State of California
The Resources Agency
Department of Water Resources
Department of Fish and Game

Evaluation Testing Program Report for Delta Fish Protective Facility State Water Facilities California Aqueduct North San Joaquin Division

Memorandum Report

1973

PREFACE

The Delta Fish Protective Facility on the intake channel to the Delta Pumping Plant was completed in 1969 as part of the California State Water Project. It's sole purpose is to help to preserve the fishery resources of the Sacramento-San Joaquin Delta.

Only the U. S. Bureau of Reclamation's Tracy Fish Collecting Facility is comparable in concept, purpose and operation. Consequently, there were no accepted standards to gage the performance of the facility in regard to operation and efficiency. The major question was how efficient can this facility be in removing the small anadromous fish from the intake channel.

A determination of the efficiency of this installation and the optimum mode of operation of the fish collecting features of the facility were undertaken by the Evaluation Testing Program in 1970 and 1971.

This testing program, funded by the Department of Water Resources was developed and conducted jointly by the Departments of Water Resources and Fish and Game.

This report describes and presents the results of the evaluation testing. Recommendations for future operation of the facility are presented and comparisons are made with the results of other investigations and the operating results of the U. S. Bureau of Reclamation's Tracy Fish Collecting Facility are discussed. Data are provided that may serve as basic criteria for future louvered principle installations, and information is presented which will add to the general knowledge concerning successful removal of small fish from large volumes of flowing water.

ACKNOWLEDGEMENTS

The Delta Fish Protective Facility Evaluation Testing Program evolved from several years of investigations, and exchange of information and ideas between the Departments of Water Resources and Fish and Game. Many people, engineers, biologists, and technicians were involved in the development of the program. The final version of the testing program was formulated by Herbert C. Hyde, Senior Engineer of the Department of Water Resources and John E. Skinner, Research Supervisor of the Department of Fish and Game. Robert C. Gaskell, Supervising Engineer of the Department of Water Resources was Program Manager, and George H. Warner, Chief of the Anadramous Fisheries Branch administered the Fish and Game aspects of the program.

A. B. DeJarnett of the Department of Water Resources Construction Branch served as Engineer-in-Charge of field testing during 1970 with the following Construction Inspectors; Warren Jarboe, Dick Downer and D. Criner as Crew Chief. John Von Sosten of the Department of Water Resources was Office Engineer during the tests in both 1970 and 1971. William Heubach, Associate Fishery Biologist, Department of Fish and Game, directed testing operations and provided guidance on biological aspects. During 1971 he also assumed charge of field testing. Test crews were composed of Fish and Wildlife Seasonal Aids led by Junior Aquatic Biologists Mark Sazaki and Phil Hansen.

William Heubach and Mark Sazaki with contributions and review by John Skinner analyzed the fish collection data, devised the graphs and tables of results, wrote the methods and results chapters and compiled a large portion of the conclusions and recommendations of this report.

Herbert Hyde wrote the Introduction and edited this report under the supervision of Robert Gaskell.

Drafting of the graph, figures and plates was done by the Department of Water Resources Design Branch Aqueduct Drafting Unit.

Invaluable assistance was furnished by personnel of the Water Resources Delta Field Division of the Division of Operations and Maintenance in maintaining and repairing the testing of equipment and in coordinating the operation of the Delta Fish Protection Facility with the field tests.

Mr. Jim Willis of Morrow Bay was a consultant on net design, fabrication and repairs.

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CHAPTER I

SUMMARY

The Delta Fish Protective Facility was evaluated to measure the efficiency of louvering fish up to 125 mm in length and to determine the optimum modes of operation of the fish collection features. Testing was conducted during six month periods in 1970 and 1971.

Two main features, the primary and secondary channels, were tested separately and in combination. Test parameters investigated were, fish species and length, the velocity of approach, bypass ratio, primary channel center wall influence, effect of side of entry into the secondary channel, screened water ration in the secondary channel, diurnal effect and the effect of the louver alignment.

These parameters, described in detail in Chapter VI, varied throughout ranges, some of which were outside recognized limits for the efficient collection of a particular specie and size of fish being tested.

Basic testing consisted of collecting fish in nets placed in two of the primary channels downstream of the louvers and bypass intakes, in the secondary at the outlet of the primary bypasses, and in the secondary channel downstream of the louvers and the intake to the holding tanks. Data were gathered on four principal species of fish; king salmon, striped bass, white catfish, and threadfin shad.

Results and Conclusions

Facility Features

1. The overall fish salvage efficiency of the Delta Fish Protective Facility compares favorably with the U. S. Bureau of Reclamation's Tracy Fish Collection Facility.

2. Design innovations such as the division of the primary waterway into a number of separate bays with wing gates for control of flow are advantageous. The facility, as constructed, meets virtually all of the design criteria set forth in Chapter III.

3. Irregularities in louver panel alignment in the secondary channel within the range of lateral displacement (up to 2 inches) evaluated in this study did not affect efficiency significantly.

Specific Results and Conclusions by Fish Specie

King Salmon:

1. Bypass ratio did not affect efficiency significantly in either the primary or secondary channels.

2. The efficiency of louvering salmon 50 to 100 mm in length increased slightly as the approach velocity increased but there was no clear relationship between the louver efficiency of larger salmon and approach velocity.

3. Bay A was slightly less efficient than Bay B.

4. The efficiency of the primary and secondary systems combined ranged from 65 to 90 percent.

Striped Bass:

1. Efficiency was highest in Bay A at bypass ratios less than 1.48. In Bay B efficiency was higher at bypass ratios greater than 1.48.

2. Efficiencies were higher in both the primary and secondary channels at approach velocities less than 2.5 ft/sec.

3. The best balance in efficiency between the primary and secondary channel is achieved under the following conditions:

(a) When the primary approach velocity is less than 2.5 ft/sec. the bypass ratio should be greater than 1.47.

(b) When the primary approach velocity is greater than 2.5 ft/sec. the bypass ratio should be 1.2.

(See Chapter XII, Conclusions, for a detailed explanation of above.)

4. Bay A is more efficient in louvering striped bass than Bay B. Thus, the combined efficiency of fish entering Bay A and the secondary system is considerably higher than the combined efficiency for Bay B and the secondary system.

5. Secondary efficiency was highest at a screened water ratio of 0.0 (no screened water) and lowest at a ratio of 1.4.

6. At low to moderate velocities striped bass were louvered slightly more efficiently at night in the primary system. At velocities greater than 2.5 fps efficiency was greater during the day.

White Catfish:

1. Primary channel louvering efficiency was not affected significantly by bypass ratio. Secondary efficiency was best at bypass ratios less than 1.48.

2. Efficiency was highest at the lowest approach velocities in Bay A. In Bay B efficiency was greatest at velocities greater than 3.0 fps for catfish less than 30 mm long. Efficiency was greatest at the lowest velocity for fish 30 to 75 mm long. Secondary efficiency was not significantly affected by approach velocity.

3. Generally, Bay A was more efficient than Bay B.

4. The combined efficiency for catfish greater than 30 mm in length was higher for fish entering Bay A than for fish entering Bay B. For fish smaller than 30 mm in length there was no significant difference.

5. Efficiency was best during the day at approach velocities greater than 2.5 ft/sec. At lower velocities efficiency was only slightly better at night.

Threadfin Shad:

1. Specific conclusions are not made for threadfin shad as testing of this specie was incidental to other species. Efficiencies for threadfin shad were similar to those of striped bass and white catfish.

Recommendations

Recommendations developed from the program are presented in two categories: (1) Operation and Maintenance and (2) Structural Modifications.

Operation and Maintenance

1. A rigid program of inspection and maintenance of velocity measuring and recording equipment should be initiated for both the primary and secondary systems.

2. The following operating criteria should be adopted:

King Salmon

1. Approach Velocity: 1.5 to 3.5 feet per second.
2. Bypass Ratio: Maintain 1.2 to 1.6 in both primary and secondary channel.
3. Primary Bay: Not critical but use Bay B as first choice.
4. Screened Water Ratio: Should not exceed the secondary channel approach velocity.

Striped Bass and White Catfish

1. Approach Velocity: Keep at lowest rate possible in both the primary and secondary channels.
2. Bypass Ratio:
   - (a) When only Bay A (with center wall) is in operation maintain a 1.2 ratio.
   - (b) With both primary bays in operation and approach velocity less than 2.5 ft/sec. the bypass ratio should be 1.5. When approach velocity is greater than 2.5 ft/sec. the bypass ratio should be 1.2.
   - (c) When Bay B only is operating the bypass ratio should be 1.5.
   - (d) Secondary channel bypass ratio should be 1.2 for all approach velocities.

3. Primary Channel: Use Bay A (with the center wall) in preference to Bay B.

4. Screened Water Ratio: If the use of screened water is necessary the velocity should not exceed the velocity of the secondary channel approach velocity (ratio of 1.0 to 1.0).

5. Clifton Court Forebay Water Level: Maintain at the highest practical level.

Structural Modifications

Structural modifications would involve changes or additions to the facility. Decisions regarding implementation of suggested structural modifications should take into consideration the potential gains in fish salvage efficiency, the cost of the proposed modifications, project water operation criteria, and the potential impact of fish salvage facilities proposed for the Peripheral Canal.

1. Primary Channel:
   (a) Activate the presently unused channels.
   (b) Construct center walls in all bays.

2. Secondary Channel:
   (a) Provide a longer and smoother transition between the bypass discharge and the line of louvers.
   (b) Modify the bypass inlet pipes to the secondary valve chamber to permit independent operation in addition to the present unison operation.
   (c) Provide a system ahead of the line of louvers to deflect fish to the bypass side.

3. <u>Louvers</u>:

Minimize gaps between louvers (primary and secondary channels) and keep lateral displacement of adjacent louver section to minimum.

CHAPTER II

INTRODUCTION

California State Water Project

The California State Water Project includes projects for the conservation and distribution of water. The primary natural water supply is in the northern part of the State. Most of the present and future demand for water will be in the Sacramento Valley, the San Francisco Bay area, the San Joaquin Valley, and southern California. This geographic conflict between supply and demand makes it necessary to transport water from areas of abundance to areas of deficiency. The California State Water Project provides for such geographic redistribution of water.

In addition to the geographic maldistribution of water, there is an extreme seasonal variation in the water supply. Precipitation occurs primarily during the winter months. Some storage is provided by the accumulation of snow. This storage, however, is not sufficient to meet the summer water demands. The California State Water Project therefore includes numerous water storage facilities throughout the State to provide the required additional storage.

Included in the State Water Project are several dams constructed on the Feather River in northern California. Among them is Oroville Dam, the primary storage facility of the State Water Project. Water from Oroville Reservoir is released to flow down the Feather and Sacramento Rivers to the Sacramento-San Joaquin Delta. From the Delta, the water is lifted and transported by means of pumping plants and the California Aqueduct along the west side of the San Joaquin Valley. Some water is released along the aqueduct to meet the agricultural needs of the western San Joaquin Valley. The remaining water will be pumped over the Tehachapi Mountains and into southern California where several storage reservoirs are being provided.

Presently, water is diverted to the California Aqueduct from the Sacramento-San Joaquin Delta near Tracy, California at a maximum rate of 6,000 cfs. By 1990 the maximum rate of water through the California Aqueduct will be about 10,000 cfs with a total annual volume of about 4 million acre-feet.

Ultimately, the water is planned to be diverted from the Sacramento River near Hood. The water would then be carried from the Sacramento River to Clifton Court Forebay by the proposed Peripheral Canal.

Need for Protection of the Delta Fishery Resources

The majority of the anadromous fish resources of the State, king salmon, striped bass, white sturgeon, American shad, and steelhead trout, depend on environmental conditions in the

Delta. About 25 percent of all non-trout angling in California and about 80 percent of the State's commercial salmon catch depend on this environment.

Striped bass are not native to the West Coast of the United States and were initially introduced from the East Coast in 1879. Their increase in California waters was phenomenal. Over 1,200,000 pounds were taken commercially in California 20 years later. Present estimates of the adult striped bass population (16 inches and over) are about 1.4 million, but as recently as 1960 the population was about 3 million.

Striped bass have long been one of California's top ranking sport fish. The Stanford Research Institute estimated the net economic value of the sport fishery for 1970 at about 7.5 million dollars (Altouney, Crampon, and Willeke; 1966). The intangible benefits of angling, the enjoyment and relaxation afforded by the sport, which cannot be measured in dollars, are perhaps even more important considerations. Two million angler days are supported annually by this resource.

King salmon are present in the rivers and tributaries of California's Central Valley from Keswick Dam on the Sacramento River near Redding to Crocker-Huffman Dam on the Merced River in the San Joaquin Valley. Historically, this range extended to the upper tributaries of the Sacramento River, such as the McCloud and Pit Rivers, and to above the present location of Friant Dam on the San Joaquin River (Clark, 1929).

King salmon are seasonal occupants of Central Valley streams; however, some are present in the Delta during every month of the year. Three runs, fall, winter, and spring, occur in the Central Valley.

Central Valley king salmon support a commercial as well as a sport fishery. The commercial fishery is restricted to ocean waters while sport angling occurs in fresh water as well as in the ocean.

Since 1953, commercial landings of king salmon in California have ranged from a high of 958,000 in 1956 to a low of 338,000 in 1967 (Jensen, 1972). Marine recreational landings of king slamon, since 1953, have ranged up to 184,000 in 1955. The bulk of these fish are produced in the Central Valley. Inland landings of Central Valley king salmon amount to about 25,000 annually. The landings are made almost exclusively in the Sacramento River and its tributaries.

About 10,000 American shad fry were transported from New York to the Sacramento River in 1871. Additional plants were made in 1873, 1876, and 1881. By 1879 several thousand shad appeared in the San Francisco markets. After 1900 and until 1945 the commercial catch was regularly over 1,000,000 pounds.

About 1950 a shad sport fishery developed in the upper Sacramento River, its major tributaries, the American, Feather, and Yuba Rivers. The number of anglers participating in this fishery has grown tremendously in the last few years with "elbow-to elbow" type fishing typical. Fly rods and light spinning gear are the normal tackle.

In addition to the above three species, which are of major economic and recreational value, other important species influenced by the State and Federal pumping facilities are white sturgeon, white catfish and several members of the sunfish family including largemouth black bass and black crappies.

White sturgeon are a trophy fish reaching a very large size and eagerly sought by anglers.

The white catfish caught in the Delta constitute about 50 percent of the statewide catch.

The importance of both migratory and resident fishes and their young in the Delta made it obvious that adequate fish screens had to be built at the intake to the Delta-Mendota Canal. The U. S. Bureau of Reclamation constructed the Tracy Fish Collecting Facility at the intake to the Delta-Mendota Canal in 1955. The need for a similar fish salvage facility at the intake of the California Aqueduct was apparent in the earliest stages of planning.

As a result of investigations by the Department of Water Resources and consultation with the Department of Fish and Game, the louver concept was adopted as the most practical salvage method available. Thus the louver system, somewhat modified from the Tracy design, was constructed.

Thirty-three different species of fish have been collected at the Delta Fish Protective Facility. Through 1970, this facility salvaged an average of 6.4 million striped bass, 1.3 million catfish and 42,000 salmon annually. The average annual number of fish salvaged at the Tracy Fish Collecting Facility include 18 million striped bass, 2.3 million catfish and 112,000 salmon.

CHAPTER III

FACILITY DESCRIPTION

Description

The Delta Fish Protective Facility is located in Contra Costa County, approximately 11 miles northwest of Tracy, California. The facility is between Stations 40+00 and 50+00 on the Intake Channel of the California Aqueduct.

Upon completion of the facility in early 1969, water was diverted to the intake channel from Italian Slough at a point about two miles above Italian Slough's junction with Old River. After completion of Clifton Court Forebay in late 1969, the intake channel connection to Italian Slough was plugged permanently, and all water for the California Aqueduct is diverted through Clifton Court Forebay.

Clifton Court Forebay is located in the southeast corner of Contra Costa County and borders on Tracy-Byron Road. The forebay is approximately 22 miles from Antioch and 10 miles from Tracy. This 30,000 acre-foot capacity impoundment with a surface area of over 2,200 acres created by dikes was designed to provide weekly regulative storage capacity which would meet the requirements of the Delta Pumping Plant's offpeak pumping schedule.

A control structure with radial gates connects Clifton Court Forebay with West Canal, a side channel of Old River. Until the Peripheral Canal is constructed the control structure will be operated to provide storage for offpeak pumping operation by retaining the pool elevation resulting from high tides. Normal operating water surface elevation will range between -2.0 and +4.5 (mean sea level). Once the Canal is in operation, the gated control structure will prevent the forebay water surface fluctuation from occurring in the Peripheral Canal.

Operation of the Delta Fish Protective Facility

The Delta Fish Protective Facility was designed so that small fish from 1 to 3 inches in length could be removed from the intake channel, collected, held, and transfered to tank trucks.

How It Works

Successful operation of the facility depends on the ability of fish to sense and avoid an obstruction in their path as they drift downstream with the current. Taking advantage of this phenomenon, an obstruction is created by installing a system of louvers across the intake channel. The louvers, placed at an angle of 15° to the centerline of the channel, divert the fish into bypass pipes which lead to a smaller secondary louver system. The secondary louver system in turn diverts the fish into four adjacent holding tanks. (Plates 1 and 2).

The holding tanks have cylindrical screens in the center through which incoming water from the secondary louver system passes and is piped off while the fish accumulate in the outer portion of the tank. When a truck load of fish has accumulated, all but 500 gallons of water is drained off. Then a bucket is lowered to the bottom of the holding tanks, the screen raised, and the water and trapped fish flow into the bucket. The bucket is then emptied into a specially built tank truck, and the fish are transported downstream in the Delta outside the pumping influence of the U. S. Bureau of Reclamation's Delta-Mendota and the State's Delta Pumping Plant.

Design Criteria

The following is a summary of the ichthyological design criteria established from the investigations that evolved the Delta Fish Protective Facility. These criteria are not intended as a complete statement of design criteria, but only as criteria pertaining to optimum fish protection. These criteria were:

1. The louver method of fish guidance and a diversion method of fish removal shall be used.

2. The range of approach velocities for the primary channel shall be 1.5 to 3.5 feet per second. The range of approach velocities for the secondary channel shall be 2 to 3 feet per second.

3. Both the primary and secondary systems shall be designed to provide a bypass ratio (bypass intake velocity to approach velocity) of 1.2 to 1.6.

4. The primary channel shall be designed with a saw-tooth louver arrangement with each pair of louver lines leading to a single bypass. The secondary channel shall be designed with a straight-line louver arrangement.

5. The bypass width for the primary channel shall be 12 inches. For the secondary channel the bypass width shall be 6 inches.

6. The louver assemblies for both the primary and secondary channels shall have slat spacings of approximately 1-inch.

7. The length of each line of louvers in the primary channel shall be a maximum of approximately 80 feet.

8. The truck method of fish delivery shall be used.

Principal Features

Primary Channel

The principal features consist of a trashboom, trashrack, primary channel, louver assemblies, and bypasses.

Trashboom: The Delta waters are laden with very fine vegetive fibers in suspension. In addition, during the height of the fish collecting season there is a large quantity of floating debris such as water hyacinth, tules, logs and other debris. To alleviate the problem of floating debris in the primary channel, there is a floating boom and a trash conveyor system. The floating boom is placed immediately upstream from the facility and is angled toward a conveyor belt. A metal plate on the leading edge of the boom extends 2 feet into the water to facilitate movement of the debris toward the junction of the boom and conveyor belt. The conveyor then picks up the debris and deposits it in a waiting truck.

Trashrack: The trashrack severs a dual purpose of preventing trash entry and keeping out fish larger than can pass through the 2-inch clear opening between bars. Furthermore, since large fish are strong enough to swim against the current which leads toward the pumping plant, it is likely that they react to the trashrack and turn around and swim away back upstream. Thus, the trashrack probably keeps out most fish strong enough to swim against the current. This is verified by the fact that although millions of small fish are taken, very few large fish are.

An electrically powered rake removes debris from the trashrack.

Primary Bays: In order to provide the required velocity control, the primary channel is divided into seven bays with a total width of 160 feet and an invert level at Elevation -21.0. This velocity control is necessary to provide effective fish collection. Bay 1 and Bay 2 can each be operated independently. Bays 3 and 4 are not divided in the louver area, and therefore, must be operated together. The operation of these bays is independent of Bay 1 and Bay 2. Bays 5, 6, and 7 will be operated together. However, these bays will not be operable until the completion of second-phase construction. Second-phase construction will be initiated when it becomes necessary because of water demands to increase the capacity of the Delta Pumping Plant above the initial 6,000 cfs capacity.

The trashrack roadway is located at the upstream end of the channel. The piers for this roadway form the seven bays of the primary channel. These piers extend a short distance downsteam from the roadway deck. Control gates are provided just downstream from the roadway deck to maintain the desired velocity in the primary channel. Gates are not provided in the initial construction for Bays 5, 6 and 7. Stoplogs are used to prevent the flow of water in these bays. These stoplogs are designed for only one-foot differential water head and therefore cannot be used to dewater these bays.

The wall between Bays 1 and 2 extends downstream to just ahead of the bypass inlet for those bays. The walls between Bays 2 and 3, between Bays 4 and 5, and between Bays 6 and 7 extend to a line approximately 25 feet downstream from the bypass inlets to form continuous interior walls.

Louver Assemblies: Louver assemblies are in the primary channel to divert the fish into the bypasses.

All flow through the primary channel to the Delta Pumping Plant passes through the louvers. The louvers create a turbulence which the fish apparently tend to avoid. The fish maintain their position in front of the louvers and are carried along the louver line by the current into the bypass inlets.

The louver assemblies resemble vertical venetian blinds and are panels each 13 feet high and approximately 8 feet long. The vertical slats are positioned perpendicular to the direction of flow. Clearance between the vertical slats is approximately 1-inch. The louver assemblies are arranged in a vee with each leg angling across the bay at an angle of approximately 15 degrees with the side wall. The length of line of louvers is 82 feet - 8 inches. Water passing through the louvers is redirected downstream by flow straighteners every eighth louver slat. Two louver assemblies are bolted together vertically to provide a total height of 26 feet.

Bypasses: The inlets to the bypasses are located approximately 110 feet downstream from the control gates. Each bypass is an open channel 12 inches wide and 26 feet high at the inlets.

The flow is transitioned to a closed circular conduit within a length of approximately 40 feet. Fish and flow (about one-fortieth of the primary channel flow) are diverted through bypass pipes to the secondary system valve chamber.

The primary bypass pipes are precast reinforced concrete, one 54 inches in diameter and three 48 inches in diameter.

Effective fish guidance requires that the flow velocity into the bypasses be maintained within certain limits. Bypass velocity is dependent upon the difference between the water surface elevation in the primary channel and the water surface elevation in the secondary channel.

Water surface elevation in the secondary channel is controlled by the setting of the bypass valves in the valve chamber, the number of return water pumps in operation, and the settings of the return water pump recirculating valves.

Secondary System

The secondary system consists of a valve chamber, open channel, pumping plant, screen water system, and holding tank features.

Valve Chamber: The valve chamber structure is a reinforced concrete box, open at the top, which houses the shutoff valves, the velocity meters, the control valves for the primary channel bypasses, and two 48-inch diameter steel pipe bypass conduits.

At the upstream end of the valve chamber, butterfly valves are provided to shut off the flow of water through the bypasses. Downstream from the shutoff valves, venturi-type meters are provided for measuring the flow through the bypasses. This flow is controlled by the control valves located immediately downstream from the velocity meters.

The secondary channel inlet transition provides a transition from the two 48-inch diameter bypass pipes to the 10-foot wide, open channel flow secondary. The first 8 feet of the transition changes the section from the two circular conduits to two rectangular conduits each 4-foot square. The remaining 29 feet - 3 inches of the transition changes the section from the rectangular conduits to the open channel. The center wall between the rectangular conduits extends for approximately 9 feet downstream.

Louver Area: The secondary channel is an open channel 10 feet wide and 18 feet deep. The invert is at Elevation -10.00 and the top of the side walls at Elevation 8.00. The structure is approximately 129 feet long. The channel was sized to provide a water velocity between 2 and 3 feet per second. To facilitate testing of the facility for fish collecting effectiveness, net guide slots were provided in the side walls of the secondary channel both upstream and downstream from the louvers.

Return Water Pumping Plant: The return water pumping plant structure consists of a reinforced concrete box open on one side. Flow from the secondary channel enters the pumping plant through the open side. Four return water pumps, each of a nominal capacity of 59 cfs, are mounted on the top deck of the structure. The deck is at Elevation 8.00. The invert of the wet well is at Elevation -18.00.

Water is pumped from the wet well through the back wall into the discharge conduit. Three 20-inch butterfly valves are provided in the back wall to allow recirculation of water from the discharge conduit back into the wet well. These valves are regulated to obtain the desired net outflow from the secondary channel. Outflow also depends on the number of return water pumps in operation. Discharge from the return water pumps is carried by closed conduit back to the primary channel, where it is discharged on the right side immediately upstream from the trashrack structure.

Louver Assemblies: The same method of fish guidance is used in the secondary channel as in the primary channel. The louver assemblies are interchangable between the primary and secondary channels. Five assemblies are used in the secondary. Since the maximum normal operating water depth in the secondary channel is only 10 feet, only one assembly is needed to obtain the required height. The leading edge of the louvers is set at an angle of approximately 15 degrees to the sidewalls.

Screened Water System: A screened water supply is provided to minimize the mortality rate of fish held in the holding tanks, and to permit the utilization of the fine mesh screens in the holding tank. Otherwise a rapid accumulation of debris in the holding tanks would occur. A traveling water screen removes debris from water diverted from the secondary channel. Water is taken from the secondary channel through the screen. This relatively clean water passes into the screened water wet well and is then pumped into a sump by the screened water pumps. A butterfly valve is provided in the wall between the sump and wet well. The manipulation of this valve controls the net flow from the wet well to the sump. The screened water from the sump flows back to the secondary channel through the screened water pipe which is equipped with a venturi-type meter. Screened water enters the secondary channel just upstream from the louvers. The outlet of the 8-inch wide screened water conduit is in the west wall of the secondary channel. The invert of the outlet is at the same elevation as the invert of the secondary channel so that the depth of the screened water is approximately the same as the depth of water in the secondary channel. The screened water flows along the side wall of the secondary into the same bypass as fish diverted by the louvers.

Collecting Features

Influent System: Water entering the bypass inlet of the secondary channel passes through the bypass transition to the holding tank influent pipe. The 24-inch steel influent pipe is enlarged to 30 inches in diameter. From the location of the second phase influent pipe connection downstream. The entire holding tank system from this point downstream is sized for ultimate phase operation. A flow tube is in the 24-inch section of the influent pipe and monitors the velocity of flow at the secondary bypass inlet.

The influent pipe is manifolded to each of the holding tanks. Valves on each section of the influent line leading to the holding tanks permit selection of the holding tank into which fish are diverted. The valves are always in a full-open or full-closed position. To minimize fish injury gate valves, rather than butterfly valves, are used to reduce flow obstruction when the valves are in the open position.

Holding Tanks: The holding tanks are buried circular concrete tanks. Two concentric sumps are provided in the bottom of the tanks for positioning of either the transporting or counting bucket and for dewatering.

A vertical cylindrical screen inside each holding tank keeps the fish outside the screen. Water passes through the screen and out the effluent pipe located in the side wall of the sump at the bottom of the holding tank. Overhead jacks lift the cylindrical screen to drain fish into the transporting or counting bucket.

The 500 gallon transporting bucket removes fish from the holding tanks and carries the fish to the trucks at the truck loading ramp. The 250 gallon counting bucket removes fish from the holding tank and carries them to a counting barrel.

All but the water below the sill of the cylinder screen is drained from the holding tank to remove the fish. The appropriate bucket is lowered into the sump at the bottom of the tank. The screen is raised to let the fish and water pass under the screen into the bucket. The bucket is lifted from the holding tank and carried by a monorail hoist to the counting area or to the loading area at the north end of the building. Water and fish are drained from the buckets through a pipe and ball valve in the center of the tapered bottom of the buckets.

Auxiliary Water: To improve the dissolved oxygen content an auxiliary water supply may be delivered to the holding tanks directly from the screened water sump. Butterfly valves are provided at each holding tank and at the screened water sump to control the flow of auxiliary water through a 6-inch diameter pipe.

Collection and Counting

As the collecting operation continues, the concentration of fish around the periphery of the tanks increases. When a load of fish has been collected, one tank must be taken out of operation and another placed in operation. The influent water is switched to a different tank.

A "load of fish" is the number of fish which can be safely transported by the hauling trucks. Load size varies greatly with the size and specie of fish and the water temperature. Data in the Bureau of Reclamation's publication entitled, "Efficiency Evaluation, Tracy Fish Collecting Facility", established the basis for permissible concentrations of fish.

A sampling technique is used to determine when a load of fish has been collected. Periodically, the fish are diverted to one of the holding tanks used exclusively for counting. The fish are diverted into this tank for a short period of time, normally five minutes every odd hour. The fish caught during this period are then enumerated by size and species. The number caught during the sampling period can then be extrapolated to determine the approximate number collected furing the longer period represented.

Delivery of Fish

The collected fish may either be loaded immediately or held until a transporting truck is available. Fish and water are released into the hatch in the top of a tank truck already partially filled with water.

The tank trucks (two 1,200 and one 2,000 gallons) are similar to trucks developed by the California Department of Fish and Game for hauling fish. They are equipped with refrigeration and aeration units to aid in the maintenance of correct water temperatures and dissolved oxygen conditions.

CHAPTER IV

THE EVALUATION PROGRAM

Background

The need to evaluate the Delta Fish Protective Facility was recognized during the planning stage. A preliminary test program of three years duration was developed by the Department of Water Resources in late 1964, with close cooperation from the Department of Fish and Game.

Valuable experience was gained by the Department of Water Resources at the U. S. Bureau of Reclamation's Tracy Fish Collecting Facility during tests of primary bypass spacing in 1963, and of louver slat spacing in the secondary louver system in 1964.

During 1968 the test equipment; floating platforms, hoists, hoisting frames, secondary net frames, and mechanical and electrical features, were designed by Water Resources with Fish and Game assistance. Plans and specifications for the material and fabrication of equipment were issued early in 1969. The test program was finalized in March of 1969.

A shakedown and familiarization period was scheduled from July 1969 to January 1970. Testing for salmon was to start in February 1970 and to continue with the appearance of striped bass in late spring on to the end of June 1970 for a total of five months of on-site testing. On-site testing was then to be discontinued until February 1971 when a second five-month run of tests would be initiated.

Contract completion for fabrication and installation of test equipment lagged into late 1969 due to a delay in delivery of the hoists. Also a considerable number of malfunctions were uncovered in the facility control system. Thus, an overall shake-down of the test equipment was not achieved; however, most items were tried-out by the end of February 1970.

As often happens when dealing with natural phenomena the planned test schedule was delayed because salmon did not appear at the facility in sufficient numbers for testing until late in March of 1970.

Young-of-the-year striped bass did not arrive in appreciable numbers until mid-June. Testing for striped bass extended into August. The large number of fish collected required extension of the laboratory processing of samples until the end of the calendar year.

Purpose

The Delta Fish Protective Facility was evaluated for several purposes. These were to:

(1) Assess the functional performance of the facility as a whole and its component parts in relation to the design criteria;

(2) Develop operating criteria to maximize the efficiency of the facility; and

(3) Assess the applicability of design features and operating criteria to Phase II of the facility.

Because of irregularities in the alignment of adjacent louver sections, it was decided to conduct a preliminary study in the secondary channel to determine if louver misalignment affected efficiency.

A limited evaluation of primary channel velocity patterns was undertaken and a louver alignment study was carried out in July of 1971, after completion of scheduled tests.

Specific Objectives

Specific objectives of the Evaluation Testing Program included:

(1) Measure and evaluate the efficiency of the primary louver system.

a. Compare the efficiency of the divided and non-divided saw-tooth louver arrangement.

(2) Measure and evaluate the efficiency of the secondary louver system.

(3) Determine optimum modes of operation for primary and scondary channel features.

Scope

It is a major problem to adequately test a facility such as the Delta Fish Protective Facility because of the sheer size of the installation and the volume of flow involved.

Preliminary estimates showed that a prohibitive amount of equipment and manpower would be required to fish collection nets across all four operating channels, a total waterway area 86 feet wide by 25 feet deep. Also collecting from all channels could produce several thousand fish per minute which, along with debris, and aquatic organisms would present an almost insurmountable task of sorting and counting.

To limit the scope of the program within reasonable bounds it was decided to employ only two of the 21-foot wide primary channels. This decision was based on the premise that channels 1 and 2 like channels 3 and 4 are mirror images. The assumption was made that data obtained from channels 2 and 3 could apply to channels 1 and 4 respectively.

A minimum of 732 tests were planned to be run in the primary channel in 10 months of on-site testing. Each test would consist of collecting in nets all fish diverted by the louvers and those fish that passed through the louvers within a specific length of time, varying from 5 minutes up to 2 hours.

The 732 figure was derived from the mathematical combination of specie of fish, size of fish, primary velocity, type of channel louver arrangement, and bypass acceleration ratio, with reductions due to expected absence of smaller sizes of salmon and the possibilities of obtaining both striped bass and catfish data from certain tests.

The program was expanded to include the testing of identical parameters in the secondary system which nearly doubled the scope of the program. Later initial testing showed that the side on which fish entered the secondary channel and the screened water ratio affected efficiency. Consequently, the program was further expanded to include these variables. As a further result approximately 1,500 different tests were necessary to measure the efficiency of the facility and its components.

There was no definite way to estimate the total number of fish that would be collected. The Delta Fish Protective Facility had been in operation less than a year. Furthermore, the water supply during that time came directly from a Delta channel rather than through Clifton Court Forebay, as it would during the test. From fish collection records and previous testing at the U. S. Bureau of Reclamation's Tracy Fish Collecting Facility, it was evident that several hundred thousand fish would be collected during the tests. The Tracy Facility data were used as a guide in determining manpower requirements as well as timing the tests for the State's evaluation program.

Test schedules were based on the "offpeak" operating schedule of the Delta Pumping Plant. Under this schedule water is pumped (drawn from Clifton Court Forebay through the Intake Channel), for 9 hours each night from 10 p.m. to 7 a.m., Monday through Friday morning, and for 48 hours over the weekend.

Tests were planned to be run at least every 2 hours resulting in 4 to 6 tests per night. Several daylight tests were planned for weekends.

Manpower requirements were estimated to be two 7-man crews with an engineer-in-charge and a supervising field biologist. The biologist was budgeted full time for 2 continuous years, and the engineer-in-charge and the 14 men for two separate 5-month periods.

In addition to field personnel, the program included a biological reaearch supervisor, and up to four laboratory technicians, who sorted, enumerated and measured the samples.

As testing progressed the required manpower resolved to the engineer-in-charge, a supervising field biologist, an office administrator, two crew chiefs, two six-man test crews.

Two additional investigations that were carried out in the course of the program were a measurement of approach velocity in the primary channel and an effect of louver misalignment study.

The velocity investigation as described in Appendix A was conducted by a crew chief during non-testing periods of the schedule program and in between tests without extra manpower or an increase in testing time.

The louver alignment study was performed in July of 1971, following completion of the regular schedule of tests and was a direct extension of the program with attendant increase in cost.

Considerable repairs to the nets and floating platforms, hoist modifications, the need for additional sample containers, and a portable air compressor increased the estimated program cost significantly.

An appreciable amount of the work involving modification, repair, replacement and maintenance of the testing equipment was performed by the Delta Field Division, Department of Water Resources, Division of Operation and Maintenance.

Approximate cost of the testing program was:

Equipment	$ 91,000
Testing Manpower including overhead	285,000
Data and Report Preparation	48,000
Total	$424,000

CHAPTER V

TEST EQUIPMENT

Net Frames and Net Frame Supports

Primary Channel

The two primary channel net frames and the three net frame supports were fabricated and supplied under a separate contract in early 1969 so that they could possibly be used in an emergency to collect fish if the secondary system were out of service for any reason. Each of the frames are 26 feet high with a top width of 19 feet - 5 inches, and bottom width of approximately 18 feet - 10 inches. The bottom widths are narrower due to the widening of the lower nine feet of the pier between channels two and three. A difference of almost one inch between as-built measurements of the channel inverts prevented the frames from being identical in all dimensions.

Mild steel guides 2-1/2 inches deep and 3-3/4 inches wide had been attached to the primary channel walls during construction of the facility to serve as guide slots for test net frames. Stainless steel guides 2 inches deep and 3 inches wide had been embedded for the same purpose in the walls of the secondary channel. Also anchor bolts for net frame hoist supports were provided in the top of walls.

