from these tests could not be used to determine avoidance; however, they did suggest that fish avoided the plume. For example, when test water was pumped from the dredging plume during two tests on February 28, and extra sediments were not added in the laboratory (TNFR = 12.8 and 14.1 mg/liter), the test fish spent 83 and 100% of their time in control water (TNFR = 10.4 and 9.1 mg/liter, respectively). However, it was not certain that test fish preferred the control water because it had lower TNFR levels or because it had lower temperatures (0.8° and 0.6°C less, respectively) and/or higher DO levels (0.8 and 1.1 mg/liter more, respectively). Canal water was not used to form test water after March 16, thereby reducing water quality variations, other than TNFR, between control and test water. Tests conducted between March 16 and April 7 used overburden sediments and tests made from April 7 to May 25 used glacial till sediments added to control water.

7.4.2.1 Overburden Sediments

Sixteen tests were conducted using channel fish and overburden sediments. Generally, there were no significant differences in water quality, except TNFR, among the tests or between control and test water halves of the test chamber per test (Table 7-18). Temperature, salinity, conductivity, pH, and DO ranged from 8.0° to 9.6°C, 28.0 to 29.7 ppt, 30.3 to 32.1 mmhos/cm, 7.8-7.9, and 9.0 to 9.8 mg/liter, respectively. Differences in fish size were also considered negligible. Mean fork length was 4.2 cm, ranging from 3.7 to 4.9 cm; wet weights, ranging from 0.3 to 0.8 g, averaged 0.4 g.

Results are presented in Table 7-19. The 16 tests were separated into four TNFR groups: TNFR values ranging from: a) 25.6 to 30.3; b) 131.4 to 151.6; c) 169.8 to 189.0; and d) 225.0 to 262.0 mg/liter; each group was comprised of four tests (Fig. 7-19). Generally, there was no increased frequency of the avoidance response associated with the higher TNFR groups. Two tests showed significant avoidance (TNFR = 151.6 and 262.0 mg/liter) and one test showed significant preference (TNFR = 181.4 mg/liter).

7.4.2.2 Glacial Till Sediments

Thirty-seven tests were conducted using local fish and glacial till. Variations in water quality, other than TNFR, among and within tests were considered insignificant (Table 7-20). Temperature, salinity, conductivity, pH, and DO ranged from 9.3° to 12.4°C, 27.3 to 30.0 ppt, 31.1 to 32.0 mmhos/cm, 7.9 to 8.2, and 8.8 to 9.9 mg/liter, respectively.

The mean fork length of test fish was 5.2 cm, and ranged from 3.4 to 7.4 cm; wet weights, ranging from 0.3 to 4.7 g, averaged 1.1 g. The

Table 7-18. Water quality and fish data for channel fish exposed to suspended overburden sediments.

Test number	Date	TNFR conc. group	Water quality				pH	DO		X̄ TNFR (mg/liter)	Fish wet weight (g)	Fork length (cm)				
			temperature (°C)	Salinity (ppt)	Conductivity (mmhos/cm)	Clear		Turbid	Clear				Turbid	Clear	Turbid	Clear
1	March	A	8.0	29.1	29.1	30.4	7.8	7.8	9.8	9.8	7.3	25.6	0.3	0.3-0.4	4.1	3.9-4.3
			8.4	29.3	29.3	31.0	7.8	7.8	9.7	9.7	7.4	30.3	0.4	0.3-0.6	4.2	3.8-4.9
			8.8	29.7	29.7	32.1	7.8	7.8	-	-	10.5	25.8	0.3	0.3-0.4	4.1	3.9-4.3
			8.2	29.3	29.3	31.5	7.8	7.8	-	-	11.4	28.2	0.4	0.3-0.5	4.2	3.9-4.5
			8.5	28.6	28.6	30.6	7.8	7.8	9.2	9.2	7.9	228.8	0.3	0.3-0.4	4.1	3.9-4.2
			8.8	28.4	28.4	30.7	7.8	7.8	-	-	5.8	151.6	0.4	0.3-0.7	4.3	3.9-4.9
			8.9	28.3	28.3	30.8	7.8	7.8	-	-	5.1	142.4	0.4	0.3-0.4	4.1	3.8-4.3
			8.5	28.6	28.6	30.6	7.8	7.8	9.4	9.4	7.0	169.8	0.4	0.3-0.7	4.2	3.9-4.3
			8.8	28.6	28.6	30.9	7.8	7.8	9.4	9.4	5.8	134.0	0.4	0.4-0.5	4.2	4.1-4.3
			9.2	28.6	28.6	31.1	7.8	7.8	9.4	9.4	5.8	131.4	0.4	0.4-0.6	4.3	4.0-4.7
			8.8	28.6	28.6	30.8	7.8	7.8	9.5	9.5	4.8	189.0	0.4	0.3-0.5	4.2	3.9-4.4
			8.5	29.2	29.2	31.2	7.8	7.8	9.5	9.5	6.0	181.4	0.4	0.3-0.5	4.0	3.7-4.4
			8.8	28.0	28.0	30.3	7.8	7.8	9.2	9.2	9.0	250.4	0.4	0.3-0.4	4.1	3.9-4.3
			8.9	28.0	28.0	30.3	7.8	7.8	9.0	9.0	10.1	169.8	0.4	0.3-0.5	4.1	3.8-4.3
			9.6	28.3	28.3	30.5	7.9	7.9	9.5	9.5	8.9	225.0	0.5	0.4-0.8	4.4	4.1-4.9
			9.6	28.5	28.5	31.6	7.9	7.9	9.5	9.5	10.9	262.0	0.5	0.4-0.7	4.3	4.1-4.6

Table 7-19. Comparison of avoidance or preference for different overburden TNFR concentration groups based on percent of time channel fish spent in clear water. Values significantly greater than control (theoretically, 50%) indicate avoidance; preference indicated by values significantly less than control.

Test number	Date	TNFR concentration group	\bar{X} test TNFR (mg/liter)	\bar{X} group TNFR (mg/liter)	% time spent clear water (side B) ¹		\bar{X} Test		
					Control	Test			
March									
1	16	A	25.6	27.5	49	55	53		
3	17		25.8		48	50			
4	18		28.2		47	52			
2	17		30.3		53	54			
B									
10	24		131.4	139.8	48	45	56		
9	24		134.0		59	42			
7	23		142.4		53	55			
6	23		151.6		58	A 81			
C									
8	24		169.8	177.5	54	48	44		
14	30		169.8		54	59			
12	30		181.4		54	P 20			
11	25		189.0		52	49			
April									
15	6	D	225.0	241.6	59	53	67		
March									
5	23		228.8		49	63			
13	30		250.4		54	53			
April									
16	7		262.0		49	A 98			

¹ A = significant avoidance;
P = significant preference.

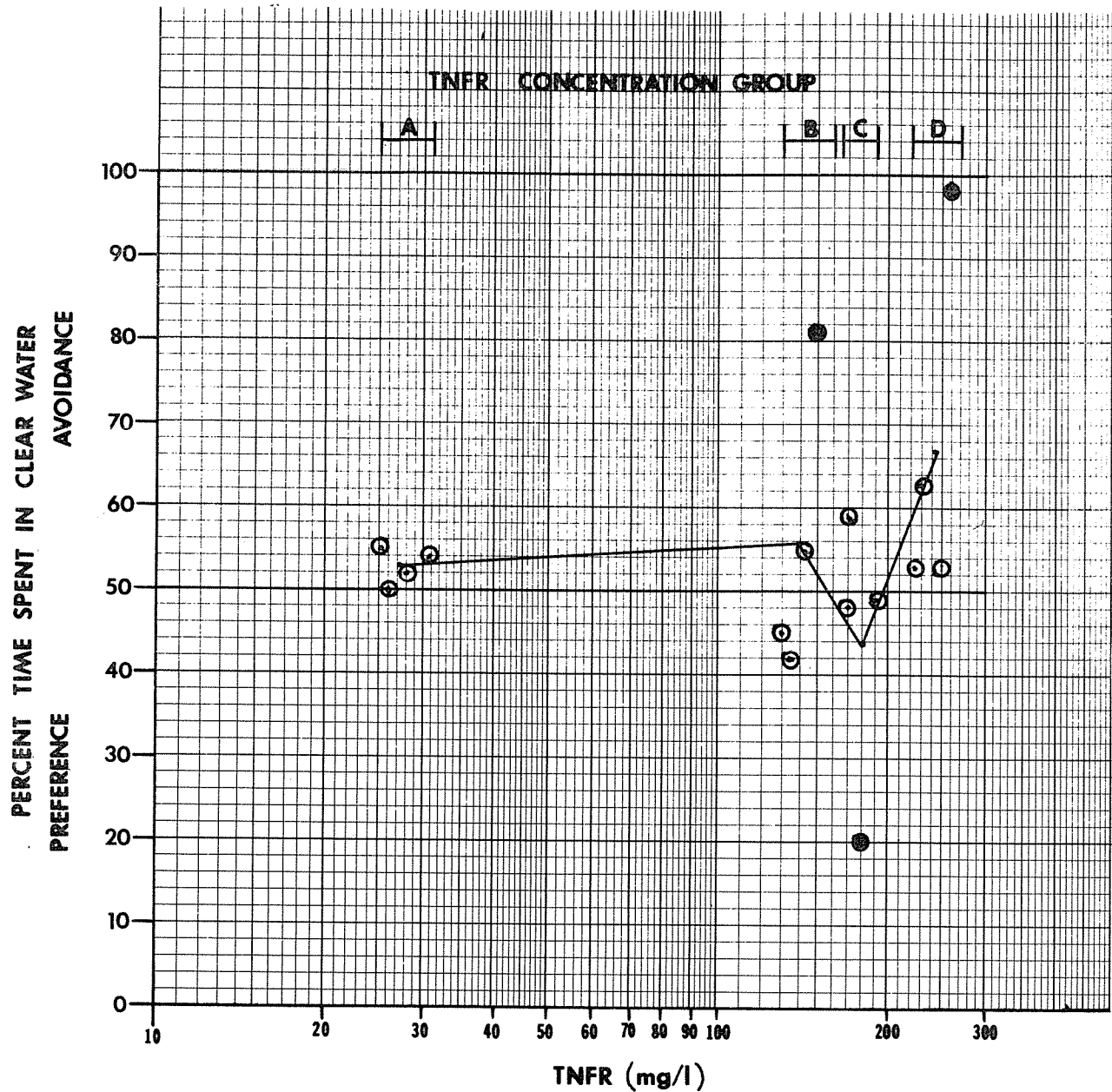


Fig. 7-19. Avoidance of suspended overburden sediments by channel fish. Solid points represent statistically significant responses, open points are nonsignificant responses. The line depicts the mean values per TNFR concentration group, which are shown above the graph.

Table 7-20. Water quality and fish data for local fish exposed to suspended glacial flour.

