Columbia River White Sturgeon (Acipenser transmontanus) Enhancement

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COLUMBIA RIVER WHITE STURGEON
(*Acipenser transmontanus*)
ENHANCEMENT

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Fred Holm, Project Manager

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ABSTRACT

Section 800 of the Columbia River Basin Fish and Wildlife Program provides for the protection, mitigation and enhancement of resident fish. White sturgeon (Acipenser transmontanus) were noted as a species of interest in section 801. Specifically section 804(b)(l)(c) calls for studies of the effects of hydroelectric operation on reproduction and rearing of white sturgeon, while sections 804(e)(3) and 804(3)(B) seek to determine the potential for artificial propagation of white sturgeon.

Studies were undertaken to examine and define the early life history characteristics of Columbia River white sturgeon as a working base from which enhancement measures could be developed. Research consisted of four tasks to be completed by the end of 1983. Task 1.1, directed at spawning and incubation, was successfully conducted in cooperation with "The Fishery," a private aquaculture firm. Adult sturgeon were captured and held for spawning at Covert's Landing, the site of the hatchery facilities below Bonneville Dam. Pituitary hormones stimulated ovulation; ripe females were live spawned surgically and the eggs incubated in hatching jars. Larvae were either reared at the hatchery site after incubation to advanced fingerling stages or transferred to the University laboratory for more detailed study.

Task 1.2 examined the distribution behavior of larvae and fry. Displacement downstream occurs as a means of distribution and can last several days before a strong substrate preference is manifested. Once bottom contact is sought by the larvae, displacement is abated, and a general preference for sandy surface appears to predominate. Since potentially extensive displacement downstream could result in the distribution of larvae in saltwater, the tolerance of young sturgeon to saltwater was examined.

Task 1.3 was directed at larvae and fry feeding behavior. The responsiveness of young sturgeon to artifical feed was positive. With these results, the original concern for identifying an adequate diet and food source that would be readily accepted by fry was greatly attenuated. Acceptability of the artificial diet indicated that further search for food material for maintaining experimental fish stock was unnecessary at this stage, and study was limited to examination of the feeding behavior.

Task 1.4 was to identify techniques to initiate feeding in larval sturgeon. Again, the readiness of young fry to initiate feeding on the artifical diet made further study on feeding stimulants unnecessary. Exaination of the feeding response suggested that as long as the diet used in the present study was initiated at the proper time and with adequate frequency, the fry would feed quite well and survive.

Results from the present study indicate a need for examinations of white sturgeon early life history which provide information relating distribution, movements, behavior and the impact of environmental alterations. Analysis of results can build an understanding toward the goals of protection, mitigation and enhancement of white sturgeon throughout the Columbia River basin.

INTRODUCTION

Section 800 of the Columbia River Basin Fish and Wildlife Program proposes a wide range of methods to protect resident fish, mitigate fishery losses caused by hydroelectric projects, and compensate for past losses through enhancement measures. Section 801 notes the white sturgeon, biologically an anadranous fish but now confined to certain stretches of the river because dams have blocked migration, as a species of interest.

Specifically, Section 804(b)(l)(c) proposes studies which would assess the impact of hydroelectric operation on the reproduction and rearing of white sturgeon. Investigations are to assist in determining when and where the fish are present, food requirements and sources, effects of pollutants, population recovery, and propagation methods. Section 804(e)(3) seeks to restore sturgeon populations where they once existed. Section 804(e)(B) calls for a study to determine the potential for the artificial propagation of white sturgeon.

Studies included in this report assist in providing a basis for understanding the status of Columbia River white sturgeon. Emphasis was placed on habitat and feeding behavior of new larvae and fry. Least was known about this period of the sturgeon life cycle. Larval and fry are the stages where the greatest mortality occurs and hence, the stages that should provide the best insight on how sturgeon populations can be enhanced.

Columbia River white sturgeon populations have followed a pattern of exploitation characteristics of other economically important fish species. Intensive commercial harvest contributed to a severe decline in the population size. Recovery to any appreciable significance has been slow according to available catch statistics. Harvest production peaked in 1882, precipitouslv declined, and remained relatively low until renewed commercial interest was generated in the late 1960's. In 1979, 1.1 million pounds were harvested, and 30,000 to 56,000 fish have been harvested annually every since (King, 1983).

Revival of interest in white sturgeon has been caused by two factors (King, 1980). First, the incidental catch of white sturgeon by salmon fishermen became more important as restrictions on salmon fishing increased. Second, and the more important reason, was the price increase in sturgeon flesh and caviar. The final result of this renewed interest in sturgeon is the potential for this species to be overfished again. Above Bonneville Dam, upstream access is limited and each stock must depend on its own reproduction capacity in a greatly different environment than it historically used for spawning. The apparent recovery of white sturgeon below Bonneville Dam is encouraging, but the concern is that actual population strength may not be adequately represented in a fishery that is beginning to exploit the species again.

A positive aspect concerning the sturgeon management progra on the Columbia River is that state agencies responsible for the species are assigning biologists specifically to the task. Time is available to develop rational management programs for this species. Although population strength is not presently known throughout the river, fishing effort can be controlled until sufficient biological understanding of the species is obtained. Managers will then have an effective base from which to develop the sport and commercial potential of Columbia River white sturgeon. Enhancement progras may be necessary on the Colunbia River, especially in the upriver populations, but methods to be employed in such enhancement efforts may not require artificial culture technology. Another appropriate use of hatchery fish may be to augment natural production. Before any enhancement effort can be undertaken with white sturgeon, it is imperative that the life history be understood in order to know how, when, and at what age enhancement measures should be taken.

OBJECTIVES OF STUDY

Objectives of Columbia River white sturgeon enhancement studies were to observe the early life history and feeding behavior of sturgeon larvae and fry. Future studies were to develop culture technology for sturgeon using the early life history information and behavioral characteristics of the young fish. Information gathered during this study, however, made continuation of certain tasks in the proposed research plan unnecessary and in those instances emphasis was given to expanding the examination as it applied to other tasks. This approach was anticipated in the original research agreement, but as a general approach four tasks were identified for the first year:

Task 1.1. Spawning and Incubation. This task was successfully undertaken at the field site on the river, with assistance provided by personnel from The Fishery.

Task 1.2. Larvae and Fry Distribution Behavior. Behavior studies undertaken at the University laboratory included habitat preference with regard to substrate, velocity, and salinity.

Task 1.3. Larvae and Fry Feeding Behavior. Feeding behavior of larvae and fry was undertaken with emphasis on feeding mechanisms. Initial tests conducted with a basic culture diet and food considered similar tc natural diets for young sturgeon, demonstratea tnat the artificial diet would oe acceptable for rearing the experimental animals.

Task 1.4. Determination of Techniques to Initiate Feeding. Feeding responses of the young sturgeon using a variety of olfactory stimulants was Dlanned, but the positive feeding response with the basic diet used for rearinc at tne laboratory deemed this task unnecessary and the other tasks were given more attention.

DESCRIPTION OF STUDY AREA

The study area involved both the field and laboratory facilities. Spawning stock was captured from the Columbia River, below Bonneville Dam. Subsequent spawning and incubation was undertaken at Covert's Landing a few miles downstream from the dam on the Oregon side of the river (Fig. 1). Facilities at the site were made available for the project by owners of The Fishery, a commercial sturgeon hatchery developing on the river. Observations of incubating eggs and subsequent assessment of culture techniques were made at the hatchery site. Studies on the feeding and behavioral responses of larvae and fry were undertaken with stock transferred from the hatchery to the University of Washington, School of Fisheries laboratory in Seattle. Laboratory facilities have temperature and light controls to permit examination of behavioral responses without interference from ambient variation of these factors, and they allowed segregation of test fish through temperature controlled development rates.

Incubation and rearing containers were available at the laboratory in which fish could be cultured or tested during the study period. Larvae tested in the continuous flow aquaria for substrate preference or for displacement behavior in simulated stream flow conditions were transferred from the incubation or rearing containers to the flow chambers installed in the same laboratory room. Sustained rearing performance of the sturgeon was evaluated for the remainder of the study in rearing tanks at the laboratory facilities.

METHODS AND MATERIALS

Task 1.1. Spawning and Incubation

Columbia River white sturgeon were collected by personnel of The Fishery, a commercial sturgeon hatchery during May and June 1983. Sexual dimorphism is not exhibited in this species. Experience suggests that sexually mature female white sturgeon with ripe oocytes likely exceed six feet in length and have distended abdomens. Sturgeon meeting this criteria were brought aboard a boat and a small 10-mm incision was made on the abdomen, allowing visual examination of the gonads (K. Covert, personal communication). Oocytes in which the germinal vesicle had begun to move toward the animal pole were deemed acceptable. The incision was sutured. Columbia River males, maturing at a smaller site, were tested for ripeness by applying pressure to the abdomen to detect the presence of milt. Selected fish were transported to the hatchery and all other fish examined were returned to the river. Female spawners were injected with a small dose of carp pituitary suspension tc induce ovulation. Twenty-four hours later, female and male spawners were injected with a large dose of carp pituitary suspension. Upon ovulation the female was removed from the holding tank and the abdominal cavity surgically opened. A portion of the oocytes were removed into a stainless steel bowl and sperm was added by applying gentle pressure to the male's abdomen. A mud-water suspension mixed with the eggs and sperm cleared the eggs of the adhesive substance surrounding the outer membrane. Approximately 40,000 eggs were placed in each McDonald incubation jar. Spring-fed water, 9-10°C, was initially used for incubation. Water temperature was increased to 16°C utilizing a recirculating heat exchange system to stimulate hatching. Hatching was complete in three days. Free-swimming larvae (sac fry) spilled from the top of the McDonald jars into a collection box. Fish were distributed to 6' x 4' circulars for rearing in temperatures maintained at 9-10°C. BioDiet starter mash was first offered when the yolk sac disappeared. Fish were occasionally graded and distributed to 6' square tanks to reduce rearin: density and decrease size variation. As size of fish increased, feed was changed from BioDiet to a commercial trout diet.

Sac fry, approximately 12 days post hatch, were placed in a plastic bag 20-liter capacity) one quarter filled with water and three quarters filled with oxygen and sealed. The bag was put on ice and transported to the University of Washington. Upon arrival at the laboratory facilities, the fish were acclimated to temperature and release in small rearing tanks.

Task 1.2. Larvae and Fry Distribution Behavior

Distribution behavior tests were designed to provide some insight into how young sturgeon may distribute in the Columbia River and what factors may limit or enhance their survival ability. Since the eggs are demersal and spawned in large numbers, one can expect that they are exposed to a variety of hazards and experience very high mortalities. Similarly, when the young are hatched they are very small and susceptible to other hazards as they seek feedinq areas appropriate for their small size and different from the swift current used by the female to deposit her adhesive eggs. Tests on the response of larvae and fry to current, substrate, and different salinities were developed to gain a better understanding of the influence these three variables have on sturgeon behavior and distribution.

1.2.1. Tests of the temporal response of sac fry in current.

Observations on the response of sturgeon sac fry to current were conducted in a doughnut shaped-arena (Fig. 2). Clear acrylic sheets 30.5 cm wide were shaped to form the walls and fitted onto a 1.9 cm thick plywood sheet cut as a doughnut with an outside diameter of 122 cm and a surface area of 81 cm^2 forming a 30 x 30 x 383 cm circular trough.

Ambient Lake Washington water was used as the water source and set at a flow rate of 4.8 l/min. Water temperature during the test ranged between 17°C and 19.5°C. The floor of the arena was covered with 5 cm of l-cm diameter gravel as substrate, and the water level was maintained at 20-cm depth with a circulating velocity of 2.5 cm/sec. At 13 days post hatch, 100 sac fry were p!aced in the arena. Numbers of fish swimming in the water column, on the gravel surface and in the gravel were recorded during a 16-hour photoperiod. Additional observations were conducted in the early morning and late evening before and after the light period. The test was terminated after 10 days, and the survivors were weighed and measured.