Detailed design of the net frames brought out that the guide slots, particularly those in the primary channels were very minimal in width and depth. The skimpy guide slots on the primary channel prevented direct bearing on them by net frame members and ruled out the use of wheels or rollers. This led to the necessity of welding 1/2-inch by 3-inch ears onto the sides of the net frames to serve as guide bearing members. Initially the primary frame member sizes were based on the following design criteria:

1. One foot of water (62.4 lbs/sq.ft.) across net mouth area.

2. Weight of nets wet plus a 3/32-inch film of water.

3. Allowance for weight of debris, and friction on the guide slots.

4. Hollow watertight structural members (no added water in frames).

5. Earthquake (0.1) and 40 mph wind forces applied separately during lifting of the frames (with consideration of the frames becoming cocked across the guide slots).

Loadings were assumed for loads from the nets being brought into the frame members uniformly along the length of each member and for loads being taken into only the corners of each opening. Mild steel rectangular structural shapes were selected as being the most adaptable to the requirements of net attachments. The minimum sizes as determined by structural analysis were smaller than were required to facilitate clearances for net attachment. Final selection of 8-inch by 6-inch by 1/2-inch tubular shape for all members was dictated by hook considerations and the advantages of uniform members. Fabricated weight of each frame was 6,400 pounds.

The primary channel net frame supports were designed to hold the net frame up with the lowest members above Elevation 5.0 (expected highest water). They could extend only to a height that would permit a net frame to be lifted vertically clear of the supports by a 10-ton hoist attached to the facility gantry crane.

Each primary net frame was designed to be suspended between the support frames by six hand-operated, throw-bolt type, 3-inch by 1-inch high strength steel bars attached to the supports. Thus the net frames fully loaded with nets could be held up out of the waterways for an extended period without tying up the ten-ton hoist. Also safety regulations required while working with loads held by a hoist were not applicable to the net frames when held up by the support frame throw bolt bars.

Specific details of the primary net frames and supports may be found in Specfication 68-51 and the two drawings for that contract.

Secondary Channel

Two separate sets of net frames and hoist frames were required for the secondary system; one at the outlet of the primary bypasses and the other in the secondary channel behind (downstream) the louvers.

Each net frame (10 feet high and 9 feet - 10-3/4 inches wide) was designed according to the same basic criteria as used for the primary net frames. Frames, member sizes were ultimately determined on the basis of uniformity and net attachment clearances rather than structural stresses. Thus 4-inch square structural mild steel tubing was used for all exterior members and 8-inch by 4-inch tubing for the center members of the primary bypass nets.

One-quarter inch diameter bars with one-half inch radius hooks on 1-foot centers and 5/8-inch diameter shank safety hooks at each corner were provided for attachment of nets.

Smaller total loads in the secondary made it feasible to install roller bearings on the secondary net frames. These rollers reduced friction significantly on the guides and afforded smoother lowering and raising of the frames. An indication of the shallowness of the previously installed guide slots was the necessity of cutting the roller shaft retainer nuts to one-half normal thickness in order to provide adequate clearance.

Hoist frames for the two secondary nets were designed as simple frames with 12-foot high 6-inch wide flange columns with an 11-foot - 6-inch long I beam as the cross member for hoist support. Connections of the cross beams to the columns were bolted to facilitate field erection.

Test loading of the hoist frames twisted the hoist support beams nearly an inch out of plane. It was determined that the load was being brought into the beam by the electric hoist several inches off of the vertical axis of the beam section. The beam, which had been selected on the criteria of loading being applied directly in line with its centerline, could not withstand the torsional effect of the eccentric load application. Accordingly the hoist beams were strengthened by welding a channel onto each side of the beam. This added section provided more than adequate rigidity and the hoisting beams served satisfactorily throughout the tests.

Electrically powered jib cranes were selected for picking up the ends of the bypass and secondary channel collection nets. The cranes specified were of one-ton capacity, with 10-foot high masts and 12-foot reaches.

These two cranes were located downstream from each net hoist frame in positions such that the cod ends of the nets could be raised and readily swung out over the secondary channel handrails.

Two 7-foot square, 18-inch deep, reinforced concrete pads with anchor bolts were placed next to the secondary channel to serve as foundations for the jib cranes.

Floating Platforms

Retrieval of the cod ends of the primary channel nets presented a major challenge. Initial ideas of winches on the existing cross walk immediately downstream from the net frame slots were soon discarded. It became very apparent that hauling the ends of 60-foot nets (filled with a substantial volume of fish and debris) up to 8 feet above the water, would be a tedious, time-consuming task with potential mishaps. Also, the 3-foot width of the cross walk was considered too narrow, and the aluminum handrails were not designed as anchorage for winches. Lack of space on the piers and walls prevented the simple solution of adding a span below the existing walkway.

Further studes showed that many of the problems associated with the simultaneous lifting of six nets (three vertically stacked pairs) could be overcume by the use of a floating platform. The final configuration of the floating platforms evolved through many paper trails was a 19 by 20 foot rectangle with a 9 by 14 foot open well in the center.

Numerous flotation methods and devices were investigated, including hulls (steel, timber, plastic, fiberglassed, plywood and even a quick glance at concrete), interlocking pontoon components, pipe with and without foam filling and a wood frame around foam billets. Consideration of foam filling led to a minor research of foam properties and uses with convincing findings that the use of cheap material or one having inappropriate properties could be diastrous.

Lack of definite commitments for further use of the floating platforms led to the discarding of schemes involving high first costs and long life, such as those requiring steel plate or pipe for hulls.

After a thorough review of first costs, ease of construction and expected performance, a heavy wood timber frame enclosure of polystyrene billets was selected as the flotation structure. Main members, the columns, were 6 inches by 6 inches and the stringer and decking were 2 inches by 8 inches.

Construction grade Douglas fir lumber, pressure treated with pentachorophenol was specified for all wood members.

The computed factor of safety for flotation for the total dead and live loads (estimated to be over 8 tons) was 1.47. Freeboard under working conditions was about 2 feet and the maximum list experienced from unequal loading during net retrieval was only an inch or two. The platforms safely weathered strong winds, which created 3-foot high waves; however the floating access walkway which was positioned between the two platforms and the end of a facility pier was badly battered and was replaced by another floating walkway from the left bank.

A non-slip paint was specified for the platform decking but the use of diesel oil in connection with the preservative treatment coupled with wet weather prevented its application. Despite the absence of any particular non-skid treatment no serious problems were encountered with footing on the decking.

The inner well opening was lined with 16 gauge galvanized sheet metal shaped around the bottom of the 6-inch columns adjacent to the well to present a smooth surface to the nets as they were raised and lowered. Trial runs showed the need for a greater radius on the downstream side of the well opening. A remedial measure consisting of a 15-inch diameter corrugated metal pipe attached by wire rope was not satisfactory, and the scheme was abandoned when the pipe broke loose and sunk. The problem was finally solved by the installation of a heavy nylon boot. This boot, shaped like a square angel food cake pan, fitted inside the well opening over the sheet metal, covered the entire bottom of the platform and came up about 2 feet on the outside faces of the platform.

One and a half inch diameter steel pipe handrails three and one-half feet high, enclosed the inner well opening, and the outer perimeter of each platform. Two openings were provided on one outer side for access. These rugged handrails proved invaluable not only for safety reasons, but as bracing members, tie-off fixtures, hangers for tools, gear and material, racks for hanging nets on, and many other uses associated with the work.

A manual winch mounted on an upstream corner of each platform provided for adjustment of a steel anchorage cable attached to a facility pier. Also single deck cleats were installed on the upstream and downstream ends of the platform for anchorage.

A 3/4-inch wire rope was strung across the channel approximately 33 feet downstream to stabilize mooring. Each floating platform was attached to this mooring line by wire rope (floated by three 18 foot by 12 foot diameter logs).

The structural steel net hoist support frame was fabricated from 8-inch American Standard 1 beams. Six 13-foot - 6 inch lengths of beams located in pairs at the centerline of the inner well and 5 feet upstream and downstream of the centerline were mounted along the outer edges of the platforms to serve as columns. Three hoist support beams attached to bearing plates on top of the columns spanned 18-feet - 10 inches across the platform.

The columns were seated on 1/2-inch thick bearing plates bolted to U-shaped plates which, in turn, were attached as caps over the top of the platform's timber columns with horizontal bolts.

For added rigidity, gusset plates were installed between the tops of the columns and the hoist support beams and, 3/4-inch diameter tie rods with turnbuckles were attached from the tops of the upstream and downstream cloumns to the base of the center columns. All beam, gusset plate, and tie rod plate connections were welded.

Positioned level with the walkway around the top of the gantry the 10-ton hoist could raise a net frame to a top member height of Elevation 38.

All connections of the platform members and of the completed unit to the gantry crane were welded. Painted in matching color the 10-ton hoist, platform and appurtenances appear to be an integral part of the gantry crane and will remain in whole for possible future use.

Hoisting tackle for the 10-ton hoist consists of a block with a hook, a yoke of heavy steel plate, two wire rope leads and a lifting beam. Pickup devices on the ends of the lifting beam fit down over pickup brackets on the top of the net frame and spring-loaded pickup devices automatically engage an arm into the net frame lifting brackets. Release of a pickup is made through a manual release cable, which cannot be operated under load.

Hoists

Capacity and characteristics of the hoists were as follows:

Primary Channel

Location	Capacity	Power	Speed	Hook Travel
Gantry Crane	(1) 10 ton	Electric	10 & 30 fpm	40 ft.
Floating Platforms	(6) 1 ton	Air	26 fpm	50 ft.
Secondary Channel				
Bypass Outlet	2 ton	Electric	20 & 60 fpm	17 ft.
Secondary Louvers	2 ton	Electric	20 & 60 fpm	17 ft.
Jib Crane	(2) 1/2 ton	Electric	13 & 40 fpm	26 ft.

Initially all hoists were equipped with wire rope of appropriate sizes for the rated capacities. The wire rope on the air hoists was replaced by synthetic rope, when it became evident that the wire strands could not withstand the abrasion and wear encountered in reeving in at an angle far from the normal vertical. Picking up nets from over the upstream end of the floating platforms resulted in dragging the line over the edge of a guide bar (which actually served as an upward limit for the hook) which soon frayed the wire rope and made it unservicable.

Primary Channel 10-Ton Hoist Platform

A structural steel platform was attached to the downstream leg of the facility gantry crane to support the 10-ton crane used to raise and lower the primary channel net frames.

This frame fabricated of steel plate, angles, and rectangular tubing was cantilevered out from the downstream leg of the gantry crane.

Design and Construction of the Test Nets

Design Considerations

A combination of factors required careful design and fabrication of the test nets. Factors that had to be considered included:

1. Durability: This quality was essential because of the length of the program (March to August of 1970 and 1971), the debris load and the repeated raising and lowering of the nets (as many as six tests per eight hour shift).
2. Mesh Size: Striped bass, the principal species affected, occurs at the fish facility in great abundance from the larval stage up to about 75 mm (3 inches) in length. Successful sampling of large numbers of these small fish necessitated a net of small mesh size. Based on previous experience, a mesh size capable of collecting most small fish, but especially those greater than 15 mm (0.69 in.) was desired.
3. Debris: The waters of the Sacramento-San Joaquin Delta are characterized by an extremely high volume of suspended material. Most of this material is comprised of fibrous plant material (called peat moss) and decaying vegetation. Mysid shrimp, *Neomysis awatschensis*, also are very abundant in the vicinity of the test facility in the spring. In addition, larger debris, such as sticks, paper, leaves and plant roots are common.

4. Water Velocity: The normal operating range of the facility includes approach velocities up to 3.5 feet per second. This required the inclusion of velocities of this magnitude in the testing program and nets that could withstand the force of such velocities for the required sampling period.

5. Sampling Period: Since the integrity and efficiency of nets are affected by the accumulation of debris, it was necessary to consider the maximum sampling period of the test program. King salmon were the least abundant of the species to be tested, required the longest sampling time. Data at hand indicated the need for sampling periods of two hours or more.

Selection of Materials and Design of Nets

Netting Material: Based on the foregoing considerations various neeting materials were investigated for compatibility with the desired objectives. In addition, a competent outside consultant[1/] was retained to assist in designing and testing a pilot net.

Because of its proven strength and durability over many years of sampling in the Delta by the Department of Fish and Game, and its compatibility with the fish-size objective, Marion Textiles Pattern No. 281 nylon bobbinet was selected for the pilot tests. Being a braided material, it is exceptionally strong when hung properly. In mesh, the breaking strength is about 45 pounds per mesh or 360 pounds per linear inch (approximately 8 meshes per

[1/] Mr. James Willis, Netmaker of Morro Bay California.

inch). Hung loosely at points of attachment, strain can be reduced substantially. However, care must be taken in hanging this material. If hung cross-mesh, the meshes will tend to close in the fishing position and the material is much more susceptible to bursting and tearing.

The principal disadvantage of the material is the large amount of bulk in relation to other patterns and styles of netting. To assess its practicability for the proposed task, the material was examined in detail. Microscopic examination showed that the oval-shaped openings in the material averaged about 2 by 2.5 mm (0.08 by 0.10 in.). Since the pores are oval rather than rectangular, the effective open area was only about 4 rather than 5 square millimeters (0.06 sq.in.) per pore. Repeated counts in different areas of the material provided estimates of 7.4 openings per square centimeter or approximately 47.7 pores per square inch. This amounts to 30 percent open area. Therefore substantially more netting was required than other materials having a larger proportion of open area.

Net configuration was arbitrarily patterned after direct tapering trawl nets because of their proven effectiveness, both in stream fishing for fingerling salmon and widespread use throughout the Delta for young-of-the-year striped bass.

Primary Nets: In planning the testing program, it was decided that the primary bays would be sampled with six nets, two abreast and three deep, each 10 by 9 feet at the mouth (see Plate 4).

Since the maximum velocity in the primary bays is on the order of 3.5 feet per second, each net had to be capable of passing up to 315 cfs. Total volume of water to be netted in each of the primary bays at maximum Q is on the order of 1,750 cfs.

The Canadian Department of Fisheries (Clay, 1961) recommended 10 square feet of fish screen (50 percent clear area) for each cfs where the screens are not cleaned continuously. Application of these criteria would have required approximately 5,250 square feet of bobbinet per net.

Considering the strength of the material and the estimated maximum test time (2 hours) an arbitrary decision was made to construct and test a pilot net 75 feet in length with a mouth 10 by 10 feet. The length was extended to 77 feet when it was learned that the material came only in 7 foot widths. The pilot net therefore, had a total surface area of 1,771 square feet or 17.71 square feet of net for each square foot of mouth area. Since the material contained only 30 percent open area, the effective area was 531 square feet or 5.31 times the mouth area. At a channel approach velocity of 3.5 ft/s, the mean velocity through the net (if spread evenly over the entire surface) would be approximately 0.66 ft/s.

Following several trials of up to two hours duration at velocities up to 3.5 ft/s or more under moderate debris conditions at the Tracy Fish Collecting Facility, it was concluded that the net was easily capable of withstanding conditions anticipated in the evaluation program. A later trial was undertaken with the pilot net shortened to 63 feet with the same general conclusion. Based upon the experimental tests, the concensus was that the surface area of the nets should be approximately 15 times the mouth area.

Since the netting material was available only in 7 foot widths, the length of the primary nets was determined ultimately by the closest multiple of 7 which approximated the experimental ratio of surface to mouth area. With the mouth area of the primary nets fixed at 90 square feet, the surface area of the primary louver nets would need to be about 1,350 square feet.

Sizing of the cod ends of the primary nets was based upon the amount of detritus that the net would collect in a one hour test. Previous evidence from frequent sampling in the Delta indicated that 1/3 of a quart was about the maximum amount of "peat moss" that could be expected in a five minute tow of a net with one square foot of mouth area. Projecting this amount results in an estimate of 0.133 cubic feet per square foot per hour. Since the mouth of the primary nets have an area of 90 square feet, the potential volume entering the net could reach 12 cubic feet in a one hour test. The cod end therefore, was designed to handle at least 12 cubic feet of debris. It should be noted that the amount of detritus and debris is lightest near the surface and increases with depth.

Because the material came in 7 foot widths, it was decided that the cod end should not exceed that length. Based on an arbitrary decision that the detritus and debris should not take up more than 75 percent of the capacity of the cod end, and other dimensions were fixed at 1.5 foot. The total volume of the cod end therefore came to 15.7 cubic feet with 4 surface areas of 42 square feet.

In considering fabrication of the cod ends, the weight of wet debris had to be considered. The total volume of the cod end was multiplied by the weight of water to approximate the weight of debris if the cod end were fully laden. The final specifications were arbitrarily revised to require the cod to hold one ton without bursting or tearing. This necessitated reinforcement of the bobbinet with Number 18 thread 2-inch mesh nylon webbing on all but the terminal foot. The latter was not reinforced to facilitate pursing of the bobbinet.

With the surface area necessary to pass sufficient water and the dimensions of the mouth and cod end selected, the length of the primary nets exclusive of the cod section was calculated. This was done using the following modification of the standard formula for the area of a trapezoid:

$$A = 2\left(\frac{W+W^1}{2}\right) L + 2\left(\frac{H+H^1}{2}\right) L + C$$

$$A = (W+W^1)\ L + (H+H^1)\ L + C$$

$$L = \frac{A-C}{W+W^1 + H+H^1}$$

Where: A = Area of net
W = Width at mouth
W^1 = Width at cod end
H = Height at mouth
H^1 = Height at cod end
L = Length of net
C = Area of cod end

Then by substituting the dimensions reported above:

$$L = \frac{1350-42}{10 + 1\frac{1}{2} + 9 + 1\frac{1}{2}}$$

$$L = 59.5 \text{ feet}$$

Given the length (in this case eight-seven-foot panels or 56 feet) the surface area is:

$$A = L(W-3)+6L+C;$$

and substituting values:

$$A = 56(19-3)+6(56)+42$$

$$= 896+336+42$$

$$= 1{,}274 \text{ square feet.}$$

Secondary Nets: The nets for the secondary system were sized in essentially the same way as the primary nets. However, space restrictions in the secondary channel limited their overall length. Nets in excess of 18 feet would have extended into the secondary louvers.

The maximum possible flow in the secondary channel was 240 cfs and the cross-sectional area was 90 square feet. The channel is 10 feet wide and the maximum depth of water about 9 feet. At these dimensions, the velocity is about 2.75 ft/s when flow is at the maximum.

Applying the same velocity through the nets in the secondary as in the primary (0.63 ft/s) would have required about 400 square feet of net. However, the test requirements of the program favored four nets at the entry to the secondary. These were to separate fish entering from each primary bay and to assess the relative depth of entry into the secondary channel.

The cod end was arbitrarily shortened to four feet and the other dimensions were retained (1.5 x 1.5 feet). The length of the cod end therefore, fixed the maximum length of the main secondary nets at 14 feet. Since four nets were necessary, the dimensions of each net at the mouth was set at 5 by 4 feet after the net frame was included. The surface area of each secondary net, based on the dimensions of 5 x 4 x 14 feet was 168 square feet plus the 24 square feet in the cod end. The combined area of the four nets amounted to 768 square feet, which would reduce the normal velocity to an average of about 0.3 ft/s when Q is at the 240 cfs maximum.

Because of the greatly reduced flow in the secondary, the detritus problem was not considered severe enough to warrant reinforcement of the cod ends. The dimensions of the nets are shown in Appendix B and on Plate 5.

Net Fabrication: Because of the anticipated hydraulic force on the nets, the large amount of debris and the potential cost in time and manpower of lost samples due to net failure, extra precautions were taken to strengthen and reinforce each net. The detailed specifications are listed in Appendix B. All riblines and mouthlines were reinforced with 9 ounce bullistic nylon and each corner had a two-foot-square patch of bullistic nylon folded over it in triangular fashion to distribute the tension at the corners over the mouthlines, as well as the rib-lines. All bobbinet, at the point of attachment to the riblines and mouthlines, was sewn to four-inch-wide bullistic 9 ounce nylon tape to distribute the strain over the maximum amount of surface area.

The bobbinet was hung loosely at the mouthlines to increase lateral flexibility and spread the strain over a greater number of lateral meshes.

To minimize clogging and the accumulation of detritus in the interior of the nets, all bobbinet seams were merrow-sewn (a rolled seam) and kept on the exterior surface. The interior surface was thus kept perfectly smooth to facilitate the movement of "peat moss" and debris toward the cod end.

Each net was originally fitted with pursing rings and lines at terminal end of the cod end, and splitting straps and rings to close the nets ahead of the cod end.

Each main primary louver net terminated in a fyke tapered from 1.5 x 1.5 feet to 6 x 6 inches which extended one foot into the cod end.

Thimbles, eye-spliced to each of the four riblines, constituted the principal points of attachment to the net frames. In addition, around the mouth of each net 1/2-inch I.D. grommets were spaced 6 inches apart to accommodate rope lacing for attach-ment to the net frames.

Modifications: During the tests the nets and appurtenances were modified to facilitate the testing operation.

Prior to the evaluation program, a large forebay was completed at the entrance to the aqueduct intake system. This forebay reduced the amount of debris and detritus to almost insignificant levels thereby eliminating the need for the reinforcement on the cod ends. Consequently, this material was removed to minimize snagging and to facilitate opening and closing of the cod end.

The surface nets behind the primary louver eventually were shortened to about 40 feet because they repeatedly got caught on the floating platforms which were located directly over them when in the fishing position. Shortening resulted in a 2.3 foot square terminal opening in these nets.

It was soon observed that a net catching the flow of water from an operating bay would tend to flare laterally toward the quiescent areas of adjacent inoperative bays. This would cause the nets to fold on themselves near the terminal end resulting in a reduction of the surface area and trapping the fish some distance ahead of the cod end. It became necessary, therefore, to tie each pair of nets together to fish properly and keep them directly downstream of the bay being fished.

Apart from these, for the most part minor problems, the nets performed above expectations. Repairs were frequently necessary due to snagging on the floating platforms, walkways and from miscellaneous causes. It is believed that some tears were also induced by the highest velocities. Otherwise, they withstood the rigors of the test program well for the 18 month period they were in use.

Based on this experience and independent investigations on the swimming capabilities of small fish, it appears that the mean normal velocity through nets designed to capture fish smaller than one inch in length should not exceed 0.5 ft/s.

CHAPTER VI

METHODS

Test Parameters

A paramount purpose of the louver evaluation program was to determine operating conditions that will maximize the efficiency of the Delta Fish Protective Facility in salvaging the various species of fish which enter the system. The hydraulic and structural parameters that were thought to affect efficiency were investigated. Studies at other fish salvage facilities aided in the selection of the test parameters.

The hydraulic parameters are difficult to control because of their inter-related nature and dependence on the amount of head which varies as water is admitted to and pumped from Clifton Court Forebay. Therefore, for test purposes it was necessary to establish a range within which each hydraulic parameter could be controlled. The hydraulic parameters tested were within the operating capacity of the facility.

The test parameters, their definition and the methods employed to measure them are described below.

Approach Velocity

The approach velocity is the mean velocity of the water in the channel approaching the louvers in both the primary and/or secondary channels.

The main factors controlling approach velocity in the primary bays are the volume of water being pumped, the water level in the primary channel, and the number of primary bays open.

Four test velocity ranges, 1.5 to 2.0 ft/s (46-61 cm/s), 2.0 to 2.5 ft/s (62-76 cm/s), 2.5 to 3.0 ft/s (77-91 cm/s) and 3.0 to 3.5 ft/s (92-107 cm/s), were employed for both primary and secondary systems. The approach velocity in the primary system is measured by three venturi meters located approximately 70 feet upstream from the bypass inlet at a depth of 9.0 feet above the channel bottom. One meter is located in the middle of each of the channels on either side of the center wall (Bay A) while the other is in the middle of the bay without the center wall (Bay B) (Plate 1).

Velocity data are transmitted to and recorded on tape on a control panel. When all bays were open the highest velocity recorded by the meter in Channel 2 was accepted as the velocity in all bays. The basis for this decision was that (a) the meter in Channel 2 exhibited less variability than the others and (b) the recorded velocity of this meter consistently was closest to the calculated velocity.

Primary approach velocity was the most difficult parameter to measure. Mechanical failures of the meters, fluctuations in pumping rates, minor diversions and changing water depths were the principal reasons why accurate measurements were difficult to obtain. Frequently the recorded velocities fluctuated from 0.16 to 0.47 ft/s during a test.

Approach velocities measured by the meters in the primary channels were generally from 0.23 to 0.47 ft/s greater than the calculated mean approach velocity.

The approach velocity in the secondary channel was computed by dividing the volume of water being pumped by the cross sectional area of the area. These parameters are also recorded on the control panel.

Since the approach velocities measured in the primary are higher than the calculated mean velocity, the metered velocities in the primary are not directly comparable with the calculated mean velocities in the secondary system.

Bypass Ratio

Bypass ratio is the ratio of water velocity entering the bypass to the measured approach velocity. It is primarily an index because the approach velocity in the channel varies both spatially and with time. The ranges in bypass ratios tested were 1.20 to 1.33; 1.33 to 1.47; and 1.47 to 1.60.

The amount of water entering the primary and secondary bypasses (and therefore the water velocity at the entrance of the bypasses and the bypass ratio) is controlled by the difference in water levels (head) and control valve openings. The specific bypass ratios were calculated and transcribed to a nomograph to facilitate the proper valve setting.

Screened Water Ratio

Screened water is used only in the secondary and is intended to reduce the amount of detritus entering the secondary bypass and fish holding tanks. The screened water ratio is the ratio of the velocity of water exiting from the screened water conduit to the secondary approach velocity. It also is only an index also due to fluctuations in the secondary channel approach velocity.

The screened water ratios tested were 0.0 (no screened water) 1.0, and 1.4. These ratios were selected because of noticeable differences in the flow pattern at the exit of the screened water donduit. It was hypothesized that the screened water discharge could affect louver efficiency by turning fish away from the bypass entrance back towards the louvers.

The volume of screened water is controlled by pumps actuated at the control panel.

Center Wall

A center wall in one of the primary bays bisects the distance between the two vee-shaped lines of louvers and terminates at the primary bypass entrance (Plates 1 and 2). This concept was incorporated to facilitate velocity control. The existence of this wall in Bay A (includes Channels 1 and 2) permitted the assessment of the effect of a center wall as a fish guidance feature. In this report, the primary bay with the center wall is referred to as Bay A while the bay without the center wall is referred to as Bay B (includes Channels 3 and 4).

Entry Into Secondary Channel

Fish entering the bypass from Bay A must enter the secondary channel on the same side as the secondary bypass entrance

(Plate 2). Conversely fish entering the bypass from Bay B enter the secondary on the side opposite the bypass. It was hypothesized that the side fish enter the secondary channel may affect efficiency because of the difference in the length of louvers that the fish must traverse to reach the secondary bypass. Therefore, tests were conducted to determine if the side of entry affected efficiency.

Diurnal Efficiency

Tests conducted during the day and night were compared to determine if louver efficiency was affected by daylight or darkness. Presently, most pumping is done at night and on weekends, so relatively few tests were made during the day. No special effort was made to conduct daylight tests under conditions directly comparable to night tests.

Species Occurrence and Relative Abundance

Tests were conducted on downstream migrant king salmon (Oncorhynchus tshawytscha), young-of-the-year striped bass (Morone saxatilis), white catfish (Ictalurus catus) and threadfin shad (Dorosoma petenense) as a substitute for American shad (Alosa sapidissima). Salmon were tested in both 1970 and 1971. All testing was completed in 1970 for the other species except for the louver alignment tests which involved striped bass only.

King Salmon

King salmon entered the facility from January through mid-June in both years, but were in sufficient numbers for testing only from March through May 1970 and April through May 1971.

Densities of salmon entering the facility ranged from 0.1 to 2.0 fish per acre-foot pumped and were mostly from 50 to 125 mm in length. Fish over 125 mm generally were yearling salmon.

Striped Bass

Striped bass generally pass through the facility the entire year but those of the desired test size were only present in sufficient numbers for testing from approximately June 1, 1970 until testing was terminated the last of August. They were extremely abundant from mid-June until mid-August reaching densities of 200 fish per acre-foot. Approximately 75 percent of the bass were from 25 to 75 mm in length. Bass 7.5 to 25 mm in length and 75 to 100 mm in length comprised approximately 24 and one percent, respectively of the total number.

White Catfish

Young-of-the-year catfish appeared in the facility from June to August but were not caught in sufficient numbers for testing until mid-July. This specie was evaluated only in 1970. Generally, densities ranged from 10 to 30 fish per acre-foot. Over 75 percent of the catfish tested were between 20 and 75 mm in length. Those greater than 75 mm long were yearlings primarily, which entered the facility throughout the summer.

Threadfin Shad

Threadfin shad were tested from mid-July, when the larvae could be positively identified, to August when most were in the juvenile form. Nearly 80 percent of those tested were from 17.5 to 40 mm in length.

Net Placement and Operation

Primary Louver Nets

One-half of each primary bay was sampled by six nets on a single net frame (Plate 4 and Photo 2). The net frame accommodated two nets abreast and three deep.

Nets were placed on the net frame in pairs. To prepare the nets for placement on the frames, two nets were spread and aligned adjacent to one anouther. The sides of the nets were tucked so that only the top side of the nets was visible. Each pair of nets was tied together with lines 5 feet long by the top and bottom riblines at distances of 25 feet, 37.5 feet, and 50 feet from the mouth of the nets (Plates 3 and 5). This prevented the nets from flaring toward the adjacent inactive bays during tests (Photo 4). Flaring of the nets prevented the cod ends from opening properly and trapped fish in the body of the net. Each net was then folded as in accordian plaits in 6.5 foot sections. Folded in this manner, the mouth of the net was readily accessible for attachment to the net frame and the net opened freely with minimum entanglement when placed in the water.

The mouth of the nets was attached to hooks on the net frame by a line woven through grommets around the mouth of the nets. The net frame was lowered slowly as the nets were attached (Photo 3). As attachment of each pair of nets was completed and the frame submerged, the nets were released into the water.

The cod sections of the two deepest pair of nets were attached to a hoist line that went through the well of the floating platform (Plate 3 and Photos 1 and 5). The cod ends of the surface pair were attached to hoist lines in front of the platform. The hoist lines were retrieved after the nets were released into the water. The nets were examined for rips and twists afer they were secured.

The hoist line on the floating platform was yoked. Each end was snapped to the splitting strap at the mouth of the cod section of each net (Plate 5 and Photo 5). When the hoist line was slack the yoke spread and allowed the cod sections of the nets to separate. When the hoist line was raised, the arms of the yoke were forced together tightening the splitting straps to close the code ends.

The nets were removed, cleaned, and examined for holes approximately every 2 weeks. The nets were cleaned by stretching them on the ground and rinsing with water through a high pressure hose. Small holes were mended while the nets were drying. Nets with larger tears were replaced. After cleaning, repairing and drying, the nets were folded and placed back in the channel.

Before each series of tests, the nets were examined for rips near the cod sections and to make certain the nets and lines were not entangled.

Before each test, the primary louver nets were lowered with the ends of the cod sections open, allowing fish to pass completely through the net. To begin a test, hoist lines were reeled in, thus closing the cod section and trapping the fish in the body of the net. The ends of the cod sections were tied closed and the nets relowered. When tension was relieved from the hoist line, the splitting strap at the mouth of the cod end slackened and allowed fish to pass on into the cod section.

At the end of a test, the hoist lines were raised closing the mouth of the cod sections. After retrieving the cod ends and removing the fish the nets were lowered with the cod sections open to release fish that had accumulated in the body of the net. The nets were again ready for testing.

Primary Bypass Nets

The terminal exit of each primary bypass was covered by two nets, one above the other. A single net frame held all four nets and served both bypasses (Photo 6). It was not necessary to fold or prepare the primary bypass nets for placement on the frames. The anterior opening to the cod sections of each net was provided with a splitting strap which was secured to a common ring on the hoist line. As in the primary, tension on the hoist line tightened the splitting strap to close the mouth of the cod section.

Before a test, the end of the cod section of each net was tied and sufficient hoist line released to allow the cod section to sink, but the net frame was kept clear of the water to prevent the entry of fish. To start a test, the net frame was lowered, and the hoist lines were released to ensure opening of the cod sections.

At the end of a test, the net frame and hoist lines were elevated simultaneously. The mouth of a net was clear of the water before the splitting strap had completely closed the cod section.

All nets were examined for holes without removing them from the net frame.

Secondary Louver Net

A single net was used to cover the entire area behind the secondary louvers (Plate 1 and Photo 7). It was attached to a net frame in the same manner as the primary and bypass nets. The cod end was opened and closed by a splitting strap attached to the hoist line. A test began and ended in the same manner as the primary bypass nets.

The secondary net also could be examined without removing it from the frame.

Fish Holding Tank

When possible, the first holding tank was used to collect fish for the secondary tests. The first holding tank was preferred because it was the shortest distance from the inlet of the secondary bypass, thus minimizing the chance for error due to the travel time through the bypass. Also, by using the same tank any inherent factors in the bypass and influent line system which may affect fish entering the holding tank (and therefore the estimate of louver efficiency) remain constant among tests.

Testing

During the period of these tests the Delta Pumping Plant operated primarily on an off-peak basis. That is, the pumps operated on week nights from 10 p.m. to 7 a.m. and around the clock on weekends.

Normally, testing began from one to two hours after the main pumps were actuated each evening, to allow the primary approach velocity to stabilize. After the primary approach velocity had stabilized the primary bypass ratio was set. Occassionally, the primary bypass ratio required adjustment because of fluctuations in the approach velocity.

Secondary test parameters were set in a similar manner.

Originally, it was planned to test primary and secondary louver efficiency simultaneously. This is possible by fishing the primary louver nets, secondary louver nets, and holding tank simultaneously. However, tests with marked salmon and yearling striped bass introduced into the primary bypasses indicated:

1. A variable percentage of the test fish were retained in the secondary, and;
2. A variable number of fish were entering the secondary system via the bypass of the primary bay not in use. Both primary bypasses must be operated simultaneously to minimize turbulence in the secondary channel. Apparently fish which remain in the closed bays or pass through the

apertures between the control gates and the walls of each bay and hence enter the bypasses of inoperative bays.

These unreconcilable variables necessitated testing each separately.

Primary Tests

A single test of the primary system involved fishing the nets behind the primary louvers and the primary bypass nets at the entrance to the secondary channel (Plate 1). The former is a measure of fish not deflected by the louvers, and the latter the number of fish successfully louvered.

The tests were initiated by raising the cod ends of the primary louver nets to tie them off. After they were tied off they were immediately returned to the water. The primary bypass nets were lowered into the water about one to two minutes after the start of the primary louver nets were raised. This delay was determined experimentally and was designed to compensate for the time required for fish to travel from the primary bypass entrance to the primary bypass nets. Travel time was inverse to the velocity of water in the bypass system. Termination of tests followed the same pattern.

Secondary Tests

The secondary test procedure was similar to the primary tests. The secondary net was lowered and raised from 1/2 to 1 minute before opening and closing the valve for the holding tank. This delay was based on the water velocity in the secondary bypass system.

Fish were removed from the collecting tank for placement in the facility counting barrel. During these tests the fish were emptied into a small net of the same mesh as the test nets rather than directly into the larger meshed screen of the counting barrel. This was necessary to compare results among the smaller fish.

Length of Tests

Test procedures were essentially the same for all species except for the length of the tests. Test length depended on the abundance of the test species or other fish and detritus. The shortest tests were limited to five minutes to minimize variation caused by the time required to begin and end a test and the lapse in time for fish to travel through the bypass.

In 1970, salmon tests were limited to one hour because of high densities of threadfin shad and detritus. Frequently, the number of fish collected was insufficient for a valid test. In 1971 it was possible to extend salmon test time to three hours due to a reduction of other species and detritus.

Striped bass were very abundant and in no instance was it necessary to test over one-half hour. Upwards of 15,000 bass were collected in many five-minute tests. High bass densities precluded an adequate number of catfish tests during most of the summer. During the last of August when striped bass densities decreased, catfish tests were increased to fifteen minutes. Threadfin shad were collected incidentally to the other test species.

Processing of Fish

Field

At the end of each test, the contents of the nets were emptied into labeled containers indicating the test and net numbers. The containers were taken to the field laboratory where the samples were prepared for preservation. Miscellaneous fish, invertebrates, and detritus were removed by straining through variable mesh screens, by floating the fish through the addition of salt to the samples or, when practical, picking by hand.

Each sample was preserved separately in either a quart or gallon jar. When striped bass samples were too large, no more were retained than could be kept in a gallon jar. They were further reduced by distributing the fish randomly in a 116 square cm plastic tray into which a lattice divider was inserted to form 16 sections (Photo 8). Samples were preserved in a solution of 5 to 10 percent formalin with rose bengal dye added to stain the fishes red for easier detection.