Test number	Date	TNFR Water quality		Salinity (ppt)		Conductivity (mmhos/cm)		pH		DO (mg/liter)		TNFR (mg/liter)		Fish wet weight (g)		Fork length (cm)		
		concentration (°C)	Clear	Turbid	Clear	Turbid	Clear	Turbid	Clear	Turbid	Clear	Turbid	Clear	Turbid	Clear	Turbid	Clear	Turbid
April																		
1	7	10.8	10.6	27.3	27.3	31.1	31.1	7.9	7.9	9.6	9.6	8.2	37.4	0.4	0.3-0.5	4.2	3.9-4.4	
2	18	10.4	10.4	29.2	29.2	31.6	31.6	8.0	8.0	9.4	9.4	5.1	41.3	0.6	0.3-0.8	4.3	3.5-5.4	
3	18	10.4	10.4	29.2	29.2	31.6	31.6	8.0	8.0	9.9	9.9	7.4	38.6	0.5	0.3-0.8	4.2	3.9-4.7	
4	19	9.8	9.8	29.6	29.6	32.0	32.0	8.0	8.0	9.6	9.6	6.8	35.4	0.5	0.4-0.6	4.3	4.1-4.5	
5	19	9.6	9.6	29.0	29.0	31.6	31.6	8.1	8.1	9.6	9.6	5.0	37.0	0.4	0.3-0.5	4.2	3.9-4.4	
6	25	9.3	9.3	29.8	29.8	31.6	31.6	8.1	8.1	9.8	9.8	4.2	170.2	0.4	0.3-0.6	4.2	4.0-4.5	
7	26	11.3	11.3	29.0	29.0	31.6	31.6	8.2	8.2	9.4	9.4	8.6	175.6	0.6	0.4-0.9	4.5	4.2-5.1	
8	26	11.3	11.3	29.0	29.0	31.8	31.8	8.2	8.2	9.6	9.6	8.8	158.0	0.5	0.4-0.6	4.4	4.1-4.8	
9	29	11.2	11.2	29.6	29.6	31.7	31.7	8.1	8.1	9.4	9.4	6.7	144.0	0.4	0.3-0.5	4.0	3.4-4.4	
10	29	11.8	11.8	29.6	29.8	31.8	31.8	8.1	8.1	9.2	9.2	6.5	165.6	0.5	0.3-0.5	4.1	3.9-4.4	
May																		
11	3	11.0	11.0	29.5	29.5	-	-	8.1	8.1	9.1	9.1	5.4	269.1	0.5	0.4-0.6	4.1	3.9-4.4	
12	3	11.2	11.2	30.0	30.0	-	-	8.1	8.1	9.0	9.0	6.2	277.0	0.5	0.4-0.8	4.2	3.9-4.8	
13	4	10.5	10.7	29.3	29.3	-	-	8.0	8.0	9.4	9.4	11.6	326.2	0.6	0.4-0.8	4.6	4.0-4.7	
14	5	11.0	11.1	29.0	29.0	-	-	8.0	8.0	9.2	9.2	12.1	284.6	0.6	0.4-0.8	4.5	4.0-4.8	
15	9	12.0	12.0	29.0 ¹	29.0	Discontinued	Discontinued	8.0	8.0	8.8	8.8	15.3	303.6	0.9	0.6-1.5	4.9	4.1-5.9	
16	9	12.1	12.2	29.0	29.0	-	-	8.1	8.1	8.8	8.8	15.2	441.2	0.9	0.5-1.7	5.0	4.3-6.2	
17	10	10.7	10.4	30.0	30.0	-	-	8.0	8.0	9.0	9.1	10.5	684.8	0.9	0.6-1.5	5.3	4.7-5.8	
18	10	10.9	11.1	29.0	29.0	-	-	8.0	8.0	9.2	9.1	10.0	669.2	1.1	0.6-1.7	5.6	4.8-6.2	
19	10	10.8	11.0	29.0	29.0	-	-	8.1	8.0	9.0	9.4	10.0	640.0	1.3	0.7-1.8	5.6	4.8-6.4	
20	12	10.4	10.5	30.0	30.0	-	-	8.0	8.0	9.3	9.8	7.8	565.4	1.1	0.7-1.4	5.3	4.7-5.8	
21	12	12.2	12.4	30.0	30.0	-	-	8.0	8.0	8.8	9.1	10.6	478.0	1.2	0.7-1.8	5.5	4.7-6.3	
22	16	10.8	10.9	29.0	29.0	-	-	7.9	7.9	9.2	9.0	7.5	688.0	1.1	0.7-1.5	5.3	4.5-6.2	
23	16	11.0	11.2	29.0	29.0	-	-	8.0	8.0	9.1	9.0	7.4	701.6	1.1	0.8-1.7	5.4	4.8-6.3	
24	17	10.8	11.0	29.0	29.0	-	-	7.9	7.9	9.2	9.2	6.9	142.0	1.9	0.9-3.6	6.4	5.1-7.2	
25	17	11.1	11.2	30.0	30.0	-	-	7.9	7.9	9.2	9.2	7.5	123.0	1.9	1.0-2.4	6.5	5.3-6.8	
26	19	10.8	10.9	29.0	29.0	-	-	8.0	8.0	9.1	8.9	8.3	117.0	2.1	1.3-2.7	6.6	5.8-7.2	
27	19	11.0	11.0	29.0	29.0	-	-	8.0	8.0	9.1	9.1	8.3	107.8	1.8	1.1-2.1	6.3	5.6-6.7	
28	19	11.8	12.0	29.0	29.0	-	-	8.0	8.0	9.2	9.1	8.6	121.9	2.2	1.2-4.7	6.7	5.8-7.2	
29	20	11.2	11.1	29.0	29.0	-	-	8.1	8.1	9.2	9.0	7.0	90.4	2.3	1.7-2.7	6.7	6.0-7.4	
30	23	10.9	11.0	29.0	29.0	-	-	8.0	8.0	8.9	8.9	7.6	486.0	1.2	0.7-2.2	5.6	4.9-6.4	
31	24	10.8	10.9	29.0	29.0	-	-	8.0	8.0	8.9	9.0	6.8	690.0	1.2	0.7-1.7	5.5	4.5-6.5	
32	24	10.9	10.9	29.0	29.0	-	-	8.0	8.0	9.0	9.0	7.8	488.2	1.2	0.8-1.7	5.6	4.9-6.4	
33	24	10.8	11.0	29.0	29.0	-	-	8.0	8.0	9.0	9.0	7.7	536.0	1.8	1.1-2.5	6.4	5.4-7.1	
34	24	11.0	11.0	29.0	29.0	-	-	8.0	8.0	8.9	9.3	7.9	117.1	1.4	0.6-2.1	6.4	4.5-7.0	
35	24	11.2	11.1	29.0	29.0	-	-	8.0	8.0	8.9	9.0	8.2	92.2	1.2	0.8-2.5	5.6	4.9-7.3	
36	25	11.5	11.5	30.0	30.0	-	-	7.9	7.9	9.2	9.2	7.3	80.8	1.1	0.6-1.6	5.5	4.3-6.4	
37	25	11.6	11.4	30.0	30.0	-	-	7.9	7.9	9.1	9.2	8.5	67.6	1.4	0.5-2.5	6.0	5.2-6.8	

¹ Salinometer replaced with refractometer.

variation in fish size may be a complicating factor, should larger fish respond differently than smaller fish encountering sediments.

Results are presented in Table 7-21. Despite wide ranges of TNFR values, tests were separated into seven groups: TNFR values ranging from: a) 35.4 to 41.3; b) 67.6 to 92.2; c) 107.8 to 144.0; d) 158.0 to 175.6; e) 269.1 to 326.2; f) 441.2 to 565.4; and g) 640.0 to 701.6 mg/liter (Fig. 7-20). Generally, there was no consistent increase in the frequency of the avoidance response associated with the higher TNFR groups. Twelve tests showed significant avoidance; 90.4 mg/liter was the lowest TNFR value associated with an avoidance response. One test (TNFR = 142.0 mg/liter) showed significant preference.

Stratification within the test water during tests using higher concentrations of suspended sediments created a relatively clear layer near the water surface. Since most fish were observed to be less than 7.0 cm from surface in the test water, they may have been exposed to TNFR concentrations less than those recorded (TNFR samples siphoned from 7.0 cm below surface). A series of TNFR samples siphoned from 3.0 and 7.0 cm below surface showed a significant difference (Table 7-22; Fig. 7-21) and these values were used to adjust the TNFR values recorded during the behavior tests (Table 7-23).

Results with adjusted TNFR values are presented in Table 7-24. Tests were separated into four groups: TNFR values ranging from: a) 35 to 40; b) 55 to 80; c) 115 to 150; and d) 170 to 190 mg/liter, despite unequal numbers of tests per group (Fig. 7-22). There was an increased frequency of the avoidance response associated with increased concentration of suspended sediments; the lowest concentration to induce avoidance was 55 mg/liter. These results were used to determine threshold avoidance.

7.4.2.3 Threshold Avoidance

Buerkle (1967) defined threshold as, "that stimulus intensity at which a positive response can be expected in 50% of the presentations" (in Sprague 1968). Based on this definition and the net percentage of tests showing significant avoidance (Table 7-25), 182 mg/liter would be the threshold avoidance concentration of glacial till for local fish. This value is considered a conservative estimate for four reasons:

- 1) Test fish appeared to prefer the upper layer of the test water which was stratified, and siphoning for TNFR samples created a vortex which sucked water from the lower, more concentrated regions of the test water. Therefore, the TNFR value that was recorded for each test was probably not the concentration of sediments that the test fish encountered.

- 2) A group of 10 fish in the laboratory may respond to stimuli differently than in situ fish in a large school. Test fish probably lacked migratory motivation since they were in captivity for 7 to 14 days before testing and migrating fish would be expected to have higher

Table 7-21. Comparison of avoidance or preference for different glacial till TNFR concentration groups based on percent of time local fish spent in clear water. Values significantly greater than control indicate avoidance; preference indicated by values significantly less than control.

Test number	Date	TNFR conc. group	\bar{X} Test TNFR (mg/liter)	\bar{X} Group TNFR (mg/liter)	% time spent clear water (side B) ¹		\bar{X} Control Test	\bar{X} Test
April								
4	19	A	35.4	37.9	52	58	59	
5	19		37.0		54	62		
1	7		37.4		56	60		
3	18		38.6		55	62		
2	18		41.3		58	53		
May								
37	25	B	67.6	82.7	47	52	61	
36	25		80.8		52	43		
29	20		90.4		53 A	81		
35	24		92.2		50 A	68		
C								
27	19		107.8	124.7	47	39	43	
26	19		117.0		55	48		
34	24		117.1		52 A	80		
28	19		121.9		51	39		
25	17		123.0		50	38		
24	17		142.0		48 P	15		
9	29 Apr		144.0		56	45		
D								
8	26		158.0	167.3	47 A	97	80	
10	29		165.6		56 A	71		
6	25		170.2		50	55		
7	26		175.6		65 A	98		
E								
11	3		269.1	292.1	60	69	61	
12	3		277.0		52 A	82		
14	5		284.6		53	63		
15	9		303.6		53	48		
13	4		326.7		53	45		
F								
16	9		441.2	499.1	51	62	66	
21	12		478.0		47	61		
30	23		486.0		50	61		
32	24		488.0		50 A	76		
33	24		536.0		56 A	88		
20	12		565.4		51	47		
G								
19	10		640.0	678.9	47 A	90	71	
18	10		669.2		52 A	72		
17	10		684.8		48	50		
22	16		688.0		61	67		
31	24		690.0		54	60		
23	16		701.6		53 A	86		

¹ A = significant avoidance;
P = significant preference.