1.2.2. Tests of fry on sculptured substrate within a current.

Three substrate types, gravel, sand, and detritus, were selected for testing fry response to typical river bottom materials. Substrates were placed in separate sections of the doughnut shaped test arena (Fig. 3) and contoured as mounds and alternating basins to provide shallows and pools over each substrate type. Lake water at ambient temperature (21.6°C) supplied the arena. Velocities varied over the sculptured substrate from .25 cm to 12.4 cm/sec.

Five fish at 55 days post hatch, averaging 23 mm in length and 0.06 g, were placed in the test arena on the afternoon preceding the day of the test and remained unfed for the duration of the study. Five observation periods were conducted throughout the day. Two sets of observations were made during each test period. Fish were observed as a group, and selected individuals were observed. During group observations, the observer would identify the locations of the group members at a timed interval during the observation period. Behavior of the group would be recorded during the period as well. Upon conclusion of the group observations, an individual fish would be selected for a lo-minute, more detailed examination of behavior.

Swimming pattern, substrate choice, and length of time spent on substrate or in the water column were noted.

1.2.3. Tests of fry on flat substrate within a current

Four substrate types, gravel, sand, detritus, and mud, were selected to test fry response to flat substrate surfaces. Substrates were placed on the doughnut shaoed test arena floor in four separate, but equal sections to a depth of 4 cm (Fig. 4). Lake water at ambient temperature (21.7-C) and a flow rate of 3.4 l/min was used in the test.

Five fish, 62 days post hatch at an average length of 56.8 mm and weighing 0.89 g, were placed in the arena the afternoon preceding the day of the test. Seven observation periods consisting of two examination sets were conducted throughout the day. Group observations were made noting position of each group member at a timed interval and the particular behavior. The second examination was made of the behavior of an individual fish. Observations of location and behavior were noted at five second intervals over a three minute period. Fish were weighed and measured at the conclusion of the experiment.

1.2.4. Tests of individual fry on substrate without current

Four substrates, gravel, sand, detritus, and plant material, were placed as pairs on the floors of 28-liter circular fiberglass aquaria, with each substrate covering 50% of the area. Replicate combinations consisting of gravel/sand, qravel/plant, gravel/detritus and sand/detritus compared to a control without substrate were made. Ambient lake water (21.4°C) used in the study was supplied at 2.5 l/min.

Five 53-day old sturgeon were placed in each of nine aquaria the evening prior to the test. Fish were not fed during the study and were under a controlled 16-hour photoperiod (0533-2130). Three minute observations on location and behavior were nade on one selected fish in each aquarium at timed intervals. Cumulative time spent on each substrate or in the water column was recorded. Observations began at 0930 and ended at 2130. Fish length and weight were determined at the conclusion of the experiment.

1.2.5. lest of fry groups on substrate without current

Experimental design follows that described for substrate preference tests of individual fry (Section 1.2.4), except that tests were made on groups of fish. Replicate combinations consisting of sand/gravel, gravel/plant, gravel/detritus, and sand/mud were used. Five fish, 54 days old, were randomly distributed to each of eight aquaria the evening before the tests. Periodic observations were made to note the position and behavior of each fisn in the tank, as before. The observer would stand over the aquarium, and after a timed interval, record the position of every fish within the tank, noting which substrate the fish was on or if the fish was swimming in the water column. At the conclusion of the experiment, fish were anesthetized, weighed and measured.

1.2.6. Die1 activity behavior

Substrates consisting of sand, mud, gravel, or detritus/leaf litter were placed in eight circular aquaria each containing 2.5 l/min continuous flow of ambient Lake Washington water at a depth of 30 cm. Tests conducted on 10 August 1983 and 12 August 1983 utilized gravel and sand in separate sets of four containers. In tests of 17 August 1983 and 18 August 1983 mud and detritus/leaf litter were used in separate sets of four containers. Water flow was maintained at 2.5 l/min. Average temperatures for all four tests were 21.6°C.

Four groups of forty sturgeon were utilized (one group per test) ranging in size fran 48.2 mm - 73.2 mm and 0.6 g - 2.0 g. Fish used on the 10 August 1983 test were 61 days post-hatch; on 12 August, 63 days post-hatch; on 17 August 1983, 68 days post-hatch; and on 18 August 1983, 69 days post-hatch. Five fish were placed in each test container the evening before the tests were executed. Photoperiod was controlled at 16 hours of light per 24-hour period. Observations of behavior and orientation on substrate were conducted by one observer. The observer would stand over the test aquarium for a timed interval noting swimming behavior of the fish. At the end of the interval the position of each fish (either on the substrate or in the water column) was noted, as well as the particular behavior. Observations began in the morninq shortly after the beginning of the photoperiod. The last observations were conducted just before the end of the photoperiod. Fish were not fed during the test period.

1.2.7. Salinity tolerance

Thirty, 29-day-old, sturgeon averaging 0.4 g and 3.7 mm, were subjected to three salinities for a 24-hour exposure perioo. Fresh seawater was collected from Seattle Metro's Westpoint laboratory in Puget Sound and its salinity of 28.6 parts per thousand (ppt) was determined at the Water Quality Laboratory, University of Washington. Seawater was diluted with dechlorinated city water to produce desired treatment groups. Replicate four liter test aquaria were filled with 0.0, 15.4, and 28.6 ppt seawater and placed in a water bath at 18.4°C. Water temperature increased to 19.2°C during the 24-hour exposure period. Aeration provided oxygen and mixed the water. Five fish were randomly chosen and added to each aquaria. Observations on mortality and swimming behavior were made at periodic intervals by removing airstones and peering from the top of the aquaria.

Task 1.3. Larvae and Fry Feeding Behavior

1.3.1. Feed initiation

Sturgeon fry possess teeth only during the first month of their life (Beer, 1980). The presence of teeth suggests that these fish initially are aggressive carnivorous feeders. Zooplankton (cladocerans) have been used to successfully rear sturgeon through the critical first month of life. Feed initiation on an artificial starter diet could decrease the weaning mortality experienced in culture and provide the means to maintain stock in the laboratory for experimentation. To address this need, an experiment was designed to test the effectiveness of BioDiet, a commercial diet, as a starter feed for white sturgeon. Zooplankton, collected from Lake Washington, was selected as a diet treatment to represent a natural food. A control treatment with no food was included to help discern the effectiveness of the artificial diet.

On 23 June 1983, 100 yolk sac fry, 13 days old, were placed in each of six 28-liter circular aquaria. Ten cohorts were anesthetized, weighed, and measured (these fish were not used in the feeding experiment). Continuous flow at 2.5 l/min ambient Lake Washingtn water, filtered through glass wool, supplied the containers. Water temperature varied from 18 to 19.8°C during the experiment. Replicate diet treatment groups consisted of zooplankton and BioDiet starter mash. Replicate control groups were not fed during this experiment. Zooplankton was collected daily through a no. 20 mesh plankton net. Table 1 provides a list of dominant zooplankton species representative of Lake Washington and Columbia River communities.. Typical composition of Lake Washington zooplankton, at this time of year, is dominated by <u>Daphnia</u>. Zooplankton was secondarily filtered through a no. 10 mesh net to separate large zooplankton such as mysid shrimp. BioDiet starter mash is a protein-rich diet with l-mm particles. Composition analysis of BioDiet starter mash is provided in Table 2.

Sac fry were fed every two hours from 0800 to 2100. Amount of zooplankton fed per feeding was not quantified. Qualitatively, a dense concentration was presented so that food was in excess, facilitating random encounter by the sac fry. BioDiet starter mash was sprinkled on top of the water. The aquaria were brushed and water siphoned daily. Cleaning did not remove all zooplankton as density of zooplankton was too high and some zooplankton appeared to avoid the siphon. Unconsumed starter mash eventually sank to the bottom and was removed by the cleaninq methods. Mortality of all groups was recorded daily and observations on swimming and feeding behavior were made. At the conclusion of the experiment, survivors were anesthetized, weighed and measured.

1.3.2. Sustained feeding

While researching early life history of white sturgeon, the opportunity was available to examine growth during this period of their life. Records were kept on weight and length in relation to temperature and feeding rate as the studies progressed. Young sturgeon were raised in aquaria described in Task 2. Half of the fish were raised in ambient lake water and the other half were reared in chilled dechlorinated city water. Cooler temperatures were used to slow the development rate and lengthen the time that small fish were available. With the onset of wanner Summer weather, Lake Washington temoerature and the incidence of disease increased while clarity of water decreased. At forty days post hatch, all fish were raised on a mixture of city and lake water to provide cleaner water and better temperature control than experienced with lake water exclusively.

As a general rearing schedule, BioDiet starter mash no. 4 was used until the fish reached 50 days post hatch (0.55 g). At this time, the fish were switched to BioDiet no. 6 (pellets) for an additional 30 days (2.0 g) and then followed by the change to the University moist pellet for the remainder of the study. Initially, on BioDiet no. 4, the fish were fed freauently and to satiation. On BioDiet no. 6, fish were fed at a daily rate of 5% body weight, and at a frequency of 3 to 4 times per day to keep food waste in the tank at a minimum. The older fish fed the moist pellet received 3% body weight delivered over three feedings per day.

In addition to data gathered from fish reared to meet project objectives, three replicate groups of 107-day-old fry were subjects of a sustained feeding trial using feeding rates of 2.5% 5.0% and 10.0% body weight daily. Five fish were placed in each of six aquaria with dechlorinated city water at a mean temperature of 16.9°C and a flow of 1.2 l/min. Initial average weight of fish was 5.9 g and a length of 112.6 mm. After 9 days and again after 26 days into the study fish were anesthetized in 100 ppm MS-222 and measurements taken on weight and length. At 26 days, the chlorine filter used on city water malfunctioned, resulting in an immediate mortality and attenuation of feeding among the survivors. Sustained feeding evaluation was terminated at that time.

RESULTS

Objective 1.0: To characterize the early life history and feeding behavior of white sturgeon larvae and fry.

Task 1.1. Spawning and Incubation

The Fishery, a commercial fish farm, proved to be most helpful in obtaining and maintaining stock for culture and behavior investigations. Stock obtained frm spawned females exhibited high survival through incubation and early rearing at the field site as well as at the laboratory. The Fishery has operated successfully for three years and has shown that artificial propagation for enhancement programs is feasible. Response of larvae and fry to incubation and early rearing procedures indicates that artificial spawning and culture of sturgeon can be executed on a production level. Columbia River white sturgeon will accept artificial feed, and maintenance of experimental animals on BioDiet is possible. Further studies should be designed to assess nutritional requirements, food preference, and food availability. Such studies, however, were not within the scope of the present investigations. The artificial feed, BioDiet, was merely a convenient source to rear the test fish upon while other aspects of early life history could be explored.

On two occasions at the laboratory, chlorine levels in the city water supply used for holding test fish exceeded 0.45 ppm which resulted in high mortality. The sensitivity of sturgeon fry is much higher than that observed for salmonids raised in similar water. Losses of sturgeon during the later fry rearing stages at both the field station and laboratory were higher and tended to continue for several weeks with no agent found responsible. Accanpanying the mortality was a high incidence of columnaris, a myxobacterium that attacks gill surfaces, reducing the capability for gas exchange. Chemotherapy demonstrated mixed success. The Fishery treated the fish with saline baths and nitrofurazone with positive results. Furanace (nifurpirinol) was utilized at the University laboratory. Positive effects were temporary with incidence of the disease reappearing in a few days. Effectiveness of the chemical treatment decreased with time.

Task 1.2. Larvae and Fry Distribution Behavior

1.2.1. Temporal response of sac fry to current

NULL HYPOTHESIS: Larvae and fry are randomly distributed throughout the test arena during all times regardless of current or substrate presented.