Laboratory and Analytical

Most samples contained too many fish for a total count. When this occurred the samples were reduced in the labroatory through the use of a lattice divider. Ultimately, each sample was reduced so that approximately 100 fish were counted and measured (Photos 8 and 9). This number was multiplied by the reciprocals of the fractions initially preserved and counted to obtain an estimate of the total number sampled.

Expanded fractional counts when compared to the actual number in 10 samples of up to 2,000 fish produced erros of 2 to 10 percent for any one net. Since there were eight nts involved (6 louver and 2 bypass) in the primary tests it is reasonable to assume that the deviation (error) among individual nets offset each other to some extent. Thus, it is probable the error of the combined sample for either the six louver nets or the two bypass nets is smaller than the maximum observed error. Further, it is presumed on the basis of the foregoing that errors in computed louver efficiency are less than the extreme deviations of individual net samples and approximate those of the total sample for both louver and bypass nets.

Past studies have shown an inverse relationship between variations in louver efficiency and fish length. Therefore, fish less than 20 mm were measured at 2.5 mm increments; fish 20 to 30 mm at 5 mm increments; 30 to 50 mm at 10 mm increments; and greater than 50 mm at 25 mm increments. Fish were measured by fork length.

Louver efficiency was determined as:

Primary $\frac{B}{L+B}$; Secondary $\frac{H}{l+H}$; Combined $\frac{B}{L+B} \cdot \frac{H}{l+H}$

Where:

B is the number of fish taken in the primary bypass nets;

L is the number of fish taken in the primary louver nets;

H is the number of fish taken in the secondary holding tank; and

l is the number of fish taken in the secondary louver net.

The numberator is the number of fish that were successfully louvered into the bypass while the denominator is the total number of fish that entered the channel.

The bypass catch from the primary bay without the center wall (Bay B) was divided by two since it was composed of fish that had successfully traversed both lines of louvers in that bay. Fish lost through the louvers were only collected in nets on the test side of Bay B. The bypass catch from the bay with the center wall (Bay A) was divided by two only when the channels were open on both sides of the center wall.

The division of the bypass catch by two assumes; (1) that the fish are equally distributed on each side of the bay, and (2) louver efficiency is the same for both lines of louvers. Neither assumption was verified as nets could not be placed in the bay above the louvers and the primary louver nets could be placed behind only one line of louvers.

Test data for all species except salmon were punched on IBM cards, which included test number, number of fish collected in each net, and the test parameters. A tabulation was prepared for each species that included for each test parameter, the number of fish of each size range to determine the number of valid tests for each test condition. The data were processed, using the electronic data processing and computer facilities of the California Department of Water Resources.

Analysis of variance was used to combine or segregate length groups and to determine statistical differences in efficiency among parameters. Analysis of variance was selected in lieu of chi square because the latter does not take individual test variation into account. Chi square would be much more likely to indicate significant differences than analysis of variance. Methods employed by Cochran (1943) were used to determine if the percentage figures should be weighted or unweighted in relation to sample size. Since, in most cases, variation was primarily binomial, a weighted analysis was used for all species. An unweighted analysis of variance using an arc-sin transformation was calculated as a check and was generally more conservative in indicating significant differences.

Only tests containing 10 or more fish were considered to constitute a valid sample. Furthermore, only those test parameters were compared, for which there were at least three replicates of valid samples.

Statistical differences in louver efficiency among length groups were calculated for each species, disregarding test parameters. Adjacent length groups that were not significantly different were combined. There were statistically significant differences in length groups between species, among primary bays and the secondary system and within the test parameters.

All test results for a given parameter were combined where there was no significant statistical variation within that parameter.

Net Catches

Primary louver net catches were examined to determine the vertical and horizontal distribution of the various species. For this analysis, it was assumed that the spatial distribution of the fishes did not change significantly as they passed through the louvers. Vertical net catches supported this assumption, as king salmon, young-of-the-year striped bass, and white catfish were caught at the same depths they generally occur in the river channels (Sasaki, 1966, and others; Chadwick, 1974; and Turner, 1966).

The net catch-distribution data were used primarily to determine where fish went through the louvers with respect to the primary bypass inlet. Fish caught in the nets adjacent to the bypass were assumed to have passed through the downstream half of the louvers (Plate 1). Conversely, fish caught in the outside nets, with respect to the bypass, were assumed to have passed through the upstream half of the louvers.

Knowledge of the general location that fish passed through the louvers facilitated interpretation of how the test parameters affected efficiency.

CHAPTER VII

KING SALMON

Results

Tests of louver efficiency on downstream migrant king salmon were conducted in the spring of both 1970 and 1971. Those in 1970 were restricted to primary Bay A (Channels 1 and 2) and the secondary system because the test equipment for primary Bay B (Channels 3 and 4) was not completed.

Tests in 1970 were conducted to determine efficiency in relation to fish length, approach velocity and bypass ratio and involved approximately 8,300 salmon. Data collected in 1971 were used to evaluate the relative efficiency of the louvers in both primary bays and the secondary system. Approximately 3,200 salmon were involved in the 1971 tests.

Primary System

Fish Length: Primary efficiency of salmon ranged from 67 to 86 percent with the highest efficiency occurring among the largest salmon (Table 1). In the primary system salmon 100 to 125 mm in length were louvered significantly less efficiently than larger and smaller size groups, which we have no tangible explanation. Little importance is attached to the differences in louver efficiency among the other groups since the disparity was only about six percent and not consistent with respect to size.

TABLE 1

Primary and Secondary Louver Efficiency of King Salmon in Relation to Their Length, (1970) 1/

	Length Classes (mm)				
	40.1 50.0	50.1 75.0	75.1 100.0	100.1 125.0	125.1
Primary System		.83 (909)	.79 (1194)	.67 (441)	.86 (83)
Secondary System	.71 (108)	.87 (1440)	.92 (1997)	.94 (1559)	.97 (315)

1/ All test data combined. Figures in parentheses show number of fish involved in tests.

TABLE 2

Louver Efficiency of Downstream Migrant King Salmon in
Relation to Approach Velocity and Bypass Ratio (1970)

Primary Bay A

	Length Classes (mm)									
	50.1-100.0					100.1-125.0				
	Approach Velocity (ft./sec.)					Approach Velocity (ft./sec.)				
Bypass Ratio	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5		1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	
1.20-1.33		.81	.88	.88			.83	.73	1.00	
1.34-1.47	.77	.74	.83	.90		.70	.61	.65	1.00	
1.48-1.60		.84	.82	.75			.64	.71	.74	
Significance		*	x	x			x	x	x	
Combined Data	.77	.80	.83	.84	**	.70	.65	.69	.84	x

Levels of Significance x => .05
* = .05
** = .01

TABLE 3

Primary, Secondary and Combined Louver Efficiency
of King Salmon (50-100 mm) in Relation to the
Presence or Absence of a Center Wall (1971)

	Approach Velocity (ft./sec.)							
	1.5-2.0		2.0-2.5		2.5-3.0		3.0-3.5	
	A1/	B2/	A1/	B2/	A1/	B2/	A1/	B2/
Primary	.93	.95	.92	.95	.90	.96	.90	.90
Secondary	.96	.95			.94	.92		
Combined3/	.89	.90			.84	.88		

1/ Fish entering primary bay with center wall and into secondary in line with bypass.

2/ Fish entering primary bay without center wall and into secondary in line with louvers.

3/ Product of primary and secondary louver efficiency.

(Table 4). The difference between bays in terms of the percentage of fish that went through the upstream half of the louvers was generally less than one percent. At velocities greater than 3.0 ft/s, efficiencies were the same in both bays, although losses through the downstream halves were greater than through the upstream halves.

Secondary System

Fish Length: Efficiency in the secondary system increased directly with size. The largest increase occurred among the smaller size groups (Table 1). All size groups were louvered more effectively in the secondary than in the primary system (Figure 1).

For analysis of the secondary test parameters, salmon were separated into two length groups (50.1 to 100 mm and 100.1 to 125.0 mm). Not enough salmon less than 50 mm long were collected for statistical analysis.

Bypass Ratio: The effect of bypass ratio was evaluated only in 1970 with the screened water ratio fixed at 1.4. All fish tested entered the secondary in line with the secondary bypass (from Bay A).

There was no consistent relationship between secondary efficiency and bypass ratio in either size group of salmon (Table 5). Therefore, data collected at different bypass ratios were combined for analysis of the remaining secondary test parameters.

TABLE 4

Louver Efficiency of Downstream Migrant King Salmon (50-100 mm) in the Primary Bays With (A) and Without a Center Wall (B) and the Proportion Lost in the Upstream and Downstream Halves of the Louver (1971).

	Approach Velocity (ft./sec.)							
	1.5-2.0		2.0-2.5		2.5-3.0		3.0-3.5	
	A	B	A	B	A	B	A	B
Efficiency	.92	.94	.91	.96	.89	.96	.90	.90
Total proportion lost	.08	.06	.09	.04	.11	.04	.10	.10
Upstream loss	.03	.04	.03	.02	.03	.02	.04	.04
Downstream loss	.05	.02	.06	.02	.08	.02	.06	.06

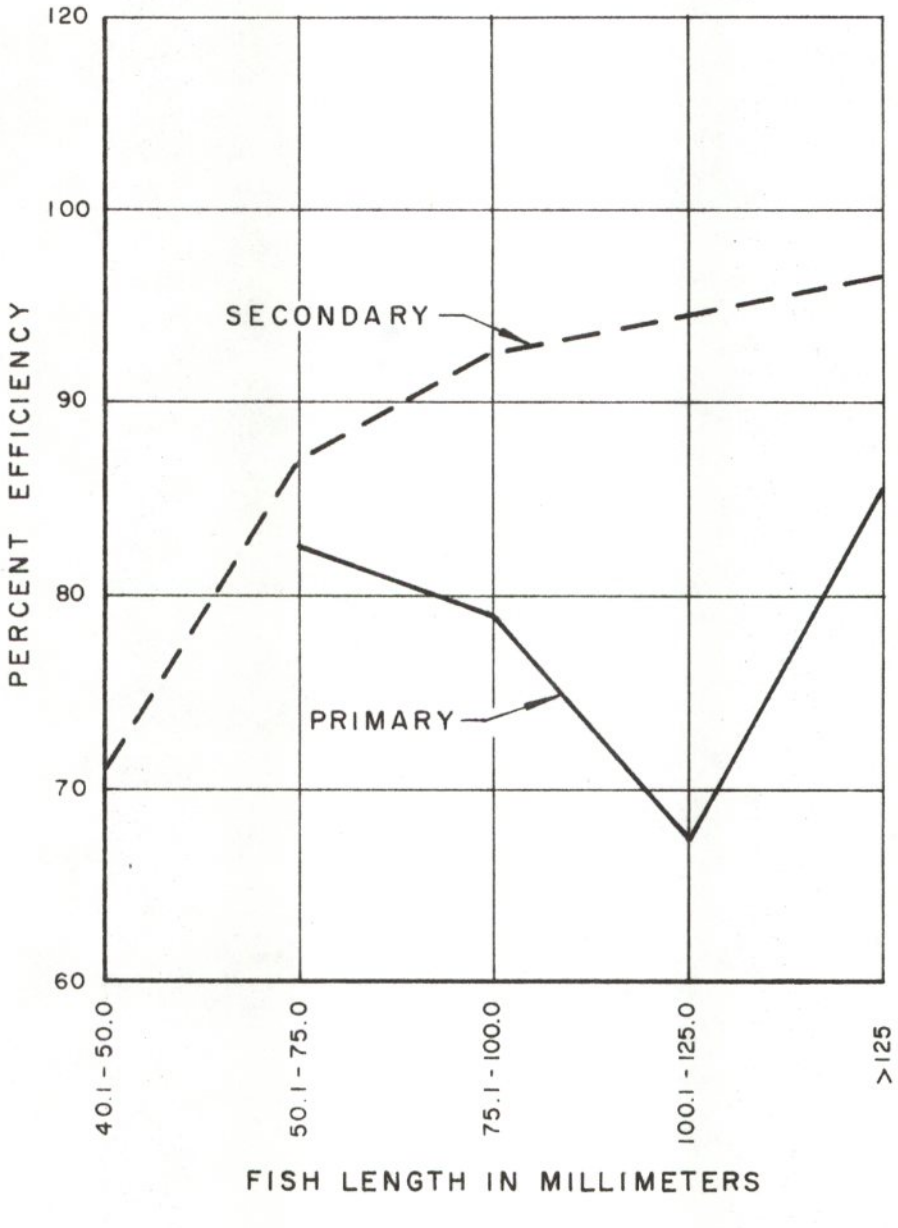


Figure I

Observed Relationship Between Length and Louver Efficiency of Downstream Migrant King Salmon (All Test Data Combined)

TABLE 5

Secondary Louver Efficiency of Downstream Migrant King Salmon in Relation to Approach Velocity and Bypass Ratio. Screened Water Ratio 1.4 (1970)

	Length Classes (mm)										
	50.1-100.0					100.1-125.0					
	Approach Velocity (ft./sec.)					Approach Velocity (ft./sec.)					
Bypass Ratio	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5		1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5		
1.2-1.33	.90	.89	.91	.96		.97	1.00	.85	1.00		
1.33-1.47	.91	.92	.93	.95		.97	1.00	.95	1.00		
1.48-1.60	.98	.89		.96		.96	1.00				
Significance	x	x	x	x		x	x	x	x		
Combined	.90	.90	.92	.96	*	.97	1.00	.92	1.00	x	

Levels of significance x = >.05
* = .05
** = .01

Approach Velocities: Secondary efficiency of king salmon 50 to 100 mm in length was significantly better (statistically) at approach velocities greater than 3.0 ft/s than at lower velocities (Table 5). There was only a difference of two percent in efficiency between velocities of 1.5 to 3.0 ft/s. There was no relationship between efficiency and approach velocity for salmon 100 to 125 mm in length. As in the primary system efficiencies were generally 90 percent or better.

Entry into Secondary: Only 1971 data were used for this analysis.

At approach velocities of 1.5 - 2.0 ft/s and 2.5 to 3.0 ft/s, louver efficiencies were one and two percent higher respectively, when fish entered the secondary in line with the bypass (Table 3). These differences are not appreciable considering that louver efficiency was greater than 90 percent regardless of the side salmon entered the secondary channel.

Combined Primary and Secondary Louver Efficiency

In 1970, tests were conducted only in the primary bay with the center wall (Bay A) and in the secondary with fish that enter from Bay A. Combined efficiency of salmon 50 to 100 mm in length ranged from 69 to 81 percent and was related directly to approach velocity (Table 6). Combined efficiency of salmon 100 to 125 mm in length was more variable with respect to approach velocity, ranging from 65 to 84 percent, with the highest efficiency at the higher velocity.

Salmon were divided into two groups, 50 to 100 mm and 100 to 125 mm for analysis of the primary test parameters. An insufficient number of salmon longer than 125 mm were collected for statistical evaluation of test parameters.

Bypass Ratio: There was little relationship between efficiency and bypass ratio for salmon (Table 2). Since the differences were not satistically significant, bypass ratios were combined for analysis of the remaining test parameters.

Approach Velocity: In 1970 the efficiency of salmon 50 to 100 mm long was related directly to approach velocity in primary Bay A (Table 2). Although differences between velocities were small, they were statistically significant. In 1971, the efficiency of similar size salmon was not as clearly related to approach velocity in either Bay A or Bay B (Table 3). The efficiency of slamon 100 to 125 mm long was not related to approach velocity (Table 2).

Center Wall: At approach velocities less than 3.0 ft/s, salmon 50 to 100 mm long were louvered slightly more efficiently in the bay without the center wall (Bay 3) (Table 3). At velocities greater than 3.0 ft/s, salmon were louvered with equal efficiency in both primary bays with efficiency being 90 percent or better in all cases.

Net catches behind the primary louvers indicated that the differences in efficiency between the two bays at velocities less than 3.0 ft/s, was attributable principally to a greater loss of salmon in the downstream half of the louvers in Bay A

TABLE 6

Primary, Secondary and Combined Louver Efficiency of Downstream Migrant King Salmon Entering Primary Bay With Center Wall and Secondary in Line with Bypass. Screened Water Ratio 1.4 (1970)

	Length Classes (mm)							
	50.1-100.0				100.1-125.0			
	Approach Velocity (ft./sec.)				Approach Velocity (ft./sec.)			
	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5
Primary	.77	.80	.83	.84	.70	.65	.69	.84
Secondary	.90	.90	.92	.96	.97	1.00	.95	1.00
Combined	.69	.72	.76	.81	.67	.65	.65	.84

In 1971, when both bays were tested, combined efficiency ranged from 84 to 90 percent (Table 3). Salmon entering the primary bay without the center wall and the secondary in line with the louvers were louvered slightly more efficiently.

Discussion

Comparison of Louver Efficiency in 1970 and 1971: Louver efficiency for salmon 50 to 100 mm in length was better in 1971 than 1970 at all velocities in both the primary and secondary (Table 7). Statistically, differences in the primary between the two years were highly significant at all velocities except 2.5 - 3.0 ft/s. Insufficient salmon greater than 100 mm in length were collected in 1971 to provide a meaningful comparison with 1970.

The causes of the difference between the two years are largely speculative. Possibly, it was due to the better control and measurement of the parameters achieved in 1971, particularly approach velocity. However, efficiency varied so little with approach velocity that this could hardly account for all of the disparity between the two years.

The slightly higher efficiencies in the secondary may be attributable to a difference in the screened water ratio. In 1970, the screened water ratio was maintained at 1.4 while in 1970 it was kept at 1.0. Unfortunately, no tests were conducted with salmon to determine the effect of the screened water ratio on efficiency. This parameter was not incorporated into the test program until after the 1970 salmon tests.

TABLE 7

Comparison of Salmon (50 to 100 mm) Efficiency in 1970 and 1971

	Approach Velocity (ft./sec.)			
	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5
		Primary		
1970	.77	.80	.83	.84
1971	.93	.92	.90	.90
Diff.	.16	.12	.07	.06
		Secondary		
1970	.90		.92	
1971	.96		.94	
Diff.	.06		.02	
		Combined		
1970	.69		.76	
1971	.89		.84	
Diff.	.20		.08	

Overall, the efficiency of king salmon outmigrants ranged from approximately 60 percent to 100 percent. The greatest variation apparently was related to size. In the primary system louver efficiency varied among size groups but no clear relationship between size and efficiency was evident. In the secondary, efficiency was directly related to size although the disparity was not great among fish over 50 mm. The latter results agree with observations in the secondary of the Tracy Fish Collecting Facility (California Department of Water Resources, 1964).

The efficiency of 50 to 100 mm salmon in relation to approach velocity was variable in 1970 but there appeared to be a direct relationship in primary Bay A and the secondary channel. The efficiency of 100 to 125 mm salmon was not as closely related to approach velocity although efficiency was generally highest at the highest velocities. In 1971 there was a slight inverse relationship between approach velocities and efficiency, although differences were not significant.

Slight increases in efficiency at the higher approach velocities were noted by Bates, et al, op. cit., at the Tracy Fish Collecting Facility. There, the largest increase in efficiency occurred between velocities of 1.0 and 1.5 ft/s with slight but consistent increases to velocities of 3.5 ft/s. Later tests showed efficiency to remain relatively constant at velocities from 1.25 to 3.5 ft/s, DWR op. cit. Ruggles and Ryan (1964) found an increase in salmon efficiency at velocities from 1.5 to 2.5 ft/s with little difference at 2.5 and 3.5 ft/s.

These tests did not demonstrate any apparent relationship between efficiency and bypass ratio in either primary Bay A or in the secondary. This relationship was not tested in primary Bay B. Bates, et al, found a two to five percent increase in efficiency between bypass ratios of 1.2 and 1.4. In contrast, a later study at the same facility indicated a slight inverse relationship at bypass ratios of 1.2 to 1.8, DWR op.cit. Studies by Ruggles and Ryan, op.cit., showed little difference in efficiency between bypass ratios of 1.0 to 1.45. The combined results of these studies suggest that bypass ratios in excess of 1.2 have little, if any, effect on louver efficiency for downstream migrant king salmon between 40 and 125 mm in length.

Louver efficiency was slightly higher in the primary bay without the center wall (Bay B) than the bay with the center wall at velocities less than 3.0 ft/s. Apparently, the difference was due to a disproportionately higher loss of salmon through the downstream half of the louvers in Bay A.

At velocities greater than 3.0 ft/s efficiency was similar in both bays.

The difference in efficiency between Bay A and Bay B at the lower velocities may be due to the narrower bypass caused by extension of the center wall into the bypass entrance of Bay A. Extension into the bypass effectively reduced the bypass width by one-half to 6 inches. Ruggles and Ryan, op.cit., found little difference in the efficiency of king salmon with and without the center wall when the wall extended into the bypass. However, when the wall was shortened so it did not extend into the bypass, efficiency increased from 68 to 76 percent. Some sockeye salmon refused to enter a 6-inch bypass and dispersed upstream or scattered through the louvers. Possibly king salmon react in a similar manner.

Conclusions

Louver efficiency of downstream migrant king salmon increased with size in the secondary louver system. The increases were most significant for fish less than 75 mm. In the primary bay this relationship was not as apparent. Salmon 100 to 125 mm in length were louvered less efficiently than smaller and larger fish in the 1970 primary tests involving Bay A.

No consistent relationship was found between efficiency and approach velocity, although other investigators have generally found a positive relationship for salmon.

Efficiency was slightly lower in the primary bay with the splitter wall at velocities less than 3.0 ft/s. This may be related to the narrower bypass width. The efficiency of salmon did not appear to be related to bypass ratio.

CHAPTER VIII

STRIPED BASS

Results

Over 1.3 million striped bass were involved in the louver evaluation study. Somewhat more than half (54 percent) were involved in tests of the primary system and the remainder in secondary tests.

The mean size of fish in the primary tests was slightly smaller than that of fish in the secondary (Figures 2 & 3). This difference was not unexpected. Fewer small bass reach the secondary from the primary because the smaller fish are not louvered as efficiently as the larger fish. A length frequency distribution and cumulative frequency curve of all test fish combined is shown in Figures 2 and 3, respectively.

Primary System

Fish Length: Size was the most important determinant of louver efficiency for striped bass. Louvers were virtually ineffective for bass less than 7.5 mm. Efficiency increased rapidly with size, reaching nearly 70 percent at 25 mm. Approximately 85 percent of all bass larger than 75 mm were louvered in the primary system.

Following analysis of the size-efficiency relationship (Figure 4) bass collected during the primary tests were divided into the following six length groups for analysis of the test parameters: $\leq$ 12.5 mm; 12.6-15.0; 15.1-20.0; 20.1-30.0; 30.1-40.0; and 40.1-100 mm.

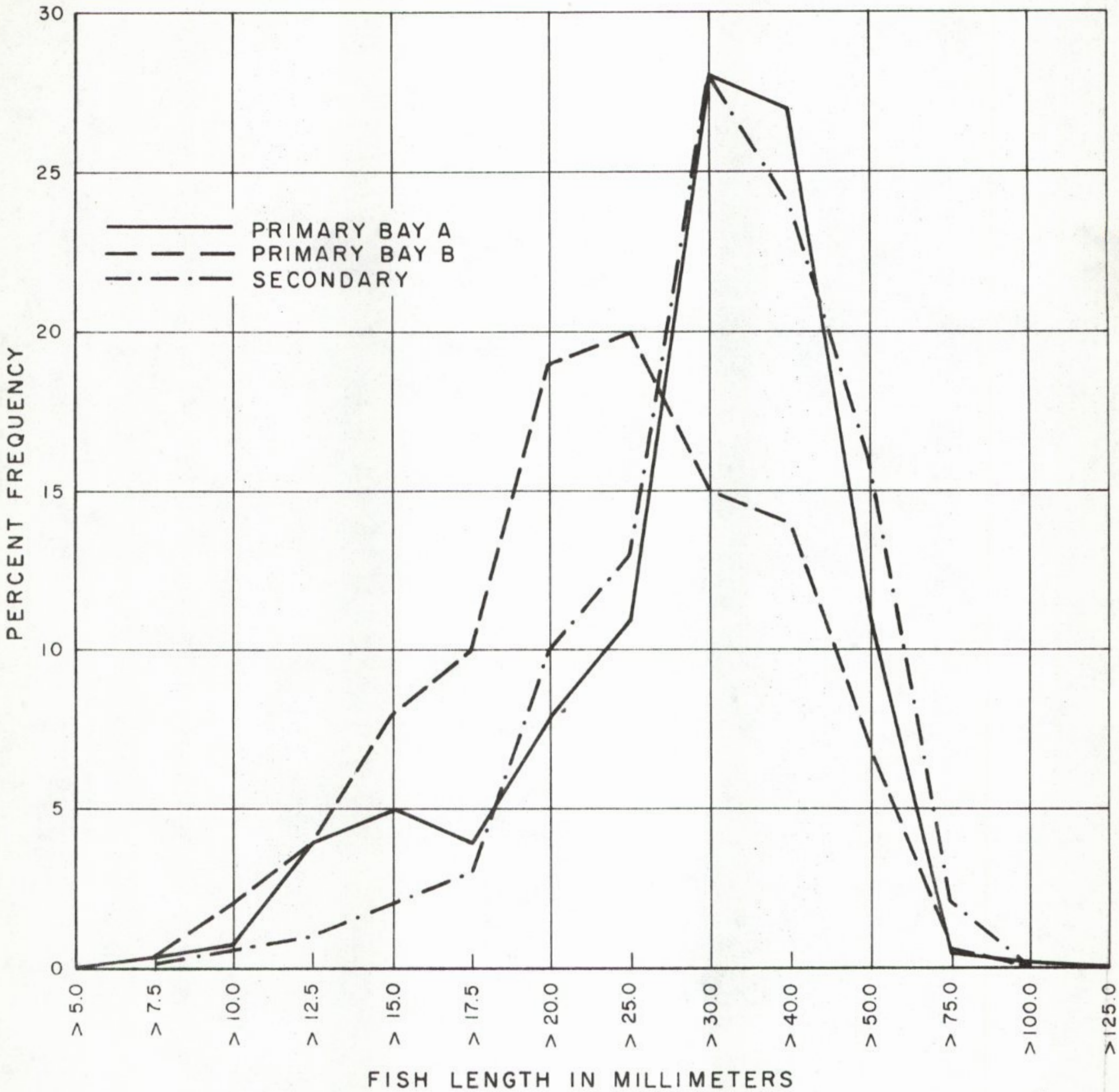


Figure 2

Length Frequency Distribution of Striped Bass Tested

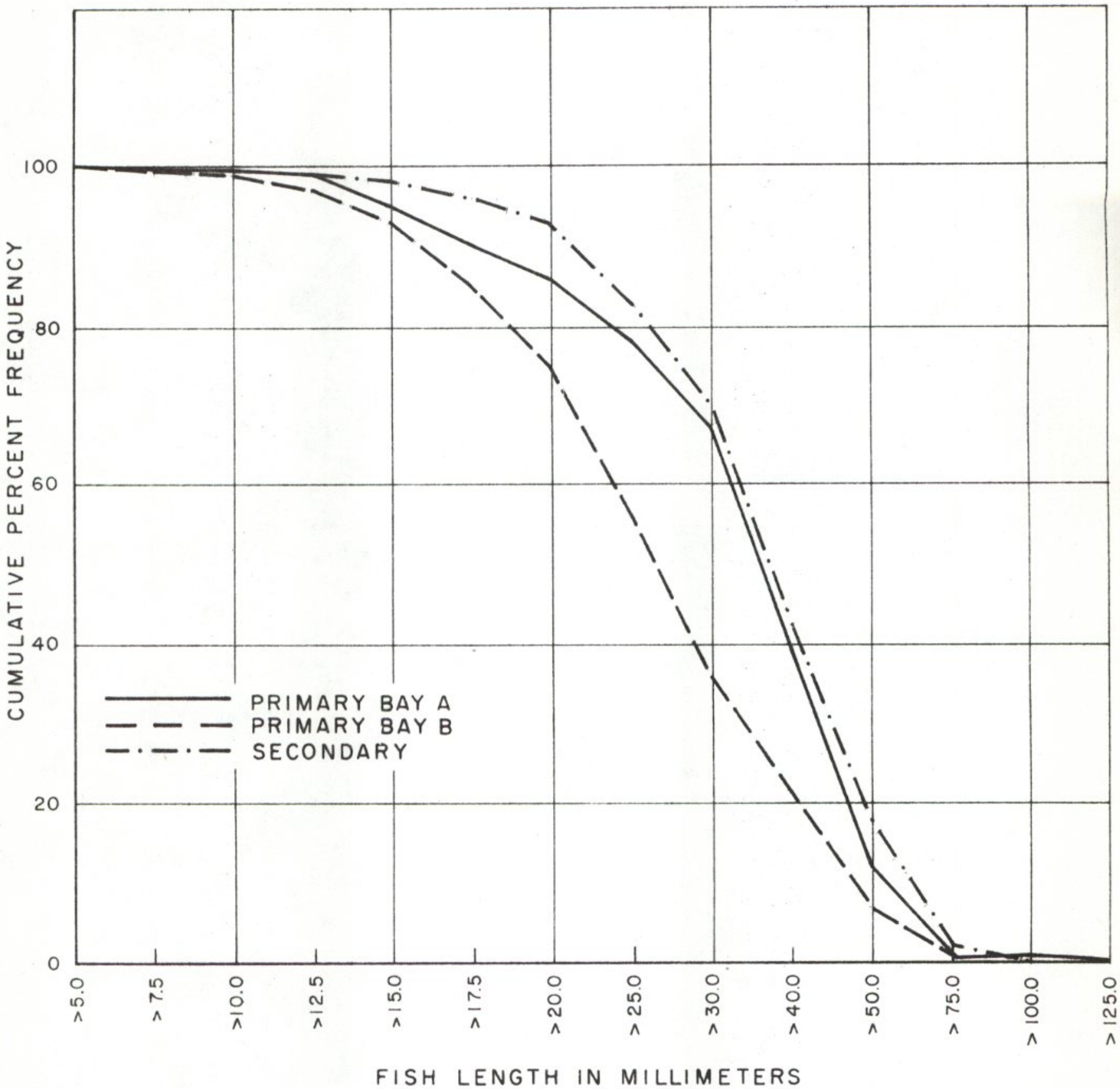


Figure 3

Cumulative Percent Frequency
Showing Percentage of Striped Bass Larger
Than Any Selected Length Class

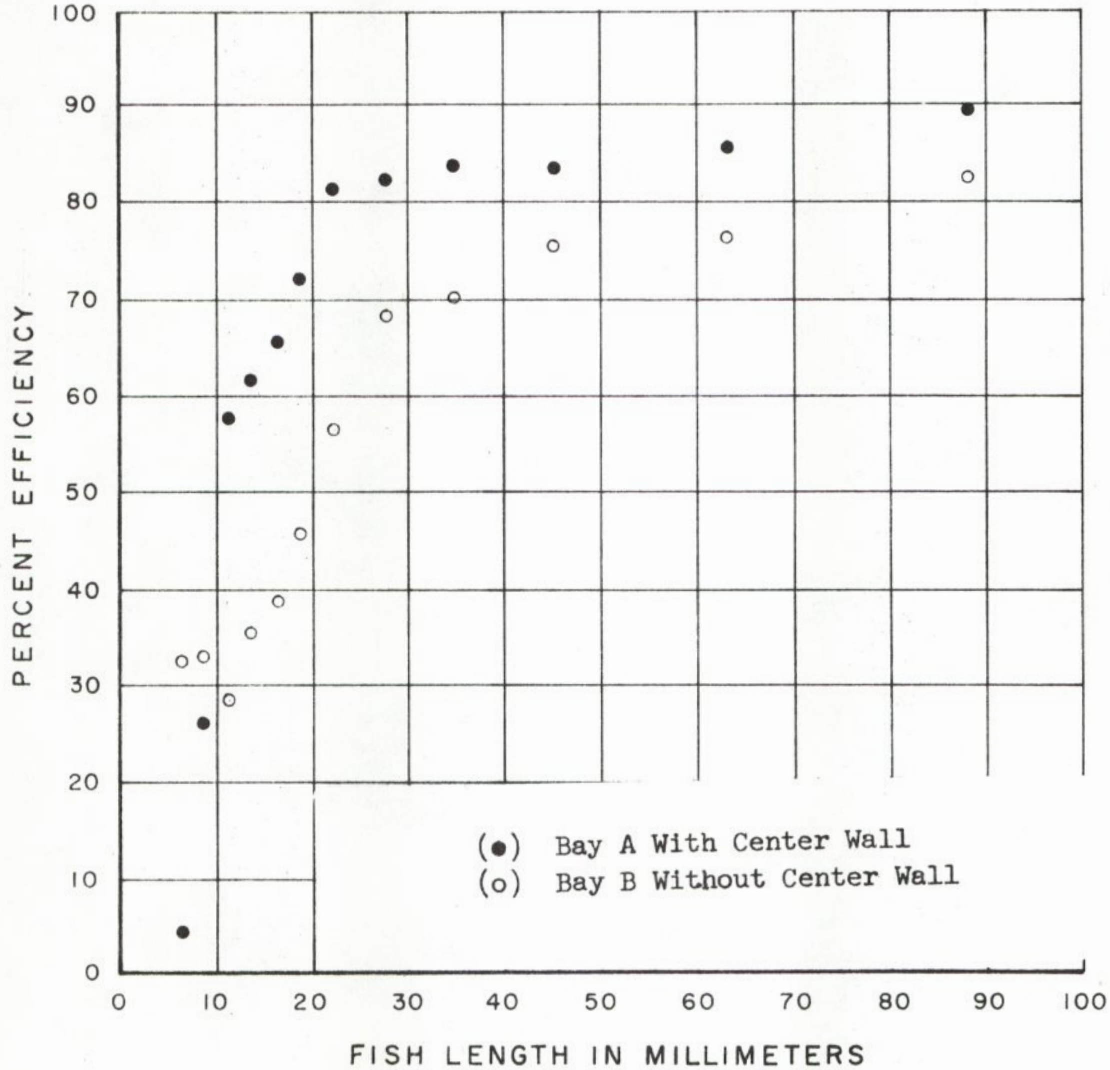


Figure 4

Primary Louver Efficiency of
Striped Bass in Relation to Size

Bypass Ratio: In Bay A efficiencies at bypass ratios of 1.34-1.47 were generally better than at lower or higher ratios, although little significance can be attached to the relationship. At approach velocities greater than 3.0 ft/s, bass were louvered least efficiently at bypass ratios less than 1.33. The differences were statistically significant for all size groups greater than 15 mm (Table 8).

In Bay B bass were louvered more efficiently at bypass ratios greater than 1.48 irrespective of fish size or approach velocity, although not enough tests were made to assess the effect of bypass ratio at velocities greater than 3.0 ft/s. Bypass ratios of 1.34-1.47 were clearly inferior to higher and lower bypass ratios (Table 9). The relationship between louver efficiency and bypass ratios is abstruse because efficiency was lowest in Bay B and generally highest in Bay A at bypass ratios of 1.34-1.47.

The variability in efficiency among bypass ratios decreased as fish size increased. On the basis of the above, bypass ratios were segregated for both bays for analysis of the remaining parameters.

Approach Velocity: In both bays all size groups of bass generally were louvered more efficiently at the lowest approach velocities. The efficiency of bass less than 30 mm was inversely related to velocity. For bass greater than 30 mm the inverse relationship held for velocities up to 3.0 ft/s after which efficiency increased (Figure 5).