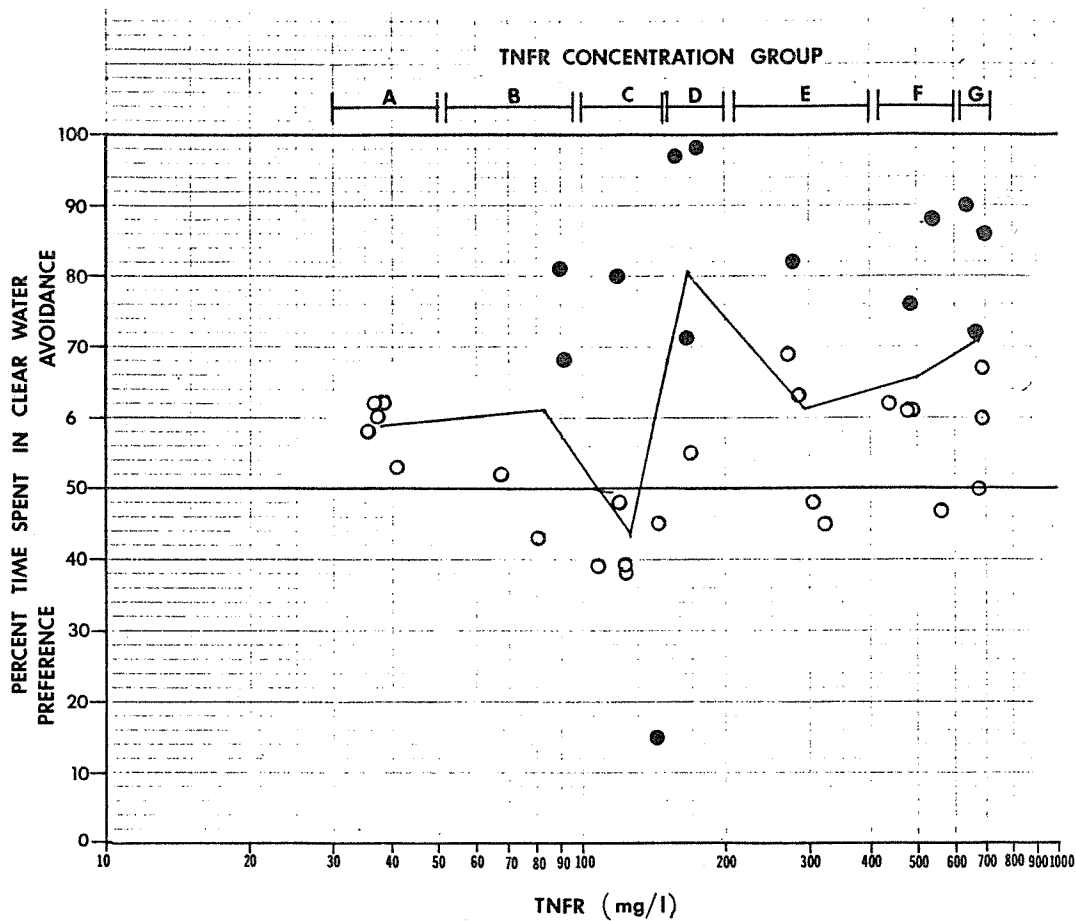


Fig. 7-20. Avoidance of suspended glacial till sediments by local fish. Solid points represent statistically significant responses, open points are nonsignificant responses. The line depicts mean values per TNFR concentration group, which are shown above the graph.

Table 7-22. Results of stratification tests comparing TNFR concentrations from 7.0 and 3.0 cm below surface in behavior chamber.

Ml stock sediment added to sediment mixture tank	Trial number	TNFR (mg/liter)			
		7.0 cm depth \bar{X}	3.0 cm depth \bar{X}		
25 ml	1	39.4	39.3	41.2	39.6
	2	36.5		37.2	
	3	42.5		40.9	
	4	38.9		39.2	
100	1	106.0	112.9	87.6	83.7
	2	109.2		82.6	
	3	120.4		84.7	
	4	115.9		79.8	
500	1	160.0	176.1	42.6	50.9
	2	199.8		64.8	
	3	169.7		48.2	
	4	174.9		47.9	
1000	1	282.0	297.8	75.6	73.9
	2	311.0		67.0	
	3	294.7		81.4	
	4	303.6		71.8	
2000	1	812.8	847.8	194.0	228.3
	2	896.4		292.4	
	3	860.1		224.9	
	4	821.0		202.3	

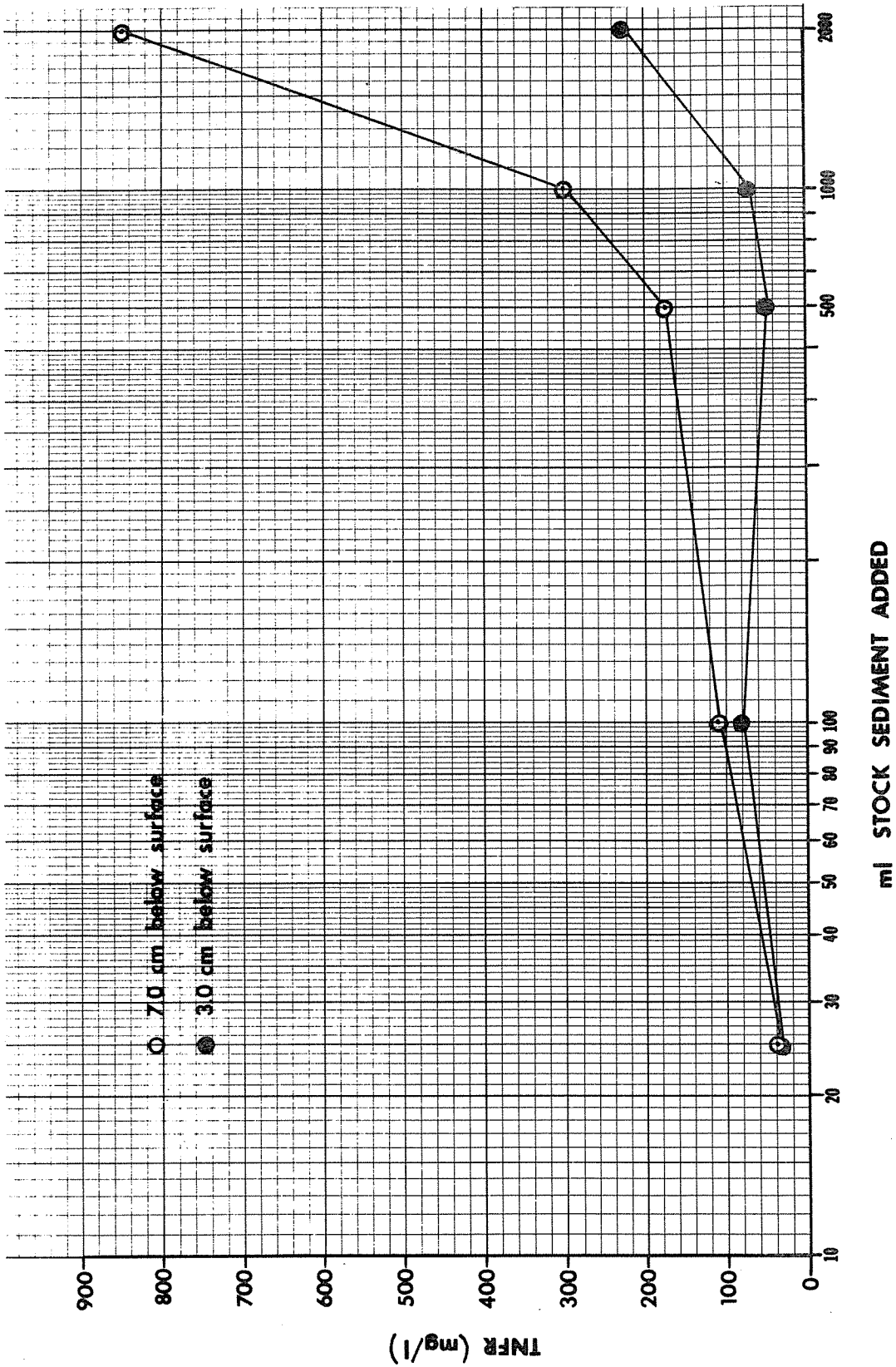


Fig. 7-21. Comparison of TNFR values siphoned from 7.0 and 3.0 cm below surface in the test chamber using glacial till sediments. This figure was used to adjust the TNFR values recorded during behavior tests (Table 7-23).

Table 7-23. Presentation of adjusted TNFR concentrations that test fish may have been exposed to; adjusted values were extrapolated from Fig. 7-30 which illustrates results from a series of stratification tests.

Test number	Recorded 7.0 cm TNFR (mg/liter)	Adjusted 3.0 cm TNFR (mg/liter)
4	35.4	35
5	37.0	35
1	37.4	35
3	38.6	40
2	41.3	40
37	67.6	55
36	80.8	65
29	90.4	70
35	92.2	70
27	107.8	80
26	117.0	80
34	117.1	80
28	121.9	80
25	123.0	80
24	142.0	70
9	144.0	70
8	158.0	60
10	165.6	60
6	170.2	55
7	175.6	55
11	269.1	65
12	277.0	65
14	284.6	70
15	303.6	75
13	326.2	80
16	441.2	115
21	478.0	120
30	486.0	130
32	488.0	130
33	536.0	140
20	565.4	150
19	640.0	170
18	669.2	180
17	684.8	185
22	688.0	185
31	690.0	185
23	701.6	190

Table 7-24. Comparison of avoidance or preference of adjusted glacial till. TNFR concentration groups based on percent of time local fish spent in clear water. Values significantly greater than control indicate avoidance; preference indicated by values significantly less than control.

Test Number	Date	TNFR conc group	\bar{X} Test TNFR (adjusted) (mg/liter)	\bar{X} Group TNFR (mg/liter)	% time spent clear water (side B) ¹		\bar{X} Test
					Control	Test	
1		A	35	37	56	60	59
4			35		52	58	
5			35		54	62	
2			40		58	53	
3			40		55	62	
6		B	55		50	55	
7			55	69	65	A 98	59
37			55		47	52	
8			60		47	A 97	
10			60		56	A 71	
11			65		60	69	
12			65		52	A 82	
36			65		52	43	
9			70		56	45	
14			70		53	63	
24			70		48	P 15	
29			70		53	A 81	
35			70		50	A 68	
15			75		53	48	
13			80		53	45	
25			80		50	38	
26			80		55	48	
27			80		47	39	
28			80		51	39	
34			80		52	A 80	
16		C	115	131	51	62	66
21			120		47	61	
30			130		50	61	
32			130		50	A 76	
33			140		56	A 88	
20			150		51	47	
19		D	170	182	47	A 90	71
18			180		52	A 72	
17			185		48	50	
22			185		61	67	
31			185		54	60	
23			190		53	A 86	

¹A = significant avoidance;
P = significant preference.

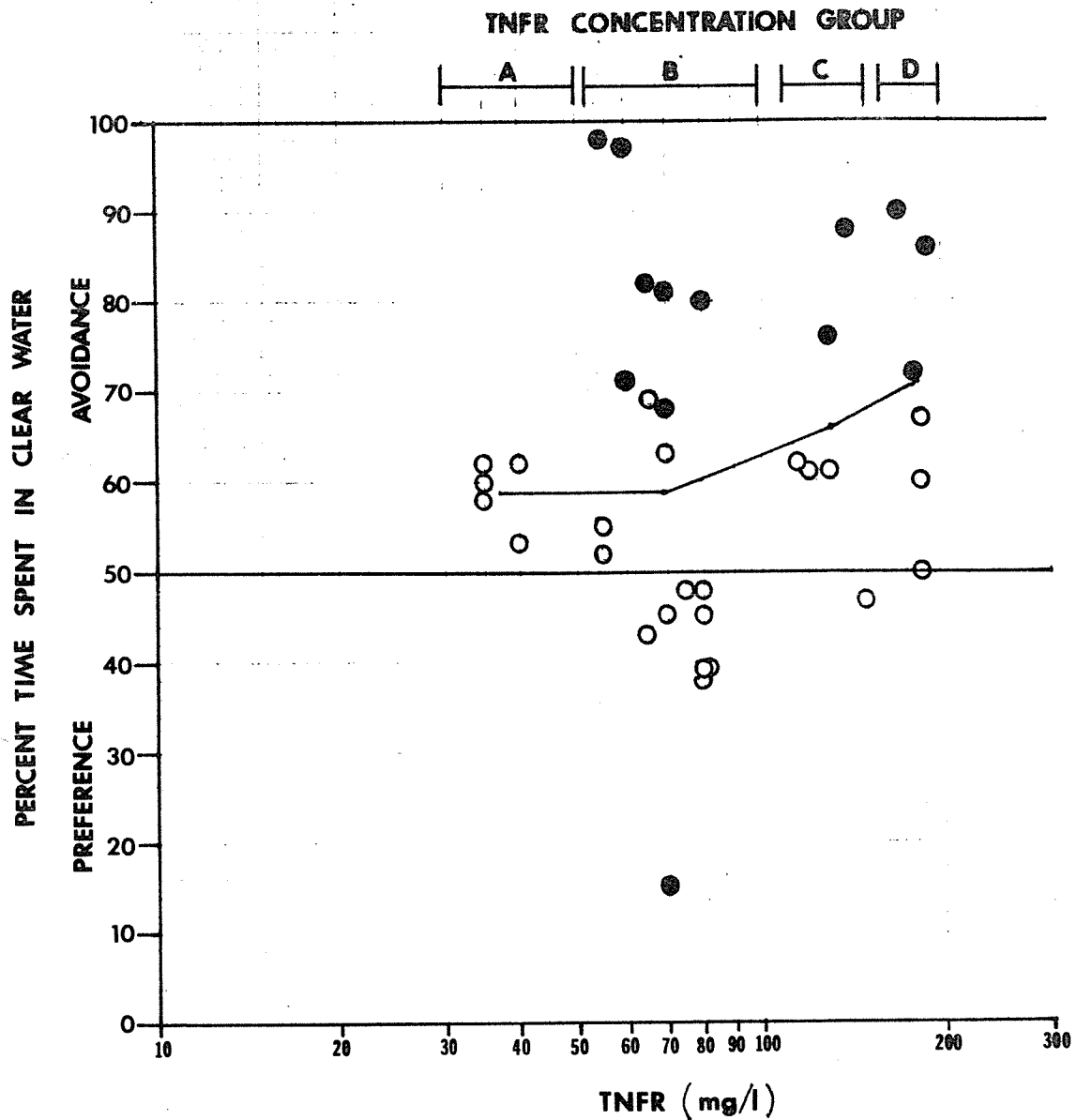


Fig. 7-22. Avoidance of suspended glacial till sediments by local fish, based on adjusted TNFR values. Solid points represent statistically significant responses, open points are nonsignificant responses. The line depicts mean values per TNFR concentration group, which are shown above the graph.