Larvae and fry were observed as they oriented to a substrate during this crucial period in their life history. Descriptive observations are presented relating to the days post hatch. Figure 5 provides a summary showing the number of fish swimming in the water column throughout each day of the experiment.

13 Days

One hundred 13-days-post-hatch larvae, reared in cold, treated city water (approximately 12°C), were released in the test arena upon acclimation to the warmer lake water (approximately 19°C). Larval fish at this stage in development still possess a yolk sac as their source of nourishment. Within two minutes all but one fish had dropped out of the water column. Sac fry buried into the gravel head first or found shelter from fast flows in eddies behind gravel. Fish on the surface were oriented against the current. Fifty-seven fish were still visible on the substrate surface by the end of the first observation period (or at the end of 2 hours). Throughout the day, at least one fish continued to swim in the water column with the current.

14 Days

Temperatures on this day ranged from 17.9' to 18.0°C. ND fish were observed swimming in the water column. Twenty-four fish were visible in the substrate at the first observation period. Half of the fish were buried within the substrate while the others were partially buried or lying upon the substrate. As the day progressed, fewer fish were visible at any one place in the arena. A total of 20 mortalities was counted during this day, 10 of which were recorded during the first observation period. The number of visible larvae decreased as they buried into the substrate. Fish at this stage of development were photopnobic. Areas with slow velocity were sought, conserving energv necessary to maintain position. Since yolk sacs are still visible it is assumed fish were not feeding. Only one swimmer was observed around midday.

15 Days

Fewer fish overall are evident this day. No swimmers were observed and only two fish appeared on the gravel surface during the observation conducted at first light of day. Fish buried or partially buried were facing into the current and in the gravel head first. Temperatures ranged from 18.0' to 18.5°C. The number of fish visible ranged from 13 to 19 throughout the day. No mortalities were noted.

16 Days

One swimmer was seen during the first observation period. Two sac fry were noted on the gravel surface during midday. The rest of the fish remained buried or partially buried in the gravel head first and against the current. One mortality was counted at the first observation period. The number of fish visible per observation period varied between 17 and 22. Water temperatures ranged fran 18.2' to 19.0°C.

17 Days

Two fish were swimming in the water column against the current at the beginning or the photoperiod. Yolk sacs were not visible on these fish; quantitative measurements of yolk sac remaining were not taken. One swimmer was at the water surface with the head angled upward. The other swimming fry would skim along the gravel surface often stoppinq behind larger pieces of gravel to maintain a position in the current. By 0800 hours, fish were no longer observed swimming in the water column. More fish, however, were noted on the gravel surface maintaining position against the water flow. No mortalities were recorded on this day. The number of fish visible during any one observation was steady, ranging from 17 to 18. Temperatures throughout the day varied from 18.8' to 19.9°C. Observations would suggest that emergence occurs when the yolk sac disappears. This developmental and behavioral event could appear as early as 17 days post hatch under the described experimental conditions.

18 Days

Six fry were observed swimming in the water column, but only during the first observation period at 0600 hours. Five fish were noted on the gravel surface at this time. Yost of the swimmers oriented toward the water surface, head end angled upward. Within three hours, swimmers were no longer evident, but more fish could be observed on the gravel surface. Temperature ranged between 19.4' and 20.0°C. The number of fish visible at each observation oeriod varied from 20 to 24. Zooplankton from Lake Washington, described in Materials and Methods, Task 1.3.1. Feed Initiation, were added to the test arena. Fish were not directly fed otherwise. Lake water, however, was not completely filtered and it may be expected that some plankton were delivered into the test water.

19 Days

Eight fish were swimming during the first observation period. Five fish were counted maintaining position on the gravel surface. Within three hours, the swimmers had retreated to the substrate. Six fish remained on the gravel surface throughout the day. At midday, one fish was observed skimming along the gravel surface orienting against the current. Fish on the surface were maintaining positions between gravel pieces and against the current. Observations were conducted after the end of the photoperiod and no fish could be observed swimming in the water column. Within three hours, aporoximately 12 fish were actively swimming. Some went with the current, while others, swimming at angles perpendicular to the current, crossed the width of the test arena. Lake Washington zooplankton was added after the end of the photoperiod when most fish were noted swimming. Temperature was steady between 19.4' and 19.5°C. No mortalities could be accounted for this day. The number of fish visible ranged fran 18 to 22. These numbers do not include the observation made at night since poor light conditions made it impossible to see fish on the substrate surface.

20 Days

Seven fish were observed in the water column swimming with the current. Swimmers remained in the water column throughout the day. Fish would point head upward while "bouncing off" surface tension at air/water interface. Afterwards, they would dive to the bottom, then back up to the surface again. Non-experimental fish reared in circulars and fed BioDiet would behavior similarly when food was placed in the tanks. At times, fish tended to swim against the current, but not for more than a few seconds. Fish observed in the gravel at the sides of the test arena appeared to be buried from 1.5 to 2.5 cm. Body movement was constant while buried in the gravel. From 3 to 6 fish were always noted on the gravel surface. During midday, swimmers would be head first at water surface, holding a few seconds while maintaining position against the current. Next, fry would actively swim down-current, angling toward the bottom, stop, turn toward current, then swim perpendicularly and toward the surface. Again, the fish would move with the current while maintaining position and repeat this behavior. Later, toward the end of the photoperiod, the swimmers began to show active rheotactic behavior instead of random dispersion. Fish were still positioning themselves perpendicular to the surface, but not as frequently as noted during the day. Approximately 12 fish were swimming in the water column 4 hours after the end of the photoperiod. Fish visible in the test arena varied between 20 and 22 per observation period. Temperatures fran 19.0' to 20.0°C were recorded.

21 Davs

More fish were observed swimming throughout the day, and fewer were noted on the gravel surf ace. Fish were positioned horizontally rising toward the surface, then back to the bottom again. Some would swim against the current, but were not able to maintain position for longer than three seconds. From 19 to 21 fish were visible during any one observation period. Temperatures ranged between 19.4' and 19.5°C. Fish buried in the gravel, yet visible through the side wall, appeared smaller than fish swimming in the water column. Yolk sacs had been absorbed in the majority of fish by 21 days post hatch. Swimmers may be obtaining food by grazing on gravel, fran the water source, or by supplement of Lake Washington plankton mixture.

22 Days

Number of swimmers observed during the day averaged between 13 and 15 fish-. Fish were scattered throughout the water column often at the surface with snouts pointed up. They would move to the gravel, maintain position momentarily, then swim up, position aqainst the current, and angle down to the bottom. Fish buried in gravel appeared to be trapped. About 20-23 fish were visible per observation period. Temperature ranged between 18.9° and 19.1°C.

<u>23 Days</u>

Fish were exhibiting the same behavior as noted on the previous two days. Fish appeared to be swimming into the current with greater frequency. Only 20 fish are still evident out of the original 100. Observations were terminated and the remaining fish were anesthetized, weighed, and measured. Fish averaged 0.04 g and 20.6 mm.

1.2.2. Response of fry to sculpted substrate within a current

NULL HYPOTHESIS: Larvae and fry are evenly distributed over three sculpted substrates (gravel, sand, detritus) within a variable current.

Two sets of observations were conducted, one giving a view of all the fish together at any particular instant and the other allowing more time to provide details as to the behavior of a typical sturgeon fry. Varied and sculpted substrate presented a simulation of conditions the young fish might encounter in a river such as the Columbia. White sturgeon fry could seek various habitats as they search for food, protection, and rest.

The first observation period of the day found two of the five fish occupying a position in the trough of the sand (position A, Fig. 3). Another fry was observed on the crest of the sand downstream from the other two fish (position B, Fig. 3). Ninety minutes later, three fish were noted maintaining position in the sand trough (position A, Fig. 3). By midday no fish were observed on any of the substrates. All fish were actively swimming throughout the water column. These observations are in contrast with experiments conducted in the aauaria (see Section 1.2.6. Die1 Activity Behavior). Same age fish in the aquaria tended to be more active during the morning hours. Later in the day, although fish were actively swimming, the majority were in the proximity of the suspended detritus and leaf litter area of the tes arena. Fish would move about the cover of plants, in and out of the open water current.

Individual fish observations exhibited slightly different behavior than those for the group. Although the majority of the fish spent time swimming in the water column, at least one fish was on a substrate for each observation period (Fig. 6). When on a substrate, preference seemed to be sand (position K, Fig. 3). with less time spent on gravel during the same period (position I, Fig. 3). When swimming, the fish would often hover within the detritus/plant material. Unlike that indicated by group observations, the individual fish had a tendency of being on the substrate during midday.

Although the individual fish would spend a majority of time actively swimming, substrate appeared to be integral to orientation. As mentioned, a fish would move within the detritus/plant material. Individual fish would also turn into the current with head pointed toward the surface, maintain position for a few seconds, then angle down toward a substrate. Very little time was spent on the gravel. A fish would skim along the gravel surface for a couple of seconds and then head back up into the water column. When a fish was on the sand, it would maintain position for extended periods, up to 90 seconds during some observations. An individual fish was never observed directly upon the detritus/plant material, only moving and maintaining a position within.

1.2.3. Response of fry to flat substrate within a current

NULL HYPOTHESIS: Larvae and fry are evenly distributed over four flat substrate (qravel, sand, mud, detritus) surfaces within a uniform current.

Substrates in this experiment were flat allowing for uniform velocity throughout the test arena except near the water inlet. Contrasting with the sculpted substrate test, areas to seek refuge from velocity were not available. During the first observation period, all fish were observed actively swimming with the current. Within one hour, two fish were observed on the gravel surface maintaining oosition facing uo-current. At least one fish was observed on the gravel during the rest of the observations. Swimmers were very active through the day, continuing to move with the current. Swimmers would exhibit burst activity, making a "bee-line" around the test arena for many revolutions. Toward the end of the photoperiod, fish were noted on mud and sand substrates. Half of the fish swimming at this time were positively rheotactic, while the others expressed negative rheotaxis. One observation conducted soon after the end of the photoperiod revealed all fish to be swimming actively. Fish also tended to be more oriented toward the water surface.

Observations on an individual fish again showed differences from the behavior noted for the group. The first observation revealed that when a fish was on a substrate, the choice was sand. The fish descended upon the sand, held position in the current for a moment, and with burst swimming, traversed the arena. By midmorning the fish was active but not swimming in a straight line as in the first observation period. Orientation was against the current when on sand and with the current when over the other substrates. When over detritus, the fish would drop to the substrate for a couple of seconds as if probing the substrate and then move into the water column. By midday, one fish was noted to exhibit rapid opercular movement while listing on the gravel surface. This fish was not considered healthy and was found dead the day after the conclusion of the experiment. The remaining fish, however, were actively swimming throughout the day with the current. The observation conducted after the end of the photoperiod found a fish lighting on the sand for a few seconds while maintaining a position against the current. It then swam up, went with the current around the test arena until it came back over the sand, and settled to the bottom again. This behavior was repeated throughout the 3-minute observation period. When swimming, the fish would be positioned in the lower third of the water column close to the substrate surface. Other than the "unhealthy' fish, no individual fish was observed on a substrate besides sand.

1.2.4. Response of individual fry on substrate without current

NULL HYPOTHESIS: Individual fry show no preference for a particular substrate and exhibit random movement when presented with a substrate (gravel, sand, mud, detritus) and no current.

Individual fish from each treatment group were obsewed periodically from 0930 to 2130 hours. Duration on substrate and behavior were recorded. In this experiment, sturgeon fry were observed stationary on sand and on the bottom of the test aquaria containing no substrate. No fish were observed resting on gravel, mud-detritus, or plant material (Fig. 7). In other experiments fish were observed on various substrates. When on the substrate, fish usually remained within a small area (roughly two body lengths) and the head was oriented toward the inflow.