TABLE 8

Louver Efficiency of Striped Bass in Relation to Approach Velocity and Bypass Ratio in Primary Bay With Center Wall (Bay A)

Fish Length in mm ≤ 12.5

Bypass Ratio	Approach Velocity (ft/sec) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance
≤1.33		.45	.45	.23	x
1.34-1.47		.74		.38	x
≥1.48		.53		.28	x
Significance		x		x	

Fish Length in mm 12.5-15.0

Bypass Ratio	Approach Velocity (ft/sec) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance
≤1.33		.69		.38	**
1.34-1.47	.76	.76		.36	x
≥1.48		.61		.55	x
Significance		x		x	

Fish Length in mm 15.1-20.0

Bypass Ratio	Approach Velocity (ft/sec 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance
≤1.33	.77	.78	.82	.40	**
1.34-1.47	.67	.83		.64	*
≥1.48		.69		.63	**
Significance	x	**		**	

Fish Length in mm 20.1-30.0

Bypass Ratio	Approach Velocity (ft/sec) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance
≤1.33	.88	.81	.70	.60	**
1.34-1.47	.85	.87		.71	*
≥1.48		.81	.62	.72	**
Significance	x	x	x	*	

Fish Length in mm 30.1-40.0

Bypass Ratio	Approach Velocity (ft/sec) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance
≤1.33	.89	.85		.75	**
1.34-1.47	.92	.82	.64	.80	**
≥1.48	.79	.82	.75	.85	x
Significance	**	x	x	**	

Fish Length in mm 40.1-100.0

Bypass Ratio	Approach Velocity (ft/sec) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance
≤1.33	.91	.84		.77	**
1.34-1.47	.91	.83	.80	.82	*
≥1.48	.90	.87	.73	.85	x
Significance	x	x	x	*	

Levels of significance
x = >.05
* = .05
** = .01

TABLE 9

Louver Efficiency of Striped Bass in Relation to Approach Velocity and Bypass Ratio in Primary Bay Without Center Wall (Bay B)

Fish Length in mm
≤ 12.5

Bypass Ratio	Approach Velocity (ft/sec) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance
≤ 1.33		.16	.21		*
1.34-1.47	.25	.25	.09		*
≥ 1.48	.45		.48		x
Significance	x	x	x		

Fish Length in mm
12.5-15.0

Bypass Ratio	Approach Velocity (ft/sec) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance
≤ 1.33	.57	.36	.28		x
1.34-1.47	.45	.39	.15		**
≥ 1.48	.70		.57		x
Significance	*	x	**		

Fish Length in mm
15.1-20.0

Bypass Ratio	Approach Velocity (ft/sec) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance
≤ 1.33	.63	.59	.43		*
1.34-1.47	.61	.49	.22		**
≥ 1.48	.79		.52		**
Significance	**	x	**		

Fish Length in mm
20.1-30.0

Bypass Ratio	Approach Velocity (ft/sec) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance
≤ 1.33	.72	.61	.61		**
1.34-1.47	.71	.58	.39		**
≥ 1.48	.86	.89	.61		**
Significance	**	**	**		

Fish Length in mm
30.1-40.0

Bypass Ratio	Approach Velocity (ft/sec) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance
≤ 1.33	.83	.61	.70		**
1.34-1.47	.70	.70	.45	.50	**
≥ 1.48	.88	.87	.66	.75	**
Significance	**	**	**	*	

Fish Length in mm

Bypass Ratio	Approach Velocity (ft/sec) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance
≤ 1.33	.85	.69	.71		**
1.34-1.47	.69	.74	.71	.82	x
≥ 1.48	.85	.86	.67	.74	**
Significance	*	**	x	*	

Levels of significance
x = >.05
* = .05
** = .01

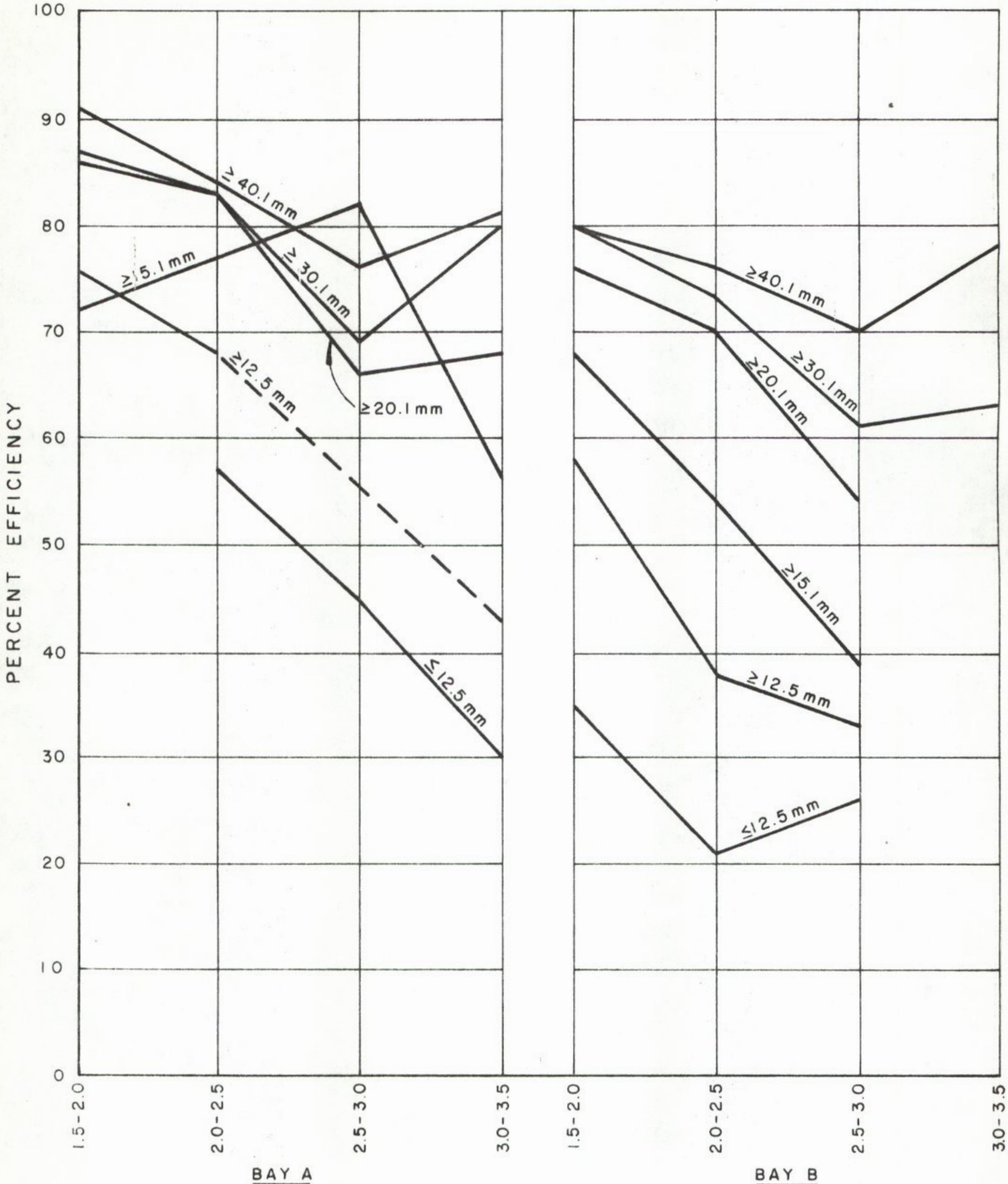


Figure 5

Effect of Approach Velocity on Striped Bass Efficiency in the Primary System (Bypass Ratios Combined)

The paucity of data on velocities greater than 3.0 ft/s for bass less than 30 mm in length precludes a comparison of the higher velocity range between Bays A and B.

Center Wall: The effect of the center wall in Bay A was evaluated by independent tests of each bay and by direct comparison when both bays were tested simultaneously. The latter tests eliminate any potential variance related to time. Most tests were conducted at velocities less than 2.5 ft/s, because of the limited quantity of water being pumped.

At all velocities striped bass clearly were louvered more efficiently in the bay with the center wall (Table 10). At bypass ratios less than 1.48 the differences in efficiency between bays ranged from less than one to almost 50 percentage points. The magnitude of the differences were inversely related to fish length. At bypass ratios greater than 1.48 the range of differences in efficiency between bays diminished.

The results of tests conducted simultaneously in the two bays were similar to those conducted separately. Bass were louvered more efficiently in both bays at approach velocities from 1.5-2.0 ft/s than at 2.0-2.5 ft/s at comparable bypass ratios (Table 11).

Net catches behind the louvers indicate that a greater percentage of bass is lost through the downstream half of the louvers in Bay B than Bay A (Table 12). The proportion of fish lost through upstream louver section is similar for both bays. These observations suggest that the advantage of the center

TABLE 10

Primary Louver Efficiency of Striped Bass in Relation to the Presence or Absence of a Center Wall (Bay A With and Bay B Without)

Approach Velocity (ft/sec)

Fish Length (mm)	BAY	1.5-2.0 Bypass Ratios			2.0-2.5 Bypass Ratios			2.5-3.0 Bypass Ratios			3.0-3.5 Bypass Ratios		
		1.2-1.33	1.34-1.47	1.48-1.60	1.2-1.33	1.34-1.47	1.47-1.60	1.2-1.33	1.34-1.47	1.48-1.60	1.2-1.33	1.34-1.47	1.47-1.60
≤12.5	A				.45	.74		.45					
	B				.16	.25		.21					
					**	**		*					
12.6-15.0	A		.76		.69	.76							
	B		.50		.36	.39							
			*		**	**							
15.1-20.0	A	.77	.67		.78	.83		.82					
	B	.63	.61		.59	.49		.43					
		*	x		**	**		*					
20.1-30.0	A	.88	.85		.81	.87	.81	.70		.62			
	B	.72	.71		.61	.58	.89	.69		.61			
		*	**		**	**	x	x		x			
30.1-40.0	A	.89	.92	.79	.85	.82	.82		.64	.75		.80	.85
	B	.83	.70	.88	.69	.70	.87		.45	.66		.70	.75
		*	**	*	*	**	x		*	x		**	x
40.1-100.0	A	.91	.91	.87	.84	.83			.80	.73		.82	.85
	B	.85	.69	.85	.61	.74			.71	.67		.82	.74
		**	*	x	*	*			*	x		x	x

Levels of Significance x = >.05
* = .05
** = .01

TABLE 11

Primary Louver Efficiency of Striped Bass in Relation to the Presence or Absence of a Center Wall (Bay A With and Bay B Without) Tests Conducted Simultaneously

Approach Velocity (ft./sec.)

Fish Length (mm)	BAY	1.5-2.0 Bypass Ratio 1.2-1.33	1.5-2.0 Bypass Ratio 1.48-1.60	2.0-2.5 Bypass Ratio 1.2-1.33	2.0-2.5 Bypass Ratio 1.34-1.47	2.0-2.5 Bypass Ratio 1.48-1.60
≤12.5	A	.63		.22	.30	.31
	B	.18		.11	.00	.28
12.6-15.0	A	.74		.26	.64	.59
	B	.47		.19	.38	.38
15.1-20.0	A	.80		.49	.56	.63
	B	.60		.40	.49	.59
20.1-30.1	A	.88	.93	.73	.78	.73
	B	.68	.90	.58	.69	.71
30.1-40.0	A	.91	.87	.76	.80	.85
	B	.77	.87	.71	.75	.74
40.1-100.0	A		.86	.77	.86	.86
	B		.89	.81	.80	.87

TABLE 12

Proportion of the Total Striped Bass Lost Through the Upstream and Downstream Halves of the Louver Sections[1/]
(Bay A With and Bay B Without Center Wall)

Proportion of the Total Bass Entering a Bay That Were Lost Through the Upstream Louver Section

Bypass Ratio

Fish Length (mm)	1.2-1.33 Bay A	Bay B	Diff. B-A	1.34-1.47 Bay A	Bay B	Diff. B-A	1.48-1.60 Bay A	Bay B	Diff. B-A
≤12.5	.33	.31	-.02	.16	.20	.04	.24	.20	-.04
12.6-15.0	.20	.26	.06	.14	.17	.03	.15	.14	-.01
15.1-20.0	.18	.16	-.02	.10	.17	.07	.12	.12	-<.005
20.1-30.0	.08	.08	.00	.06	.15	.09	.07	.08	.01
30.1-40.0	.07	.06	-.01	.06	.11	.05	.06	.06	-<.005
40.1-100.0	.07	.07	<.005	.06	.07	.01	.05	.06	.01

Proportion of Total Bass Entering a Bay That Were Lost Through the Downstream Louver Sections

Bypass Ratio

Fish Length (mm)	1.2-1.33 Bay A	Bay B	Diff. B-A	1.34-1.47 Bay A	Bay B	Diff. B-A	1.48-1.60 Bay A	Bay B	Diff. B-A
≤12.5	.33	.50	.17	.16	.64	.48	.28	.33	.05
12.6-15.0	.24	.39	.15	.15	.56	.41	.26	.26	<.005
15.1-20.0	.23	.30	.07	.13	.49	.36	.21	.24	.03
20.1-30.0	.16	.25	.09	.09	.32	.23	.16	.18	.02
30.1-40.0	.11	.17	.06	.09	.30	.21	.11	.15	.04
40.1-100.0	.10	.19	.09	.10	.19	.09	.09	.13	.04

[1/] All velocities combined.

wall in enhancing efficiency occurs along the downstream half of the louvers, possibly near the bypass entrance.

Efficiencies at bypass ratios greater than 1.48 are greater than at lower ratios in Bay B (Tables 9 and 12). Loss of bass through the downstream half of the louvers is greater for Bay B than Bay A at all bypass ratios (Table 12). The greatest disparity in efficiency between bays occurred at bypass ratios between 1.34 and 1.47 (Figure 6). Efficiency in Bay A increased while efficiency in Bay B decreased substantially at bypass ratios between 1.34 and 1.47. The difference in efficiency diminished in both bays as fish length increased.

Diurnal Efficiency: At velocities greater than 2.5 ft/s efficiency was greater during the day in both bays (Figure 7 and Table 13). In Bay B efficiencies were consistently higher at night at approach velocities less than 2.5 ft/s. In Bay A efficiency was inconsistent with respect to daylight or darkness. However, the means of the percentages for each size at velocities less than 2.5 ft/s show that efficiency in Bay A was also slightly better at night than during the day.

Secondary System

Fish Length.--As in the primary, striped bass efficiency was greatly affected by size (Figure 8). For all test conditions, bass less than 10 mm in length were rarely louvered. Fifty percent of the 25 mm bass that entered the secondary in line with the louvers were salvaged. Compared with 85 percent of the same size fish which entered the secondary in

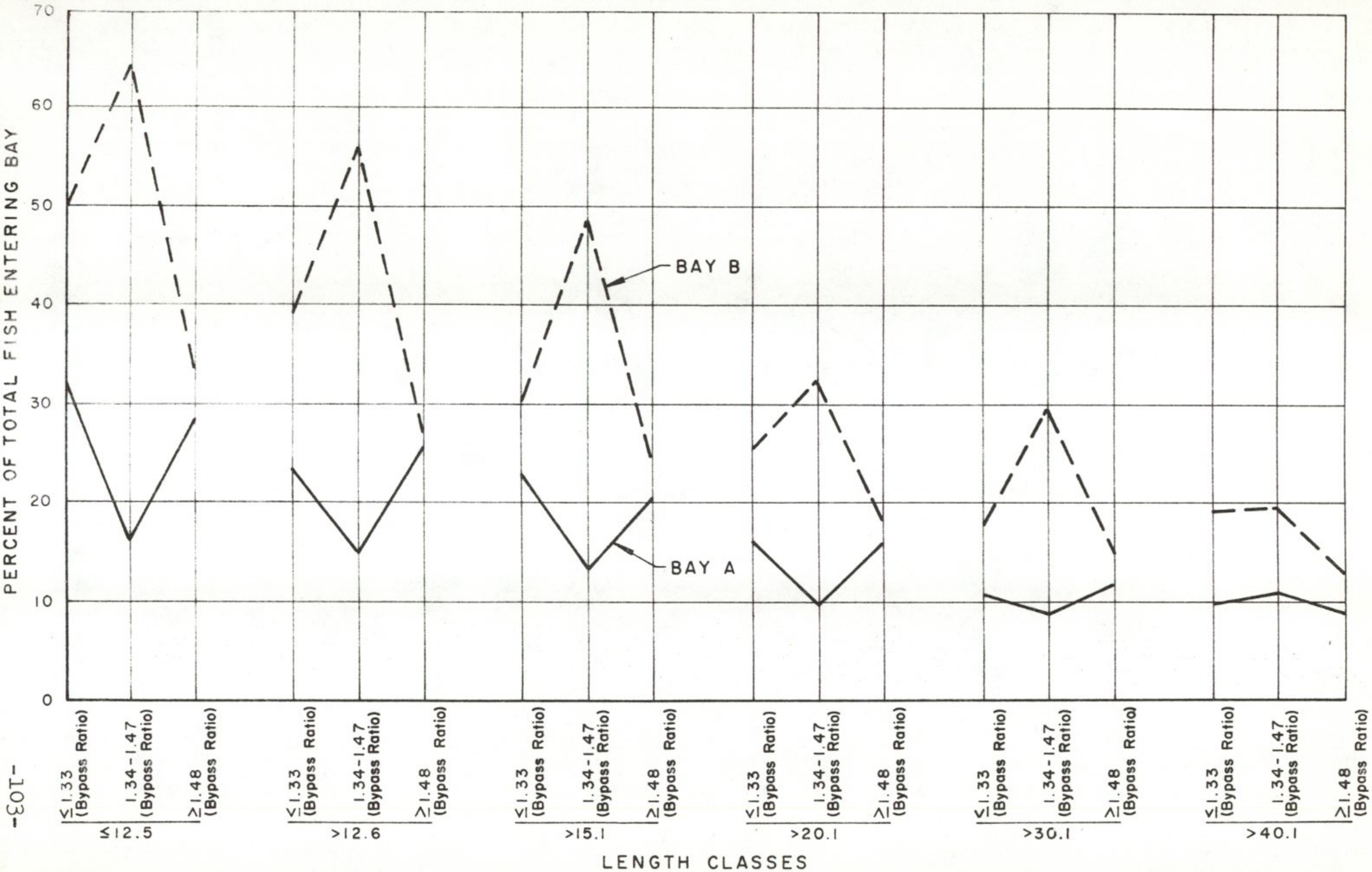


Figure 6

Proportion of striped bass lost through the downstream half of the louvers in the primary bays with (solid line) and without center wall (dashed line).

TABLE 13

Diurnal Efficiency of Striped Bass
in the Primary System

Fish Length (mm)	Time	Bay A (With Center Wall): Approach Velocities (ft./sec.) 1.5-2.0		2.0-2.5			2.5-3.0	Bay B (Without Center Wall): Approach Velocities (ft./sec.) 1.5-2.0		2.0-2.5		2.5-3.0	
		Bypass Ratios						Bypass Ratios					
		≤1.33	1.34-1.47	≤1.33	1.34-1.47	≥1.48	≤1.33	≤1.33	≥1.48	≤1.33	1.34-1.47	≤1.33	≥1.48
≤12.5	Day						.33			.13	.11		.61
	Night						.20			.17	.30		.15
							x			x	x		x
12.6-15.0	Day						.39			.29	.35	.40	.76
	Night						.30			.37	.40	.25	.24
							x			x	x	x	*
15.1-20.0	Day				.83	.58	.56			.33	.36	.49	.72
	Night				.83	.70	.34			.63	.52	.40	.40
					x	x	*			**	*	x	*
20.1-30.0	Day	.82	.88	.89	.82	.62	.69	.72	.79	.46	.57	.60	.74
	Night	.90	.85	.79	.87	.83	.59	.75	.86	.67	.59	.62	.57
		x	x	x	x	**	*	x	x	**	x	x	x
30.1-40.0	Day	.91	.86	.83	.82	.80	.88	.82	.81	.59	.67	.72	
	Night	.88	.93	.89	.81	.82	.73	.83	.92	.75	.72	.63	
		x	x	x	x	x	x	x	x	x	x	x	
40.1-100.0	Day	.91	.87	.76	.83	.88	.82	.80	.79		.72	.71	
	Night	.91	.95	.90	.82	.87	.71	.88	.90		.76	.61	
		x	**	**	x	x	*	**	**		x	x	

Levels of Significance x = >.05
* = .05
** = .01

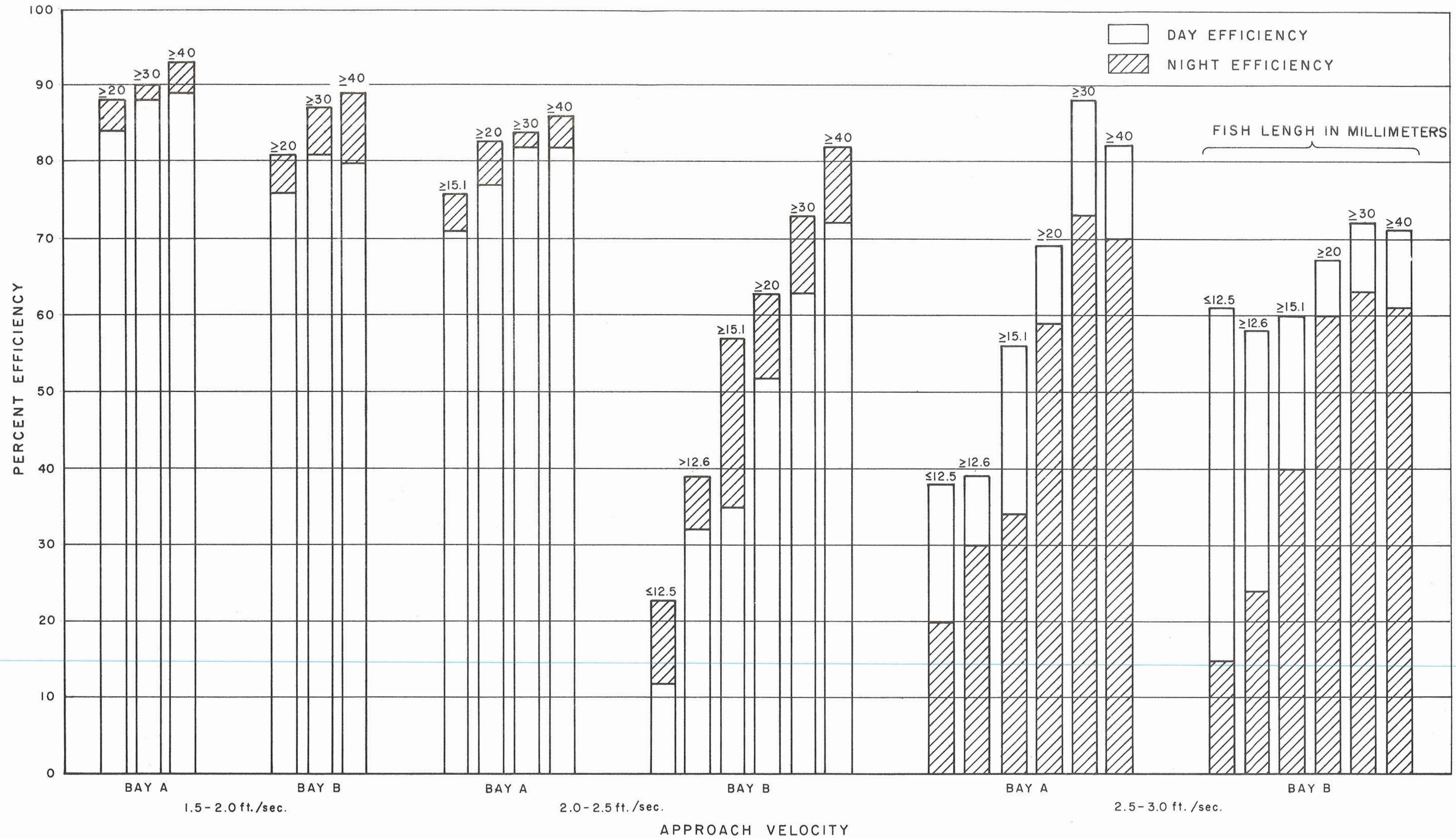


Figure 7

Diurnal Efficiency of Striped Bass
in the Primary System
(Combined Data)

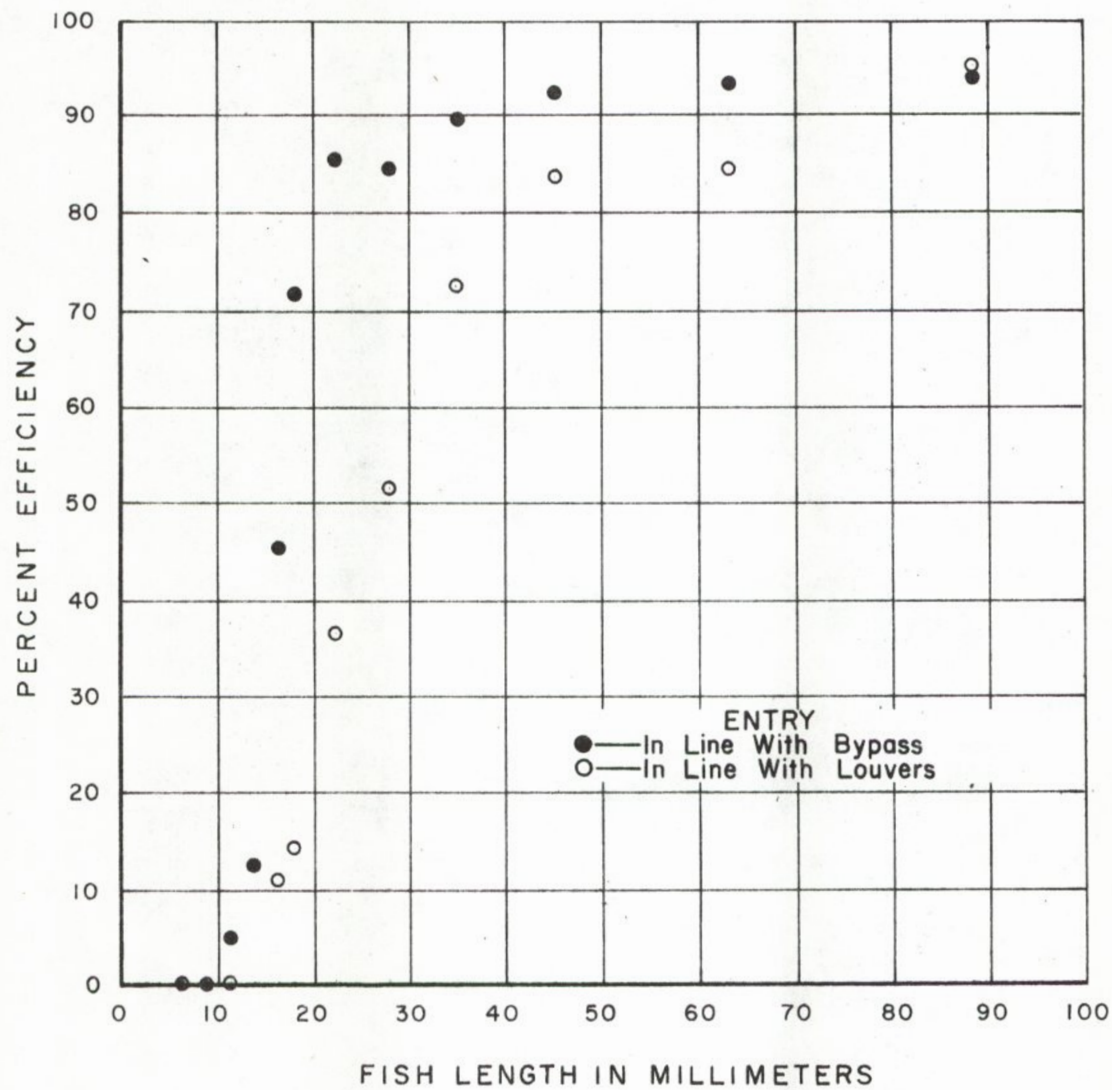


Figure 8

Secondary Efficiency of Striped Bass in Relation to Size

line with the bypass were salvaged. From 85 to over 90 percent of all bass 75 mm were louvered. For analysis of the secondary parameters, bass were combined in length groups of less than 15.0 mm; 15.1-17.5; 17.6-20.0; 20.1-30.0; 30.1-40.0 and 40.0-100.0 mm.

Bypass Ratio: Preliminary examination indicated there was little difference in the efficiency of louvering striped bass collected at screened water ratios of zero and 1.0, so tests at these screened water ratios were combined. Tests at screened water ratios of 1.4 were significantly different and were therefore analyzed separately.

Striped bass louvering efficiency varied greatly among bypass ratios. However, no consistent relationship was evident (Tables 14 and 15). Hence, tests from the three bypass ratios were combined for analysis of the other test parameters.

Approach Velocity: Striped bass louvering efficiency was inversely related to approach velocity up to 3.0 ft/s (Table 16 and Figure 9). The greatest reduction in efficiency occurred at velocities between 2.5 and 3.0 ft/s. For fish entering the secondary in line with the louvers, efficiency was slightly better at 3.0-3.5 ft/s than at the preceding velocity range. The relationship between efficiency and approach velocity did not appear to be affected by the screened water ratio.

Screened Water Ratio: Striped bass louvering efficiency was related to screened water ratio (Table 17). The disparity in efficiency was generally greater between screened

TABLE 14. Louver Efficiency of Striped Bass in Relation to the Bypass Ratio for Fish Entering the Secondary Channel in Line with the Bypass.

Screened Water Ratio ≤1.00

Bypass Ratio	Fish Length in mm: 15.1-17.5, Approach Velocity (ft./sec.)		17.6-20.0, Approach Velocity (ft./sec.)			20.1-30.0, Approach Velocity (ft./sec.)			
	2.5-3.0	3.0-3.5	1.5-2.0	2.0-2.5	3.0-3.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5
≤1.33	.09		.89	.31	.39	.94	.91	.75	.64
1.34 1.47		.08		.61	.49			.78	.77
≥1.48	.20	.02	.89	.55	.36	.84	.93	.86	
Significance	x	x	x	x	x	x	x	x	x

Bypass Ratio	Fish Length in mm: 30.1-40.0, Approach Velocity (ft./sec.)				40.1-100.0, Approach Velocity (ft./sec.)			
	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5
≤1.33	.95	.87		.86	.97	.96		.89
1.34 1.47	.95		.88	.86	.97		.94	.93
≥1.48	.94	.94	.72		.97	.96	.86	
Significance	x	x	x	x	x	x	x	x

Screened Water Ratio 1.4

Bypass Ratio	Fish Length in mm: 20.1-30.0, Approach Velocity (ft./sec.)		30.1-40.0, Approach Velocity (ft./sec.)		40.1-100.0, Approach Velocity (ft./sec.)	
	1.5-2.0	2.0-2.5	1.5-2.0	2.0-2.5	1.5-2.0	2.0-2.5
≤1.33	.86	.52	.92	.83	.95	.90
1.34 1.47	.63		.77		.96	
≥1.48	.86	.89	.90	.95	.95	.96
Significance	x	*	x	x	x	*

Levels of significance x >.05
* .05
** .01

TABLE 15. Louver Efficiency of Striped Bass in Relation to the Bypass Ratio for Fish Entering the Secondary Channel in Line With the Louvers.

Screened Water Ratio ≤ 1.0

Bypass Ratio	Fish Length in mm: 15.1-17.5, Approach Velocity (ft./sec.)	17.6-20.0, Approach Velocity (ft./sec.)			20.1-30.0, Approach Velocity (ft./sec.)			
	1.5-2.0	1.5-2.0	2.0-2.5	3.0-3.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5
≤1.33	.06	.57	.22	.12	.85	.62	.38	.51
1.34 1.47		.71	.26		.79	.50		
≥1.48	.18	.31		.07	.74	.74	.31	.45
Significance	x	x	x	x	x	x	x	x

Bypass Ratio	Fish Length in mm: 30.1-40.0, Approach Velocity (ft./sec.)				40.0-100.0, Approach Velocity (ft./sec.)			
	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5
≤1.33	.87	.86	.69	.77	.94	.93	.78	.88
1.34 1.47	.88	.79	.49	.60	.94	.94	.90	.88
≥1.48	.93	.89	.82	.67	.95	.96	.86	.86
Significance	x	x	x	x	x	x	x	x

Screened Water Ratio 1.4

Bypass Ratio	Fish Length in mm: 20.1-30.0, Approach Velocity (ft./sec.)	30.1-40.0, Approach Velocity (ft./sec.)			40.0-100.0, Approach Velocity (ft./sec.)		
	2.0-2.5	1.5-2.0	2.0-2.5	2.5-3.0	1.5-2.0	2.0-2.5	2.5-3.0
≤1.33	.58	.76			.93		
1.34 1.47	.46	.45	.35	.52	.69	.74	.85
≥1.48	.40	.47	.78	.46	.94	.93	.78
Significance	x	x	x	x	x	x	x

Levels of significance x > .05
* .05
** .01

TABLE 16

Secondary Louver Efficiency of Striped Bass in Relation at Approach Velocity and Screened Water Ratio

SCREENED WATER RATIO	Fish Length mm	Fish Entering in Line with the Bypass — Approach Velocities (ft./sec.) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance	Fish Entering in Line with the Louvers — Approach Velocities (ft./sec.) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance
1.0	≤15.0	.19	.09	.03	.01	*	.06			.03	x
	15.1-17.5	.31	.14	.17	.05	*	.19	.03	.00	.01	x
	17.6-20.0	.81	.75	.45	.46	*	.56	.25	.05	.08	**
	20.1-30.0	.91	.93	.83	.74	**	.77	.58	.37	.48	**
	30.1-40.0	.95	.94	.81	.85	*	.89	.85	.77	.72	**
	40.1-100.0	.97	.96	.91	.92	**	.94	.94	.86	.87	**
1.4	≤15.0										
	15.1-17.5										
	17.6-20.0	.42		.23		x	.30	.14	.02	.49	**
	20.1-30.0	.65	.79	.62	.41	*	.45	.35	.17	.41	**
	30.1-40.0	.82	.92	.80	.57	*	.52	.55	.47	.53	x
	40.1-100.0	.95	.94	.87	.78	**	.87	.91	.78	.69	**

Levels of Significance x = >.05
* = .05
** = .01

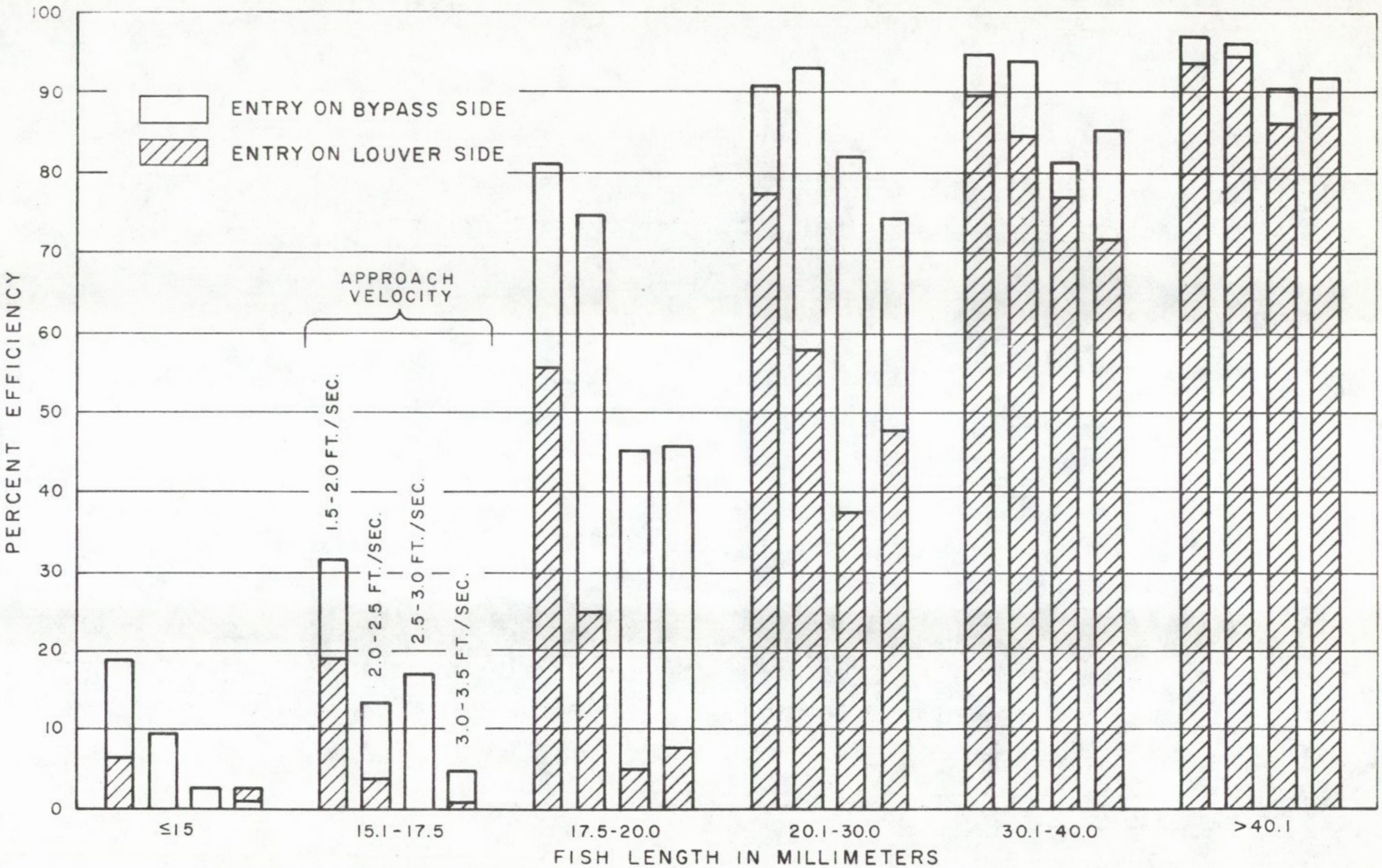


Figure 9

Efficiency of the Secondary Louver System for Striped Bass in Relation to Approach Velocity

TABLE 17

Secondary Louver Efficiency of Striped Bass in Relation to Screened Water Ratio and Entry Into the Secondary Channel in Line With the Bypass (A) and in Line With the Louvers (B)

Fish Length (mm)		Approach Velocity (ft./Sec.) 1.5-2.0 Screened Water Ratio 0.0	1.0	1.4	Sign.	2.0-2.5 Screened Water Ratio 0.0	1.0	1.4	Sign.	2.5-3.0 Screened Water Ratio 0.0	1.0	1.4	Sign.	3.0-3.5 Screened Water Ratio 0.0	1.0	1.4	Sign.
15.1-	A									.23	.15		x	.06	.04		x
17.5	B														.01		
															x		
17.6-	A	.76	.90	.42	**					.66	.32	.23	**	.47	.45		x
20.0	B		.61	.30	*		.22	.14	x		.06	.02	x	.16	.07	.49	**
			**	**							**	**		**	**		
20.1-	A	.92	.88	.65	**	.92	.95	.79	x	.92	.77	.62	**	.83	.66	.41	**
30.0	B	.85	.72	.45	**	.71	.56	.35	**	.66	.27	.17	**	.57	.45	.41	*
		**	**	**		**	**	**	**	**	**	**		**	*	x	
30.1-	A	.95	.94	.82	**	.93	.96	.92	x	.91	.74	.80	x	.89	.83	.54	**
40.0	B	.94	.86	.52	**	.87	.81	.55	*	.81	.71	.47	*	.71	.72	.53	*
		x	*	**		x	*	*		*	x	*		**	x	x	
40.1-	A	.98	.97	.95	x	.96	.98	.94	x	.95	.87	.87	*	.93	.91	.78	**
100.0	B	.96	.92	.87	x	.94	.94	.91	x	.85	.88	.78	**	.86	.88	.69	**
		x	x	x		x	x	x		x	x	x		**	x	x	

Levels of Significance x = > .05
* = .05
** = .01

water ratios of 1.0 and 1.4 than zero and 1.0. However, differences in efficiency were also quite large between screened water ratios of zero and 1.0 at approach velocities greater than 2.5 ft/s. Differences in efficiency among all screened water ratios were consistently greater when bass entered the secondary in line with the louvers as compared to entry in line with the bypass (Figure 10). The disparity in louver efficiency among screened water ratios was greater among smaller than larger striped bass.