Table 7-25. Determination of threshold avoidance concentration of glacial till based on the net percentage of tests showing significant avoidance.

TNFR concentration group	\bar{X} TNFR group (mg/liter)	(a)	(b)	(c)	Net % of tests showing significant avoidance (a-b/c)
		No. of tests showing significant avoidance	No. of tests showing significant preference	No. of total tests	
A	37	0	0	5	0
B	69	7	1	20	30
C	131	2	0	6	33
D	182	3	0	6	50

threshold concentrations for avoidance of pollutants (Sprague et al. 1965).

3) Field results indicated avoidance of plume water containing TNFR concentrations between 2.0 and 9.8 mg/liter greater than control levels (Section 7.4.1.3.3). Also, results from two laboratory tests on February 28 (Section 7.4.2) suggested avoidance of plume water with a TNFR concentration of 2.4 and 5.0 mg/liter greater than control water, although temperature and DO levels also varied between plume and control water.

4) Recent laboratory studies have indicated that the avoidance response is subtle and unless sophisticated facilities are available (e.g., video tapes analyzed by computers) the response may not be detected until it is severe (Cairns, personal communication with Salo, 1978).⁵

The avoidance of turbid water appeared to be caused directly by the concentration of suspended sediments, and not indirectly by the concentration of ionic metals (Table 7-26), decomposition waste products (see Section 4.0), or DO (Table 7-20).

7.5 SUMMARY

1) Field surveys and laboratory tests were conducted to determine if juvenile chum salmon would avoid sediments suspended during dredging in the Bangor Annex area.

2) Field surveys, conducted from March 16 to July 20, 1977, sampled the dredge area for water quality and abundance of fish using three capture techniques: a) beach seine; b) 10-min townet; and c) 5-min townet transects.

3) There were two peaks in fish abundance: one occurred in late April and was comprised primarily of nearshore fish caught by the beach seine; the second peak extended from late May to early July and was comprised primarily of offshore fish caught by the townet.

4) The periods from late April to mid-June and from late June to early July were selected for analysis of beach seine and townet data, respectively. Beach seine and 10-min townet data provided no evidence of avoidance, however, data collected during the 5-min townet transects indicated fish avoided the plume.

⁵Cairns, John, Jr., Virginia Polytechnic Institute and State Univ.; Salo, Ernest O., Univ. Washington, Fish. Res. Inst.

Table 7-26. The concentrations of ionic metals in 190 mg/liter of glacial till were less than the reported threshold avoidance concentrations for salmon parr or the LC₅₀ value for salmonids in marine water times an application factor of 0.01.

Ionic metals	Concentration of ionic metals in glacial till (mg/liter)	Laboratory threshold avoidance concentration for salmon parr (Sprague et al. 1965) (mg/liter)	LC ₅₀ x 0.01 for salmonids in marine water (EPA, 1973) (mg/liter)		
			24 hr	48 hr	96 hr
Cadmium	$< 3.8 \times 10^{-5}$		3.0×10^{-1}		
Chromium ¹	4.6×10^{-4}				6.9×10^{-1}
Copper	2.6×10^{-4}	2.4×10^{-3}			
Lead	$< 1.8 \times 10^{-2}$			3.4×10^{-3}	
Manganese	1.0×10^{-3}				1.4×10^{-1}
Nickel	3.5×10^{-4}			2.5×10^{-1}	
Zinc	2.6×10^{-4}	5.4×10^{-2}			
Zinc & copper	5.4×10^{-4}	1.3×10^{-2}			

¹Hexavalent.

5) In areas surveyed by the 5-min townet transects, fish abundance was correlated with tide height during ebb tide when the plume was not present. However, during ebb tide when the plume increased the TNFR concentration of water between 2.0 and 9.8 mg/liter above control, fish abundance was not correlated with tide height, indicating avoidance of the plume.

6) There was an indication that fish avoiding the plume may disperse during daylight but tend to accumulate outside the plume after dark.

7) Fish abundance in the MWA appeared to be related to the overall abundance of fish in the Bangor Annex area but fish in the DHA did not.

8) Laboratory tests, conducted from March 16 to May 25, 1977, used channel and local fish exposed to overburden and glacial till sediments, respectively.

9) From sixteen tests using overburden sediments it was concluded that no significant avoidance response was associated with increased TNFR concentrations between 25.6 and 262.0 mg/liter.

10) Twelve of the 37 glacial till tests showed significant avoidance; however, there was no consistent increase in the frequency of the avoidance response associated with increased TNFR concentrations between 35.4 and 701.6 mg/liter, measured at 7.0 cm below surface.

11) Test fish were exposed to TNFR concentrations less than those recorded since the test water was stratified and fish appeared to prefer the water less than 7.0 cm below surface, where the TNFR samples were siphoned. A series of TNFR samples, siphoned from 3.0 cm below surface, was used to adjust the TNFR values recorded during the glacial till tests.

12) Results of glacial till tests, using adjusted TNFR values, indicated an increased frequency of the avoidance response associated with increased TNFR concentrations between 35 and 190 mg/liter.

13) The threshold avoidance concentration of glacial till for local fish was determined to be 182 mg/liter; however, this value was considered a conservative estimate.

14) Field and laboratory avoidance of suspended sediments appeared to be caused by the concentration of the sediments and not by the concentration of contaminants associated with the sediments.

7.6 ACKNOWLEDGMENTS

I would like to thank Nic Bax and the entire outmigration crew for their patience and cooperation throughout the tedious, extra townetting and beach seining required for the field surveys.

8.0 DISEASE MONITORING

conducted by

John R. MacMillan, Douglas Ross, and Stephen C. Crumley

and compiled by

Thomas E. Prinslow

8.1 INTRODUCTION

The outbreak of disease within populations is dependent upon the interaction of host, pathogen, and environment (Wedemeyer 1970). The disease study proposed to determine:

- 1) whether increased concentrations of suspended sediments from dredging might stress outmigrating chum salmon sufficiently to lower their disease resistance, particularly to vibriosis, by monitoring the incidence of disease among chum groups exposed to test and control environments;
- 2) the effects of holding juvenile chum salmon in pens (Section 3.0); and
- 3) the effectiveness of vaccination in reducing disease and mortality of juvenile chum (presented in Appendix III).

8.2 MATERIALS AND METHODS

8.2.1 Fish Sampled

Disease incidence was monitored in three "populations": local chum salmon juveniles from weekly beach seining in the Bangor Annex area (Fig. 3.1); holding pen chums transferred from local hatcheries for use in bioassays (Section 4.0); and bioassay chums sampled during and at completion of each bioassay. Weekly samples included 60 local fish; 60 fish from the test populations used each week in the Flow-through and Live-box Bioassays (Sections 5.0 and 6.0), analyzed prior to the bioassays; and 60 bioassay fish (30 from Flow-through, 30 from Live-box) analyzed at completion of the bioassay. Holding pen fish were not sampled regularly until the isolated pen study (June 29 onward).

Sampling of local fish migrating through the test area provided an index of health with time. The length of exposure to the plume was unknown. Bioassay fish were exposed to test conditions, but were subject to unnatural handling and confinement. Thus, disease of bioassay fish could reflect stress from both dredging and confinement.

To quantify effects of confinement, during June and July holding procedures were modified from the previous eight-pen raft (Fig. 3-6) by

isolating individual pens (Fig. 8-1) and by varying the number of chum salmon held per pen, i.e., the fish "density" (Table 8-1).

8.2.2 Disease Identification Techniques

Bacterial isolates were obtained by streaking kidney tissue onto trypticase soy agar (TSA) and TSA + 2.0% NaCl. Frozen chum juveniles were thawed immediately prior to disease analysis. Isolates were identified to the nearest taxa possible.

The following identification tests were performed on isolated colonies: gram stain; Kovac's cytochrome oxidase; motility (hanging drop and motility agar); oxidation/fermentation of glucose; sensitivity to 0/129 (2,4-diamino-6,7 di-isopropyl pteridine phosphate) and novobiocin; and pigment production. Lyophilized antisera obtained from the Eastern Fish Disease Laboratory was reconstituted and used in slide agglutination tests to confirm isolates of Vibrio anguillarum (Manchester strain) and Aeromonas salmonicida.

Blood smears were made from spawning adults at Big Beef Creek Hatchery and from outmigrating chum. Wright-Gemsa stain was used to detect the presence of inclusions in erythrocytes associated with Piscine Erythrocytic Necrosis Virus (PENV).

8.3 RESULTS AND DISCUSSION

8.3.1 Bioassays

The results of the routine disease monitoring (point 1 under Section 8.1) are presented in the bioassay reports: Static (Section 4.0), Flow-through (Section 5.0), and Live-box (Section 6.0).

8.3.2 Local Populations of Chum Fry

Local populations were sampled from March 25 to July 25, 1977. Confirmed isolates of Vibrio anguillarum (vibriosis), Aeromonas salmonicida (furunculosis) and Pseudomonas spp. (bacterial hemorrhagic septicemia [BHS]) were obtained from only 18 of the 1,002 fish examined (Table 8-2). Apparently local fish were, for the most part, "healthy" throughout the course of the project.