For the most part, fish were active, usually swimming along the walls of the aquaria. Seldom were fish observed swimming in the open area of the aquaria. An exception occurred when a fish was repeatedly observed swimming in tight, frantic circles. This whirling behavior was not thought to be related to any specific substrate, but was probably more related to poor fish health or stress. Fish reared at The Fishery or at the University of Washington would occasionally display this swimming behavior. Often fish displaying this behavior would die within 24 hours, but sometimes normal swimming behavior resumed. Dn occasion, an experimental fish would exhibit burst swimming. In one instance, this behavior followed whenever a fish swam directly underneath the inflow water. The jet of water may have startled the fish, prompting the accelerated swimming. Other causes of occasional burst swimming were not obvious.

Swimming was usually at an even pace, along the wall in a clockwise direction. Often an undulating pattern was displayed in which the fish would remain close to the surface of the wall, but would swim from the upper to the lower depth of the aquarium and back again. Inflow water was directed straight down in order to avoid creating a current in the aquaria. The clockwise directional swimming exhibited may have been a learned behavior from the rearinq experience. Fish reared in aquaria with counterclockwise directional current similarly exhibited clockwise swimming orientation.

Diel activity patterns are suggested from investigating the total time spent on sand substrate versus time of day. Fish spent more time on the substrate midday and were more likely to be found swimming in the water column in the morning and evening. This pattern of activity was observed in other aquarium distribution behavior experiments. what this implies for fish in the Columbia River is that morning and night may be their major foraging time. Limited activity during daylight hours could be predator avoidance behavior among young sturqeon.

1.2.5. Response of fry groups to substrate without current

NULL HYPOTHESIS Larvae and fry show no preference to a particular substrate and dispaly random movement when presented with a substrate (gravel, sand, mud, detritus) and no current.

Location of five sturgeon in each aquarium was recorded at various times of the day. Two substrates covered the bottom of each aquarium corresponding to individual fry tests. Similar to observations of individual fry, fish were more likely to be found on the sand or on the aquarium floor without substrate. When several fish were on the sand, territorial behavior was exhibited on occasion. The larqest individual would chase away nearby fry. Social interactions such as dominance may have an important role in sturgeon life history, and serve to partition food resources.

In contrast to individual fry observations, fish were observed upon gravel and mud substrate surfaces. No fish were noted on the plant substrate, although swimming fry would tend to occupy that area. Fry would swim back and forth through the plant foliage and then return to other areas of the aquarium. Plants may provide protective cover for the young fish or they could provide an area where forage is more available. The fish swimminq in the water column tended to stay close to the aquarium walls, and few fish were in open water.

1.2.6. Die1 activity behavior

NULL HYPOTHESIS Photoperiod does not influence activity of fry presented with a substrate (gravel, sand, mud, detritus) and no current.

Experiments were conducted on four separate days over a l-week period. Fish were actively swimming in the aquaria during all observations even while on the substrate surface. Approximately five out of 20 could be found on sand while two out of 20 fish would be found on both gravel and mud substrates. Only one fish might be found on the detritus and leaf litter during any one observation period. These findings might suggest that if a 55- to 62-day-old white sturgeon were to choose a substrate to light upon, sand would be preferred. Fish upon sand would be active, but maintain a position within a radius equal to one body length. Fish on detritus and leaf litter tended to bury within the suspended plant material. Swimmers were active, but-in no particular direction. Water flowed straight into the aquaria and currents were minimal. Territoriality was displayed particularly among fish occupying the sand surfaces. A 1 arger fish would chase away smaller ones with its snout when the small ones encroached upon the maintained area mentioned above.

Time of day also appears to be correlated with time on a substrate. Figure 8 graphically depicts the die1 pattern of fish on the substrate. throughout the day. More fish tended to be on the substrates, particularly sand, durinq midday while swimming activity among total number of fish was greater at the beginning and ending portions of the photoperiod. This pattern seemed to be the case except for fish exposed to the detritus and leaf litter and mud substrates.

1.2.7. Salinity tolerance

NULL HYPOTHESIS : Fry, 29 days old, are able to survive equally well in water with salinity concentrations of 0.0, 15.4, and 28.6 ppt over a 24-hour period.

Tolerance to salinity among the fish tested was low (Table 3). Only control fish placed in freshwater survived this 24-hour experiment. Acute mortality occurred between 3 and 12 hours for those fish in 15.4‰ salinity. All fish exposed to full-strength seawater died within 3 hours from the start of the experiment.

Abnormal swimming behavior of fish in full-strength seawater was noted at tne first observation period. Fish in these aquaria were observed in a close group near the surface of the water, whereas fish in all other groups were observed swimming throuqhout the water column. After 15 minutes, one half of the fish in full-strength seawater displayed short, frantic swimming movements followed by periods of rest. Fish in the other aquaria were observed swimming in the water column Thirty minutes into the test, fish in full-strength seawater were moribund and died within the next I.5 hours. 4fter one hour, one fish in the half-strength seawater group was noted swimming in tight circles. By 3 hours, some mortality occurred and most fish in this treatment group were moribund. By 12 hours, the last fish in half-strength seawater died.

Task 1.3. Larvae and Fry Feeding Behavior

1.3.1. Initiation of feeding

NULL HYPOTHESIS Inititation of feeding and subsequent survival is the same for larval and fry groups either starved or fed.

Yolk sacs were evident when fish were introduced to the test aquaria. Little activity was noted during the first 6 days. Fourteen-day-old fish became active during the night, but remained sedentary and closely grouped during daylight. Daytime activity was observed in 18-day-old fry. This activity corresponds to the first observation of swimming by arena test fish (see Results Section 1.2.1. Temporal response of sac fry to current). At this time, the yolk sac was not evident. Photophobic response was no longer noted and swimming appeared frantic, without any obvious rheotaxis. Fish often swam with their heads pointed up and would break through the water surface with their snouts. At the surface, fry were sometimes observed rolling on their backs. Actual food consumption was not observed, but rolling on their backs could facilitate feeding on organisms at or below the water surface.

Mortality for starved and zooplankton groups rose dramatically when fish were 21 days old (Fig. 9). High mortality occurred in one BioDiet treatment group three days later. The experiment was tenninated on July 5, 1983, because of a problem with the facilities. Water level in the BioDiet test aquaria rose, allowing some of these fish to overflow the aquaria. Average length and weight of all survivors are presented in Table 4. Fish fed zooplankton did not differ in weight or length from starved fish, but both these qroups were significantly smaller than the fish sustained on BioDiet. Zooplankton fed and starved groups exhibited a slight increase in length during the experiment, but did not gain weight. BioDiet fed fish increased in both weight and length from the initial values.

Growth and mortality data support the hypothesis that the Lake Washington tooplankton community did not supply an adequate diet. Data indicate the fry were not eatinq zooplankton. Nutrients absorbed from yolk could contribute to the observed increase in length without a coincident increase in weight. Reasons for the lack of success include the possibility that zooplankton were not the correct size or species composition. Zooplankton may not be a preferred food item. White sturgeon fry may feed on periphyton or benthic organisms. Further studies will be necessary to assess feeding behavior, food preference, and food availability for the early life history stages of Columbia River white sturgeon. Utilizing an artificial feed merely assists in determining at what point feeding commences.

Precise causes of the high mortality are difficult to determine. Fish that were fed tooplankton suffered a higher mortality than starved fish, although time of mortality coincided. Something detrimental may have been in the food. BioDiet-fed fish began to exhibit high mortality just before the conclusion of the experiment. Mortality was high in all sturgeon in the hatchery in addition to fish utilized in the feed initiation experiments. Columnaris, a myxobacterium which attacks gill surfaces, reducing the capability for gas exchange, was diagnosed in some of these fish. This bacterium is common in Lake Washington when temperature exceeds 16°C and is found in the Columbia River during the summer as well.

Feeding initiation is not a problem for the successful culture of white sturgeon. Live cultures of zooplankton do not seem necessary. Conmnercial diets are readily available and appear to be adequate in stimulating feeding and growth of fry. Survival could be enhanced by increased frequency of feedings. The Fishery has successfully experimented with automatic feeders which dispense feed every 12 minutes. Survival through feed initiation was as high as 80% (Ken Beer, personal camnunication). It is not suggested that commercial salmon or trout diets are the best food to sustain sturgeon. Nutritional needs of sturgeon for grow-out would entail a lengthy study. In terms of early feeding, however, the commercial diets used thus far provide the means to start aggressive feeding and growth.

1.3.2. Sustained feeding

NULL HYPOTHESIS: Growth rate, food conversion rate, and food efficiency are the same regardless if groups of fry are fed at rates of 2.5% 5.0% and 10.0% body weight oer day.

Growth of larvae and fry reared at the University laboratory along with average daily water temperature are presented in Figure 10. Growth rate increased up to 28 days post hatch, but showed an accelerated rate after the 40-day post-hatch period. Biomass doubled every two to three weeks as the temperature ranged from 14.8' to 19.2°C. The accelerated rate of growth continued through 130 days of rearing. Size and armor provide the best protection for sturgeon against predation. Maintenance of increased site requires a substantial amount of food as the fish gets larger. With such a high activity level the total energy required by the fish for growth, or food efficiency, would be useful for enhancement information. The sustained feeding study was terminated because of the chlorine contamination, and the data demonstrating conversion efficiency were limited to only 8 days. During the following two weeks the presence of chlorine resulted in much reduced feeding activity and hence, poor food conversion because of uneaten feed. Based on the growth of fish during the first week at feeding rates of 2.5% 5.0% and 10.0% body wt/day, the performance of young white sturgeon was as good as that demonstrated by young rainbow trout when evaluted as wet weight gain from weight of food fed. At the lower feeding rates, for every gram of food fed the fish gained more than a gram in weight (Table 5). Only at the higher feeding rate (10.0%) was the conversion rate reduced. Growth data for the following record period were much poorer because of the problem with chlorine contamination and have not been summarized It is of interest that in response to chlorine, growth was so severely affected. This may be symptomatic of stress fran contaminants in general, which would make water quality parameters for sturgeon even more critical than what is observed for salmonids. Reduced growth accompanying the sluggish behavior of the affected younq sturgeon would result in their high susceptibility to loss from predation or disease. Based on the mortality of larvae when exposed to nitrogen supersaturation (Ken Covert, personal communication), the mortality when exposed to chlorine, and the rapid loss resulting from short-term starvation, environmental quality appears to be of major importance to the young of this species. The implications of reduced water quality resulting from acute Or chronic contamination of the river make further investigation on the ecological tolerance of young sturgeon to such contaminants important.

DISCUSSION

Development of white sturgeon enhancement programs requires a detailed understanding of the sturgeon life history with special emphasis on those periods in their life that are most vulnerable to mortality. Early larval and fry stages, therefore, were chosen as the most important periods to investigate. High fecundity, very small eggs, substrate surface spawning, and free swimming larvae and fry make this species exceptionally vulnerable to the hostile environment of the Columbia River. Habitat requirements of this species in the Columbia are poorly understood, making the study of distribution behavior, early feeding, and responsiveness to other environmental influences necessary before a rational management program could be developed. Enhancement as a tool in management is inseparably linked with the principles that direct good management. Knowing how to enhance sturgeon, where to accentuate the effort and when to employ the appropriate methods must be directed by the knowledge of the life requirements of this species.

Work undertaken in the study was by nature exploratory. Some of the approaches were trial and error, and others would point to new questions. Without exception, insights were gained on white sturgeon early life history and behavior. Acquired knowledge provides a basis for continuing research on this species of interest. Protection, mitigation and enhancement of Columbia River white sturgeon is possible, but only if basic biological principles characteristics of the fish are first understood.

Spawning techniques employed in the study are well established (Beer, 1980; Lutes and Doroshov, 1983). Live spawning by surgically removing the majority of the eggs and suturing the incision prior to releasing the female, provides an effective means of securing experimental stock without harming the viability of the fish. Although more efficient methods of removinq the eggs mav be developed, such as saline rinses to evacuate the body cavity through inserted tubes, the present technique is adequate even for large canmercial culture programs because of the sturgeon's high fecundity.