Entry into Secondary: With one exception striped bass efficiency was always higher when they entered the secondary in line with the bypass than in line with the louvers (Table 17). Differences were generally statistically significant, particularly for bass less than 30 mm long.

At approach velocities less than 2.5 ft/s, the disparity in percentage efficiency for pass entering the secondary on either side was directly related to the screened water ratio. When fish entered the secondary simultaneously from both bypasses, efficiency was generally intermediate.

Diurnal Efficiency: Only a limited number of observations were made in the secondary on the diurnal difference in striped bass efficiency. Upon entering the secondary in line with the bypass, bass were louvered more efficiently during the day at velocities from 1.5-3.0 ft/s (Table 18). When entering the secondary in line with the louvers, bass also were louvered more efficiently during the day at approach velocities less than

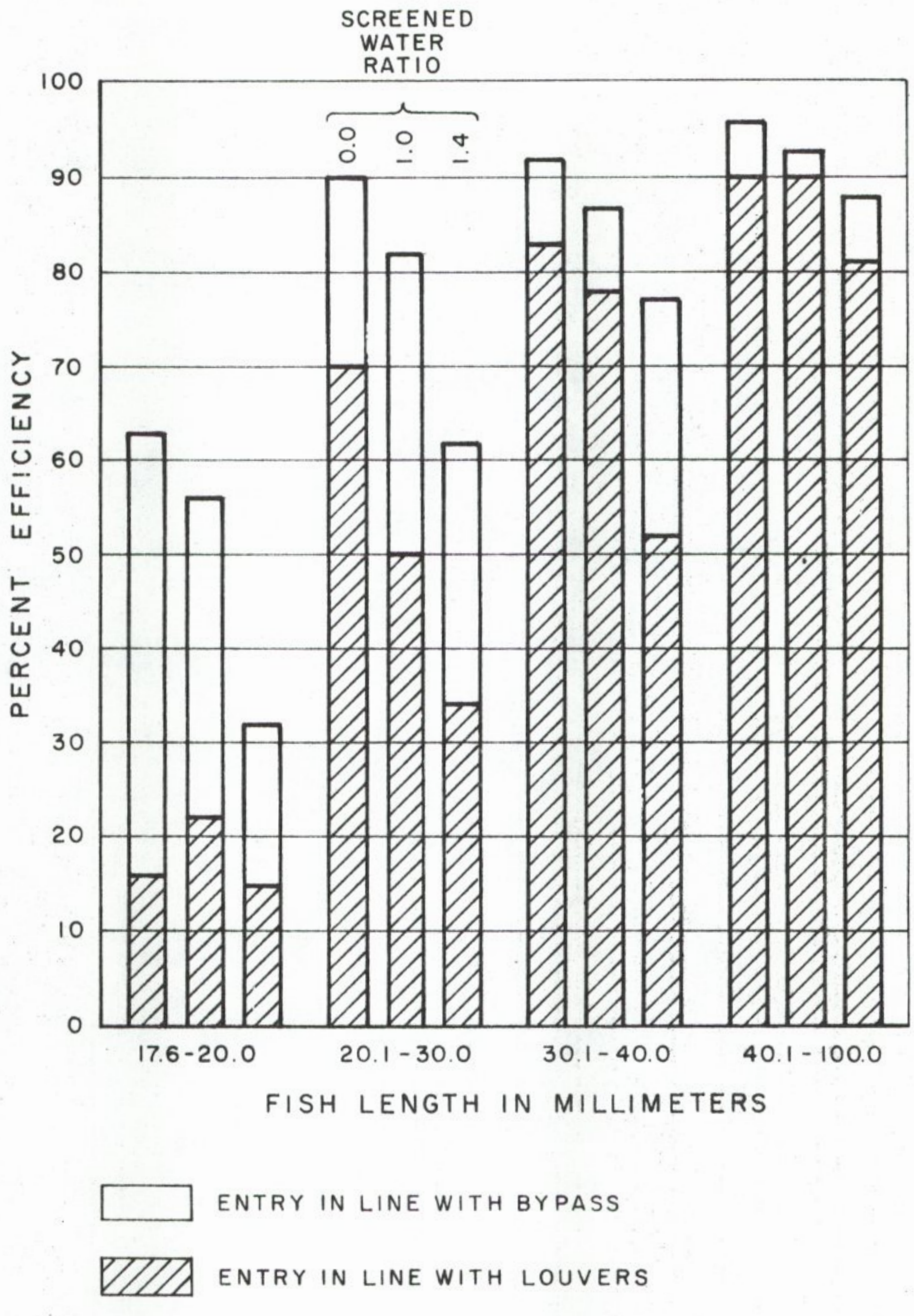


Figure 10

Secondary Louver Efficiency of Striped Bass in Relation to Entry and Screened Water Ratio

TABLE 18

Diurnal Efficiency of Striped Bass
in the Secondary Channel

Entry in Line With Bypass

Fish Length in mm		Approach Velocity (ft./sec.) 1.5-2.0		2.0-2.5
		Screened Water Ratio		
		≤1.0	1.4	≤1.0
20.1	Day	.94	.89	.90
30.0	Night	.91	.62	.87
		x	**	x
30.1	Day	.94	.94	.83
40.0	Night	.95	.76	.73
		x	**	x
40.1	Day	.97	.97	.94
100.0	Night	.96	.91	.87
		x	*	x

Entry in Line With Louvers

Fish Length in mm		Approach Velocity (ft./sec.) 1.5-2.0		2.5-3.0	3.0-3.5
		Screened Water Ratio			
		≤1.0	1.4	≤1.0	≤1.0
20.1	Day	.92	.85	.31	.26
30.0	Night	.81	.44	.26	.15
		x	**	x	x
30.1	Day	.94	.73	.45	.74
40.0	Night	.89	.52	.77	.73
		x	*	**	x
40.1	Day	.96	.88	.69	.83
100.0	Night	.93	.87	.89	.90
		x	x	**	**

Levels of Significance x = >.05
* = .05
** = .01

2.0 ft/s. At velocities greater than 2.5 ft/s results were inconsistent although night efficiencies were statistically superior in three of six cases. Efficiency was highest at the lowest screened water ratios. Daytime efficiency was substantially better than night efficiency, irrespective of entry into the secondary, when the screened water ratio was at 1.4.

Combined Efficiency

Combined efficiency was determined by multiplying the primary efficiency by the secondary efficiency using all test parameters. Combined efficiency is much greater for bass which enter the bay with the center wall and subsequently enter the secondary in line with the bypass as compared to those from Bay B which enter the secondary in line with the louvers. In Bay A 70 percent of the 25 mm bass were successful, while in Bay B the comparable efficiency was 30 percent (Figure 11). Maximum combined efficiency was approximately 80 percent. Fewer than one percent of the bass less than 12.5 mm in length reached the holding tanks.

Discussion

Size was the most important factor affecting louver efficiency of striped bass, with the difference ranging from zero to nearly 90 percent efficiency for bass less than 7.5 mm and greater than 75 mm, respectively. Differences in efficiency among size groups may be related to swimming ability, vertical and lateral distribution and/or avoidance of the louvers or bypass.

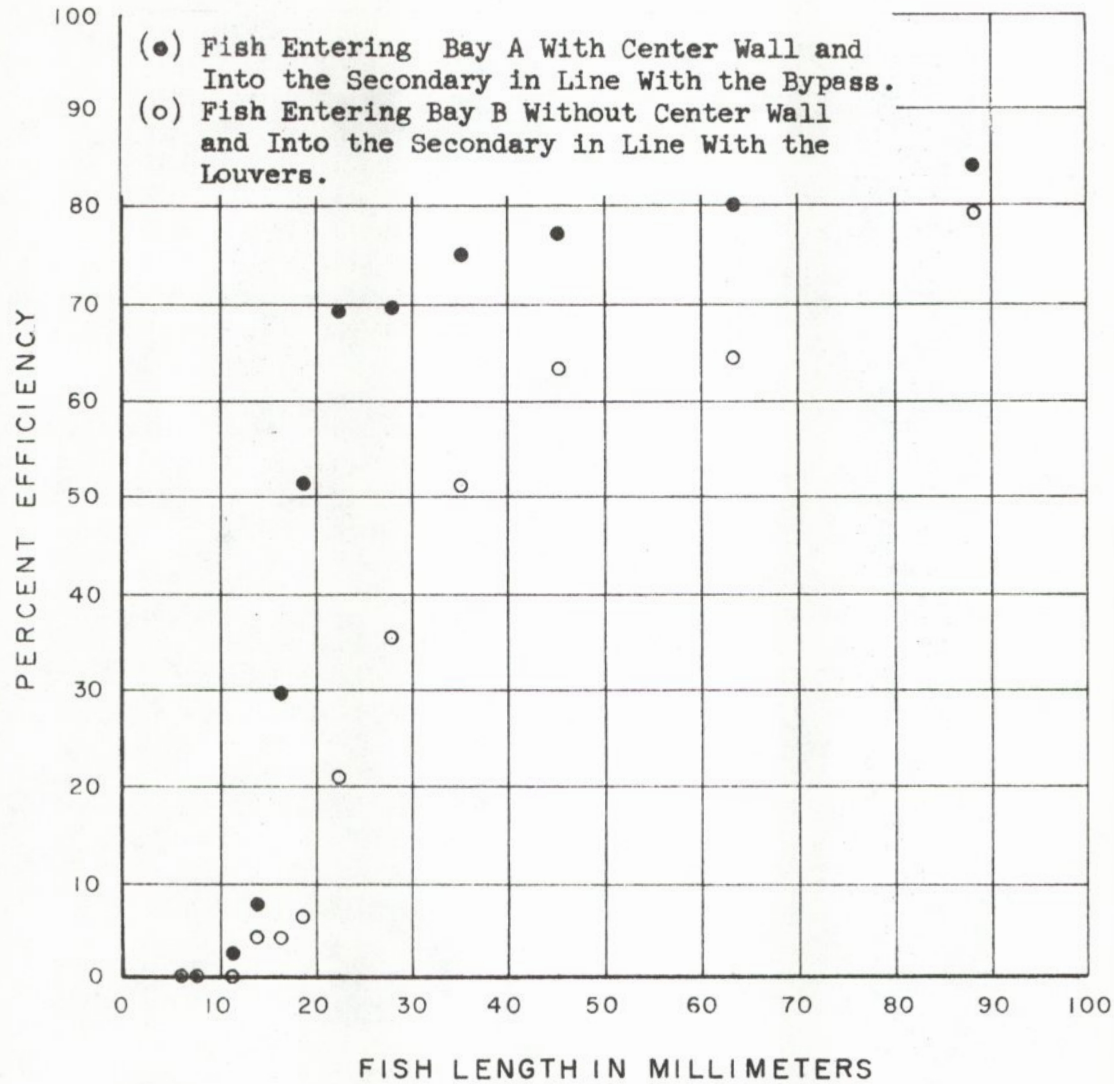


Figure 11

Combined Primary and
Secondary Efficiency of Striped Bass
in Relation to Size

The estimates of secondary louver efficiency for fish less than 20 to 25 mm are probably biased downwards. This judgement is based on: (1) the higher efficiencies measured for this size fish in the primary, where conditions are intuitively less favorable; and (2) a review of mesh size selectivity for striped bass. The latter makes it appear possible that some small striped bass which are louvered successfully are lost through the cylinder screen in the holding tanks.

The variation in efficiency due to size was greater in these tests than was observed by Bates, et al, in the secondary channel of the Tracy Fish Collecting Facility (Bates, Logan, and Pesonen, 1960). There, secondary louvers in both tandem and single array salvaged bass less than 25 mm and greater than 25 mm in length with nearly equal efficiency, particularly at velocities less than 2.0 ft/s. Louver efficiency for both size groups of bass was approximately 90 percent at the Tracy Facility.

In the primary system of the Tracy Facility, which is a single line of louvers, the efficiency of louvering bass 25 to 300 mm in length was related to size although the percentage louvered was still greater than fish of comparable size at the State facility (Hallock, et al).

Tests by Hallock, et al (op.cit.), with plankton nets resulted in efficiencies of less than two percent for fish from 9 to 19 mm, which is substantially lower than results observed at the Delta Fish Protection Facility for similar sized fish. The conflicing results among the various test programs suggest that the differences are due to inadequate discrimination among fish less than 25 mm in length. This appears particularly reasonable in view of the critical relationship between size and efficiency for fish less than 25 mm.

Louver efficiency was nearly comparable in Bay A and Bay B at bypass ratios greater than 1.48. At bypass ratios less than 1.48 there was an increase in efficiency in Bay A and a reduction in efficiency in bay B, which occurred along the downstream half of the louvers. The percentage of bass that passed through the upstream section of louvers was similar in both bays, and among bypass ratios, indicating that the center wall or bypass ratio does not greatly influence the fish in the upstream sections of the bays.

Although it was not possible to observe bass entering the bypass, it is reasonable to infer that bass in Bay A orient to the center wall and are guided by it into the bypass.

Results of Department of Water Resources tests (1964), indicate that high bypass ratios in a channel with a guide wall (comparable to a center wall) do not enhance louver efficiency.

Louver efficiency in relation to approach velocity clearly indicates that the highest efficiencies are achieved at the lowest velocities. In a number of instances louver efficiency was higher at velocities greater than 3.0 ft/s than at velocities between 2.5 and 3.0 ft/s but lower than efficiencies at velocities less than 2.5 ft/s.

In the secondary of the Tracy Facility there was a slight decrease in efficiency of louvering bass 8 to 20 mm in length and little change in efficiency among bass 37 to 100 mm in length with increasing velocities from 1.0 to 3.25 ft/s (Bates, et al, 1960). In a later study, the Department of Water Resources (1964) found louver efficiency to be inversely related to approach velocities from 1.0 to 3.75 ft/s. In the primary system of the Tracy Facility, results among size groups were variable, but efficiency generally, was inversely related to approach velocity (Hallock, et al, 1968).

The combination of the screened water ratio and side on which fish entered the secondary system of the State facility effectively influenced louver efficiency in the secondary channel by 50 percent or more. Fish entering the secondary on the side of the bypass probably pass through much of the secondary channel without being exposed to the louvers and therefore essentially move directly into the bypass. Those entering the opposite side must traverse up to the entire length of louvers before entering the bypass.

When the screened water velocity is greater than the secondary channel approach velocity, fish may be swept away from the bypass entrance and towards the louvers. It is reasonable to assume that fish nearest the louvers would be more susceptible to such losses than fish near the wall. This would also help explain the disparity in efficiency between fish entering the secondary in line with the louvers and those entering the secondary in line with the bypass.

Results of tests conducted during the day and night showed that efficiency was consistently better at night in Bay B at velocities less than 2.5 ft/s. This was not quite so apparent in Bay A, although when the data for similar parameters was combined, night efficiencies were better. At velocities greater than 2.5 ft/s this pattern was reversed and in all but one case daytime efficiencies were clearly superior.

In the secondary, efficiency was consistently better during the day. Although the data are limited, a substantial reduction in efficiency occurred at night at screened water ratios of 1.4 as comparted to 1.0 (Table 18).

The inconsistency and change in efficiency with respect to daylight and darkness precludes an analysis of the visual response involved.

Based on fewer tests conducted in the secondary of the Tracy Facility, Bates, et al (op.cit.), found efficiency to be slightly better at night. This is consistent with our observations in the primary bays but at variance with our results in the secondary. Hallock, et al (1968), reported slightly higher efficiencies during the daylight hours in the Tracy primary system. In view of the small number of night tests he regarded his results as inconclusive.

CHAPTER IX

WHITE CATFISH

Results

The louver evaluation tests included more than 87,000 white catfish up to five inches in length. A length frequency and cumulative frequency distribution of the white catfish involved in those tests is presented in Figures 12 and 13, respectively. Since the size distribution was similar for both primary bays (Figure 12), they were combined in Figure 13.

Primary System

Fish Length: Louver efficiency of white catfish in the primaries was related directly to their length (Figure 14). Efficiencies for all conditions and both primary bays combined ranged from 4 percent for 10-12.5 mm fish to 68 percent for 75-100 mm fish. Catfish were combined into the following length groups for analysis of the primary test parameters: 10.1-17.5, 17.6-25.0, 25.1-30.0, 30.1-40.0, 40.1-75.0, and 75.1-100.0 mm.

Bypass Ratio: In both primary bays, catfish efficiency was generally lowest at the highest bypass ratios. Of ten cases in which bypass ratio was statistically significant, nine showed the lowest efficiency to occur at the highest bypass ratio. Bypass ratios between 1.34 and 1.47 were somewhat better than those $\leq$ 1.33; however, the disparity among efficiencies at bypass ratios less than 1.48 was generally small. Because of the overall variability and lack of consistency among bypass

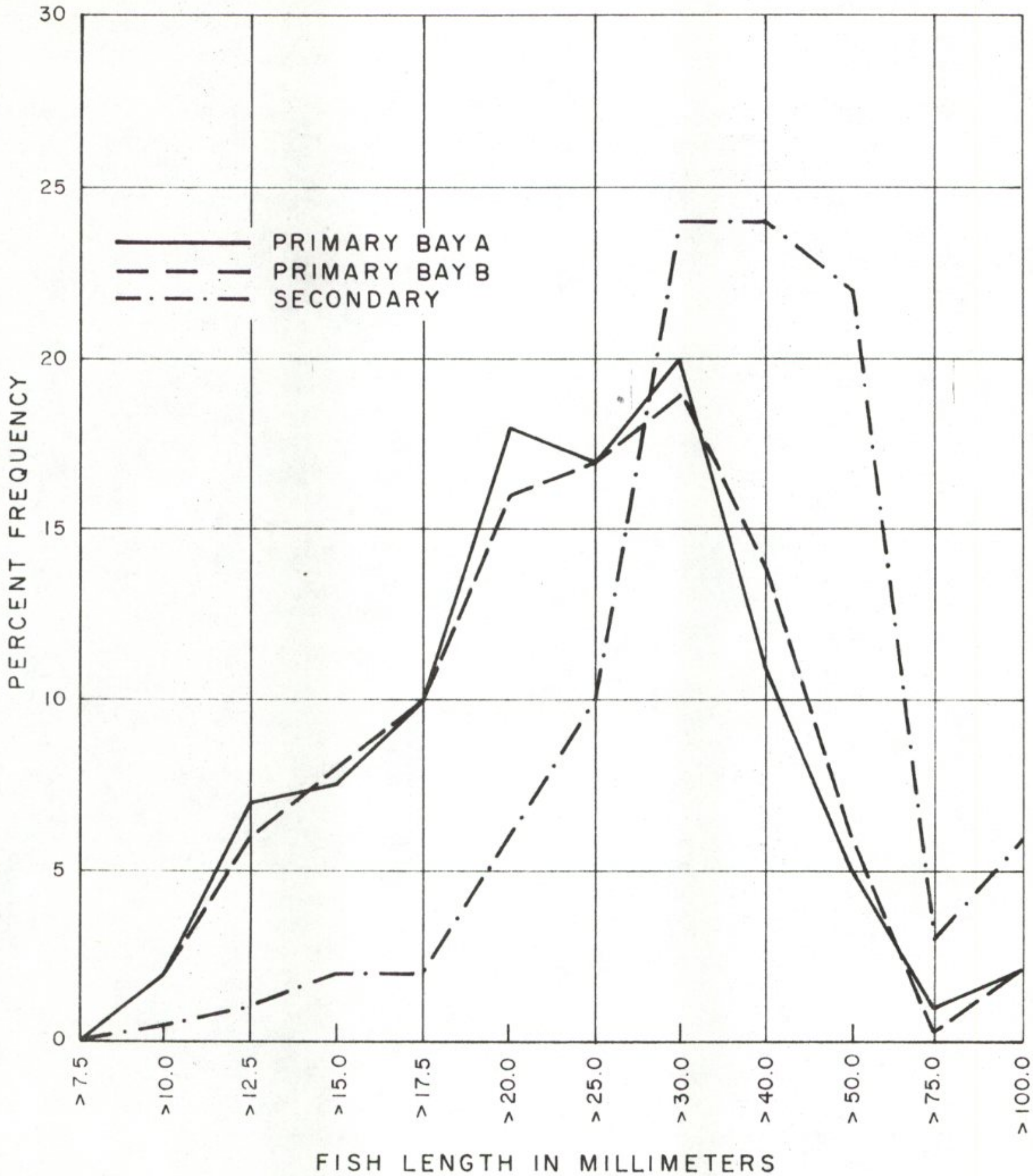


Figure 12

Length Frequency Distribution
of
White Catfish Tested

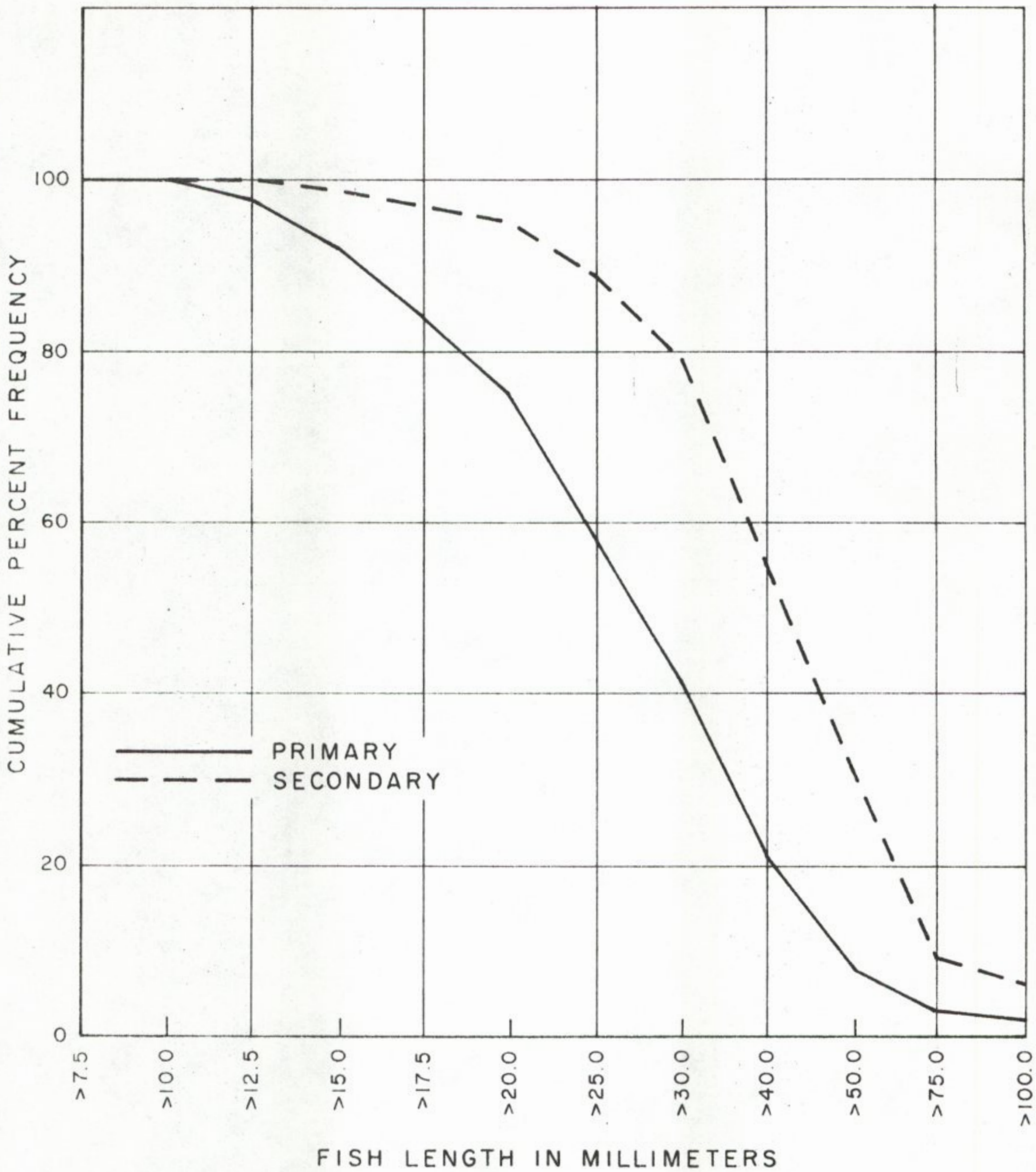


Figure 13

**Cumulative Percent Frequency
Showing Percentage of White Catfish Larger
Than Any Selected Length Class**

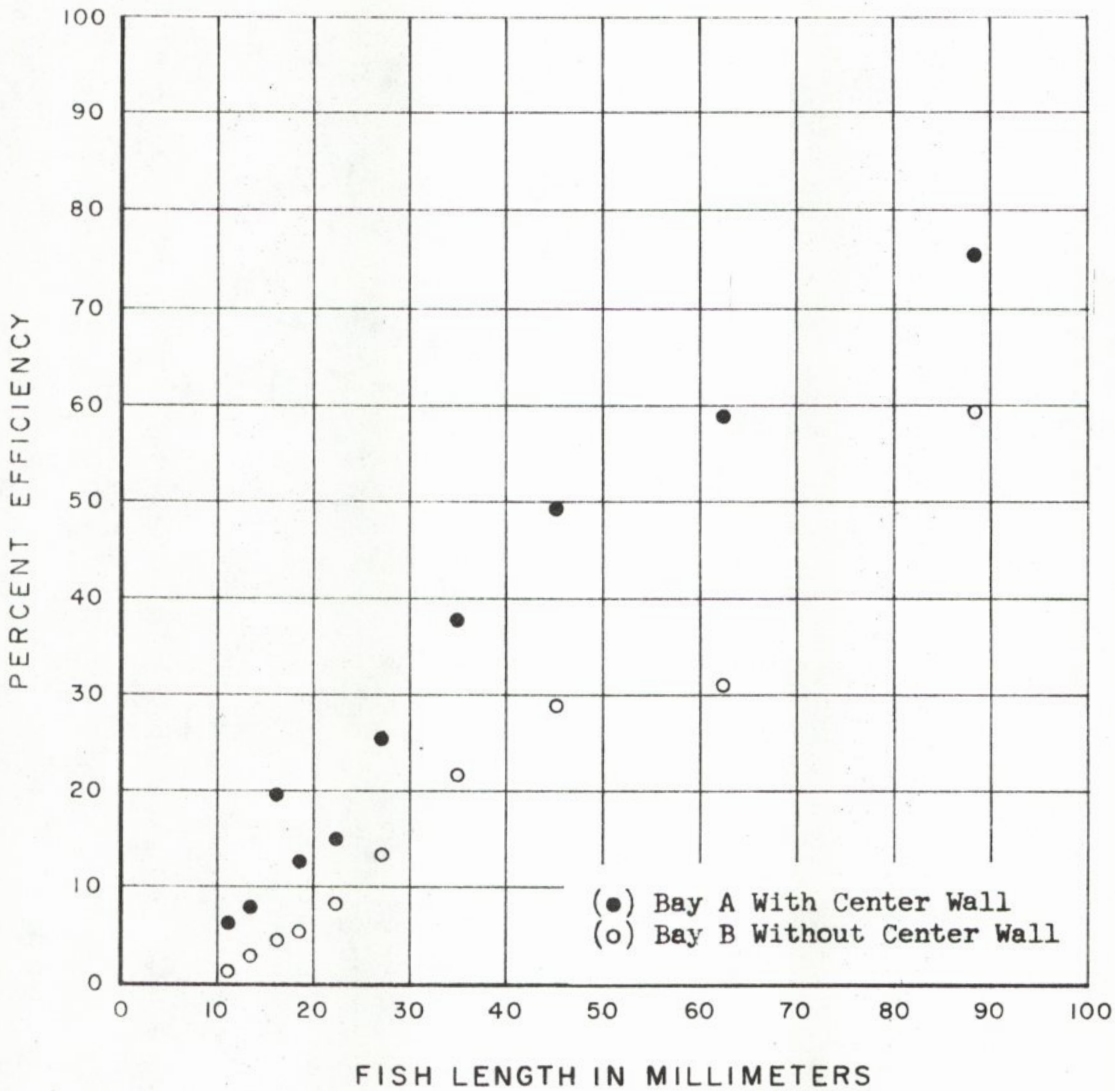


Figure 14

Primary Louver Efficiency of
White Catfish in Relation to Size

ratios it was decided to combine the data for analysis of the remaining primary test parameters.

Approach Velocity: In Bay A, louver efficiency was generally highest at approach velocities less than 2.0 ft/s (Table 19). At approach velocities greater than 2.0 ft/s, efficiency varied, but was lowest in most instances at 2.0-2.5 ft/s (Figure 15).

In Bay B, the efficiency of louvering catfish less than 30 mm in length was highest at velocities greater than 3.0 ft/s and similar among approach velocities less than 3.0 ft/s (Table 20 and Figure 15). The efficiency of catfish 30-75 mm in length was greatest at velocities less than 2.0 ft/s.

Center Wall: Louver efficiency of white catfish was always higher in Bay A than Bay B at approach velocities less than 3.0 ft/s (Figure 14 and Table 21). At higher velocities, catfish less than 25 and greater than 75 mm were louvered more efficiently in Bay B. Simultaneous tests conducted in both bays at velocities less than 2.5 ft/s also indicated higher efficiencies in Bay A, although differences in efficiency were small at velocities less than 2.0 ft/s.

Catches in the nets behind the primary louvers indicated that the percentage of catfish which went through both the upstream and downstream sections of the louvers was greater in Bay B than Bay A (Table 22). However, at approach velocities greater than 3.0 ft/s, a greater percentage of small fish generally passed through the upstream portion of Bay A than Bay B.