8.3.3 Nonisolated Raft Pens

Although less than 2% of local chum outmigrants sampled from March to July had confirmed disease (Table 8-2), Vibrio were detected by mid-June in holding pen populations (Table 8-3) and bioassays (Section 6.0, Table 6-6). Disease incidence increased to 100% by June 30, at which point the raft configuration was abandoned in favor of isolated pens. Stress from crowded holding conditions (Wolke 1975) and from capture and handling

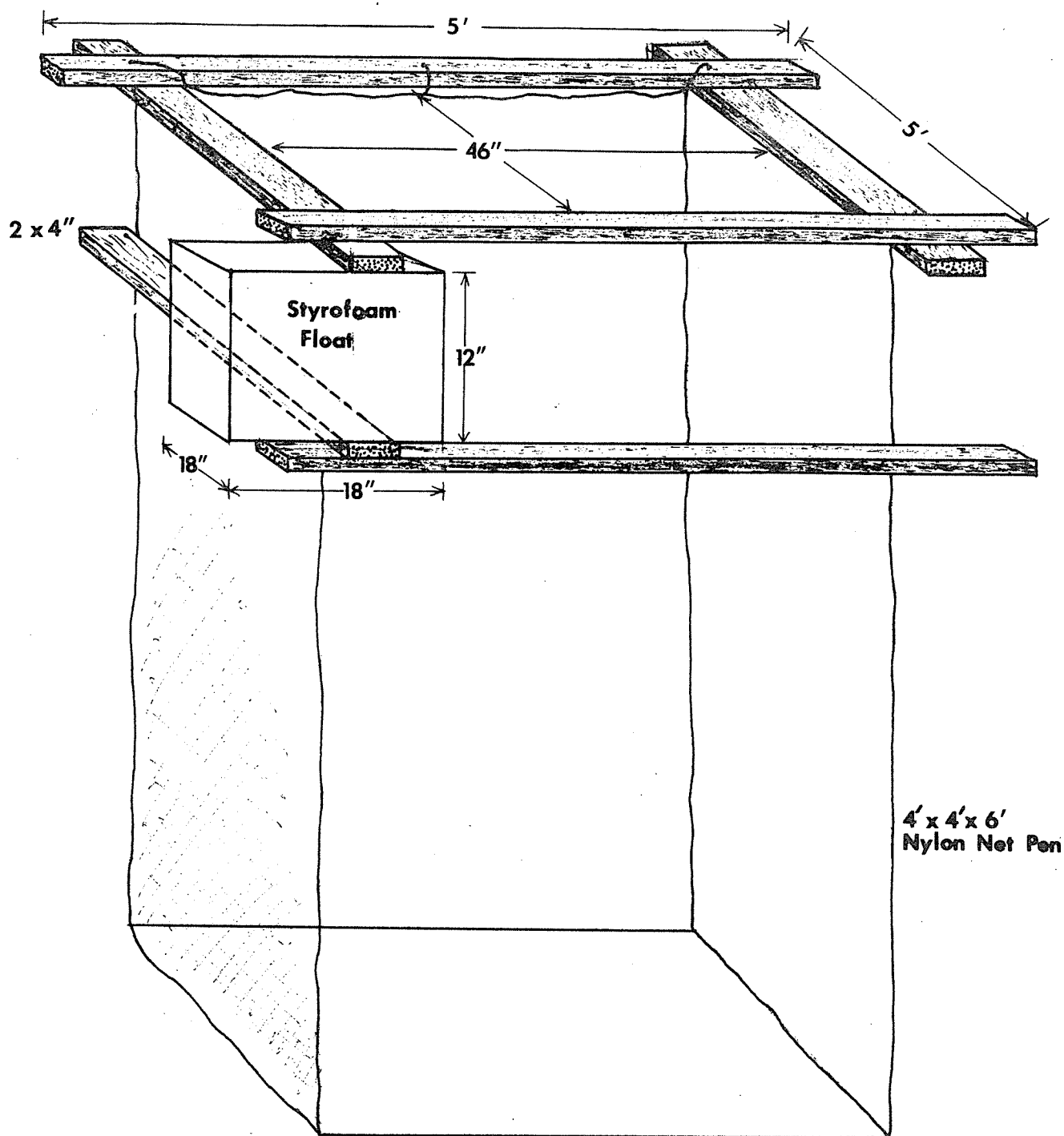


Fig. 8-1. Isolated holding pen design.

Table 8-1. Fish density in isolated pens.

Stock	Pen no.	No. fish per pen ¹
Quilcene Hatchery	1 (high density)	5,682
	2 (low density)	731
Hoodsport Hatchery	3 (high density)	2,686
	4 (low density)	375

¹Pen dimensions: 1.3 x 1.3 x 2.0 m³.

Table 8-2. Disease incidence among local fish.

Date	Fish source ¹	No. fish	No. confirmed isolates		
			<i>Vibrio</i> (vibriosis)	<i>Pseudomonas</i> (bacterial hemorrhagic septicemia)	<i>Aeromonas</i> (furunculosis)
3/25	South Carlson	60		1	
4/18	South Explosives Handling Wharf	60	1		1
4/25	South Floral	60	3	4	
5/2	Devil's Hole	60			
5/9	South Marginal	60			
5/16	Devil's Hole	60			
5/23	Devil's Hole	60	3		
5/30	Devil's Hole	60			
6/6	King's Spit	41	2		1
6/13	South Explosives Handling Wharf	60			
6/13	North Carlson	60	1		
6/13	Brown's Point	60			
7/11	South Carlson	60			
7/18	Mixed	60			
7/19	South Carlson	60			
7/22	Mixed	51			
7/25	Mixed	60			1
	TOTAL	1,002			

¹Refer to Fig. 7-3.

Table 8-3. Disease incidence among nonisolated raft pen populations.

Fish source ¹	Date of sampling	<i>Vibrio</i> confirmation
		No. isolates/no. fish streaked
mixed	5/23-5/27	0/60
mixed	5/30-6/3	0/60
mixed	6/6-6/10	0/139
BS L	6/13-6/17	3/21
mixed	6/20-6/24	44/220
BS L	6/30	30/30
HDT	6/30	30/30
HDT-Im	6/30	30/30
QLC	6/30	30/30

¹Mixed: combination local and hatchery

BS L: beach seine, local

HDT: Hoodsport Hatchery

Im: immunized

QLC: Quilcene Hatchery

(Wood 1968) contributed to outbreaks of disease. The pens were clustered and contained fish from a variety of sources, so cross-contamination was possible.

Cumulative mortality among the pen populations was negligible (<10% per population) from February to April, but substantially higher (up to 73% per population) in May and June (Table 8-4).

8.3.4 Isolated Pens

In the isolated pens, rates of mortality of juvenile chum approached 100% within 12 days in both high and low "density" test populations (Fig. 8-2). While no Vibrio isolates were obtained from any population prior to placement in the pens, disease was confirmed within 1 week of holding (Table 8-5). Apparently handling and pen confinement increased the spread of disease regardless of source (local versus hatchery), holding "density," or pen configuration.

8.4 SUMMARY

- 1) From March to July 1977, incidence of disease, particularly vibriosis, was monitored in local chum salmon populations migrating through the dredge area and in test populations (local and hatchery chum) used in bioassays.
- 2) Less than 2% of local juvenile chum sampled had confirmed vibriosis, furunculosis, or bacterial hemorrhagic septicemia; evidence indicated that dredging did not increase disease in migrating chum.
- 3) Test populations for bioassays were held in net pens. Handling and confinement apparently precipitated the outbreak of vibriosis in mid-June which continued through July. Pen isolation and reduction of the number of fish held per pen did not affect disease or mortality of captive fish.
- 4) Bioassay results (reported separately, Sections 4.0, 5.0, and 6.0) support the role of handling and confinement in disease incidence.

8.5 ACKNOWLEDGMENTS

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Table 8-4. Holding pen mortality rates.

Holding ¹			Cumulative mortality			
Entry date	No. days held	Fish ² source	Total ³ (no. fish)	Estimated ⁴ (%)		
				min.	max.	
1/26	5	BBC H	1	< 1	< 1	Jan.
1/26	11	BBC H	90	1.5	9.0	
1/31	14	BBC H	5	< 1	< 1	
2/7	17	BBC H	9	< 1	< 1	
2/14	14	BBC H	3	< 1	< 1	
2/21	16	BBC C	8	< 1	< 1	Feb.
2/28	4	BBC C	35	< 1	3.5	
2/28	7	BBC C	17	< 1	1.7	
3/8	20	BBC C	51	< 1	5.1	
3/14	16	BBC C	19	< 1	1.9	
3/21	18	BBC C	25	< 1	2.5	Mar.
3/21	35	BS L	68	1.1	6.8	
3/28	15	BBC C	70	1.2	7.0	
4/4	15	BBC C	68	1.1	6.8	
4/11	16	BBC C	30	< 1	3.0	
4/11	18	BBC H	3	< 1	< 1	
4/19	14	BBC C	39	< 1	3.9	Apr.
4/19	22	HDT	8	< 1	< 1	
4/25	15	BBC C	23	< 1	2.3	
4/27	21	BS L	20	< 1	2.0	
5/5	14	BBC C	174	2.9	17.4	
5/5	13	BS L	288	4.8	28.8	
5/10	15	BBC C	230	3.8	23.0	
5/10	5	BS L	163	2.7	16.3	
5/18	1	BS L	105	1.7	10.5	May
6/1	14	BS L	6	< 1	< 1	
6/9	13	BS L	390	6.5	39.0	
6/15	7	BS L	730	12.2	73.0	
6/22	15	QLC	2,700	45.0	--	
6/22	15	QLC	2,900	48.3	--	June

Table 8-4. Holding pen mortality rates - continued.

Entry date	Holding ¹		Fish ² source	Cumulative mortality		
	No. days held			Total ³ (no. fish)	Estimated ⁴ (%)	
				min.	max.	
6/27	10		QLC	3,300	55.0	--
6/29 ⁴	21		QLC HD	5,682	94.7	--
6/29	7		BS L	374	6.2	37.4
7/1	19		QLC LD	731	12.2	73.1
7/5	7		BS L	22	< 1	2.2
7/6	14		HDT HD	2,686	44.8	--
7/6	14		HDT LD	371	6.2	37.1
7/7	13		BS W	448	7.5	44.8
7/11	9		BS W	263	4.4	26.3
7/13	7		BS W	1,060	17.7	-- July

¹Raft pens 1/26 to 6/27; isolated pens 6/29 to 7/13.

²BBC: Big Beef Creek, C: channel, H: hatchery, Im: immunized, Ct: control, HDT: Hoodspout Hatchery, HD: high density, LD: low density, QLC: Quilcene Hatchery, BS L: beach seine, local.

³Initial population size approximately 1,000-6,000.

⁴Estimated cumulative mortality rates:

maximum: no. fish dead ÷ 1,000 (minimum population size) x 100
 minimum: no. fish dead ÷ 6,000 (maximum population size) x 100.

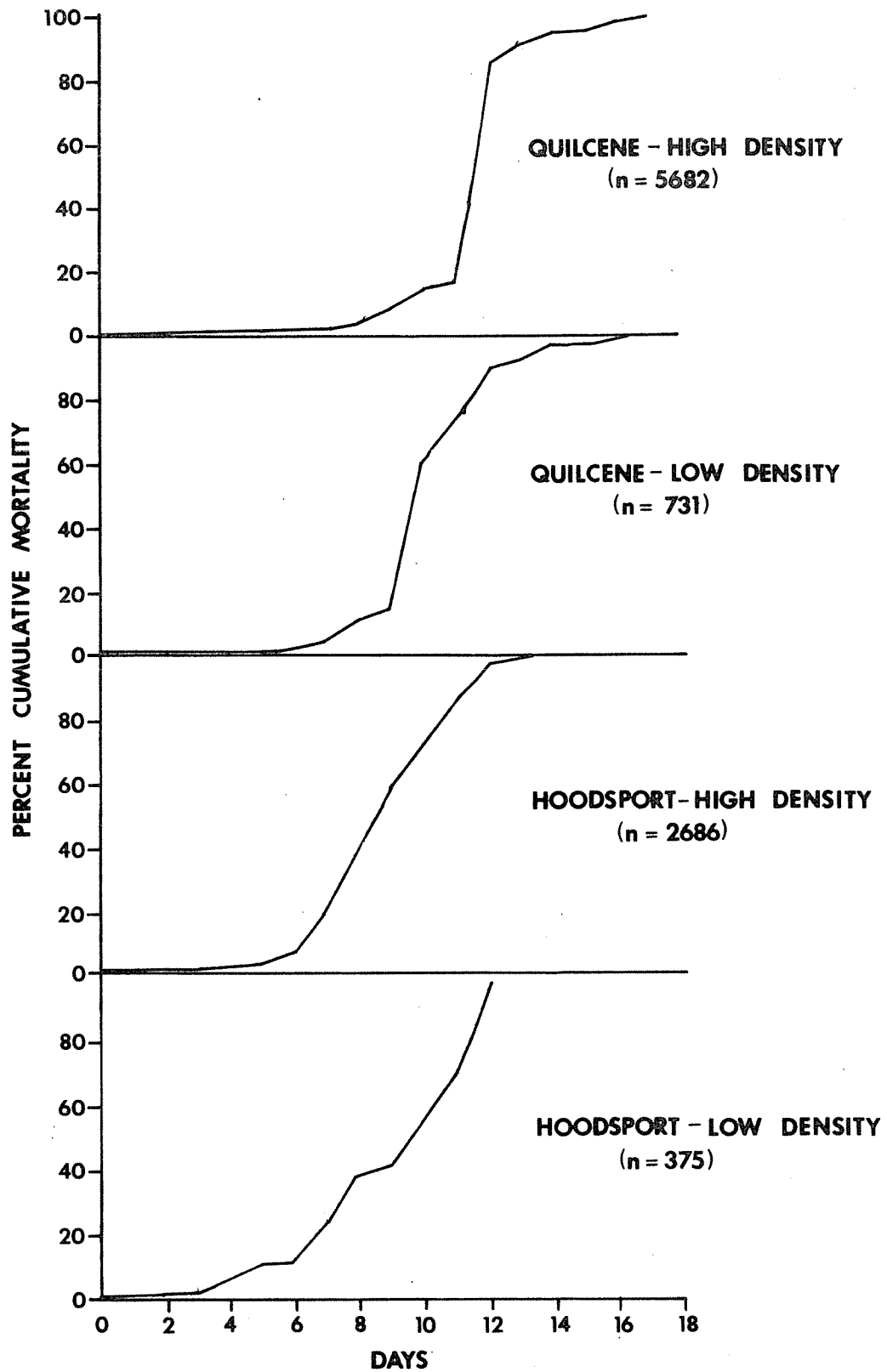


Fig. 8-2. Mortality rates of low and high density hatchery populations.