Patterns of larvae movement, diurnal activity, substrate preference, and energy requirements to meet metabolic demands were some of the major accomplishments of the study. Newly hatched larvae were not tested in the circular arena to determine the extent of disoersion by flow displacement. Observations of the larvae in the aquaria revealed that upon hatching they would swim toward the surface and remain in the water column for 5 days before returning to the bottom. The larvae would clump together on the bottom. This response may have been initiated by increased sensitivity to light. After 14 days post hatching the young fry, just absorbing their yolk sacs, left the bottom to swim up in the water colurm. Fry at this point in life exhibit an increased capacity to orient within a current.

Fry held in cooler water, to slow development and hence extend the opportunity for study, were placed in the arena 12 days post hatching. Fry moved directly to the gravel surface or buried within the gravel substrate and remained there for 5 days. At age 17 days, most of the fry showed diurnal swim-up activity patterns. Fry were beginning to feed, and by age 20 days swimming was observed throughout the day. It was at this age that mortality increased among the starved fish within the feeding study, which -Supports the notion that swim-up behavior is related to initiation of feed- inq. Similarly, in the sustained rearing study, yolk absorption occurred at age 17 to 20 days, which would require that an active search for food commence. Emergence from the gravel initiated this phase of behavior.

Diurnal pattern of movement continued throughout the study with a strong association toward the bottom and walls of the aquaria during day- light and movement into the water column at night. As the fry grew older, less displacement with the current was observed. Fish older than 55 days displayed increased frequency of rheotactic behavior on the substrate surface. Uhen free in the water column movement against the current was common, although generally at this age fish were moving downstream more frequently.

Continuous movement of the larvae and fry was characteristic throughout the study period. Fry would rise to the surface in a vertical position and then glide back to the bottom. At the surface of the water they would skim along for several centimeters with their nose extended above the water, or roll over on their backs and maneuver with equal agility.

Movement into open water immediately after hatching, and the freouent excursions into the water column even as advanced fry, indicate that the dispersal mechanism of this species, if spawned in the higher velocities of the river, would be displacement by current. Extent of the displacement in a river such as the Columbia is uncertain, but it is conceivable that in the present limitation to upstream migration many of the juveniles would reach salt water. Mortality would be high under rapid transition from fresh to salt conditions. Although the estuary could be a productive feeding area for fish with the benthic orientation shown by sturgeon, the age at which a sturgeon could make a direct transfer would have to be over 29 days post hatching. Speculation at this time is that sturgeon would not survive well if displacement carried them to the saltwater. Dispersion of fry downstream therefore, has to terminate when the larvae first become oriented and are placed in low enough velocity to allow subsequent stream residence.

Work with substrates was revealing. Open voids in the gravel invited larvae to enter once this fish became bottom oriented. Continuous and near- ly mechanical swimming activity of the juveniles caused them to penetrate the qravel and to become entrapped, resulting in mortality. When the gravel surface was removed to allow their freedom, the larvae would escape into the water column without the hesitation demonstrated by gravel dwelling larval species. Mud, plants, and even detritus was not preferred by even the fry or older fish. The preferred substrate, based on the frequency of their choice and the time spent there when on the bottom, was sand. Sand may house the food organisms that young sturgeon feed on and provide the surface for which their movement patterns are most adapted. When swimning in the water column, however, suspended plants appeared to be attractive.

Initiation of feeding was anticipated to be difficult on artificial diets. Obviously sturgeon in the Columbia River are maintained on natural food resources. Starting fish on the commercial diet, however, proved successful, with an immediate qrowth response. Fish held at The Fishery did not experience the high mortality generally associated with yolk absorption and starvation of the larvae. The response to any canparable diet would probably be the same if presented in sufficiently high quantities. Continuous activity of the fish demonstrates the high energy demand of this species. If sufficient quantities of food are not available at yolk absorption, mortality from starvation will be very high. Automatic feeders used at the field station maintained a high food density and overcame the loss generally experienced at that stage. Growth rates after yolk absorption were greater than in the natural environment, and therefore, the conclusions regarding life history must be carefully assessed when relating stages in behavioral development with time elapsed. Under hatchery conditions the sequences in development will be influenced by the size of the fish rather than by time.

Feeding behavior among the growing fry was interesting. Sight wasn't the primary mode of food identification. Either olfaction or taste was used to search for and identify feed. Continuous swimming activity appears to be the mechanism for search that will bring them within range of the chemical stimuli that leads them to the food. When food was placed in the aquaria, the tendency of the fish to drop to the bottom is probably an instinctive response to be in the position most likely to intercept food. When food was intercepted on the bottom it would be eaten on the spot. Many of the older fish would corkscrew up to the surface, grab the food and return to the bottom. Larger fish appeared to be territorial when food was present and would chase away smaller fish. Some fish would avoid food if it was in the proximity of a large fish. Feeding was quite aggressive, even among the small fry in the arena. Fish were observed carrying similar sized mortalities in their mouths.

Performance of the sturgeon utilized in artificial culture methods was encouraging. Growth of the fish was good and food conversions were as good or better than that experienced by wild salmonids brought into culture conditions. If culture of sturgeon is undertaken in enhancement operations, the responsiveness of the wild stock would be most amenable to such measures. It was particularly interesting to note that even at a feeding rate of 10% of their body weight per day, food efficiency was not much less than at the lower feeding levels.

Further investigations to determine food preference and availability in the Columbia River basin are required to provide a full understanding of white sturgeon energetics. Experiments in the present study merely demonstrated at what point in the early life history feeding is initiated. Based on work conducted at The Fishery as well as the routine maintenance of fish used in experiments at the University laboratory, artificial diets are adequate to sustain growth. Positive feeding responses to the artificial techniques indicate that Task 1.4 originally proposed was unnecessary. Objectives proposed in Task 1.4 are more appropriate to studies seeking to develop optimal artificial propagation methods. Since the primary objective of the present study is to provide a basic understanding of the early life history stages, more time was devoted in fulfillment of this goal. Standard raceways are not very suitable for long-term rearing of fish that are oriented to the physical surfaces of the containers they occupy. Large surface areas, such as wide circular ponds, would be the better system. Water quality appears to be very imoortant to sturgeon culture. They are particularly sensitive to chlorine, and showed susceptibility to columnaris in Columbia River water, as well as outbreaks in the hatchery. Although sturgeon are considered most successfully cultured in warmer water with respect to growth, mortalities were most prevalent when the temperatures rose above 16°C. Cooler water tended to reduce disease outbreaks, and treatments with furanace and salt appeared to provide control of columnaris temporarily. Culture techniques such as lower rearing density and good water quality would be some of the effective means to reduce disease occurrence.

CONCLUSIONS

Early life history studies of Columbia River white sturgeon have revealed a great deal about their biological requirements and has identified areas that need further work to facilitate enhancement efforts. Distribution behavior proves to be important fur the success or strength of a year class. Severe flow conditions in the river may have a negative affect on subsequent production if dispersal is accelerated into the estuary or undesirable habitats. Substrate deposition or the lack of substrate renewal may influence the potential for larvae to survive.

Perhaps of even greater importance is the critical nature of food availability. Fry may need to initiate feeding within hours after yolk absorption. When environmental circumstances inhibit food production, the inability to sustain high metabolic demand could limit their success in establishing a strong year class of fry.

Spawning, incubation, initiation of feeding, and rearing requirements that are experienced in the culture of sturgeon were shown to be successful for this study. Improvements in culture methodology were suggested to reduce oroblems in growth, disease, and mortality associated with their husbandry.

Further information on early life history is required before management of white sturgeon can progress' beyond basic restriction on the catch. Rather than develop technology for the culture of sturgeon during the 1984 investigation, the following items are proposed for examination during the next phase before effort is expended on culture techniques.

1. Extend research on distribution of larvae in response to current at hatching and post yolk absorption behavior of newly feeding fry to evaluate the limitations of their dispersal mechanism. The high fecundity of sturgeon indicates that mortality of spawn is also high. Determining the source of variability in survival success from year to year in response to environmental conditions, will provide background on how to most effectively enhance sturgeon.

2. Examine the salinity tolerance of larvae and fry when exposed to estuarine salinities, and determine when fry can withstand full strength seawater. The extent of limitation imposed by hydroelectric developments on distribution of sturgeon is unknown. Habitat reduction in the Columbia may be cpnpensated for below Bonneville by exploiting the marine area.

3. Extend the work on substrate preference. Reduced gravel recruitment and increased deposit of fines resulting from da construction will continue to change substrate composition in the Columbia River. Impact of this change will be determined by examining the behavior of

juveniles on different substrates and the food supplies they exploit on those substrates.

4. Research the effect of water quality variables such as dissolved oxygen, gas supersaturation, and temperature on development and survival of sturgeon. Many changes have occurred in the water quality from hydroelectric developments on the river. The sensitivity of-sturgeon to changes in water quality implies that a negative impact will be experienced by young fish rearing in the river at certain times of the year.

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Table I. Columbia River and Lake Washington zooplankton community compositions. The lists present species most comnonly found during the summer when Task 1.3.1 was conducted. Columbia River samples were collected near Hanford Reach in March-June 1976 and the Lower Columbia near Prescott, Oregon in June 1969.

Lake Washington June 1983	Columbia River June 1969 and March-June 1976
Cladocera	Cladocera
Bosmina sp.	Bosmina sp.
Daphnia galeata	Chydoridae
Daphnia pulicaria	Daphnia schodleri
Daphnia thorata	Daphnia sp.
Diaphanosoma sp.	Macrothrix sp.
Leptodora sp.	
	Copepoda
Copepoda	Calanoids
Cyclops bicuspidatus	Cyclopoids
Cyclops vernalis	Diaptomus sp.
Diaptomus ashlandi	Harpacticoids
Epischura nevadensis	
Rotifera	
Conochllus unit	
Kellicotia longispina	
Keratella cochlearis	
Keratella guadrata	
Polyarthra sp.	
Nematoda	
Chronoqaster sp.	
Dinoflagellata	
Ceratium herundin	

Data for Table 1, Columbia River zooplankton composition, was derived from Gaddock et al. (1976) and Dauble et al. (1980).

Table 2. BioDiet starter mash specifications used as starting feed for sturgeon larvae and fry. BioDiet was utilized in Task 1.3.1 as well as for maintenance and sustained feeding for all experimental fish. Feed was provided by Bioproducts, Inc.

Component		% Dry weight	% Wet weight
Crude Protein	(min)	36.0	46.0
Crude Fat	(min)	14.5	18.5
Crude Fiber	(max)	3.0	4.0
Ash	(max)	12.0	15.5
Moisture	(max)	22.5	---

Table 3. Mortality summary of Task 1.2.7. Twenty-nine day old white sturgeon were exposed to various salinities over a twenty-four hour period. No fish were able to tolerate any of the salinity concentrations presented.

Salinity (ppt)	Mortality								
	0 hr	0.08 hr	0.25 hr	0.5 hr	1 hr	3 hr	6 hr	12 hr	24 hr
0.0	0	0	0	0	0	0	0	0	0
0.0	0	0	0	0	0	0	0	0	0
15.4	0	0	0	0	0	0	2	3	
15.4	0	0	0	0	0	1	4		
28.6	0	0	0	0	0	5			
28.6	0	0	0	0	3	2			

Table 4. Average weight and length of survivors from the initiation of feeding study, Task 1.3.1. Results are given for each of the two replicates per treatment group. Standard deviation is in parenthesis.

	Zooplankton		BioDiet		Starvation	
Weight (gram)	0.035	(0.017)	0.085	(0.021)	0.036	(0.014)
	0.035	(0.013)	0.101	(0.017)	0.034	(0.008)
Length (mm)	19.75	(1.95)	24.49	(1.90)	20.16	(0.99)
	19.75	(0.75)	25.91	(1.87)	19.95	(1.05)

Table 5. Height gain and food conversion of four-month old sturgeon in Task 1.3.2.