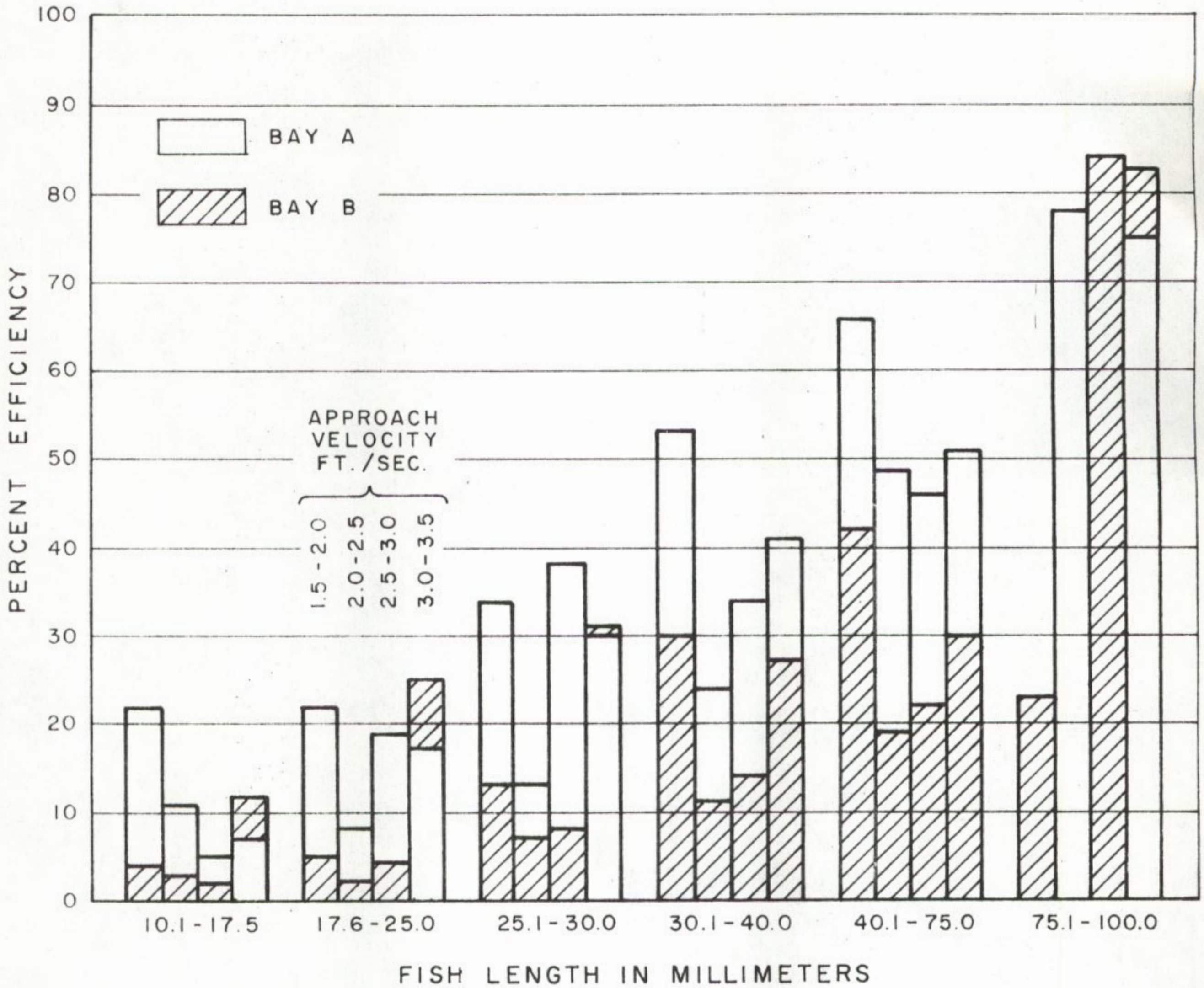


Figure 15

Louver Efficiency of White Catfish in Relation to Approach Velocity in the Primary System

TABLE 19

Louver Efficiency of White Catfish in Relation to Approach Velocity and Bypass Ratio in the Primary Bay With Center Wall (Bay A)

Fish Length in mm 10.1-17.5

Bypass Ratio	Approach Velocity (ft/sec) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance
≤ 1.33	.22	.14		.05	
1.34-1.47	.17	.10	.08	.08	
≥ 1.48	.27	.12	.05	.11	
Significance	x	x	x	x	
All Bypass Ratios	.22	.11	.05	.07	**

Fish Length in mm 17.6-25.0

Bypass Ratio	Approach Velocity (ft/sec) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance
≤ 1.33	.25	.23		.18	
1.34-1.47	.18	.20	.21	.15	
≥ 1.48	.25	.05	.18	.21	
Significance	x	*	x	x	
All Bypass Ratios	.22	.08	.19	.17	**

Fish Length in mm 25.1-30.0

Bypass Ratio	Approach Velocity (ft/sec) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance
≤ 1.33	.53	.32		.31	
1.34-1.47	.32	.31	.28	.29	
≥ 1.48	.30	.09	.42	.34	
Significance	x	**	x	x	
All Bypass Ratios	.34	.13	.38	.30	**

Fish Length in mm 30.1-40.0

Bypass Ratio	Approach Velocity (ft/sec) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance
≤ 1.33	.67	.30		.38	
1.34-1.47	.68	.42	.45	.40	
≥ 1.48	.39	.19	.28	.41	
Significance	*	x	*	x	
All Bypass Ratios	.53	.24	.34	.41	**

Fish Length in mm 40.1-75.0

Bypass Ratio	Approach Velocity (ft/sec) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance
≤ 1.33	.73	.38		.52	
1.34-1.47	.74	.64	.56	.51	
≥ 1.48	.59	.48	.30	.43	
Significance	x	x	*	x	
All Bypass Ratios	.66	.49	.46	.51	*

Fish Length in mm > 75.0

Bypass Ratio	Approach Velocity (ft/sec) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance
≤ 1.33		.84		.68	
1.34-1.47				.89	
≥ 1.48		.72			
Significance		x		*	
All Bypass Ratios		.78		.75	x

Levels of significance:
x => .05
* = .05
** = .01

TABLE 20

Louver Efficiency of White Catfish in Relation to Approach Velocity and Bypass Ratio in the Primary Bay Without a Center Wall (Bay B)

Fish Length in mm 10.1-17.5

Bypass Ratio	Approach Velocity (ft/sec) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance
≤1.33	.08	.13	.01		
1.34-1.47	.02	.01	.03	.19	
≥1.48	.03	.02	.03	.09	
Significance	x	x	x	x	
All Bypass Ratios	.04	.03	.02	.12	**

Fish Length in mm 17.6-25.0

Bypass Ratio	Approach Velocity (ft/sec) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance
≤1.33	.01	.03	.04		
1.34-1.47	.04	.01	.04	.29	
≥1.48	.06	.04	.07	.24	
Significance	x	x	x	x	
All Bypass Ratios	.05	.02	.04	.27	**

Fish Length in mm 25.1-30.0

Bypass Ratio	Approach Velocity (ft/sec) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance
≤1.33	.03		.08		
1.34-1.47	.06	.10	.11	.33	
≥1.48	.16	.02	.07	.26	
Significance	*	*	x	x	
All Bypass Ratios	.13	.07	.08	.31	**

Fish Length in mm 30.1-40.0

Bypass Ratio	Approach Velocity (ft/sec) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance
≤1.33	.08		.15		
1.34-1.47	.39	.14	.09	.30	
≥1.48	.29	.05		.20	
Significance	x	x	x	*	
All Bypass Ratios	.30	.11	.14	.27	**

Fish Length in mm 40.1-75.0

Bypass Ratio	Approach Velocity (ft/sec) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance
≤1.33			.23		
1.34-1.47	.71	.23	.14	.28	
≥1.48	.36	.11		.35	
Significance	**	x	x	x	
All Bypass Ratios	.42	.19	.22	.30	**

Fish Length in mm >75.0

Bypass Ratio	Approach Velocity (ft/sec) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance
≤1.33			.84		
1.34-1.47	.36		.74	.75	
≥1.48	.18			.95	
Significance	x		x	x	
All Bypass Ratios	.23		.84	.83	**

Levels of significance
x => .05
* = .05
** = .01

TABLE 21

Primary Louver Efficiency of White Catfish in Relation to
the Presence or Absence of a Center Wall
(Bay A With and Bay B Without)

Fish Length (mm)	BAY	Tests Conducted Separately, Approach Velocity (ft./sec.)				Test Conducted Simultaneously, Approach Velocity (ft./sec.)	
		1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	1.5-2.0	2.0-2.5
10.1-	A	.22	.11	.05	.07	.10	.02
17.5	B	.04	.03	.02	.12	.00	.02
		**	**	*	x	x	x
17.6-	A	.22	.08	.19	.17	.26	.11
25.0	B	.05	.02	.04	.25	.26	.07
		**	x	**	*	x	x
25.1-	A	.34	.13	.38	.30	.32	.17
30.0	B	.13	.07	.08	.31	.25	.09
		**	x	**	x	x	x
30.1	A	.53	.24	.34	.41	.40	.30
40.0	B	.30	.11	.14	.27	.39	.16
		**	x	**	**	x	*
40.1	A	.66	.49	.46	.51	.62	.53
75.0	B	.42	.19	.22	.30	.67	.15
		**	**	**	**	x	**
>75.0	A				.75		.87
	B				.83		.74
					x		x

Levels of Significance x = >.05
* = .05
** = .01

TABLE 22

Proportion of the Total White Catfish Entering the Primary Bays That Were Lost Through the Upstream and Downstream Halves of Louver Sections (Bay A With and Bay B Without Center Wall)[1]

Proportion of the Total White Catfish Entering Bay That Were Lost Through the Upstream Louver Section

	Approach Velocity (ft./sec.) 1.5-2.0			2.0-2.5			2.5-3.0			3.0-3.5		
Length in mm	Bay A	Bay B	Diff. (B-A)	Bay A	Bay B	Diff. (B-A)	Bay A	Bay B	Diff. (B-A)	Bay A	Bay B	Diff. (B-A)
10.1-17.5	.37	.47	.10	.50	.60	.10	.58	.52	-.06	.61	.46	-.15
17.6-25.0	.31	.55	.24	.36	.51	.15	.40	.45	.05	.49	.32	-.17
25.1-30.0	.23	.43	.20	.28	.49	.21	.26	.40	.14	.38	.32	-.06
30.1-40.0	.22	.27	.05	.24	.42	.18	.21	.37	.16	.32	.36	.04
40.1-75.0	.16	.23	.07	.25	.31	.06	.19	.30	.11	.24	.32	.08
>75.0	.07	.51	.50	.11	.10	- .051	.15	.06	-.09	.17	.01	-.16

Proportion of the Total White Catfish Entering Bay That Were Lost Through Downstream Louver Section

	Approach Velocity (ft./sec.) 1.5-2.0			2.0-2.5			2.5-3.0			3.0-3.5		
Length in mm	Bay A	Bay B	Diff. (B-A)	Bay A	Bay B	Diff. (B-A)	Bay A	Bay B	Diff. (B-A)	Bay A	Bay B	Diff. (B-A)
10.1-17.5	.41	.45	.04	.36	.37	.01	.36	.46	.10	.30	.44	.14
17.6-25.0	.46	.40	-.06	.38	.46	.08	.41	.49	.08	.33	.43	.10
25.1-30.0	.42	.44	.02	.37	.43	.06	.39	.46	.07	.31	.38	.07
30.1-40.0	.31	.43	.12	.33	.44	.11	.50	.49	-.01	.28	.37	.09
40.1-75.0	.18	.34	.16	.24	.44	.20	.34	.49	.15	.25	.37	.12
>75.0	.14	.07	-.07	.08	.38	.30	.12	.11	-.01	.06	.15	.09

[1] All bypass ratios combined.

With this exception, the center wall apparently enhances the efficiency with which catfish are louvered in both the upstream and downstream halves of the primary louvers in Bay A.

Diurnal Efficiency: In Bay A, catfish efficiency was inconsistent with respect to daylight or darkness at approach velocities less than 3.0 ft/s. At the highest velocity range, efficiency was slightly higher during the day (Table 23). From limited data collected in Bay B at approach velocities less than 2.0 ft/s, efficiency was highest at night.

Secondary System

Fish Length: The efficiency of catfish in the secondary, was related directly to their length (Figure 16). Efficiency was generally higher in the secondary than in the primary for catfish of comparable lengths. The efficiency of catfish entering the secondary channel from both primary bypasses, at all parameters combined, ranged from 4.5 percent for fish 10-15 mm in length to 93 percent for those 75-100 mm in length. Although there were differences in efficiency among all length groups of catfish, the relationship was statistically significant only for fish greater than 20 mm in length. For analysis of the secondary test parameters, catfish were placed into length groups of: $\leq$ 15.0, 15.1-20.0, 20.1-30.0, 30.1-40.0, and 40.1-100.0 mm.

Bypass Ratio: Only a few observations were available for analysis of the effect of the bypass ratio on catfish efficiency in the secondary. The efficiency of catfish entering the secondary in line with the bypass was highest at bypass ratios

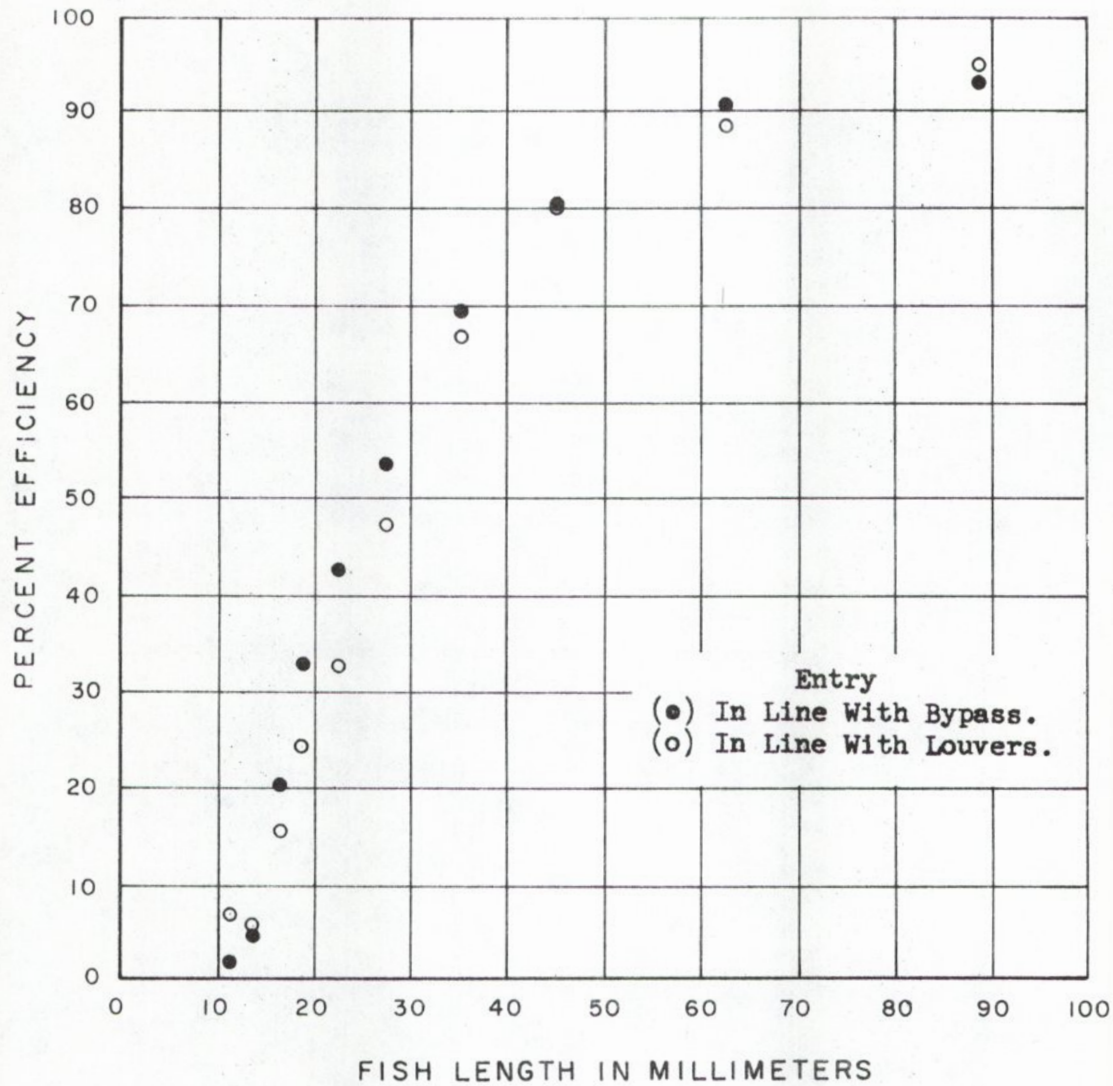


Figure 16

Secondary Louver Efficiency of White Catfish in Relation to Size

TABLE 23

Diurnal Efficiency of White Catfish
in the Primary System

Fish Length (mm)	Time	Bay With Center Wall (Bay A) Approach Velocity (ft./sec.) 1.5-2.0	2.0-2.5	3.0-3.5	Bay Without Center Wall (Bay B) Approach Velocity (ft./sec.) 1.5-2.0
10.1-17.5	Day	.27	.05	.06	.00
	Night	.18	.14	.07	.04
		x	x	x	x
17.6-25.0	Day	.20	.21	.21	.02
	Night	.20	.23	.16	.05
		x	x	x	x
25.1-30.0	Day	.53	.34	.38	.07
	Night	.36	.30	.28	.14
		x	x	x	x
30.1-40.0	Day	.44	.41	.40	.15
	Night	.71	.39	.39	.33
		x	x	x	**
40.1-75.0	Day		.41	.92	
	Night		.59	.70	
			**	*	

Levels of Significance x = >.05
* = .05
** = .01

less than 1.48 (Table 24). The efficiency of those entering the secondary in line with the louvers did not appear related to bypass ratio. Because the data collected were too sparse to separate the tests by bypass ratio they were combined for analysis of the other parameters.

Approach Velocity: The efficiency of white catfish in relation to secondary approach velocity was variable and not statistically significant (Table 25). Therefore, data collected at all approach velocities were combined for analysis of the remaining parameters. These results clearly contradict the findings in the primary. In addition, they contradict the relation between efficiency and approach velocity observed for striped bass in both the primary and secondary systems.

Screened Water Ratio: Catfish efficiency generally was inversely related to the screened water ratio, regardless of the side which fish entered the secondary channel. Differences in efficiency were statistically significant for fish 20-40 mm in length in Bay A (Table 26). Size did not appear to affect the relationship between efficiency and screened water ratio.

Entry into the Secondary: White catfish entering the secondary channel in line with the bypass were louvered more efficiently than catfish entering the secondary in line with the louvers (Table 26 and Figure 16). The disparity in efficiency appears proportional to screened water ratio.

TABLE 24. Louver Efficiency of White Catfish in Relation to Bypass Ratio in the Secondary Channel.

Secondary Entry in Line With Bypass

	Screened Water Ratio						
	1.0			1.4			
Fish length (mm)	30.1 40.0	40.1 100.0	> 100.0	15.1 20.0	20.1 30.0	30.1 40.0	40.1 100.0
Bypass Ratio							
≤1.33	.60	.85	.96	.39	.70	.70	.89
1.34 1.47	.80	.91	.97				.91
≥1.48				.21	.33	.52	.69
Significance	*	x	x	x	x	x	**

Secondary Entry in Line With Louvers

	Screened Water Ratio								
	0.0			1.0				1.4	
Fish length (mm)	20.1 30.0	30.1 40.0	40.1 100.0	20.1 30.0	30.1 40.0	40.1 100.0	>100.0	40.1 100.0	>100.0
Bypass Ratio									
≤1.33			.81			.92			
1.34 1.47	.83	.81	.87	.20	.52	.80	.98	.84	.94
≥1.48	.25	.69	.95	.13	.65	.82	.98	.61	1.00
Significance	**	x	x	x	x	x	x	**	x

Levels of significance
x = >.05
* = .05
** = .01

TABLE 25. Louver Efficiency of White Catfish in Relation to Approach Velocity in the Secondary Channel.

Secondary Entry in Line With Bypass

Fish length (mm)	Screened Water Ratio 0.0 — Approach Velocity (ft./sec.) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance	1.0 — Approach Velocity (ft./sec.) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance	1.4 — Approach Velocity (ft./sec.) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance
20.1-30.0	.62	.51	.56	.65	x	.49		.53	.40	x	.46	.23	.37	.36	x
30.1-40.0		.66	.66	.84	x	.67		.76	.75	x	.47	.63	.50	.70	x
40.1-100.0	.76	.65	.83	.89	x	.77		.90	.91	x	.87	.86	.82	.87	x

Secondary Entry in Line With Louvers

Fish length (mm)	Screened Water Ratio 0.0 — Approach Velocity (ft./sec.) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance	1.0 — Approach Velocity (ft./sec.) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance	1.4 — Approach Velocity (ft./sec.) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance
20.1-30.0	.39	.67	.52	.55	x	.66		.16	.25	*	.35	.22	.24	.55	x
30.1-40.0	.69	.64	.79	.63	x	.71		.57	.72	x	.68	.50	.33	.70	x
40.1-100.0		.82	.84	.80	x	.89		.82	.80	x	.87	.81	.80	.70	*

Levels of significance x >.05
* .05
** .01

TABLE 26

Secondary Louver Efficiency of White Catfish in Relation to Screened Water Ratio and Entry Into the Secondary Channel in Line With Bypass (A) and in Line With the Louvers (B)

Fish Length in mm	Screened Water Ratios	Louver Efficiency A	Louver Efficiency B	Significance
≤15.0	0.0	.04	.05	x
	1.0	.06	.04	x
	1.4	.04	.27	x
		x	x	
15.1-20.0	0.0	.40	.37	x
	1.0	.22	.16	x
	1.4	.31	.06	*
		x	x	
20.1-30.0	0.0	.60	.52	x
	1.0	.52	.39	x
	1.4	.34	.30	x
		**	x	
30.1-40.0	0.0	.75	.72	x
	1.0	.74	.66	x
	1.4	.68	.56	x
		**	x	
40.0-100.0	0.0	.86	.85	x
	1.0	.90	.82	**
	1.4	.85	.79	x
		x	x	

Levels of Significance x = > .05
* = .05
** = .01

Primary and Secondary Combined

Combined efficiency of white catfish entering the Bay B system ranged from less than one percent for 10-12 mm fish to 55 percent for 75-100 mm fish; as compared to less than one percent and 70 percent, respectively, in the Bay A system for the same size classes (Figure 17). The combined efficiency of catfish greater than 30 mm was substantially better for catfish entering Bay A and the secondary in line with the bypass, than for those entering Bay B and the secondary in line with the louvers. For fish less than 30 mm in length the percentage differences were relatively small.

Discussion

The most important factor affecting the efficiency of white catfish in both the primary and secondary systems of the Delta Fish Protective Facility was length of the fish. In contrast, in the secondary of the Tracy Fish Collecting Facility (Bates, et al, 1960) found that white catfish less than 25 mm were louvered only moderately less efficiently than catfish 38-76 mm in length. The Department of Water Resources (1964) reported similar results at the Tracy Facility. Both studies involved a single louver array.

Bypass ratio did not have a consistent effect on catfish efficiency in either the primary or secondary system. Bates, et al, op.cit., found that at approach velocities less than 1.5 ft/s, secondary efficiency for white catfish less than 43 mm in length was similar at bypass ratios of 1.2 and 1.4, and

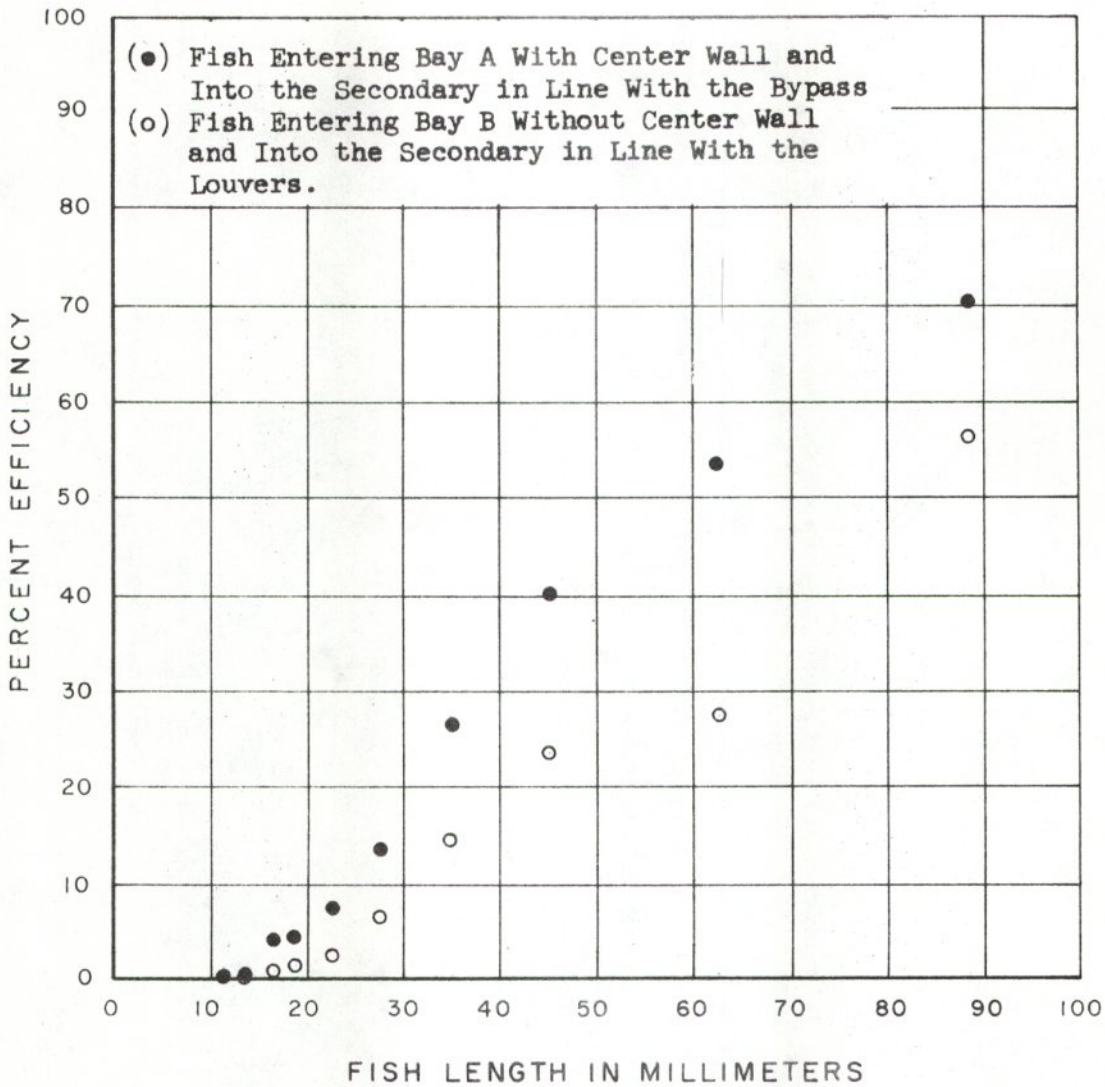


Figure 17

Combined Primary and Secondary
Efficiency of White Catfish
in Relation to Size

moderately lower at a bypass ratio of 1.0. At velocities greater than 1.5 ft/s, he found that efficiency was variable in relation to bypass ratio. With all length groups and other parameters combined, the Department of Water Resources (1964), found that efficiency, at the Trach Fish Collecting Facility, was inversely related to bypass ratio.

The efficiency of white catfish in Bay A was generally highest at the lowest range of approach velocities. In Bay B, catfish from 30-75 mm in length were also louvered most efficiently at the lowest approach velocities; while those less than 30 mm and greater than 75 mm were louvered most efficiently at the highest approach velocity. In the secondary, there was no apparent relationship between efficiency and approach velocity.

The exceptionally high efficiency observed for catfish less than 30 mm in Bay B (Table 20) at the highest approach velocities may be an artifact resulting from water velocity patterns. The velocity along the louver array without test nets behind it was moderately higher than on the side with the test nets. This suggests the possibility that the nets behind the louvers may have created some head loss on the test side. This would result in a transverse flow with higher velocities moving toward the downstream half of the unnetted line of louvers. Under such circumstances small catfish, having limited swimming ability, might possibly have followed the flow from the netted toward the unnetted section at the highest velocities. If this occurred it is probable that many fish which might have passed through the louvers, instead, moved toward the unnetted section and directly into the bypass. It is equally probable that many others passed through the louvers of the unnetted section. In the event this did in fact happen, our results for smaller catfish in Bay B would be biased upward at the higher velocities.

The secondary efficiency of catfish 38-76 mm in length was comparable to that found by Bates, et al (1960), at the Tracy Facility. Conversely, Bates reported substantially higher efficiencies for catfish less than 25 mm than were observed in these tests at the Delta Fish Protective Facility.

At the Tracy Facility, Bates reported that the secondary efficiency of white catfish less than 25 mm was inversely related to approach velocity with no general relationship for catfish greater than 75 mm. The Department of Water Resources (1964) found that the efficiency in the secondary at the Tracy Facility was directly related to approach velocity, but in their analysis, all length groups and other parameters were combined. Our tests showed no relationship between approach velocity and efficiency in the secondary.

Generally, there was an inverse relationship between secondary efficiency and screened water ratio. High velocity water emerging from the screened water outlet at ratios greater than 1.4 in relation to the approach velocity, may cause catfish to be deflected away from the secondary bypass and through the louvers.

The efficiency of catfish was generally higher in primary Bay A than Bay B. Catches in the nets behind the primary louvers indicate that a smaller percentage of catfish pass through both the upstream and downstream sections of louvers in Bay A than in Bay B. This suggests that the center wall enhances efficiency in both the upstream and downstream sections of louvers.

At velocities greater than 2.0 ft/s a larger percentage of fish less than 17.6 mm is lost through the upstream half of the louvers in both bays, as compared to the downstream half. As the velocity is increased beyond 3.0 ft/s there is a greater percentage of fish of all sizes lost through the upstream section of louvers. This suggests that velocity influences efficiency and that the center wall is more effective in the lower half of the louvers.

In the secondary channel, the higher efficiency of catfish entering in line with the bypass suggests that fish which must traverse the line of louvers are at a disadvantage. It is not known if the catfish oriented to the wall on the bypass side.

Superficial examination of test results from Bay A does not show a clear trend regarding night and daytime efficiency at approach velocities less than 2.5 ft/s. However, when the data are combined, night efficiency was slightly superior. At approach velocities greater than 3.0 ft/s daytime efficiency was clearly superior in the primary system. In general, the same trend was observed for white catfish as for striped bass.

The specific reason for the superior efficiency during daytime at the higher velocities is not understood. The data however, indicate that efficiencies at night decrease more rapidly than daytime efficiencies under comparable increases in approach velocity.

At the Tracy Facility, Bates, et al (1960), found that the secondary louver efficiency of white catfish 38-76 mm in length was similar during both day and night and unrelated to approach velocity. In a later study the Department of Water Resources (1964), determined that efficiency of white catfish in the secondary at the Tracy Facility was generally highest at night.

CHAPTER X

THREADFIN SHAD

Results

American shad (Alosa sapidissima), are among the primary game species which the Delta Fish Protective Facility was designed to salvage. Since they do not occur at the facility until late summer or fall and then irregularly and in limited numbers, no intensive effort was made to evaluate the efficiency of this species. Instead, the threadfin shad (Dorosoma petenense) which are abundant was selected to provide some insight as to the response of such delicate fishes to louvers. Data for this species was collected incidental to the other species. Consequently, it was insufficient to evaluate all test parameters. The length frequency of fish analyzed and a cumulative frequency distribution are shown in Figures 18 and 19.

Primary System

Fish Length: In primary Bay A the efficiency of threadfin shad up to 75 mm in length was related directly to length. Efficiency ranged from zero to 50 percent for 17.5 mm fish to 85 percent for 50 to 75 mm fish (Figure 20). The efficiency of 75 to 100 mm shad was 62 percent.

In Bay B, the limited amount of data are suggestive of an inverse relationship between louver efficiency and shad length. Efficiency ranged from 88 percent for 20 to 25 mm fish

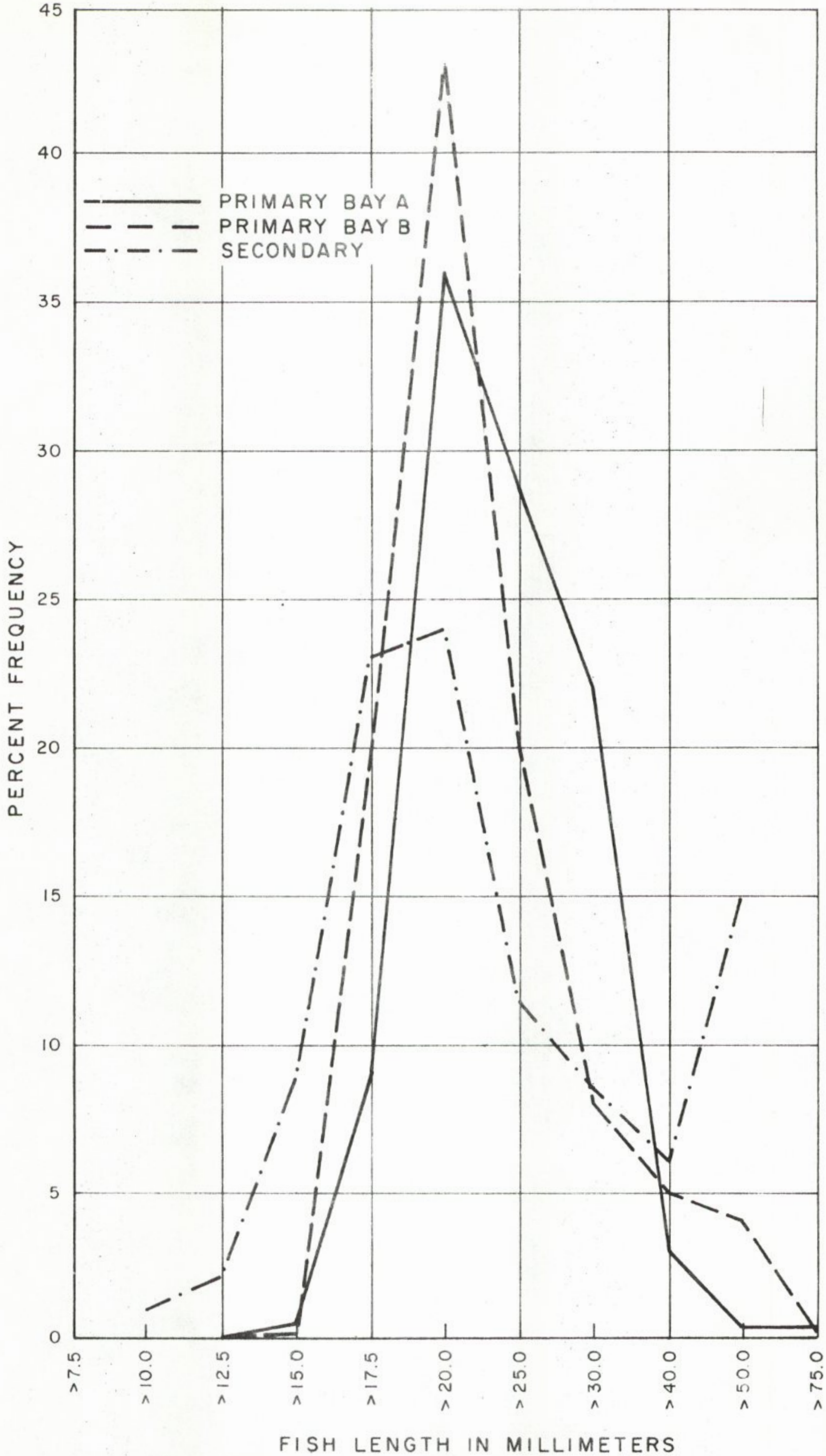


Figure 18. Length Frequency Distribution
of
Threadfin Shad Tested

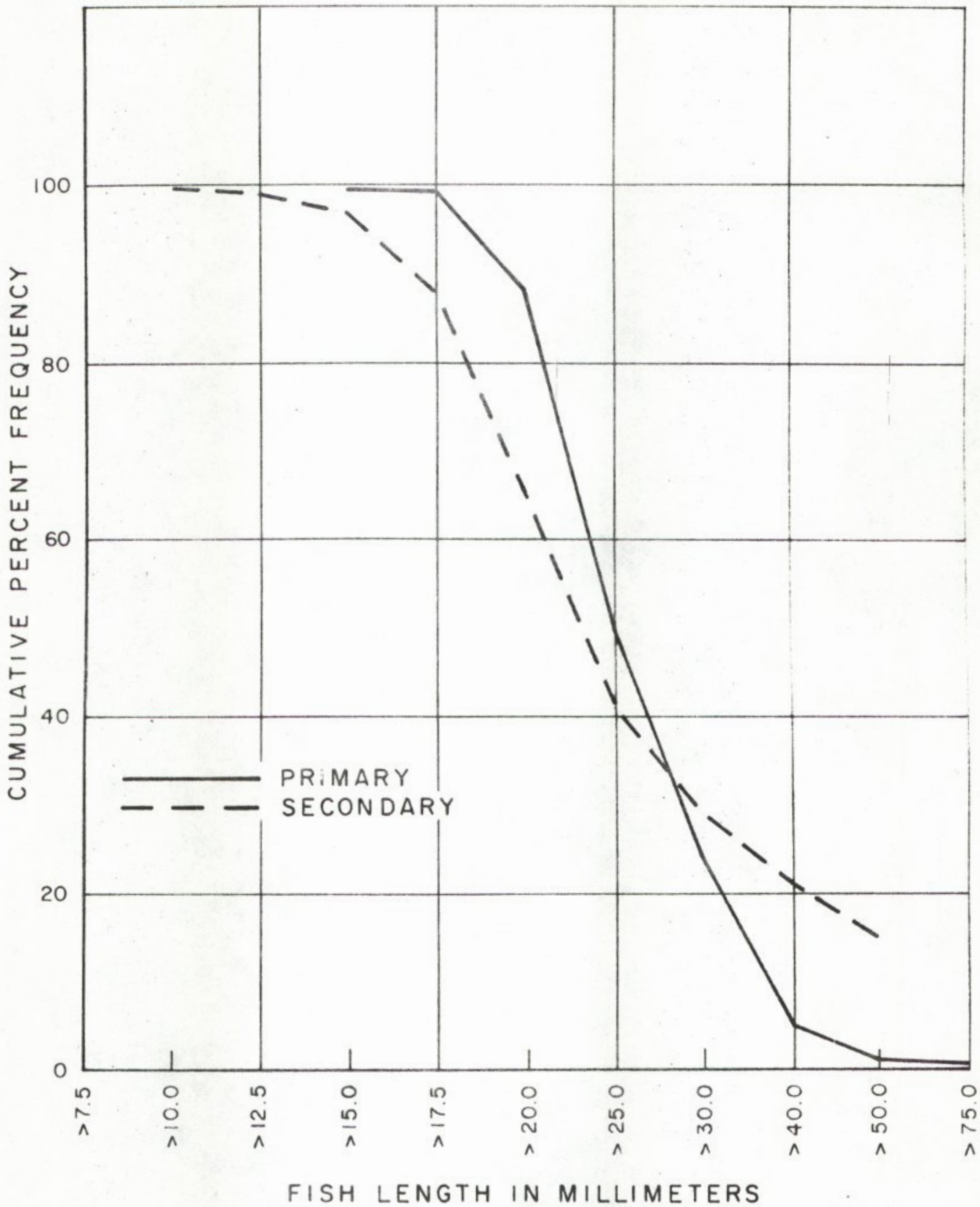


Figure 19

Cumulative Percent Frequency
Showing Percentage of Threadfin Shad Larger
Than Any Selected Length Class

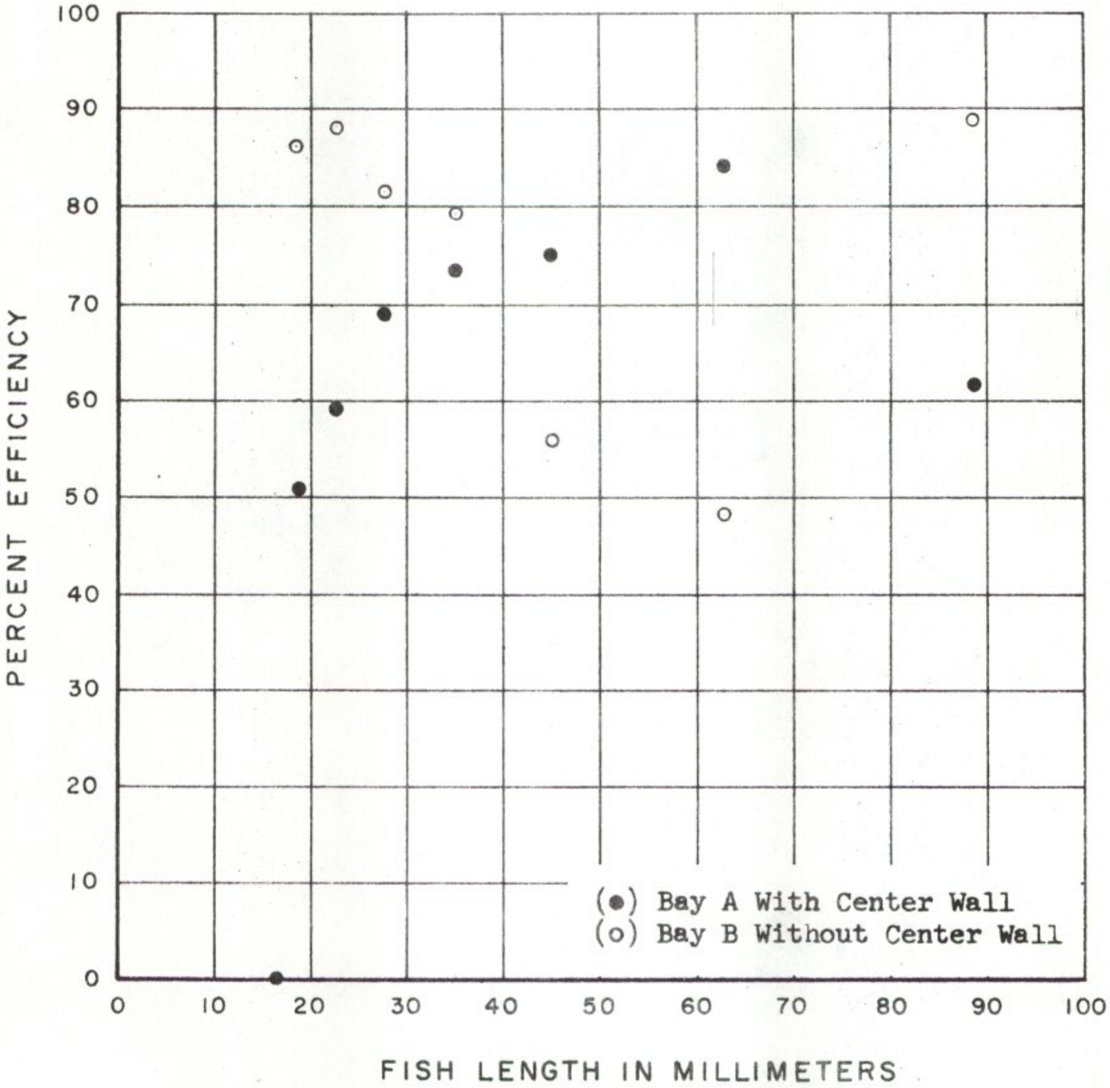


Figure 20

Primary Louver Efficiency
of Threadfin Shad in Relation to Size

to 48 percent for those 50 to 75 mm in length and back up to almost 90 percent for shad 75-100 mm in length.