Table 8-5. Disease incidence in isolated pens.

Fish source ¹	Date of entry into pens	Date	First <i>Vibrio</i> confirmation
			No. isolates/no. fish streaked
QLC HD	6/29	7/5	29/32
QLC LD	6/29	7/5	1/2
HDT HD	7/6	7/12	3/6
HDT LD	7/6	-- ²	-- ²
BS L	7/7	7/13	6/6
BS L	7/11	7/14	9/9
BS L	7/13	7/18	29/30

¹QLC: Quilcene Hatchery, HDT: Hoodspport Hatchery,
 HD: high density, LD: low density, BS L: beach seine, local.

²Data lost.

9.0 RECOMMENDATIONS

by

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9.1 GENERAL

Problems encountered during the Dredge Monitoring Program can be divided into two areas: 1) those resulting from the variable nature of the plume; and 2) those intrinsic to the bioassay technique, including obtaining and holding test animals.

9.2 PLUME VARIABILITY

The concentration of suspended sediment measured in the plume depended on:

- 1) distance between sample site and dredge;
- 2) sampling depth;
- 3) intensity of dredging activity;
- 4) type of sediment layer dredged; and
- 5) water currents in the dredge area.

During the 6 months of bioassays, only the sampling depth remained constant. Test sites (i.e., live-box, flow-through and avoidance pump intakes, beach seine and townet transect locations) were fixed, but the dredge moved throughout the dredge area (shaded portion Fig. 3-4) as sediment layers were progressively removed. Irregular dredging activity and area currents continuously altered the location and sediment load of the plume. Consequently, test animals in the flow-through, live-box, and the field segment of the plume-avoidance bioassays were only sporadically exposed to the plume; average TNFRs were four to ten times less than maximum plume sediment concentrations (Table 9-1).

To determine whether test exposures in the bioassays were representative of dredge area conditions encountered by migrating chum, i.e., whether test exposures fluctuated as frequently and to the same degree as the plume, the Dredge Monitoring Program relied on concurrent water quality analysis conducted by the Navy Ecology Office and Washington State Department of Fisheries (WDF) personnel (Fig. 9-1). Their results verified that test exposures were representative of fluctuating area TNFRs (c.f., Appendix I, "Maximum observed suspended solids").

Site location and sampling strategy are critical in effectively assessing the impact of a fluctuating stress like a dredge plume. Based on this study, we recommend that subsequent bioassays:

Table 9-1. Summary of total non-filtrable residue (TNFR) data.

Study	Mean test TNFR and range (mg/liter)	Mean control TNFR and range (mg/liter)
Live-box (all data pooled)	9.4 4-94	7.3 4-16
Plume monitoring (Devil's Hole)	-- 8.3-30.2	7.6 5.6-12.0
Flow-through	8.3 5-37	7.14 5-13

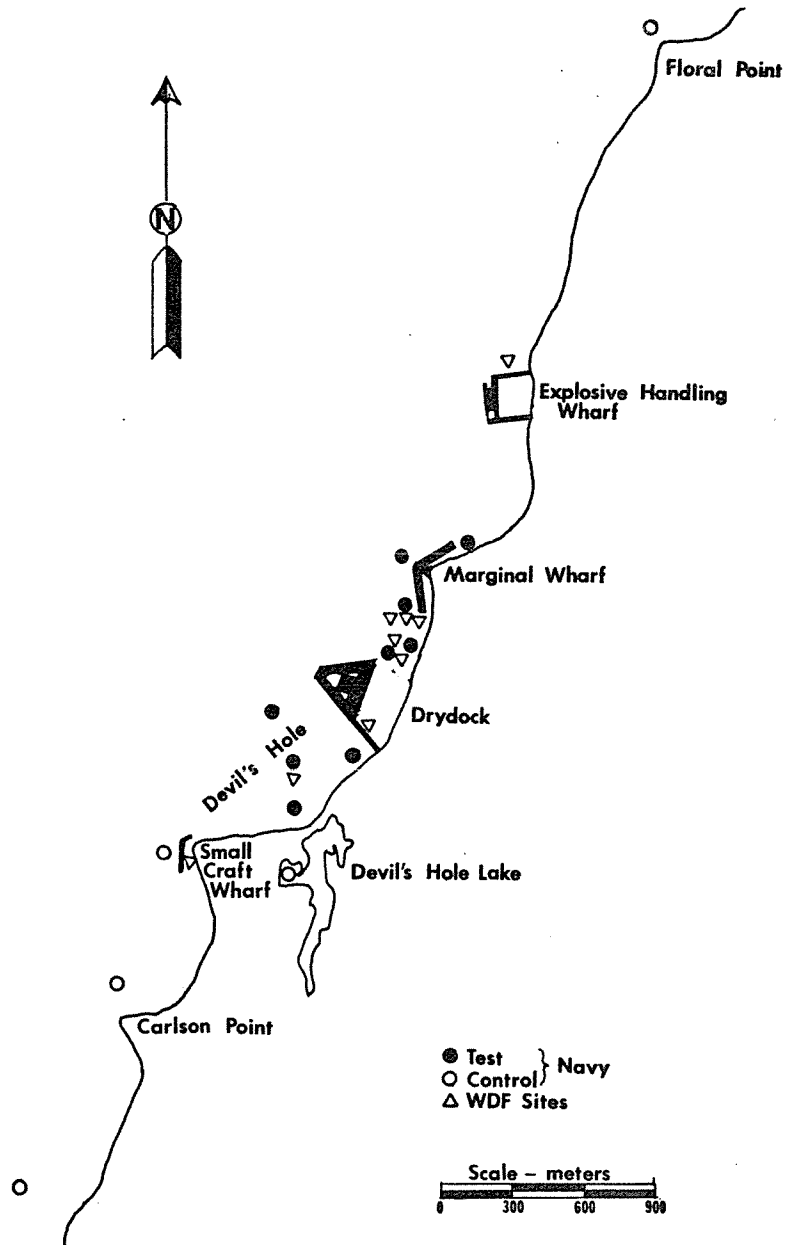


Fig. 9-1. Location of Navy Ecology Office and Washington Department of Fisheries (WDF) water quality sites along Bangor shoreline.

- 1) use continuous recording devices throughout the dredge area to integrate over time the degree of sediment (stress) exposure; and
- 2) locate test sites at the plume source (in this study, safety restrictions prevented test sites within 50 m of the dredge).

9.3 BIOASSAY TECHNIQUES

9.3.1 Test Animals--Procedures

All bioassays used fish obtained from local Hood Canal sources (see Section 3.3) and held in raft pens near the KUMTUKS prior to experiments. In mid-June a seasonal outbreak of vibriosis occurred in some of the pen-held fish. The raft design (Fig. 3-6) located pens adjacent to one another, apparently allowing transfer of the disease to previously healthy fish. These events disrupted the normal holding-acclimating schedule, and made procuring healthy test fish difficult. Subsequent use of isolated holding pens did not reduce disease or mortality, and we recommend that in future studies, warm periods should be avoided. Otherwise, the water would have to be cooled and this may not be representative of actual conditions.

The following problems and recommendations are specific to the individual bioassays.

9.3.2 Static Bioassay

It is essential to be aware of the methods used in a bioassay before using the results to formulate water quality criteria. For instance, surprisingly low chronic LC₅₀ data obtained by Herbert and Merkens (1961) and Herbert and Richards (1963) may have been at least partially due to daily handling of test specimens, and their results have been used heavily in the establishment of suspended solids standards (EPA 1973; EIFAC 1965).

Major procedural problems encountered in the study were:

- a) A consistent suspended sediment concentration was not maintained. Future studies should not employ the methodology used unless a fluctuating concentration regime is desired. Information regarding changes in TNFR over time has not been presented in other research, and thus, quantitative interstudy comparisons cannot be made. Nonetheless, methods used by Rogers (1969) and Herbert and Merkens (1961) appear to have been effective and are recommended.
- b) Blood glucose sampling was only conducted under one set of experimental conditions. It is highly recommended that future sublethal monitoring designs incorporate several exposure periods and concentrations. Basic research has not progressed to the point where one can predict when a stress-related hyperglycemic response will peak, as evidenced by recent contradictory sets of data (McLeay and Brown 1975; McLeay 1977).

c) Data from this study suggest that acute toxicity tests should be limited in duration to approximately 96 hr. Apparently, starvation-related stress can be significant thereafter.

9.3.3 Flow-through Bioassay

The principal limitation in monitoring effectiveness was the fixed location of pump intakes. The KUMTUKS could not be moored alongside the dredge, nor could the intake pipe extend within 175 m of the dredge, without interfering with construction or boat traffic.

Conversely, the KUMTUKS was too near the dredge to obtain a local source of control water. Consequently, a settling tank system was used, which required shading of the tanks to maintain temperatures at test levels (ambient dredge area), as well as periodic cleaning to remove sediment and fouling organisms. Temperature variation in the control system exceeded test levels despite the shading (Fig. 5-3), and future studies incorporating this system could encounter similar problems. Insulation of tanks would improve temperature stability.

9.3.4 Live-box Bioassay

The live-box bioassay also encountered temperature problems with controls. Control site A was located south of the dredge area in Seabeck harbor where restricted water circulation allowed a more rapid seasonal temperature increase and caused outbreak elevated fish mortality. Where test and control sites do not experience equal temperature conditions, bioassay results could be obscured.

The present live-box bioassay used multiple control sites, each with characteristic water properties. Locating control sites away from the dredge maximized differences between control and test with respect to temperature, salinity, and current. This variability made interpretation of fish response to sediment difficult. Furthermore, greater distance to control sites meant increased transport stress for control animals.

A third problem related to controls concerned using unequal numbers of replicate live-boxes to compensate for differences between the number of test and control sites (4 versus 3). Unequal replicates could introduce a handling procedure variable. In retrospect, equal numbers of test and control sites are unnecessary as long as the same fish density per box and number of boxes per site are maintained.

9.3.5 Avoidance-behavior Bioassay

Vertical stratification of suspended sediment in the behavior tank prohibited accurate determination of concentrations inducing avoidance. Laboratory apparatus should be modified to reduce stratification of suspended solids, and several water depths should be sampled to evaluate sediment concentrations in the test water. Also, tests would benefit from

determining the depth preferences of test fish and the distance moved by the test fish.

Increased frequency of field surveys, especially during the peak periods of migration, would have aided in determining the significance of results.