Ration (% body weight)	Wet weight (g) Sep 27	oct4	Weight gain	Total Food Fed wet weight (g)	Food efficiency
2.5	6.3	7.9	1.6	1.2	1.33
2.5	6.0	7.5	1.5	1.2	1.25
5.0	6.2	9.8	3.6	2.4	1.50
5.0	5.4	8.3	2.9	2.4	1.21
10.0	5.5	8.4	2.9	4.8	0.61
10.0	6.2	9.4	3.2	4.8	0.66

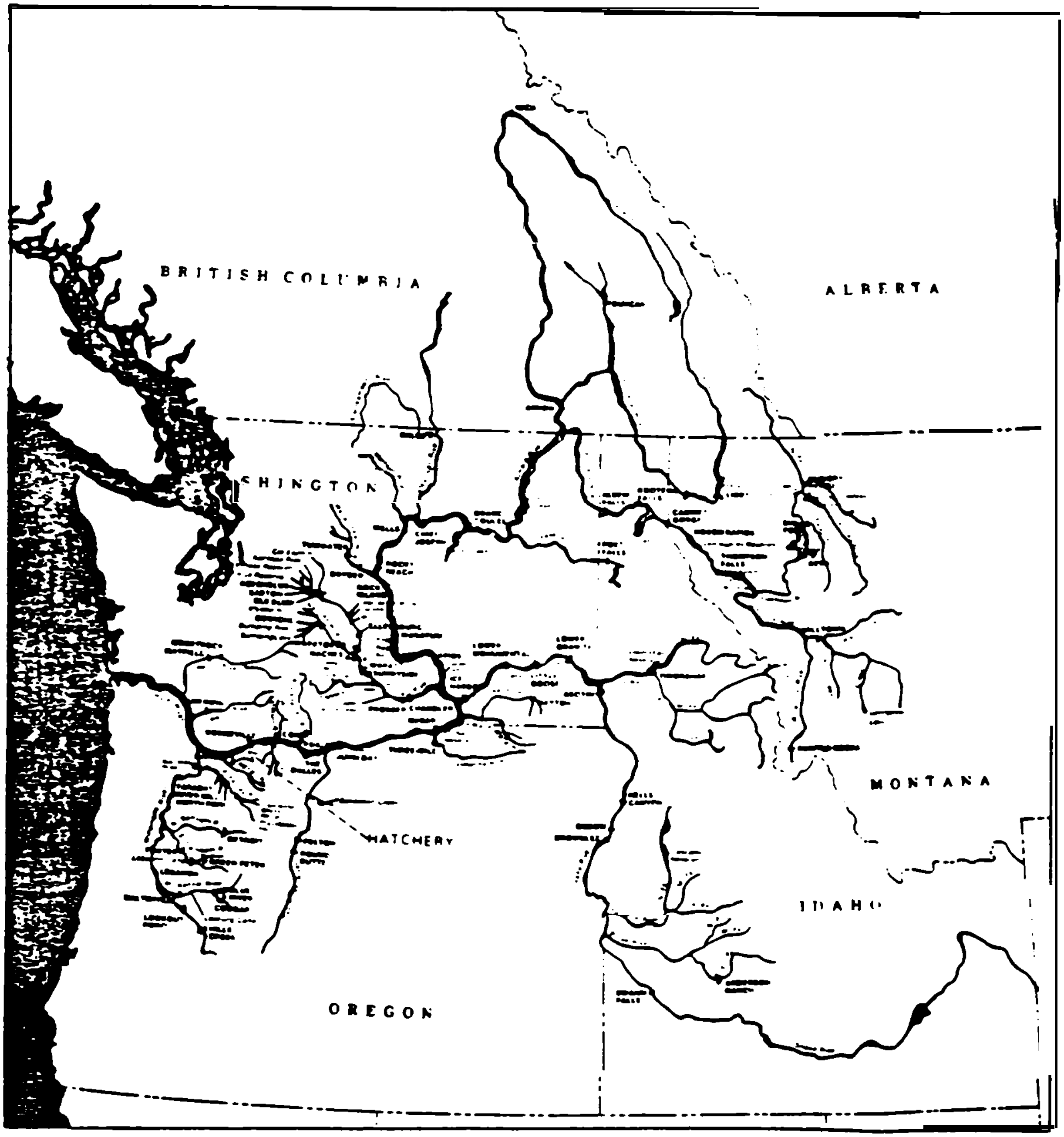


Figure 1. Columbia River Basin. Note sturgeon hatchery location below Bonneville Dam, river mile 141.

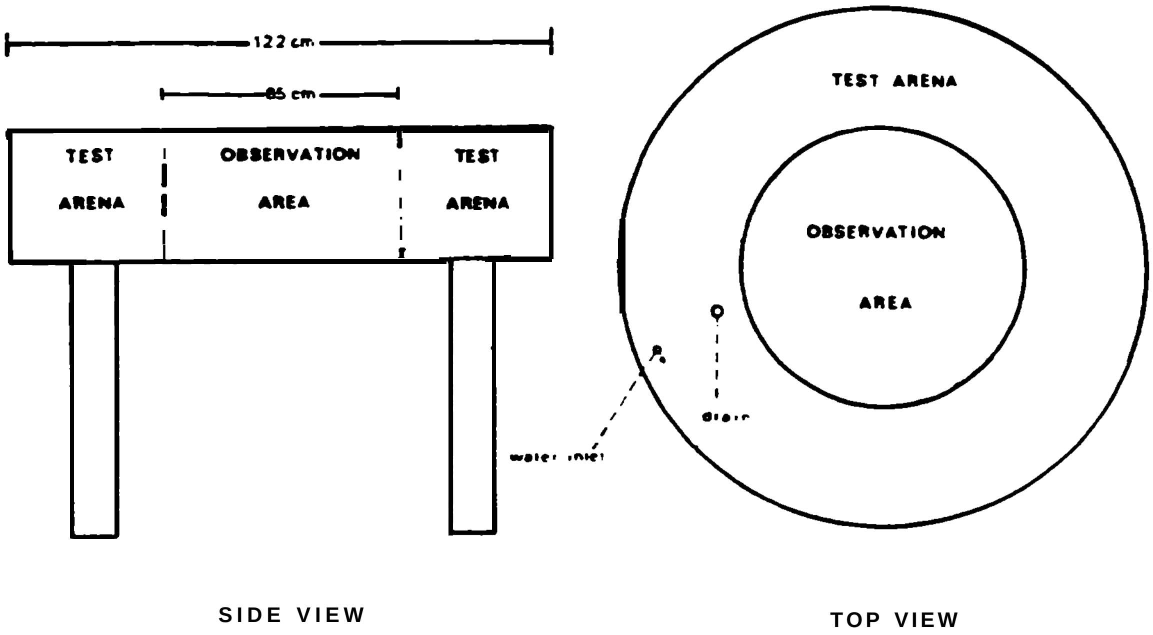
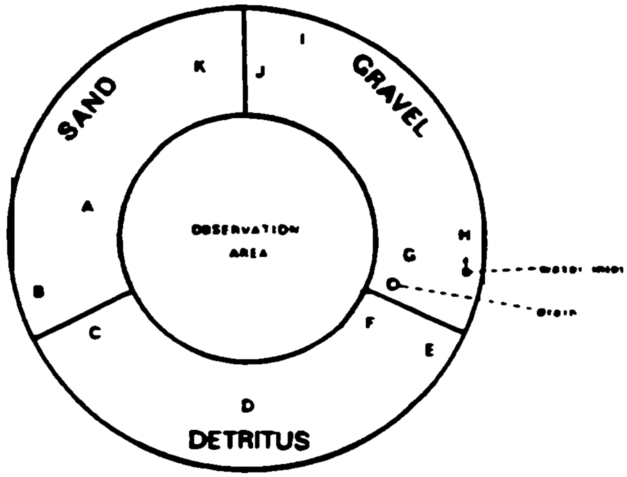


Figure 2. Schematic drawing of doughnut shaped test arena for investigations of larvae and fry distribution behavior. This test arena was utilized in Tasks 1.2.., 1.2.2, and 1.2.3.



Top view of test arena showing sites of
velocity reading in proximity to substrate

site of vel reading	velocity cm/s ec	substrate material	site description
A	4.6	sand	middle of trough
B	6.1	sand	crest downstream of trough
c	4.0	sand/detritus	sand/plant material border
D	3.0	detri tus	suspended plant material
E	6.4	detritus/gravel	plant material/gravel border
F	5.8	detritus/gravel	edge of gravel. flat
G	3.0	gravel	flat
H	11.6	gravel	flat
I	10.7	gravel	wide, flat open area before crest
J	0.6	grave/sand	deep trough
K	3.0	sand	flat in trough

Figure 3. **Schematic arrangement of substrates in doughnut shaped test arena utilized in Task 1.2.2. Upper diagram presents a top view of the arena showing proximity of substrates and location of velocity readings. Table on bottom gives velocity at each lettered site, substrate at the site, and a physical description of the site.**

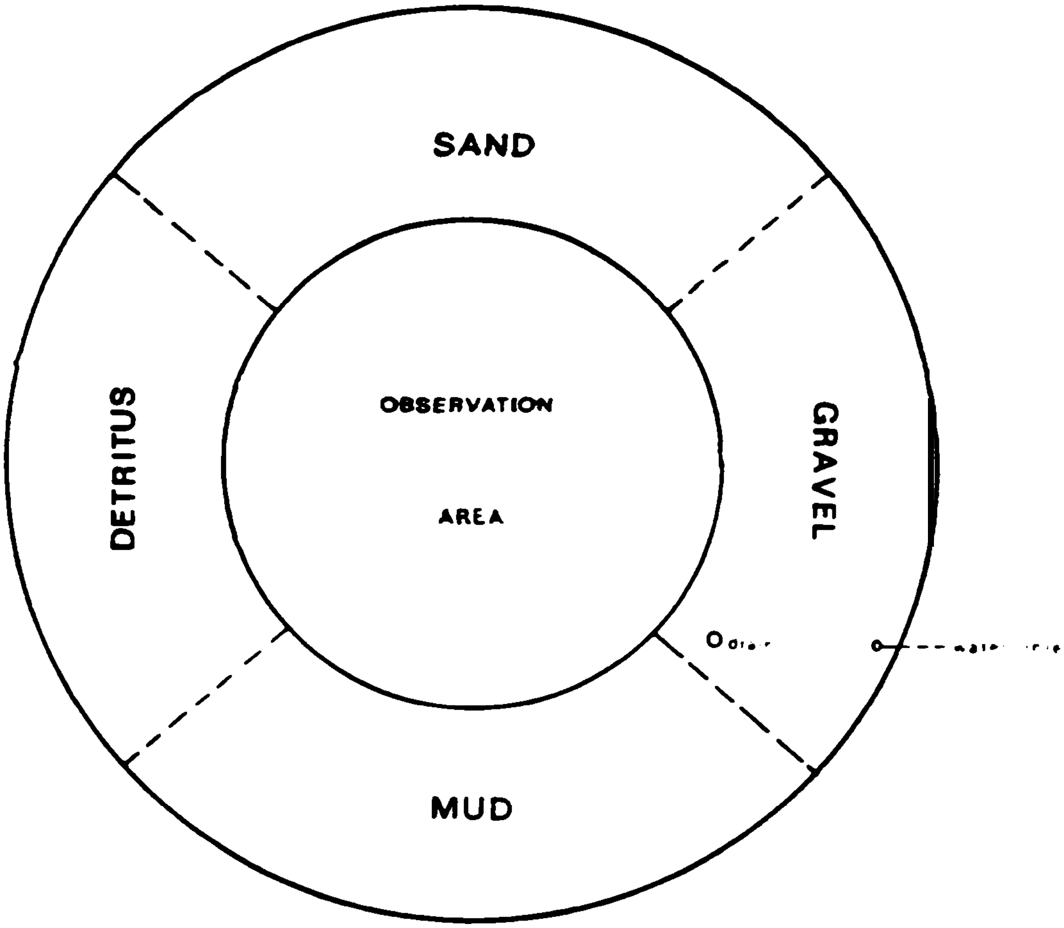


Figure 4. Top view of doughnut shaped test arena schematically representing placement of substrates for Task 1.2.3. Substrate surfaces were flat at a depth of 4 cm.