Length class selection for analysis of the primary test parameters was made on the basis of data from Bay A only because insufficient data were collected in Bay B. Shad less than 15 mm were excluded from the analysis due to inadequate data. Three length groups were selected: 17.5-25.0, 25.1-50.0 and 50.1-100.0 mm.

Bypass Ratio: Insufficient data were available to evaluate the effect of bypass ratio on efficiency. Therefore, data collected at all bypass ratios were combined for analysis of the remaining primary test parameters.

Approach Velocity: Data from both primary bays suggest that the efficiency of shad is inversely related to approach velocity (Table 27). Without exception, louver efficiency decreased at the higher velocities.

Center Wall: Insufficient data were collected to evaluate the effects of the center wall on shad louver efficiency. Louver efficiency was slightly higher in the bay without the center wall in the only two comparisons that could be made within the same velocity range (Table 27).

Secondary

Fish Length: Louver efficiency of threadfin shad entering the secondary channel from both primary bypasses and at all parameters combined ranged from less than one percent

TABLE 27

Primary Louver Efficiency of Threadfin Shad in Relation to Approach Velocity and the Presence or Absence of a Center Wall (Bay A With and Bay B Without)

Fish Length (mm)	BAY	Approach Velocity (ft./sec.) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Significance
17.6-25.0	A	.79	.67		.54	**
	B	.89		.52		x
		x				
25.1-50.0	A	.78	.72		.71	x
	B	.83		.18		**
		x				
50.1-100.0	A		.94		.49	*
	B					

Levels of Significance x = > .05
* = .05
** = .01

to 73 percent for 10 to 12 mm and 40 to 50 mm fish, respectively (Figure 21). Shad were divided into five length groups for analysis of the secondary test parameters: 10.1-17.5, 17.6-20.0, 20.1-25.0, 25.1-40.0 and 40.1-75.0 mm.

Bypass Ratio: Insufficient data were collected to analyze the effect of the bypass ratio on threadfin efficiency in the secondary.

Approach Velocity: The efficiency of shad in the secondary was highest at approach velocities less than 2.0 ft/s regardless of other test conditions (Table 28). At the two highest velocity ranges the data were too variable to establish a clear trend. In a direct comparison the highest efficiencies were equally split between the two velocity ranges.

Screened Water Ratio: Threadfin efficiency was highest when the screened water ratio was zero. Efficiency was variable at screened water ratios of 1.0 and 1.4 but, the differences were statistically significant in only one case (Table 29).

Data collected at screened water ratios of 1.0 and 1.4 were combined for the analysis of the other test parameters.

Entry into Secondary: Almost without exception, the efficiency of threadfin shad was higher when they entered the secondary in line with the bypass (from Bay A) than in line with the louvers (from Bay B) (Table 28). The disparity in efficiencies with respect to entry into the secondary was generally greater when the screened water ratio was zero (Table 28).

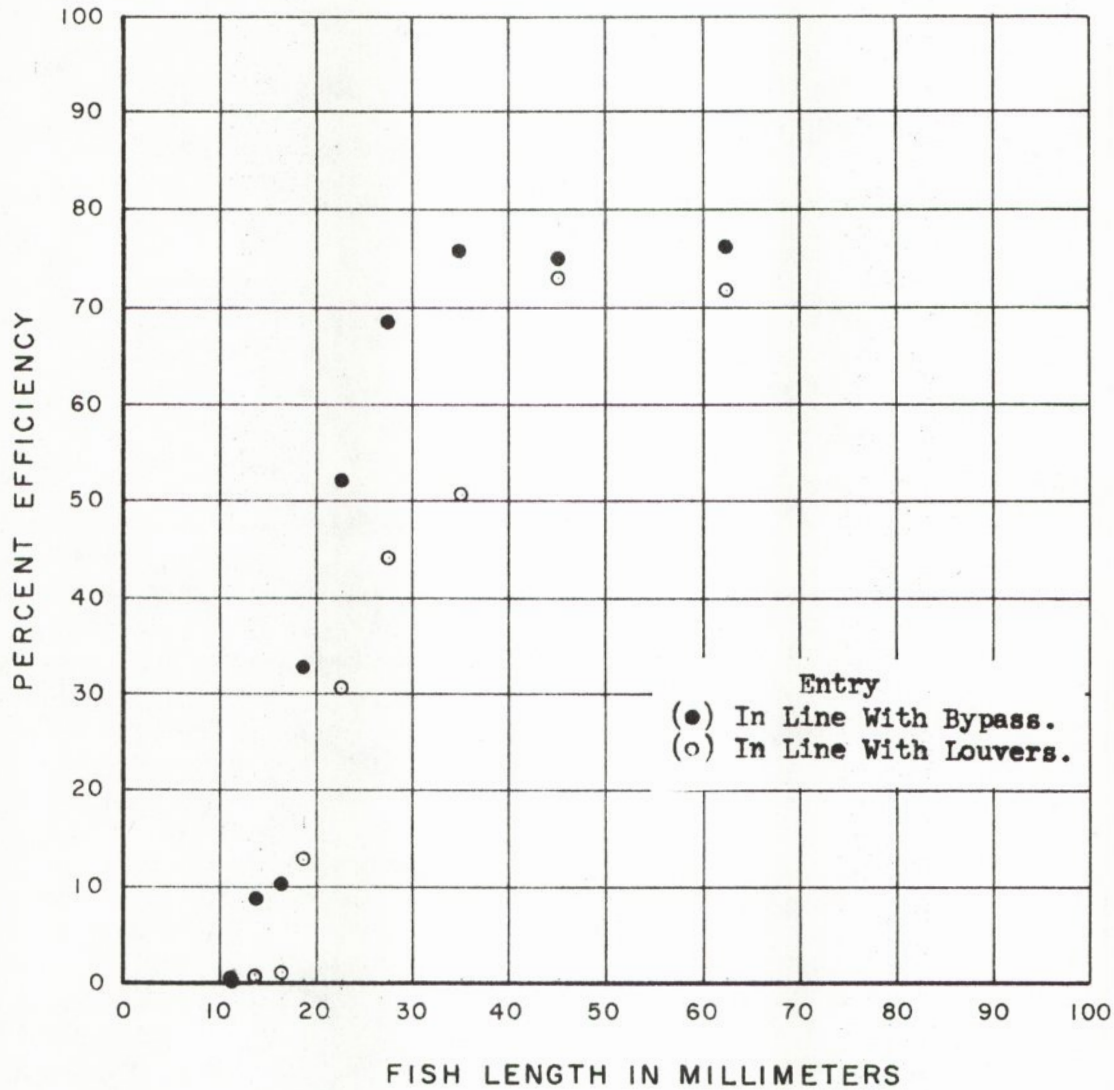


Figure 21

Secondary Louver Efficiency
of Threadfin Shad in Relation to Size

TABLE 28

Secondary Louver Efficiency of Threadfin Shad in Relation to Approach Velocity and Entry Into the Secondary Channel in Line With the Bypass (A) and in Line With the Louvers (B)

Fish Length (mm)		Screened Water Ratio 0.0: Approach Velocity (ft./sec.) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	Screened Water Ratio >1.0: Approach Velocity (ft./sec.) 1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5
10.1-	A				.14			.01	.10 x
17.5	B	.08		.01	.00 x	.02		.01	.01 x
					x			x	x
17.6-	A			.53	.30 x	.38		.15	.10 x
20.0	B	.37		.18	.02 x	.23		.05	.15 **
				*	**	x		**	x
20.1-	A			.62	.62 x	.59		.18	.31 *
25.0	B	.70		.34	.23 **	.45		.18	.11 **
				*	x	x		x	x
25.1-	A			.75	.82 x	.78		.36	.52 **
40.0	B	.75		.48	.54 x	.67		.31	.37 **
				*	*	x		x	x
40.1-	A			.47	.79 **	.76		.81	.74 x
75.0	B	.88		.83	.70 x	.70		.55	.63 x
				x	**	x		x	*

Levels of Significance x = >.05
* = .05
** = .01

TABLE 29

Secondary Louver Efficiency of Threadfin Shad in Relation to Screened Water Ratio and Entry Into Secondary Channel In Line With the Bypass (A) and in Line With the Louvers (B)

Fish Length (mm)	Screened Water Ratio	Approach Velocity (ft./sec.) 1.5-2.0	2.5-3.0	3.0-3.5	
		B	B	A	B
10.1-17.5	0.0	.08	.01	.13	.00
	1.0	.03	.01	.12	.01
	1.4	.02	<.005	.09	
		x	x	x	x
17.6-20.0	0.0	.37	.18	.30	.02
	1.0	.21	.06	.07	.11
	1.4	.24	.02	.13	
		x	x	**	x
20.1-25.0	0.0	.70	.34	.62	.23
	1.0	.43	.21	.32	.26
	1.4	.47	.09	.30	.03
		*	*	**	x
25.1-40.0	0.0	.75	.48	.82	.54
	1.0	.61	.34	.55	.32
	1.4	.74	.23	.43	.41
		x	*	**	x
40.1-75.0	0.0	.88	.83	.79	.70
	1.0	.64	.61	.76	.69
	1.4	.79	.35	.73	.58
		x	**	x	x

Levels of Significance x = > .05
* = .05
** = .01

Primary and Secondary Combined

The combined efficiency of threadfin shad entering the primary bay with the center wall and the secondary channel in line with the bypass ranged from zero to 65 percent for shad 15 and 75 mm, respectively (Figure 22). Shad entering the primary bay without the center wall and the secondary in line with the louvers were louvered less efficiently, particularly fish greater than 25 mm in length.

Discussion

Length appeared to be an important factor influencing threadfin shad efficiency in both the primary and secondary systems. In the secondary the relationship was clear with an apparent asymptote occurring at the 70 percent efficiency level for shad greater than 30 mm in length.

In the primary, the relationship between size and efficiency of Bay A coincides with the findings in the secondary except for the largest fish, where a drop in efficiency occurred. In Bay B an apparent, but probably erroneous, inverse relationship is confounded by the high efficiency of the largest shad. The normal relationship is broken by the very high efficiencies of shad 15 to 40 mm in length. We have no explanation for the contradictory results in the primary.

In tests in the secondary channel at the Tracy Fish Collecting Facility, DWR (1964), found a direct relationship between shad efficiency and length.

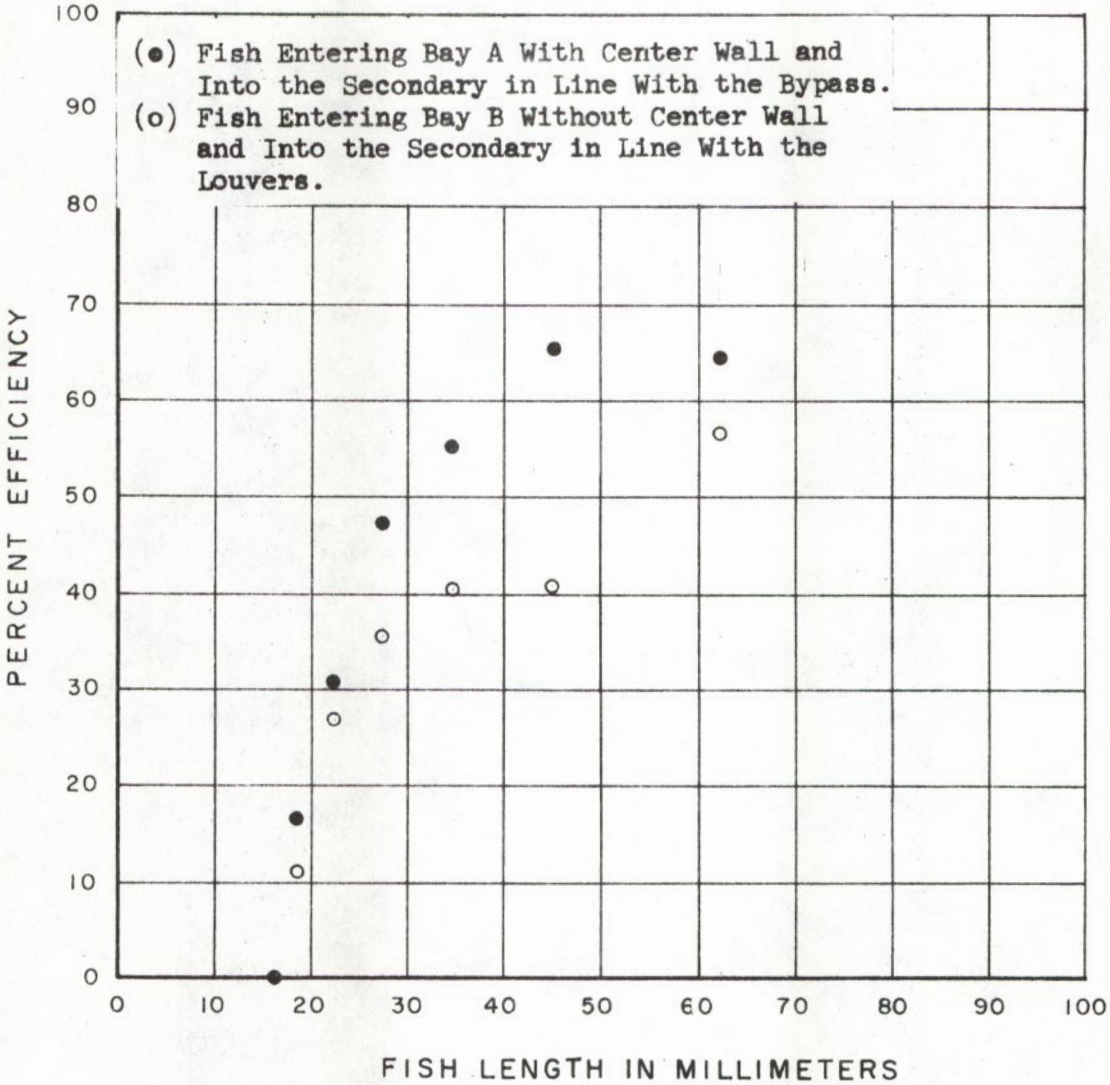


Figure 22

Combined Primary and Secondary Efficiency of Threadfin Shad in Relation to Size

The efficiency of threadfin shad was inversely related to approach velocity in both primary bays and in the secondary. Often, however, efficiency was higher at velocities greater than 3.0 ft/s than at lesser velocities. Department of Water Resources, op.cit., found a direct relationship between shad efficiency and approach velocity in the secondary of the Tracy Facility.

The efficiency of threadfin shad was highest at a screened water ratio of 0.0. Even low velocities from the screened water inlet appear to affect shad efficiency adversely.

CHAPTER XI

LOUVER ALIGNMENT

Introduction and Methods

In 1971, tests were conducted in the secondary channel with striped bass to determine the effect of louver panel misalignment on efficiency. These tests were undertaken because of misalingment among panels in the primary system. Fish were collected and enumerated in the same manner employed in the other secondary tests. Over 841,000 striped bass were involved in these tests of which 21 percent or 175,000 served as controls (perfect alignment). A length frequency distribution of fish tested is shown in Figure 23.

Misalignment is here defined as the lateral displacement between the proximate ends of adjacent panels (Figure 24). The amount of misalignment was measured one foot above the channel bottom and below the water surface. The mean extent of misalignment in these tests was approximately 1.6 inches.

Louver panels were misaligned with either the upstream or downstream edge protruding out from the adjacent panel. Different numbers and combinations of panels were misaligned to determine if certain arrangements of misalignment affect louver efficiency more than others. Tests with panels at near perfect alignment served as controls. Approximately 557,000 fish were involved in tests with the upstream edge protruding and 109,000 with the downstream edge protruding.

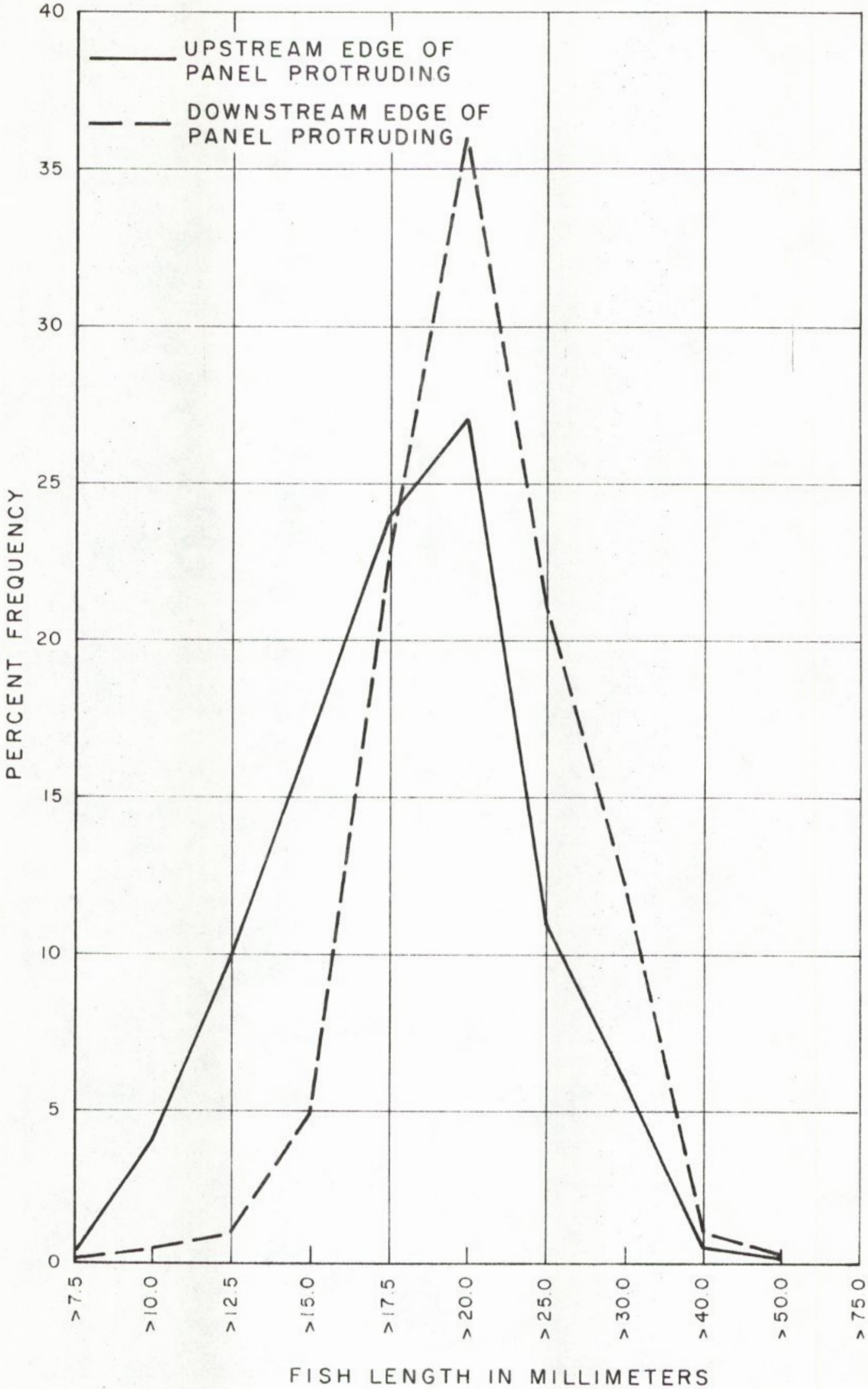
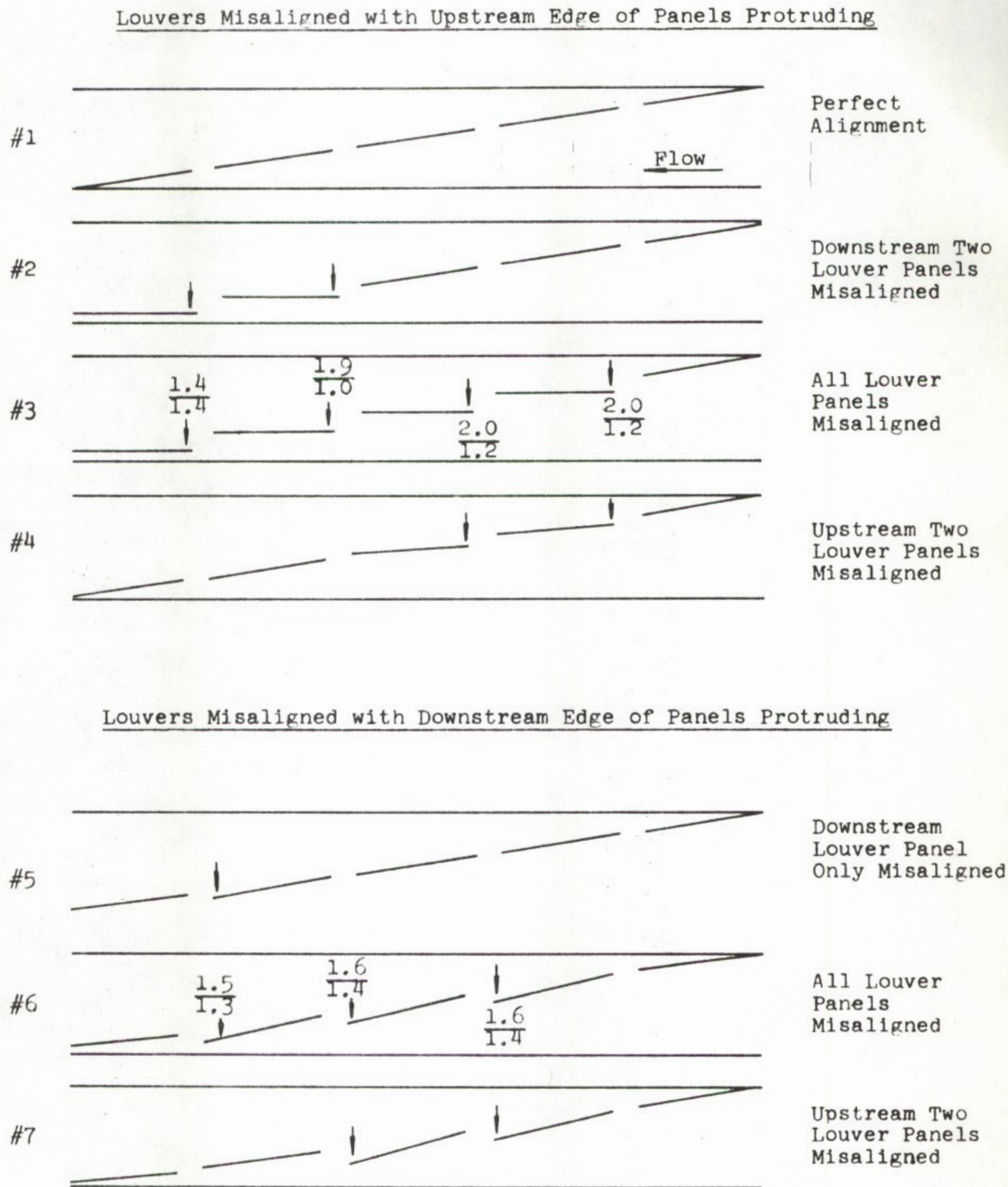


Figure 23

Length Frequency of Striped Bass in Louver Alignment Tests in Secondary

Figure 24

Secondary channel louver panel alignment configurations. Numbers shown above lines in the figure refer to the amount of lateral displacement in inches as measured at one foot below the water surface. Numbers shown below lines refer to lateral displacement as measured at one foot from the channel invert.



The various combinations of alignment and misalignment were tested at approach velocities of 1.00, 1.75 and 2.75 ft/s. During all tests, the bypasses from both primary bays were open, the secondary bypass ratios were maintained from 1.3 to 1.4 and the screened water ratio was kept at zero.

Results

Efficiency was consistently higher when the downstream edge of louver panels were protruding (Table 31) as compared to similar configurations in which the upstream edge protruded (Table 30). Differences in efficiency were usually less than 15 percent. Although the observed differences suggest that outward deflection of the downstream edge of louver panels is slightly superior, the data hardly justify that conclusion since, in most cases, the observed differences were generally within the range of differences displayed by the control situation (perfect alignment).

The best overall results were obtained when the downstream edge of the two upstream panels were deflected outward (arrangement #6 of Figure 24). The lowest overall results occurred when the upstream edge of the two downstream panels were misaligned (arrangement #2 of Figure 24).

These results demonstrate that misalignment of adjacent louver panels within one to two inches did not affect the efficiency of young-of-the-year striped bass significantly in the channel tested. In view of the large number of tests and fish tested the results are probably of general application.

TABLE 30

Secondary Louver Efficiency of Striped Bass in Relation to Louvers Misaligned With the Upstream Edge of the Louver Panels Protruding

Fish Length (mm)	Velocity (ft./sec.)	Perfectly Aligned	Downstream Two Panels Misaligned	All Panels Misaligned	Upstream Two Panels Misaligned	Significance
≤15.0	1.00	.62		.45		**
	1.75	.17	.23	.27	.18	x
	2.75	.05	.05	.07	.09	*
15.1-17.5	1.00	.88		.80		x
	1.75	.54	.57	.58	.64	x
	2.75	.24	.17	.27	.28	*
17.6-20.0	1.00	.96		.94		x
	1.75	.84	.79	.85	.87	x
	2.75	.62	.42	.65	.55	**
20.1-30.0	1.00	.97		.95		*
	1.75	.88	.89	.91	.91	*
	2.75	.75	.66	.78	.74	x
30.1-40.0	1.00	.98		.96		x
	1.75	.97	.92	.96	.94	x
	2.75	.94	.79	.93	.89	**
40.1-50.0	1.00	.95		.97		x
	1.75	.95	.95	1.00	.99	x
	2.75	1.00	1.00	1.00	.97	x

Levels of Significance x = >.05
* = .05
** = .01

TABLE 31

Secondary Louver Efficiency of Striped Bass in Relation to Louvers Misaligned With the Downstream Edge of the Louver Panels Protruding

Fish Length (mm)	Approach Velocity (ft./sec.)	Perfectly Aligned	Downstream Two Panels Misaligned	All Panels Misaligned	Upstream Two Panels Misaligned	Significance
<15.0	1.75	.08	.43	.33	.21	**
15.1-17.5	1.75	.67	.76	.74	.76	x
17.6-20.0	1.75	.86	.87	.86	.91	x
20.1-30.0	1.75	.90	.92	.91	.94	*
30.1-40.0	1.75	.96	.95	.96	.96	x
40.1-50.0	1.75	.99	.88	.97	.96	x
50.1-75.0	1.75	.94		.98		x

Levels of Significance x = >.05
* = .05
** = .01

Figure 25 shows the relationship between fish length and efficiency at the several velocities tested and with the louvers in perfect alignment. The dashed line in Figure 25 represents the control results (perfect alignment) at 1.75 ft/s during the series of tests with the downstream edge protruding. The solid lines are the control results for testing with the upstream edges protruding.

It should be noted in connection with these tests (Fig. 25) also that the results for bass less than 20-25 mm are probably low. It will be recalled from the section on striped bass that there is a possibility bass less than 20-25 mm in length were lost through the cylinder screen in the holding tank. Thus, although the results provide a proper estimate of the efficiency of the installation they probably reflect a downward biased estimate of the efficiency of the secondary louver system for these small fish.

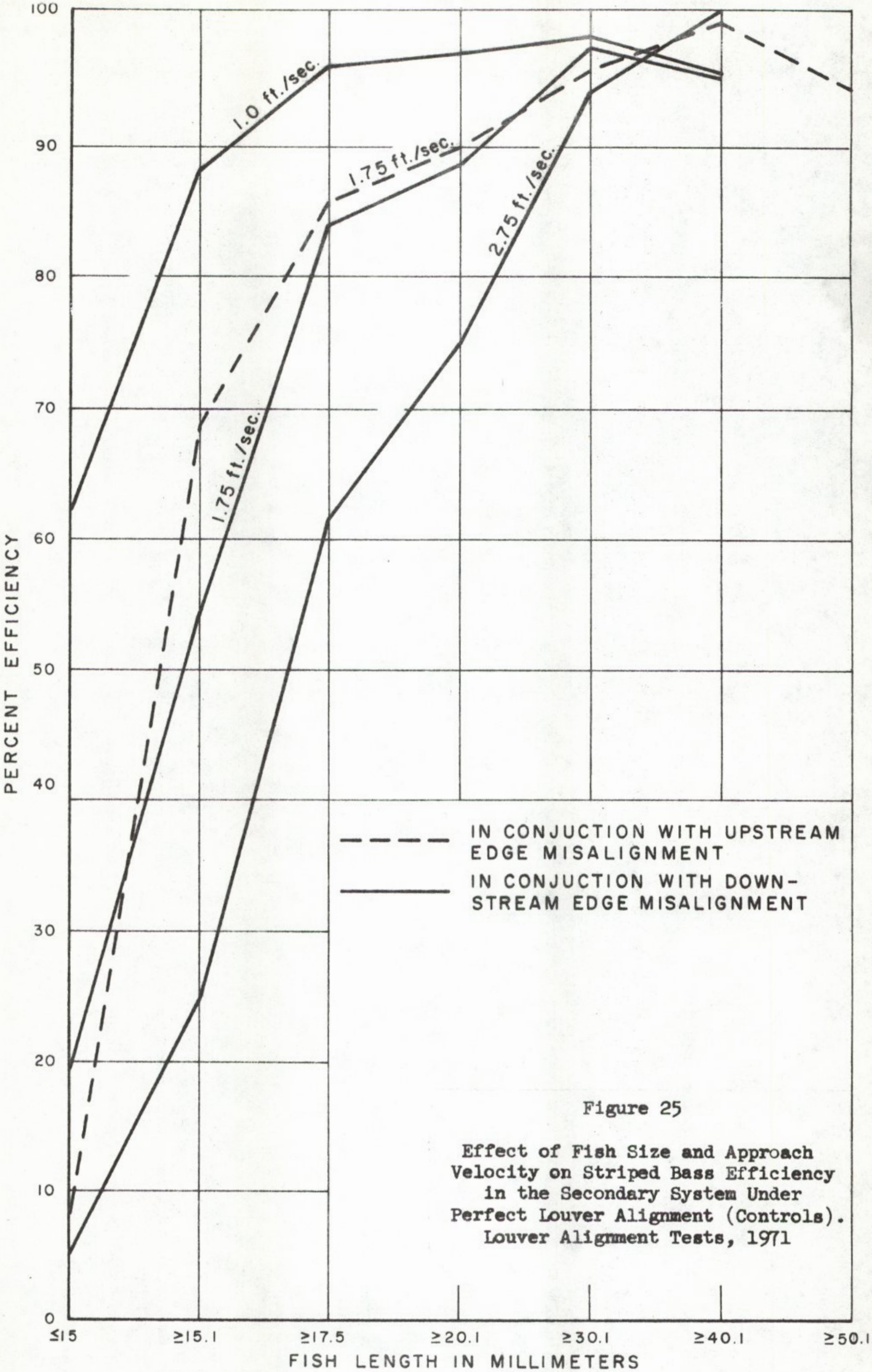


Figure 25

Effect of Fish Size and Approach Velocity on Striped Bass Efficiency in the Secondary System Under Perfect Louver Alignment (Controls). Louver Alignment Tests, 1971

CHAPTER XII

CONCLUSIONS

Introduction

In describing the conclusions from this study they will be discussed, first, in relation to the several purposes of the program as set forth in Chapter IV, and secondly as they relate to the efficiency of the Delta Fish Protective Facility.

Conclusions Regarding Program Purposes

Assessment of Functional Performance in Relation to Design Standards

It should be noted that the only other functional louver installation of comparable purpose, size and scope in the U. S. is the nearby Tracy Fish Collecting Facility where the louver concept was originally developed. The Tracy Facility was designed by the U. S. Department of the Interior, constructed in 1955-56 and is operated by the U. S. Bureau of Reclamation. The Tracy Facility's louver system being the only fish salvage concept readily adaptable to the large scale diversions from the Delta proposed under the State Water Project, was adopted by the State Department of Water Resources. However, Water Resources did some experimental work and modified the Tracy Facility layout and design criteria in several ways to effect efficiency and economy.

The functional design criteria for the Delta Facility was set forth in Chapter III. These criteria, involving approach velocity, bypass ratio, bypass width and louver slat spacings were based on experimental evidence originally developed by U. S. Department of the Interior research and were modified as a result of later research by Water Resources.

The only biological performance standard discussed in the design of the installation related to fish size. It was generally agreed between Water Resources and Fish and Game that the installation should be capable of salvaging a reasonable proportion of fish (primarily striped bass) of one inch or more in length. It was recognized at the time that louvers were not efficient for fish less than one inch in length.

Thus, there are no widely accepted standards of either design or performance by which the Delta Facility can be evaluated objectively. Rather, in this case, it was a matter of determining: (a) the performance of the Delta Facility in salvaging fish greater than one inch in length; (b) the general and specific performance of the Delta Facility as compared to known results from the Tracy Facility, and; (c) the extent to which the modified design criteria affected efficiency.

It was concluded:

(a) That the Delta Fish Protective Facility is capable of salvaging upwards of 50 percent of the striped bass one inch in length, and a major percentage of larger fish.

(b) That the overall salvage efficiency of the Delta Fish Protective Facility compares favorably with the Tracy Facility. A definitive comparison was not possible because the primary system of the Tracy Facility has not been evaluated on a comparable basis.

(c) That the design changes and criteria that were incorporated into the Delta Facility are generally beneficial. The wing gates which control the flow and, hence, approach velocity are clearly advantageous, as is, also the center wall. Most of the design criteria set forth in Chapter I appear adequate. (Exceptions will be apparent under the heading "Conclusions Regarding Efficiency".