Similar sampling operations may find the 5-min townet transect more useful than 10-min transects and beach seining. Further studies should be conducted to evaluate the relationship of fish abundance with tide height during ebb tide, and with temperature during flood tide.

9.3.6 Disease Monitoring

Due to manpower limitations local fish were captured during outmigration surveys late at night, requiring the freezing of specimens. This is not ideal since this study has indicated that stress and/or diseases may be limiting factors in the outcome of the bioassays.

9.3.7 Future Studies

In general, any future field bioassay study of this project's scope requires a minimum of 2 month's preparation and shakedown of equipment and personnel prior to beginning data collection. If possible, a complete environmental monitoring program should be carried out one season in advance of the study to provide the data base on which to direct the actual study.

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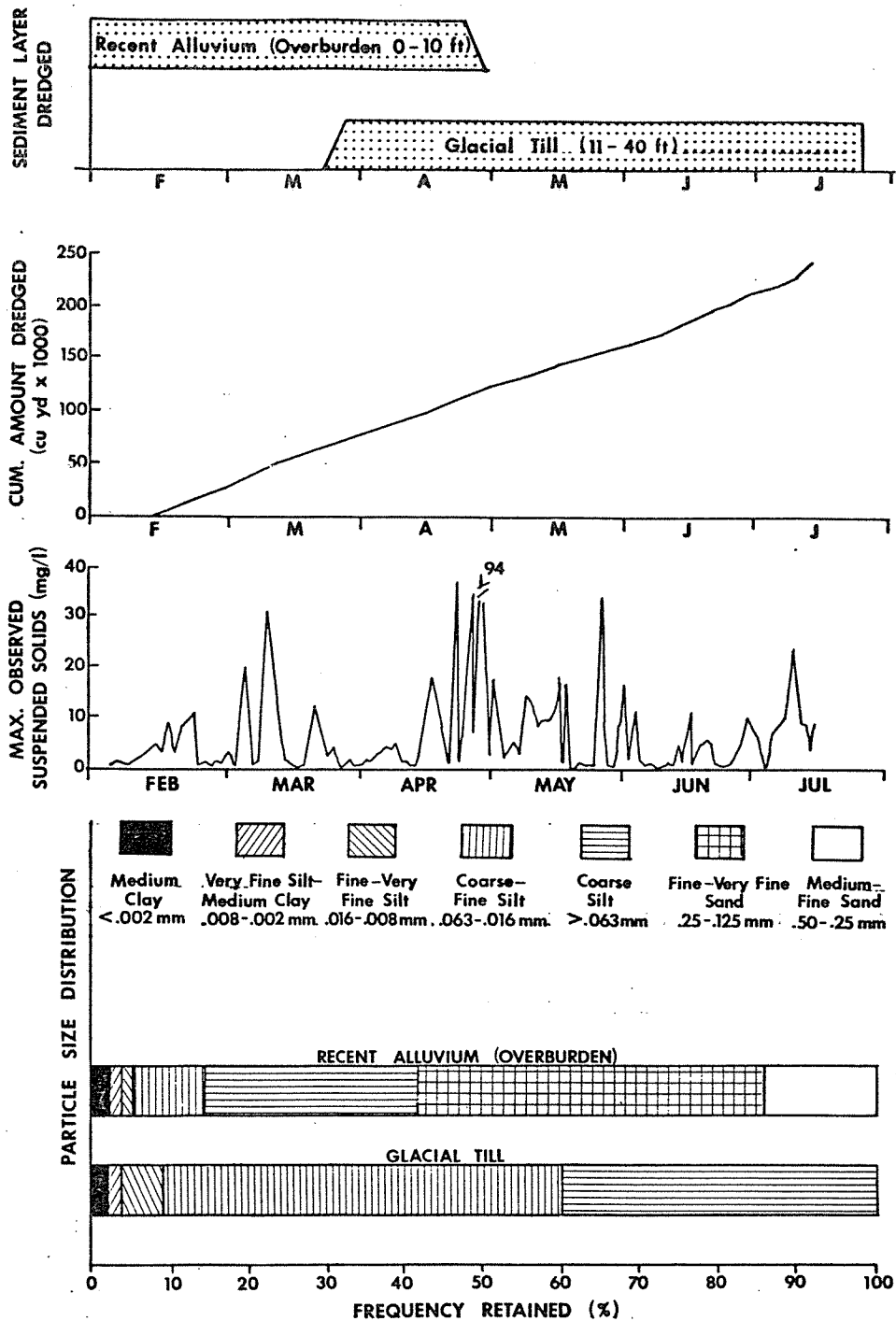
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APPENDICES



Appendix I. DREDGING SUMMARY: a) sediment layer dredged; b) cumulative amount dredged; c) maximum observed suspended solids concentration (TNFR) expressed as max. TNFR - control TNFR; d) particle size distribution, reproduced with kind permission of Sharleen Olsen, WDF.

Appendix II. Instrumentation and calibration techniques.

Water quality parameter	Sampling Methodology (if applicable)	Materials and methods used to determine concentration or to calibrate instruments
TNFR	Water samples collected in polyethylene containers and stored at 10°C.	Materials and methods were those specified in APHA, AWWA, and NPCF (1976) (gravimetric).
DO	Monitored in the field.	YSI DO meter and probe measured DO directly from the field. Calibration was conducted using the azide modification of the standard Winkler titration (APHA et al. [1976]).
pH	Water samples collected in polyethylene containers and analyzed soon after sampling.	A Coleman portable pH meter (model 37A) and an Orion specific ion meter (Model 407) were used.
Salinity	Same as above.	From February through April, a Beckman salinometer (Model RS5-3) was employed and calibrated using a silver nitrate titration procedure (APHA et al. 1976). From May through July a Goldberg temperature-compensated refractometer (Model 10419) was utilized.

Appendix II. Instrumentation and calibration techniques - continued.

Water quality parameter	Sampling Methodology (if applicable)	Materials and methods used to determine concentration or to calibrate instruments
Temperature	Monitored in the field	A thermometer or Beckman salinometer temperature probe (Model RS5-3) was used.
NH ₃ -N	Van Dorn water sampler; water was stored at <0°C in polyethylene containers. Care was taken to keep as much air as possible out of bottles.	Materials and methods were those specified in Strickland and Parsons (1972).
H ₂ S	Van Dorn water sampler; samples were placed in polyethylene containers and fixed on site with 2N zinc acetate, keeping as much air out of the containers as possible. Samples were sent to Fisheries Research Institute, Water Quality Lab for analysis.	Materials and methods were those outlined in APHA et al. (1976) Titrimetric Iodine Method.

Appendix II. Instrumentation and calibration techniques - continued.

Water quality parameter	Sampling Methodology (if applicable)	Materials and methods used to determine concentration or to calibrate instruments
Total and dissolved heavy metals	Overburden was collected by divers; glacial till was obtained off scows. Concentrated sediment-water slurries were stored in polyethylene containers below -20°C and analyzed by the Fisheries Research Institute Water Quality Lab.	Total: Materials and methods were those specified in APHA et al. (1976) (Atomic Absorption Spectroanalysis). Dissolved: Samples were aerated for 1.5 hr at 10-15°C and filtered through a .45 µm filter. The elutriant was acidified with re-distilled water and analyzed according to APHA et al. (1976) (Atomic Absorption Spectroanalysis).
Oil and grease	Same as above.	Materials and methods were those specified in APHA et al. (1976) (Soxhlet Extraction).
Total volatile solids	Same as above.	Materials and methods were those specified in APHA et al. (1976).
Total organic carbon	Same as above.	Materials and methods were those specified in APHA et al. (1976).

APPENDIX III

VACCINE STUDY

by

Thomas E. Prinslow

INTRODUCTION

Seasonal outbreaks of vibriosis hamper salmon culture and hatchery operations in the Pacific Northwest (Wood 1968; Novotny, Harrell, and Nyegaard 1975) and to meet the needs for a vaccine Tavolek Inc., of Bellevue, Washington, has conducted research and development on vaccines against Vibrio anguillarum. As an adjunct to the disease monitoring project, groups of vaccinated and control juvenile chum salmon (Oncorhynchus keta) were held to test the effectiveness of a vaccine.

MATERIALS AND METHODS

Test fish came from Big Beef Creek (BBC--University of Washington) and Hoodsport (HDT--Washington State Department of Fisheries) hatcheries on Hood Canal (Fig. 3-1). BBC fish were tested from March 4 to May 27, HDT from May 12 to July 11, 1977. BBC tests were conducted in flow-through troughs aboard the University of Washington barge R/V KUMTUKS (Fig. 3-5) and in holding pens (Fig. 3-6) moored near the KUMTUKS (Fig. 3-4). HDT tests were conducted in holding pens.

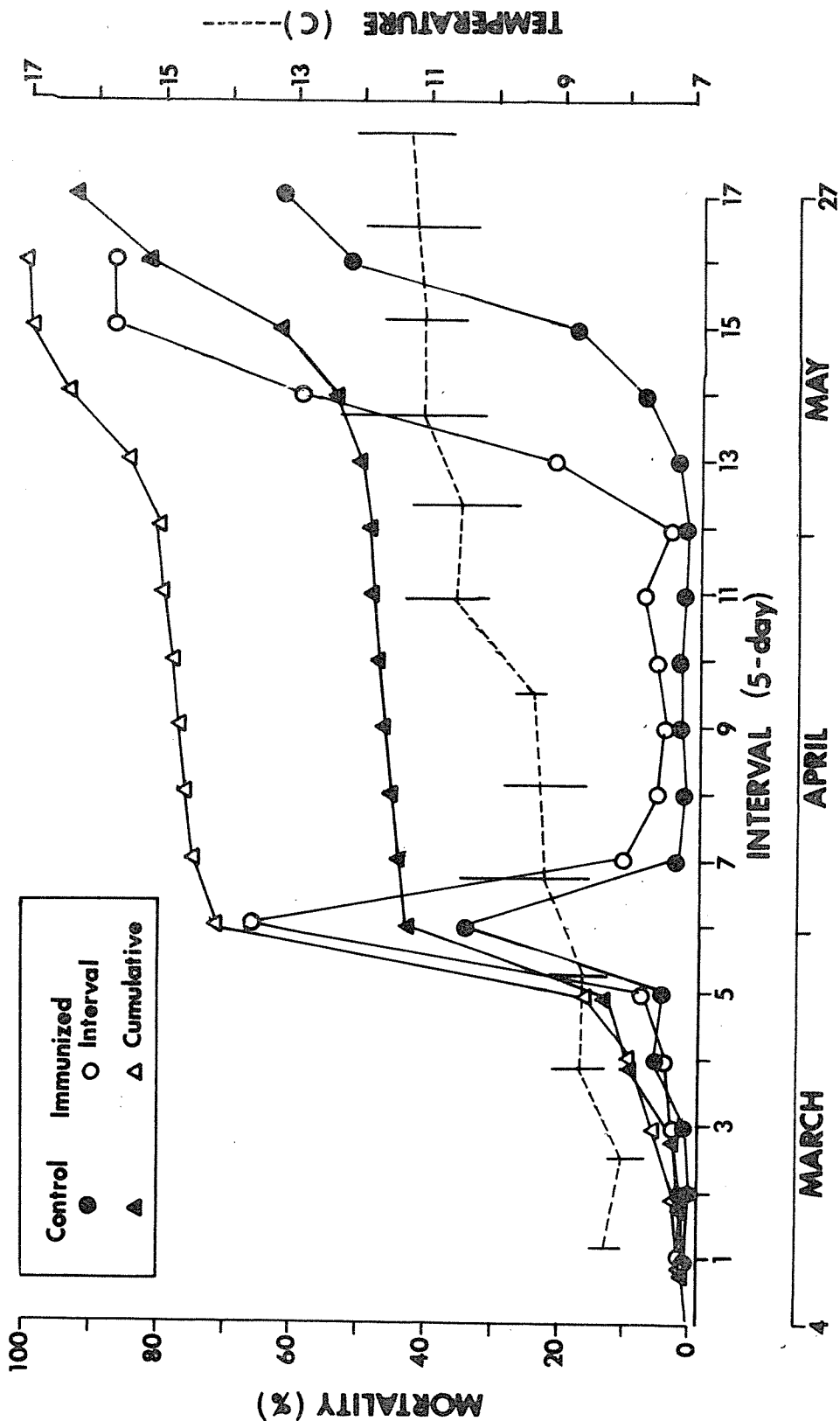
Fish were vaccinated at the hatchery, using a hypersaline bath technique, developed by Tavolek and the Western Fish Disease Laboratory (now the National Fisheries Research Center), which allowed direct absorption of the vaccine. Vaccinated fish were then held in freshwater holding troughs for approximately 25 days to allow antigen buildup, and subsequently were transferred by tank truck to seawater test facilities.