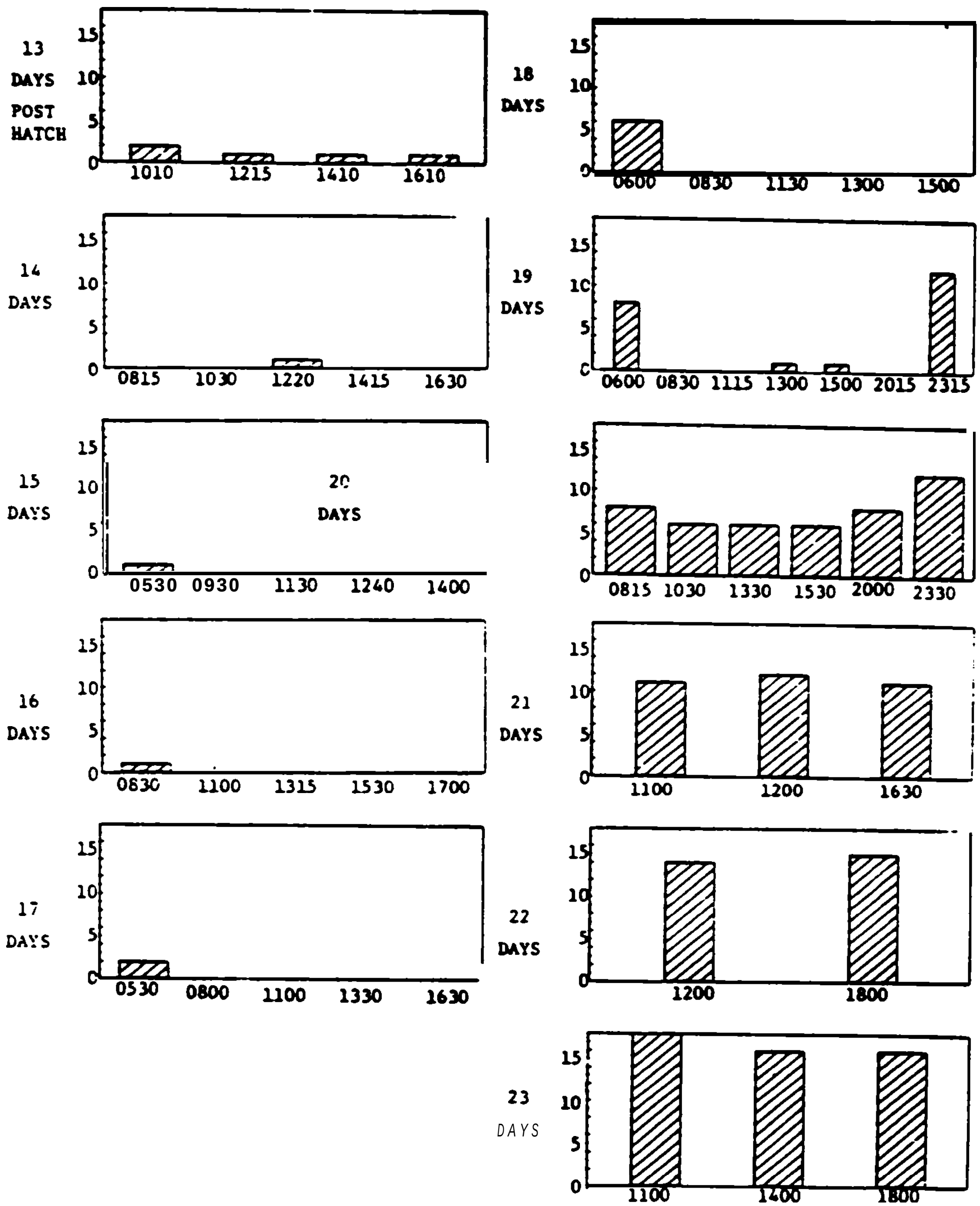


Figure 5. Number of fish swimming in the water column during each observation period of Task 1.2.1. Graphs are presented for each day of the experiment. Increased incidence of fish in the water column began when fish were sixteen days old. Diel patterns were exhibited until twenty-one days post hatch.

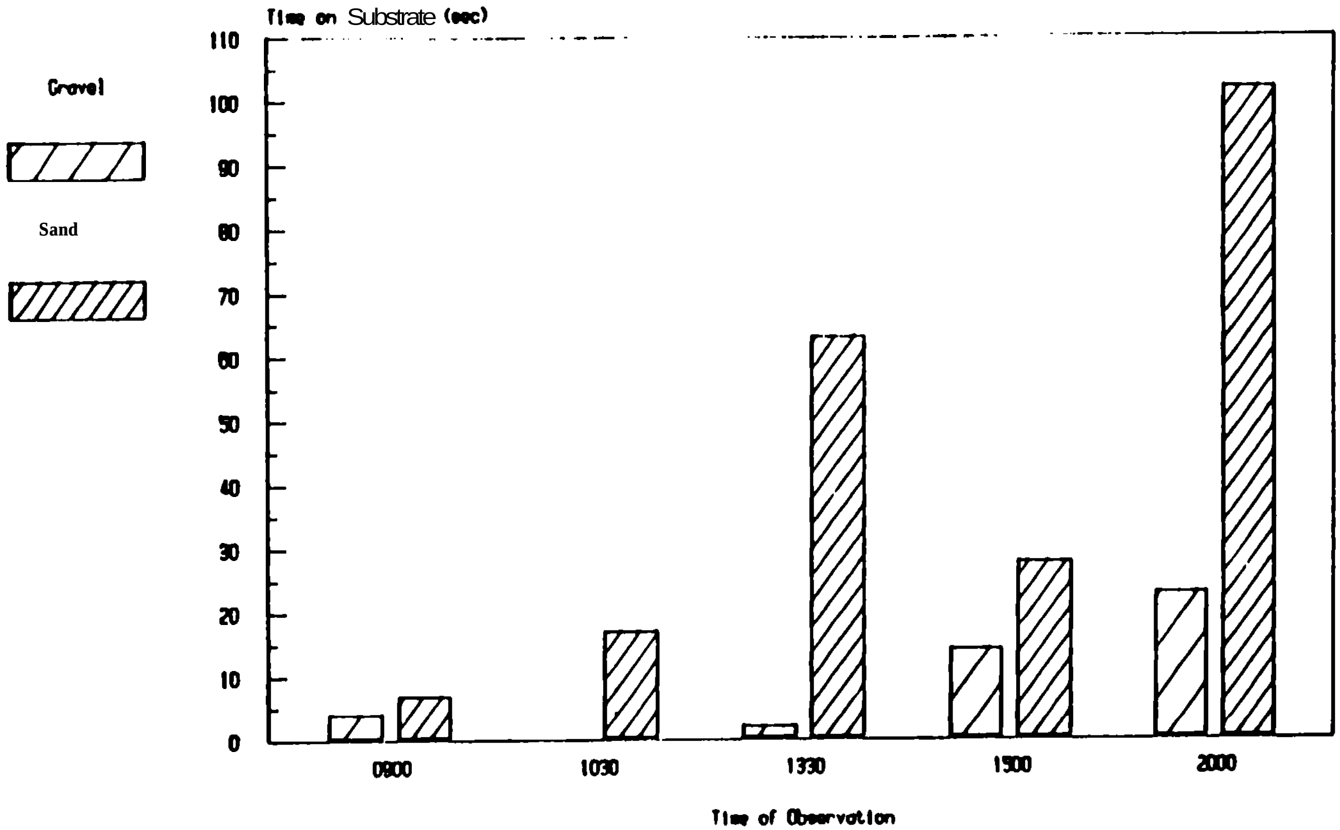


Figure 6. Amount of time fish spent on a substrate during each ten-minute observation period of Task 1.2.3. Fish in this experiment were only found on the sand and gravel substrates.

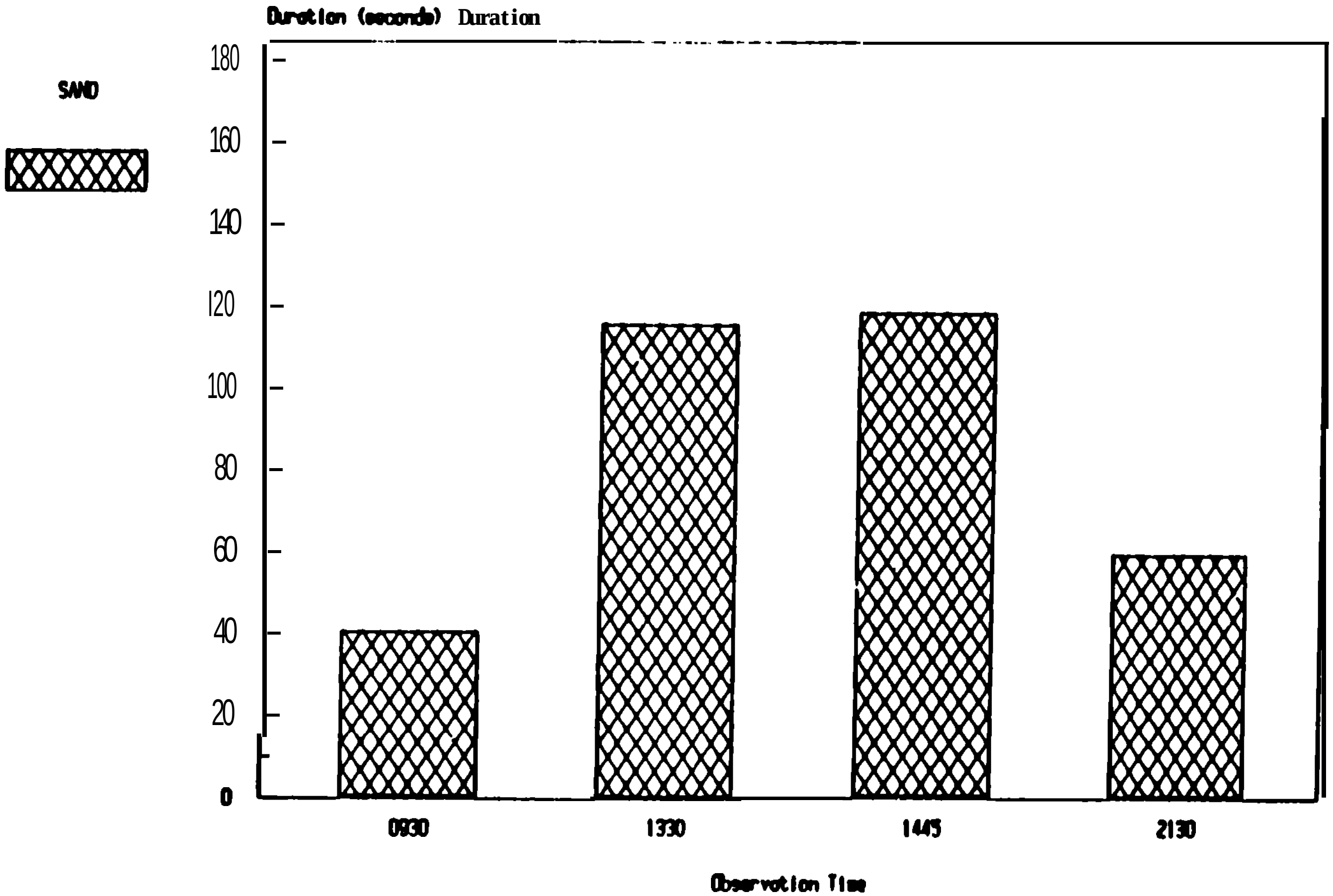


Figure 7. Time an individual fish spent on a substrate during the observation periods of Task 1.2.4. Fish were never found upon a substrate other than sand. The figure shows only time fish spent on the sand. A diel pattern is evident as fish spent more time on the sand during midday than in the morning or evening.