Control fish were immersed in a hypersaline bath without vaccine, held and transported.

RESULTS AND DISCUSSION

Big Beef Creek Tests

Initial starting populations for trough and pen tests were approximately 1,000 fish. Mortality during freshwater holding totaled 7% for control and immunized (= vaccinated) (Fig. AIII-1). Trough mortalities (Fig. AIII-1) remained below 10% per 5-day interval until May, with the exception of April 1 (interval 6) when fish were



accidentally exposed to antifouling hypochlorite wastes. Interval mortality (cumulative percent per 5-day period) rose during May to 88% of immunized, 62% of control. Because of the hypochlorite exposure, vaccine-related differences in mortality cannot be quantified. Nonetheless, mortality increases were associated with: 1) increasing incidence of disease symptoms--tail rot, hemorrhaging, exophthalmia (bug-eye)--linked to furunculosis; 2) confirmed furunculosis pathogen (Aeromonas salmonicida) in BBC pen fish (May 4); and 3) critical temperature levels (11^o-12^oC) associated with furunculosis (Wood 1968). Apparently, conditions for furunculosis outbreak were reached during this period. Unfortunately, the pen experiment was terminated May 8, just at the onset of the disease. Pen mortalities until then remained below 10% (Fig. AIII-2). At any rate, fish were vaccinated against Vibrio and would not be expected to resist other pathogens. Trough experiments were terminated May 27 when one immunized fish remained.

Hoodsport Hatchery Tests

Hoodsport Hatchery pen tests began May 12 with approximately 700 immunized and 800 control fish (mortality during freshwater holding was not recorded). Except for initial transfer losses of 10-30%, interval mortality (cumulative percent per 5-day) (Fig. AIII-3) remained below 1% until mid-June when immunized losses rose to 40% and control to 84%. This increase was associated with an outbreak of vibriosis which affected test fish, apparently spreading from a diseased group of local fish held in adjacent pens. By June 27 (interval 10) 10% of test fish analyzed had confirmed Vibrio isolates. However, cumulative control losses (100%) exceeded immunized (75%), suggesting improved survivorship from vaccination.

If the fish had been challenged earlier in the test, the effectiveness of the vaccine may have been enhanced. Wood (1968, page 30) noted a 60-day protection duration with an oral Vibrio vaccine. Hoodsport Hatchery mortalities increased after about 65 days (25 holding, 40 test). The Tavolek vaccine may have a similar protection limit.

Summary

1. From March to July 1977, groups of juvenile chum salmon (Oncorhynchus keta) vaccinated against Vibrio anguillarum were monitored to test vaccine effectiveness in reducing disease and mortality.
2. Two tests were conducted in holding pens situated in Hood Canal, Washington, and one in raceway troughs supplied with canal water.
3. Mortality from March to May remained below 10%, but rose during June and July to 75% (cumulative) of vaccinated fish and 100% (cumulative) of control. Mortalities were associated with an outbreak of vibriosis.
4. The vaccine may have better enhanced survival had fish been challenged earlier during the holding period (total 84 days, mortality increase after 65 days).

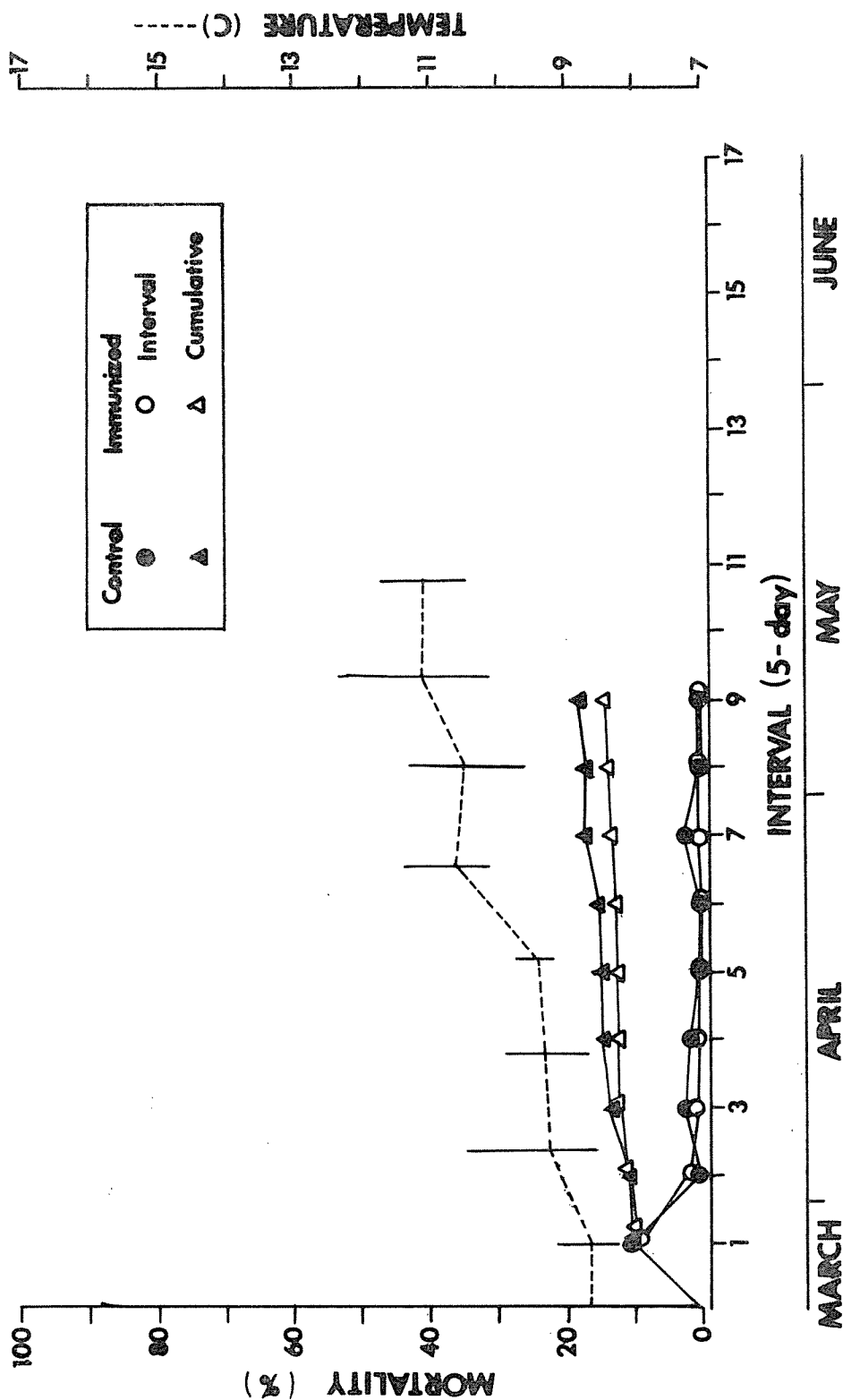


Fig. AIII-2. Big Beef Creek (BBC) pen mortality: cumulative (%) and 5-day interval (no. mortalities per 5-day interval ÷ no. survivors from previous interval x 100); temperature: weekly mean and range, means connected for clarity.

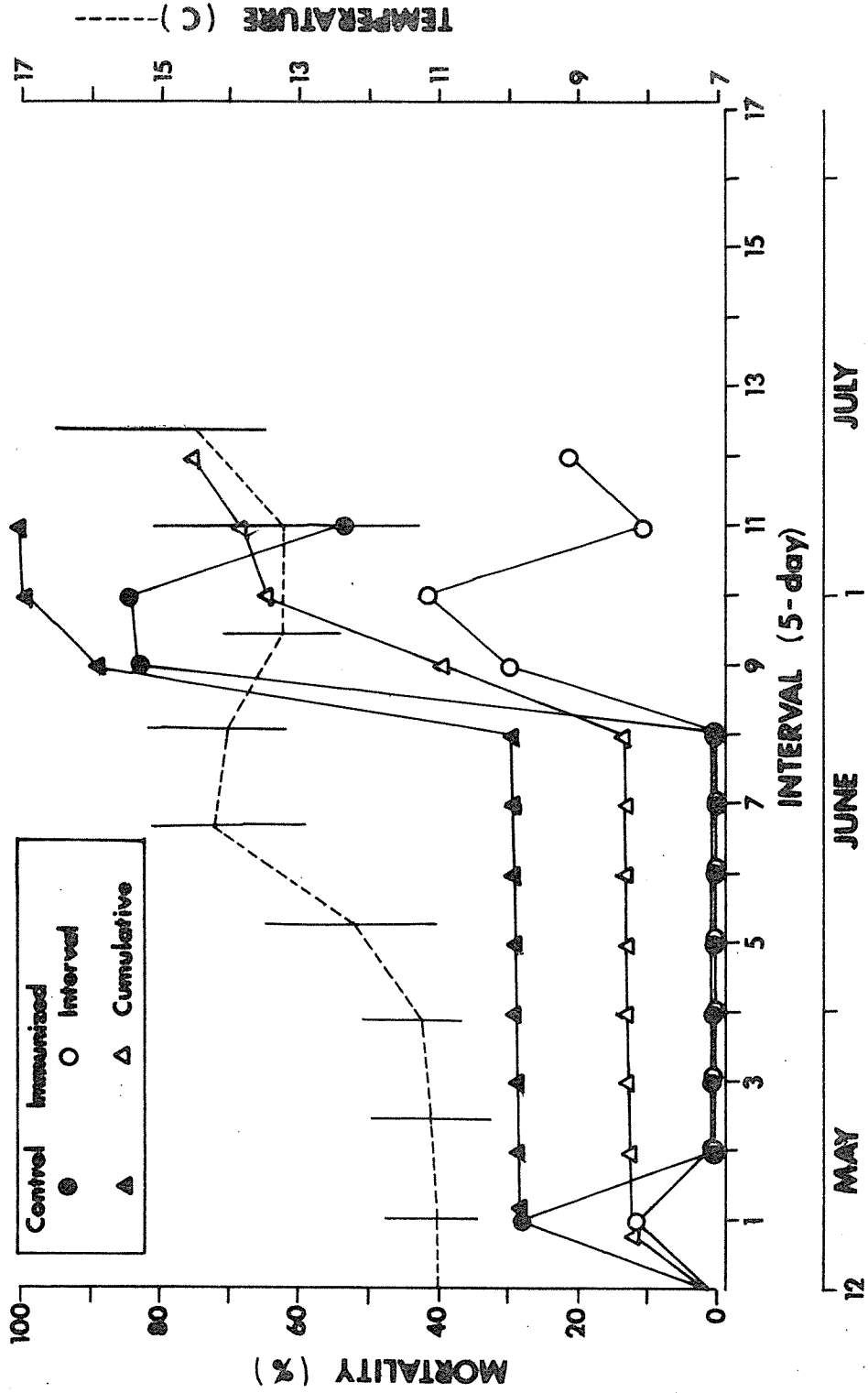


Fig. AIII-3. Hoodsport (HDT) pen mortality: cumulative (%) and 5-day interval (no. mortalities per 5-day interval ÷ no. survivors from previous interval x 100); temperature: weekly mean and range, means connected for clarity.