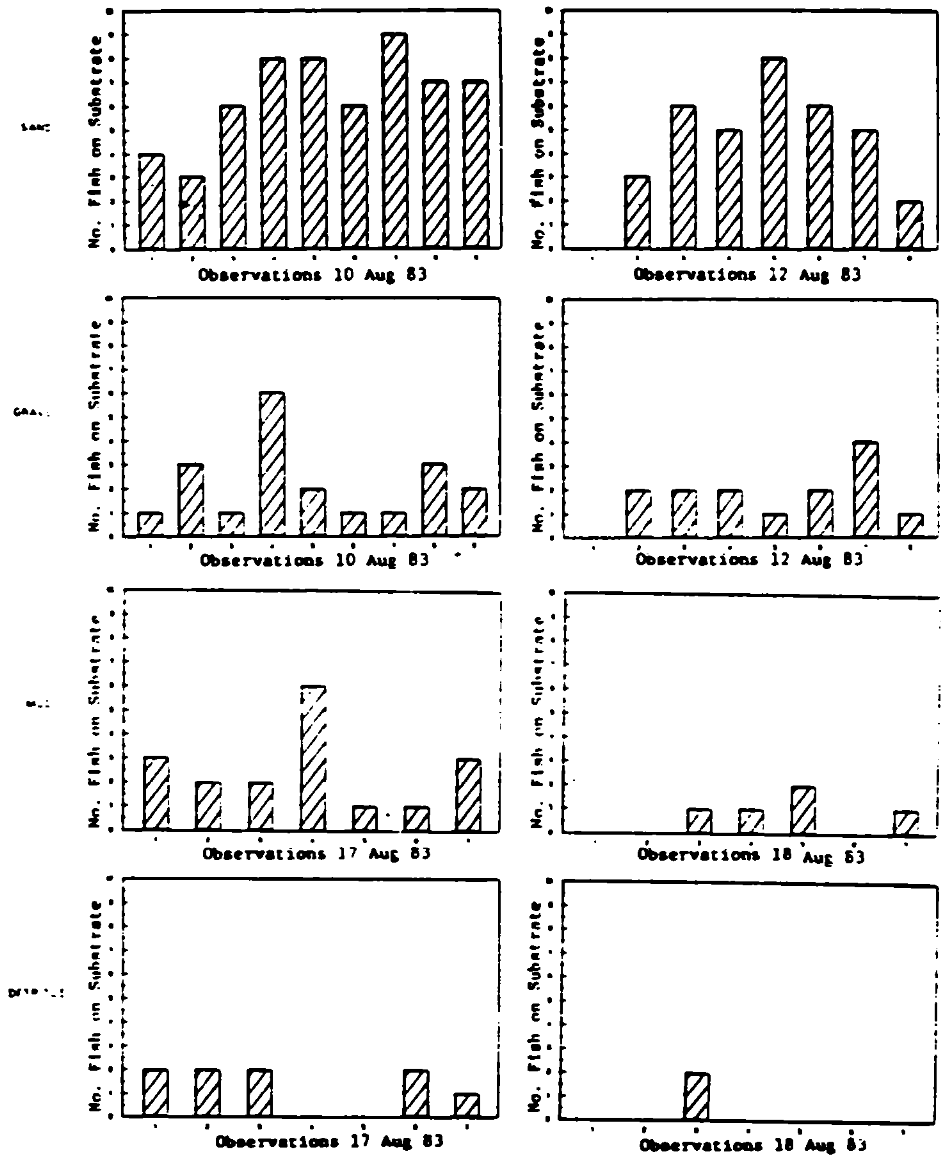


Figure 8. Diel activity pattern of fish relating to a substrate in Task 1.2.6. Fish presented with sand as a substrate spent more time on the sand surface during midday. Fish exposed to the other substrates did not exhibit the strong diel pattern evident for fish with sand substrate.

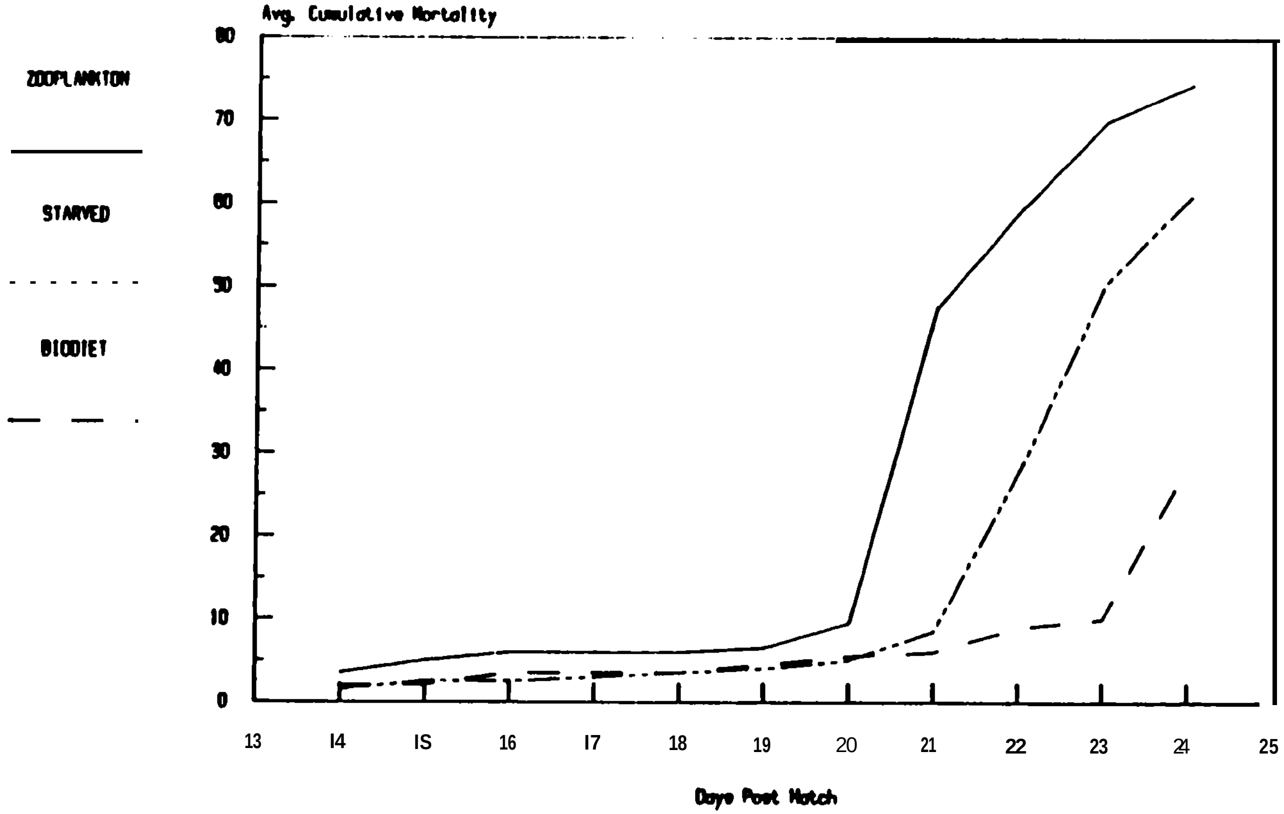


Figure 9. Cumulative mortality of fish in three treatment groups: zooplankton, starved, and BioDiet (average between replicate groups).

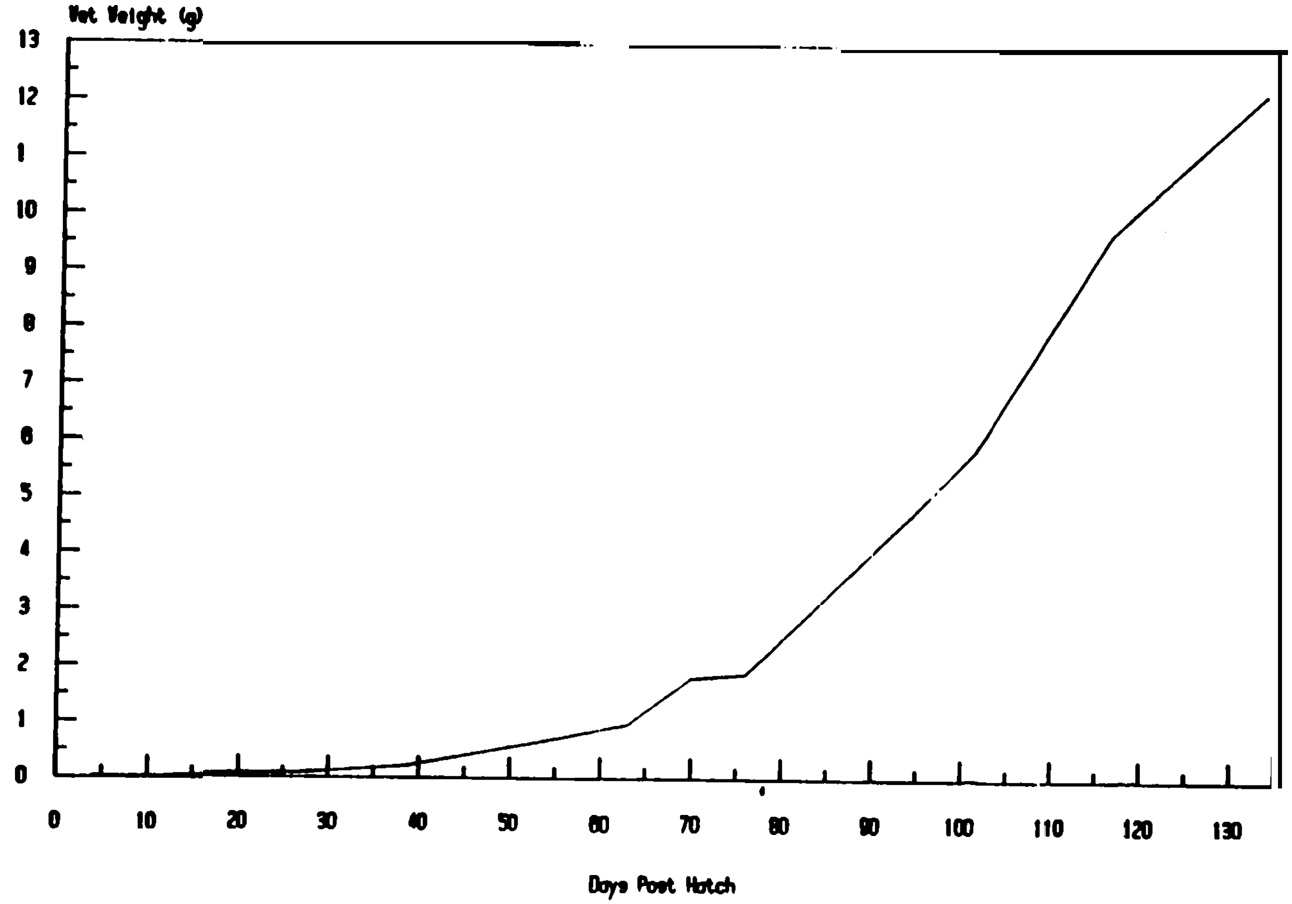


Figure 10. Growth of white sturgeon larvae and fry ra sed at he University of Washington laboratory