Development of Operating Criteria

General and specific conclusions regarding operating criteria were formulated and are presented under "Conclusions Regarding Efficiency".

Application of Design Features and Operating Criteria to Phase II of the Delta Fish Protective Facility

It is concluded that several design and structural modifications would be desirable for Phase II of the facility. The modifications could involve changes in the terminal portion of the primary bypass and secondary systems, center walls in the bays where they do not now exist, and early expansion of the total facility to its ultimate planned capacity. Because of the substantial nature of these changes and possible duplication by fish facilities being planned for the proposed Peripheral Canal, it is concluded that management should evaluate the relative merits of implementing modifications of such scope.

Effect of Louver Alignment on Efficiency

It is concluded that irregularities in louver alignment in the secondary system, within the range of lateral displacement (2 inches) evaluated in these studies, did not affect efficiency significantly. It is reasonable to assume that at some point gaps and misalignment adversely affect efficiency.

The conclusion regarding louver alignment in the secondary system should not be transferred to the primary system without reservation because of inherent differences in the two systems. Among these differences are length of the line of louvers, physical size and louver layout.

Considering the information on hand, and the need for some judgement regarding correction of the apparent louver misalignment in the primary system, it is concluded that gaps and lateral displacement up to two inches probably do not have a major impact on efficiency. Consequently, alignment deficiences up to two inches are not considered critical; however, in our judgement reasonable effort should be made to minimize gaps and misalignment of louver panels in both the primary and secondary systems.

Conclusions Regarding Facility Efficiency

Conclusions regarding efficiency are most conveniently categorized as biological, operational and structural.

The biological are those associated with the physiological limitations or capabilities of fish. Fish differ with respect to their performance due to their size or stage of development and inherent differences between species in morphometry and their propensity to respond to various environmental conditions.

Size or stage of development was the most significant biological factor affecting efficiency within the sizes of fish tested in this evaluation program.

Operational factors are those which can be manipulated within the plant system to affect efficiency such as channel approach velocity, bypass ratio and screened water ratio. Various components of the facility can be operated to effect substantial changes in efficiency, while others have little or no effect. In general, a number of operational adjustments are possible to make the facility more compatible with the various sizes and species of fish.

In reviewing the conclusions regarding efficiencies reported herein, for the system as a whole or its component parts, it should be noted that: (1) the figures reflect very small fish which the installation was not originally designed to salvage, and (2) the results reflect a wide variety of operating conditions, many of which deviated substantially from optimum criteria, in order to assess the impact of the full range of variables in the system. Consequently, any overall averages of results are biased downward in terms of the true capability of the installation.

Structural considerations include the design and presence or absence of such physical features as the center wall in the primary system, the dimensions and configuration of the secondary system, position of entry into the secondary, configuration of the louvers and their alignment.

Features such as the center wall and the wing gates at the entrance to the fish facility were clearly advantageous. The evaluation program has confirmed their usefulness and has pinpointed a number of other desirable structural modifications.

Considering the above relationships, the conclusions can be separated into those of a general nature which are common to all fish species and those which are specific for individual species.

General Conclusions

1. Fish Length:

    a. When any other variable was held constant, efficiency was directly related to fish length for all species. Since fish size is a variable that cannot be controlled it was established as the independent variable and all other test parameters were measured in relation to size.

    b. As growth occurs, fish length becomes less important as a determinant of efficiency. This transition appears to be at about 25 mm for striped bass, 45 mm for white catfish. As salmon entering the facility were larger than 50 mm, other variables were more important than size.

2. Approach Velocity:

   a. Approach velocity is an important factor in efficiency of the louver system for small fish. In general, efficiency was inversely related to velocity. Efficiency usually was best at the lowest velocities tested, and frequently the highest velocities were superior to intermediate velocities. The cause for this is largely speculative at this time.

   b. Low approach velocities are critical to the successful collection of small fish but less critical for fish greater than 50 mm.

3. Secondary Screened Water Ratio:

Efficiency of the secondary louvers was best at screened water ratios less than 1.0. Screened water ratio was most critical for small fish and for those entering the secondary from Bay B (in line with the louvers).

4. Center Wall:

The bay with the center wall was clearly superior to the bay without it for striped bass, catfish and threadfin shad. In the case of salmon, the bay without the center wall appeared slightly superior. However, it is possible that in Bay A the width of the bypass is, in effect, reduced by the terminal extension of the center wall into the middle of the bypass entrance, thus impairing the effectiveness of the bypass.

5. Entry into the Secondary:

Entry into the secondary via the bypass from Bay A and therefore, on the side of the secondary bypass, increased efficiency while entry from Bay B in line with the louvers reduced efficiency.

6. Combined Efficiency (Primary and Secondary):

Overall efficiency was best for fish entering Bay A with the center wall and entering the secondary in line with the bypass.

Specific Conclusions

King Salmon:

1. Bypass ratios tested did not affect efficiency significantly in either the primary or secondary systems.
2. The efficiency of salmon 50-100 mm in length appeared to be directly related to approach velocity. There was no clear relationship between efficiency and approach velocity for larger salmon.
3. Salmon efficiency was slightly lower in Bay A than Bay B. The extension of the center wall to the very entrance of the primary bypass may be reducing efficiency by effectively reducing the bypass width.
4. The combined efficiency of the primary and secondary systems ranged from 65 to 90 percent for the sizes of salmon tested.

Striped Bass:

1. Bypass ratio had a profound effect on efficiency in Bay B and a smaller but contradictory effect in Bay A. In general efficiency in Bay A was best at bypass ratios of 1.34-1.47. In Bay B (no center wall) efficiency was significantly better at bypass ratios greater than 1.48.

2. Since the primary bypass flows must be operated uniformly and affect velocity and flow conditions in the secondary, the best balance in efficiency between the primary and secondary systems is achieved under the following conditions:

   (a) When the primary approach velocity is less than 2.5 ft/s the bypass ratio should be greater than 1.47;

   (b) When the primary approach velocities are greater than 2.5 ft/s the bypass ratio should be 1.2.

   When the primary approach velocity is greater than 2.5 fps the primary bypass ratio associated with the highest efficiency creates relatively high velocities in the secondary. Thus efficiency in the secondary is reduced. Therefore to obtain the optimum combined efficiency between the primary and secondary systems, it is better to reduce the primary bypass ratio to 1.2 when the primary approach velocities exceed 2.5 fps. The slightly lower efficiency in the primary is more than compensated by the higher efficiency in the secondary.

3. Secondary bypass ratio did not affect efficiency of striped bass in the secondary system significantly.
4. Efficiency was best in both the primary and secondary systems at approach velocities less than 2.5 ft/s. For bass greater than 30 mm in length, efficiency was better at velocities greater than 3.0 ft/s than at velocities between 2.5 and 3.0 ft/s; but, it was still substantially lower than efficiencies at velocities less than 2.5 ft/s.
5. Secondary efficiency generally was best at screened water ratios of 0.0 and lowest at 1.4.
6. The efficiency of salvaging striped bass was higher in Bay A of the primary system than Bay B. Efficiency in the secondary was better for fish entering from Bay A than for fish entering from Bay B. Thus, the combined efficiency for fish entering Primary Bay A and the secondary system is considerably higher than the combined efficiency for Bay B and the secondary system.
7. At low to moderate velocities (up to 2.5 ft/s) efficiency was frequently but only slightly superior at night for striped bass in the primary system. At higher velocities efficiency was greater during the day.

White Catfish:

1. Bypass ratios did not consistently affect efficiency significantly in the primary system.
2. Secondary efficiency generally was best at bypass ratios less than 1.48.

3. In Bay A efficiency was highest at the lowest velocity. In Bay B efficiency was highest at the highest velocities except for fish between 30 and 75 mm; but for catfish less than 30 mm approach velocities greater than 3.0 ft/s were more efficient.
4. Secondary approach velocity did not affect efficiency significantly.
5. Efficiency generally was highest at a screened water ratio of 0.0.
6. In general, the bay with the center wall was superior.
7. Efficiency was better during the day at approach velocities greater than 2.5 ft/s and similar or slightly better at night at the lower velocities.
8. For catfish greater than 30 mm in length combined efficiency was clearly higher for fish entering Bay A and the secondary in line with the bypass than for fish entering Bay B and the secondary in line with the louvers. There was no clear difference for fish smaller than 30 mm.

Threadfin Shad:

Our testing of threadfin shad was incidental to the other species and was undertaken primarily as a substitute for American shad. Because of this, and the fact that threadfin shad efficiencies are similar to those of striped bass and catfish for fish of the same length under similar parameters, specific conclusions for this species will not be given separately.

CHAPTER XIII

RECOMMENDATIONS

As a result of the evaluation of the Delta Fish Protective Facility a number of recommendations have been formulated to potentially maximize the fish salvage efficiency of the overall installation and its components. These recommendations fall into two categories: (1) maintenance and operation, and (2) structural modifications.

Structural modifications will involve changes or additions to the facility to improve efficiency. Some will be of sufficient economic consequence that decisions regarding them need to be viewed in the perspective of the ultimate function of the facility and are, therefore, beyond the scope of this study. Specifically, decisions regarding recommendations in this category should take into consideration the potential and capability of the fish salvage facilities being planned for the Peripheral Canal. For example, if a highly efficient screen is installed at the intake to the Peripheral Canal, excessive expenditures to modify the Delta Facility would not be warranted. On the other hand, increasing exports before the Peripheral Canal becomes operational make it imperative that all reasonable actions be taken to improve the efficiency of the present facility.

Operations and Maintenance

Results of the evaluation program clearly indicate the strong relationship between efficiencies and fish length, approach velocity and bypass ratios. Accurate measurement of channel approach velocities is the key in setting bypass ratios and screened water ratios. Hence, an effective program to assure the accurate measurement of water velocities in the primary and secondary channels is fundamental to optimum operation of the facility.

Test results have also shown that to achieve maximum efficiency, some operating criteria will vary among species. Since only one set of operating criteria can be employed at any one time, it is apparent that the criteria will need to be compromised when several species occur simultaneously. Nevertheless, optimum criteria for each species have been developed and are recommended herein along with a flow diagram which greatly simplifies their selection. The criteria actually selected during operation of the facility should reflect a proper balance among species, considering such management considerations as their relative recreational or commercial importance, forage value, and population status.

In consideration of the foregoing, it is recommended that:

(1) An effective program be maintained for the measuring and recording of velocity in both the primary and secondary systems.

(2) The following criteria be adopted as standard operating procedures, subject to such modification as may be necessary to resolve conflicts among species due to an overlap in their occurrence:

King Salmon

1. Channel Approach Velocities: Channel approach velocities of 1.5 to 3.5 Fps are permissable.

2. Bypass Ratios: Bypass ratios of 1.2 to 1.6 should be maintained in both primary and secondary channels.

3. Screened Water Ratio: Although not evaluated for salmon, results with other species suggest that there should be as little screened water as possible; but, in any event the screened water ratio should not exceed 1.0 to 1.0.

4. Primary Channel: When the option is present, the bay without the center wall should be used in preference to the bay with the center wall.

Striped Bass and White Catfish

1. Approach Velocity: Approach velocity is critical and should be kept as low as is feasible in both the primary and secondary channels.

2. Clifton Court Forebay Water Level: To assure that low approach velocities in the primary channel can be achieved, Clifton Court Forebay water level should be maintained at the highest practical level.

3. Primary Channel:

   (a) The primary bay with the center wall (Bay A) should be used in preference to Bay B.

   (b) The bay without the center wall should not be used until pumping requirements cause channel approach velocities to exceed 2.5 feet per second in the bay with the center wall.

4. <u>Bypass Ratio</u>:

(a) When only the primary bay with the center wall is in operation the bypass ratio should be maintained at 1.2 (bypass entrance velocity 1.2 times the primary channel approach velocity).

(b) When both primary bays are in operation and the approach velocity is less than 2.5 ft/s the bypass ratio should be 1.5.

(c) When both primary bays are in operation and the approach velocity exceeds 2.5 ft/s the bypass ratio should be 1.2.

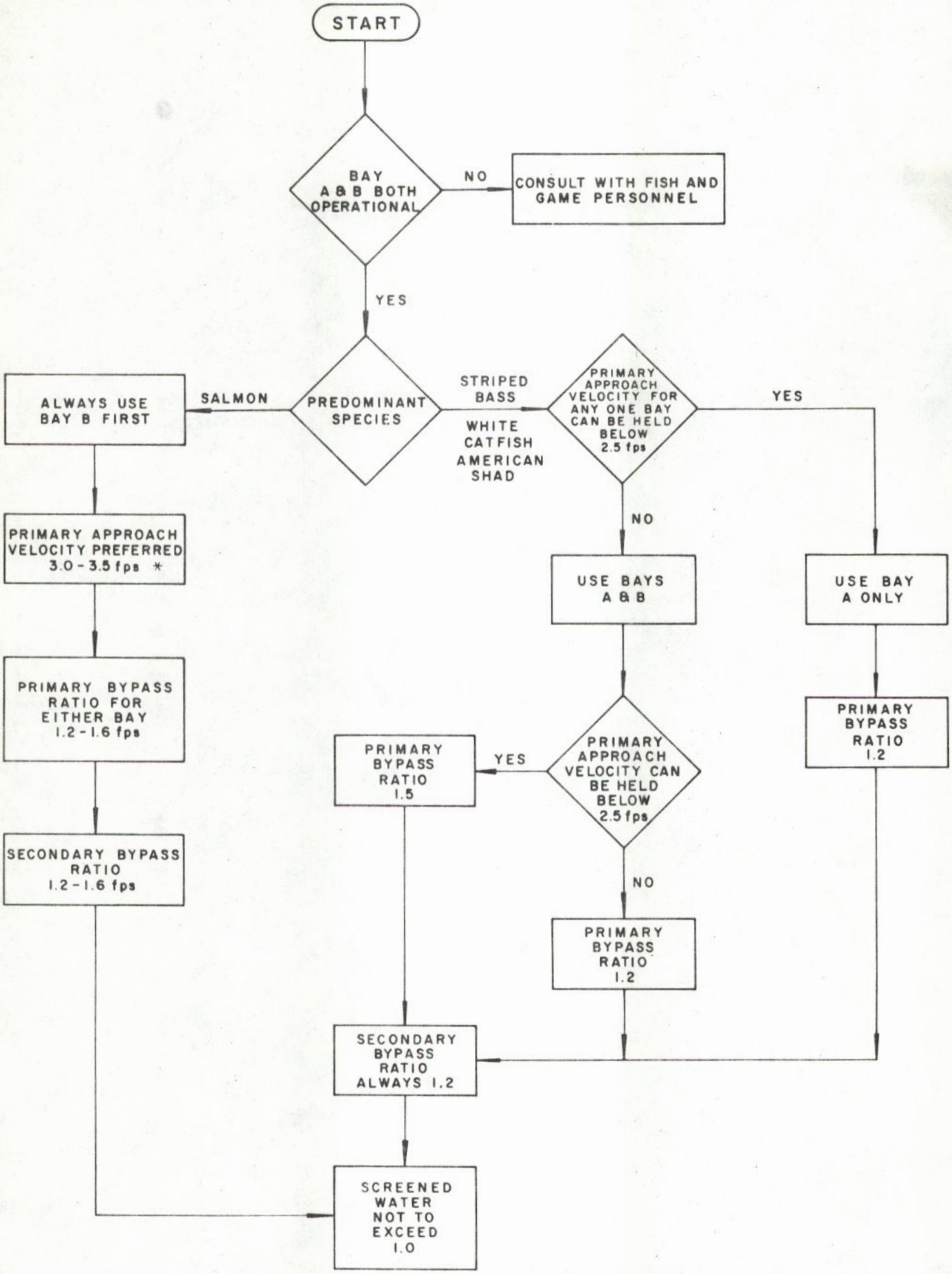
(d) If the bay without the center wall is operated alone the bypass ratio should be maintained at 1.5.

(e) The bypass ratio in the secondary channel should be maintained at 1.2 for all channel approach velocities.

5. <u>Screened Water Ratio</u>: It would be preferable not to provide screened water; but if necessary because of debris or other conditions, it should be as little as possible. In no case should the velocity exceed the channel approach velocity (ratio of 1.0 to 1.0).

Structural Modifications

Decisions regarding implementation of proposed structural modifications require that a balance be considered between the potential gains in salvage efficiency, the cost of the proposed modifications, water operations and the potential impact of fish salvage facilities proposed for the Peripheral Canal.



FLOW DIAGRAM OF OPERATIONAL CRITERIA

* CRITERIA PREFERRED BUT NOT CRITICAL

FIGURE 26

Such decisions are considered the prerogative of management and, therefore, beyond the purview of the present study. It is recommended that a management directed study be initiated by the Departments of Water Resources and Fish and Game to evaluate the feasibility of implementing the structural modifications.

1. Construction of a Center Wall in the Primary Bay Which Does Not Now Have Such a Wall: A center wall would increase the efficiency of salvaging young striped bass, white catfish, and probably other species by about 15 percent.
2. Modify the Secondary Channel:
   (a) Provide a longer and smoother transition between the bypass discharge and the line of louvers.
   (b) Permit the primary bypasses to be operated either independently or in unison. Independent operation would minimize the flow and hence velocity in the secondary when only one bay is in operation.
   (c) Provide a system ahead of the line of louvers to deflect or guide fish to the bypass side. This should improve the efficiency of the Bay B system by about 20 percent for bass and catfish.

(Design criteria for the modifications being proposed will need to be developed through engineering and biological consultation. Data from the Fish Facilities Program may be availabe within a year or so to assist in this effort.)

3. Development of Unused Primary Bays: Development of unused primary bays, including center walls, and construction of the adjunctive secondary channel. These modifications would enable much greater latitude for control of velocity, a critical factor in the louver efficiency of small fish.

These modifications were contemplated in the original design and the construction of the Delta Fish Protective Facility. Although these modifications were not scheduled to be implemented until export demands exceed 6,000 cfs, there is clear evidence from this evaluation that early development of the facility to its planned potential would permit the flexibility to improve salvage efficiency at present levels of pumping. As exports increase, the advantage of early development will become more significant.

Some of the benefits that can be derived from developing the unused primary bays can be obtained by reducing the average velocity by a lower intensity of pumping at Delta Pumping Plant. The lower intensity can be obtained by pumping more water continuously rather than off-peak. This alternative should be included in studies of developing unused primary bays. It might prove to be economically advantageous as an interim measure as the Peripheral Canal is being constructed.

4. Alignment of Louver Panels: These studies demonstrated that gaps and misalignment of louver panels up to two inches in the secondary system did not affect the efficiency of salvaging

striped bass significantly. Therefore, rigid alignment of the louver panels does not appear to be necessary. However, since it is only reasonable that at some point, deficiencies in alighment would adversely affect efficiency, it is recommended that in both the primary and secondary systems:

(a) Correct any gaps and the lateral displacement of louvers which exceed two inches between adjacent louver panels.

(b) Reasonable effort be made to keep the louvers as close to proper alignment as possible, and to minimize gaps between louvers.

5. A detailed study should be made of the velocities and flow patterns in the primary channels of the Delta Fish Protective Facility.

Appendix A

SPECIAL STUDIES

Primary Channel Velocity Study

A fundamental parameter in the operation of a louver principle facility is the velocity of the approach flow in the channel immediately ahead of and along the line of louvers.

The speed at which the flow (and fish) approaches the louvers relates directly to whether the fish are able to swim parallel along the front of the louver line and on into a bypass intake or to be lost through the louver openings. If the approach velocity is too low it is believed that the fish are given an opportunity by the lack of sufficient turbulence to go through the louver on their own volition -- if the approach velocity is too fast the fish are unable to swim at a rate high enough to prevent them from being swept through the louvers. Also the bypass intake ratio, which is the ratio of velocity of flow at the entrance of the bypass intake to the channel approach velocity, is of course directly proportional to the approach velocity.

These precepts are well explained in the Bureau of Reclamation report, "Fish Protection at the Tracy Pumping Plant", February 1957. This report presents a good analysis of flow characteristics along the louver line and includes a discussion of "favorable" and "unfavorable" flow conditions. Favorable is defined as a reasonable uniform increase in velocity along the line of louvers from the start to the bypass intake. Erratic or decreasing velocity of flow along the louver line toward the bypass intake is regarded as unfavorable for efficient fish collection.

These criteria were applied to the general layout of the State's Delta Fish Protective Facility and model tests showed that the selected channel configuration and dimensions did produce acceptable flow conditions.

Model studies also showed that a single point velocity measurement taken in the middle of each channel would be representative of the mean channel velocity. That is the velocity measured by a flow tube suspended at 0.6 depth from the water surface in the center of a channel would give readings consistently proportional to the actual mean channel velocity (Q divided by area).

Measurements recorded from the flow tubes in the completed facility were not consistently proportional with the mean channel velocities as determined from the Delta Pumping Plant discharge. This inability to develop a correlation between mean channel velocities and flow tube readings led to an investigation of flow as it actually occurred in the primary channels under operating conditions.

Price current flow measurements and observation associated with the testing program revealed that flow was not as uniform as had been indicated by the model studies and that beginning from the start-up of the Delta Pumping Plant pumps unsteady flow conditions existed in the primary channels for about 30 minutes as storage in the same two mile long intake channel between the fish facility and the pumping plant was adjusted to normal flow depth. Also, an indeterminacy factor was introduced by a small irrigation diversion betwen the fish facility and the Delta Pumping Plant. Even after the flow had become steady and allowances were made for the irrigation diversion, the flow measurements - especially for Channels 3 and 4 did not accurately represent the velocity as determined by the calculated mean velocity (Q over area). Stabilization of the flowmeters suspension systems (including bracing of the upstream gantry crane rail), and a thorough re-building of their control and recording instruments brought the flow tubes into closer accord with computed mean velocities.

A plotting of flowmeter readings against computed velocities then showed that the flowmeter in Channel 2 produced readings that correlated most closely with the computed velocities.

Inconsistencies in current meter measurements straight across the channel led to some two dozen Price current meter traverses along the front of the louver lines. Velocity measurements at 0.2 and 0.8 depths from the water surface were taken at 8 to 9 evenly spaced points along the front of the line of louvers at a distance of 3 feet normal to the leading edge of the louvers. The first point was taken at the start of the louvers and the last point near the bypass intake.

Findings derived from these measurements may be summarized as follows:

Channel 1. In general, flow conditions along the line of louvers were favorable. There were several unexplainable instances of reductions in velocities between the first and second points of measurements. At larger flows with higher velocities as related to channel depths, there was only a slight increase in velocities from about midpoint of the line of louvers on into the bypass.

Conclusion. From a standpoint of velocity increase along the louvers Channel 1 performs more favorably at lower approach velocities.

Channel 2. At lower flows (700 cfs) at velocities of about 2.5 ft/s conditions were only marginally favorable, increases in velocities were not as smooth as desirable. Midrange flows (1,120 cfs) at low velocities produced unfavorable conditions. Medium approach velocities created conditions that were nearly favorable, but displayed many erratic changes. Higher velocities (3 to 3.5 ft/s) produced the most favorable conditions.

The highest flows (1,470 cfs) produced only reasonably favorable velocity patterns.

Conclusion. Velocity increase along the line of louvers in Channel 2 is more favorable at higher than at lower channel approach velocities.

There are no obvious explanations of the contrast in the velocity conditions along the louver line between Channels 1 and 2. The dimensions and configurations, including appurtenant structures such as trashracks and control gates, are virtually identical for both channels. Possibly the primary nets which were below the louvers in Channel 2 during the velocity measurements were a factor.

Channels 3 and 4. As standard procedure, Price current meter readings were made at 0.2 and 0.8 depth at each point on the traverses along the front of the line louvers in Channels 3 and 4, as was done in Channels 1 and 2. In the cases for Channels 1 and 2, there was a consistent relationship between the velocities measured at the two depths. Velocities at the two depths at each point in Channels 3 and 4 were not consistent and in fact plots of the 0.2 and 0.8 depths measurements produced crisscrossing patterns. Because of the wide variance between the 0.2 and 0.8 depths measurements for Channels 3 and 4, they were analyzed separately resulting in the following findings:

Channel 3 - Out of 10 velocity measurements traverses only 5, all at the 0.2 depth, were favorable. At the 0.8 depth one was marginal in not having a steady increase and 4 were considered unfavorable due to erratic changes or in having instances of decreasing velocity toward the bypass along parts of the line.

Channel 4 - None of the ten traverses showed a favorable velocity condition. Five of the runs at the 0.2 depth could be labeled marginally acceptable, but the remaining five at the 0.8 depth were definitely unfavorable.

Measurements were made for only two flows (1,120 cfs and 1,470 cfs) and the corresponding approach velocities were low (less than 2.5 ft/s). There was an indication that velocity flow conditions for both Channels 3 and 4 were more favorable at greater than 2.5 ft/s velocity.

Velocities at all flows were consistently higher in Channel 4, which was probably due to head loss created in Channel 3 by the collection nets downstream of the louvers.

Considering the following list of favorable conditions in the waterways upstream of the louvers there are no readily apparent reasons for the unfavorable velocity increase conditions along the lines of louvers in Channels 3 and 4:

1. Smooth approach flows in the intake channel, which is broad and deep relative to the fish facility channels.
2. No obvious consistently undesirable currents in the inlet transition to the facility.
3. In place trashracks of 2-inch vertical spacing should be effective in creating uniform flow.
4. Debris load was light - head loss due to plugging of the trashracks was minimal (less than 0.3 feet).
5. No apparent significant swirls or other undue turbulence was created by the wing type control gates.

Secondary Turbulence

Close visual observation of the secondary channel led to the conclusion that there was an undesirable amount of turbulence in the secondary channel ahead of and in conjunction with the louvers. Uneven flow and swirls were evident at the outlet of the bypass transition to the open secondary channel and a particularly noticeable turbulence was created along the left wall by vertical joints of the steel screened water inlet structure.

Undue turbulence attributable to the louvers was created by a nearly three-inch gap between the right wall and the first louver slats, misalignment of louver panels, and a dead water area in back of the first few louvers on the right side.

No quantitative measurements (such as head loss, wave height or velocity changes) of the turbulence were taken, but rather the amount of turbulence at a particular location was visually compared to an area of smooth flow, or in the case of the louver, with the normal turbulence at vertical slats.

The specific effect of excess turbulence on the guiding of fish along the louvers and on into the bypass intake was not determined, but it is generally accepted that unusual turbulence may cause the fish to dart through the louvers. This is probably particularly true in the area near the downstream end of louver lines, where the screened water outlet and the bypass intake converge.

Model studies prior to construction of the facility had shown that unequal flow of less than 10 percent between the two bypass intake pipes would result in undesirable turbulence and that it would not be feasible to design a transition that would satisfactorily smooth out unequal flows that did occur and an undefined amount of turbulence did exist in the secondary channel immediately ahead of the louvers. Without recourse to model study or theoretical calculations a set of vertical and horizontal vanes of heavy steel plate was installed in cross-hair arrangement in each of the rectangular bypass outlet transitions. The effectiveness of these guide vanes were unmeasurable, but some apparent smoothing out of flow at the head of the louvers was attributed to them.

Smoothing out and filling in the offsets of the vertical joints of the screened water outlet structure significantly reduced turbulence along the left wall.

Discontinuity of the line of the leading edge of the vertical slats of adjacent louver panels created very noticeable variations in the amounts of turbulence along the front of the louvers. Each louver panel is held in position by two vertical guide sleeves on the backside which fit down over two non-adjustable 3-inch diameter aluminum support posts firmly and permanently anchored in the channel floor. Discrepancies in the support posts alignment and incongruity in dimensions of individual panels resulted in the leading edges of certain louver panels being up to an inch ahead or back of adjacent panels. A major portion of this louver misalignment was corrected by the installation of set screws in the guide sleeves to provide for line adjustment by forcing a panel closer to or farther from a support post.

The gap between the right wall and the first louver slat was remedied by the simple solution of filling it with an appropriate size of steel plate coated with protective coating.

Layout of the junction of the louver system and the right wall of the secondary channel resulted in a triangular shaped recessed area about seven feet in length and over a foot deep in back of the trailing edge of the closest louver guide vane. Water flowing through the first dozen or so of the louver openings is directed into this recessed area. Flow which enters these particular openings (at normal to the channel as it does through all louver openings) is redirected back downstream parallel to the sides of channel by flow straightener vanes which take the place of every eighth vertical slat. There is, however, a distinct reduction of flow through these first dozen or so openings due to a boundary of non-flowing water created in the area between the first guide vanes and the right wall.

No definite solution of this problem was developed during the testing program. One possible remedy would be to wall off as much of the recessed area as possible leaving the required opening around the support posts. This could be undertaken on a trial and error basis before a permanent installation can be made.

The velocity measurements described in this study were not extensive. In addition they were conducted while the large louver nets were in a fishing position and thus could have affected flow and velocity patterns. Nevertheless, in view of the observations reported and the apparent necessity for uniform flow patterns under the louver concept, a more detailed study of the velocity and flow patterns in the primary channels of the Delta Fish Protective Facility appears warranted.

APPENDIX B

NET SPECIFICATIONS

(a) Description.--This section covers the contract item Nets, which includes 26 nets. Each net includes a main net and a cod end.

(b) Materials.--Materials shall conform to the following:

Net Pattern	Marion Textiles Pattern No. 281, or exact equivalent
Net Material	Nylon
Riblines and Mouthlines	3/8-inch double braided nylon rope
Lifting Line; 1 coil (600 ft.)	1/2-inch Polydacron
Lacing Material, 2 coils (1,200 ft.)	5/16-inch Polypropylene
Reinforcement Material	9 ounce per square yard bullistic nylon tape and Dacron sailcloth
Mouth Thimbles	3/8-inch steel, galvanized, sized to fit 7/8-inch safety hook
Splitting Straps; 12 pcs., 9 ft. each	1/2-inch Polydacron rope
Rings	1-1/2-inch O.D., 3/16-inch steel, galvanized
Grommets	1/2-inch I.D., brass

(c) Dimensions.--Net dimensions shall be as follows:

(1) Eighteen (18) Nets:

Overall Length	63 feet
Length to Beginning of Cod End	56 feet

Mouth Size	9 feet by 10 feet
Cod End	18-inch by 18-inch by 7 feet

The nets shall taper directly from the mouth to the beginning of the cod end.

(d) Fabrication.--All material shall be merrow-sewn so that the seams will be on the outside of the net. The interior surface of the net must be smooth, with no seams or snags that will entrap, catch or hold fine debris.

Netting must be fabricated so that when net is in the fishing position meshes will not close under strain.

Along the four longitudinal seams, at the corners the netting shall be shaped and attached to riblines and mouthlines so as to relieve direct strain on the netting at the point of attachment to the mouthlines and riblines.

The mouth corners shall be reinforced inside the outside with 9 ounce bullistic nylon as shown. Grommets shall be spaced every 6 inches around the mouth as shown. Mouthlines shall be attached to the mouth and reinforced with 4-inch bullistic nylon tape.

Riblines shall be sewn to the corners of the net and through the 4-inch bullistic nylon reinforcement tape binding to prevent slippage along the riblines (see drawing). Ribline ends shall be eye spliced and fitted with thimbles.

Four (4) rings 1-1/2-inch diameter, 3/16-inch stock shall be installed at the junction of the main net and cod end for splitting strap capable of lifting 3,000 pounds (see details on Plate 5).

Splitting straps will be appropriately spliced and fitted through rings.

Rings shall be installed at the end of the cod end as shown to accommodate a line to close cod end off.

All but the last 12 inches of the cod ends of the 9' x 10' x 63' nets shall be reinforced with Number 18 thread 2-inch nylon mesh web so as to be capable of holding 2,000 pounds.

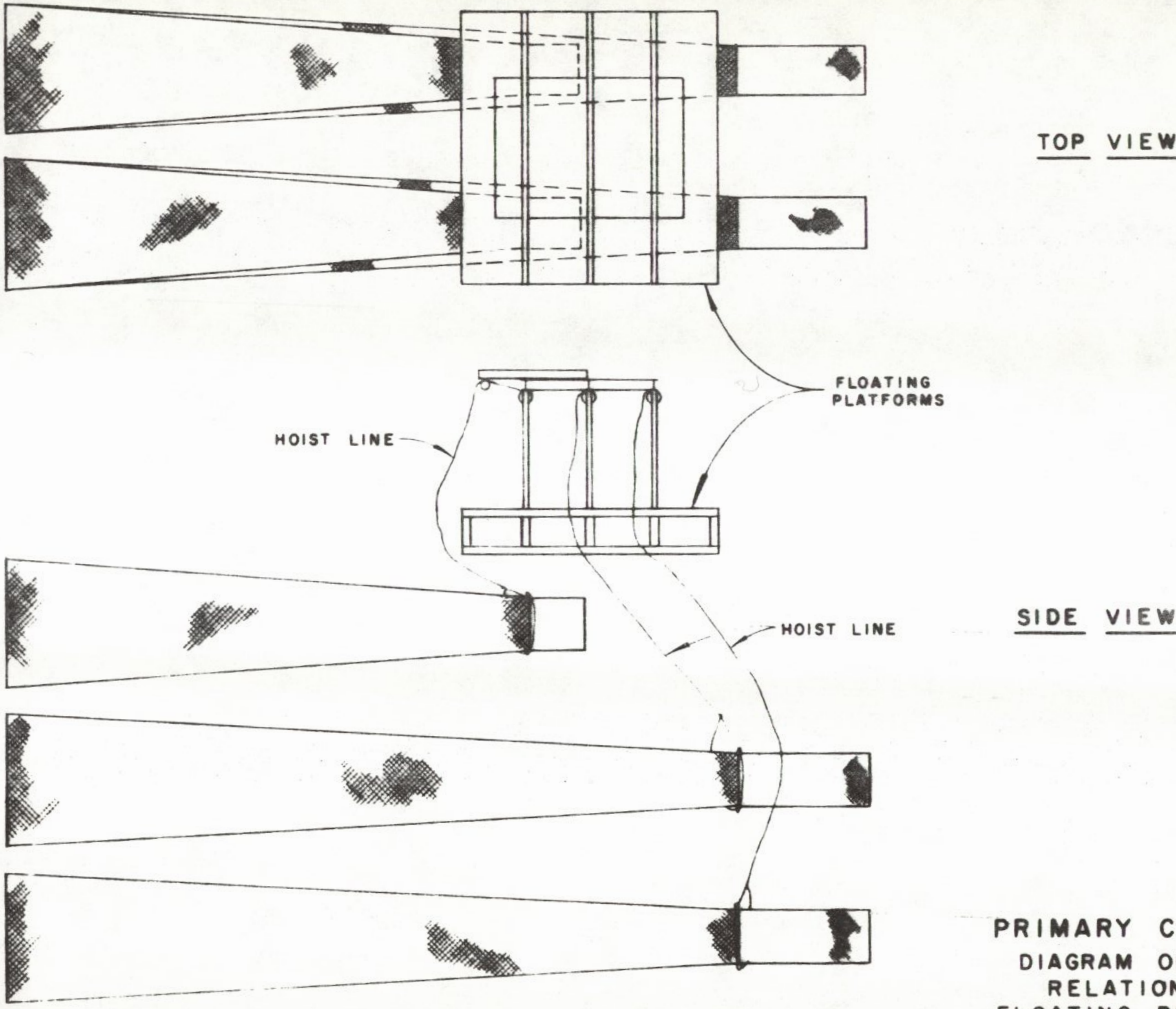
Dimensions of Modified Trawl Nets
Used in the Delta Fish Protective
Facility Evaluation Program

	Primary Louver Nets	Primary Bypass Nets	Secondary Louver Net
Number of Nets	12(6)[1/]	4(4)	
Mouth Size (feet)	9.0 x 10.0	4.0 x 5.0	10.0 x 10.0
Area of Mouth (sq. ft)	90.0	20.0	100.0
Terminal Size ft	1.5 x 1.5	1.5 x 1.5	1.5 x 1.5
Taper	Straight	Straight	Straight
Length to Cod End ft	56.0	14.0	37.5 ft
Length of Cod End ft	7.0	4.0	7.0
Dimensions of Cod End ft	1.5 x 1.5	1.5 x 1.5	1.5 x 1.5
Surface Area of Main Net (sq. feet)	1232	168	875
Surface Area of Cod End (sq. ft)	42.0	24.0	42.0
Total Surface Area (sq. ft)	1275	192	917
Ratio of Surface Area to Mouth Area	14:1	9.6:1	9.2:1
Clear (open) Area of Net (sq. ft)	383	58	275
Ratio of Clear Area to Mouth Area	4.3:1	2.9:1	2.8:1

[1/] Numbers in parentheses indicate number of spare nets.

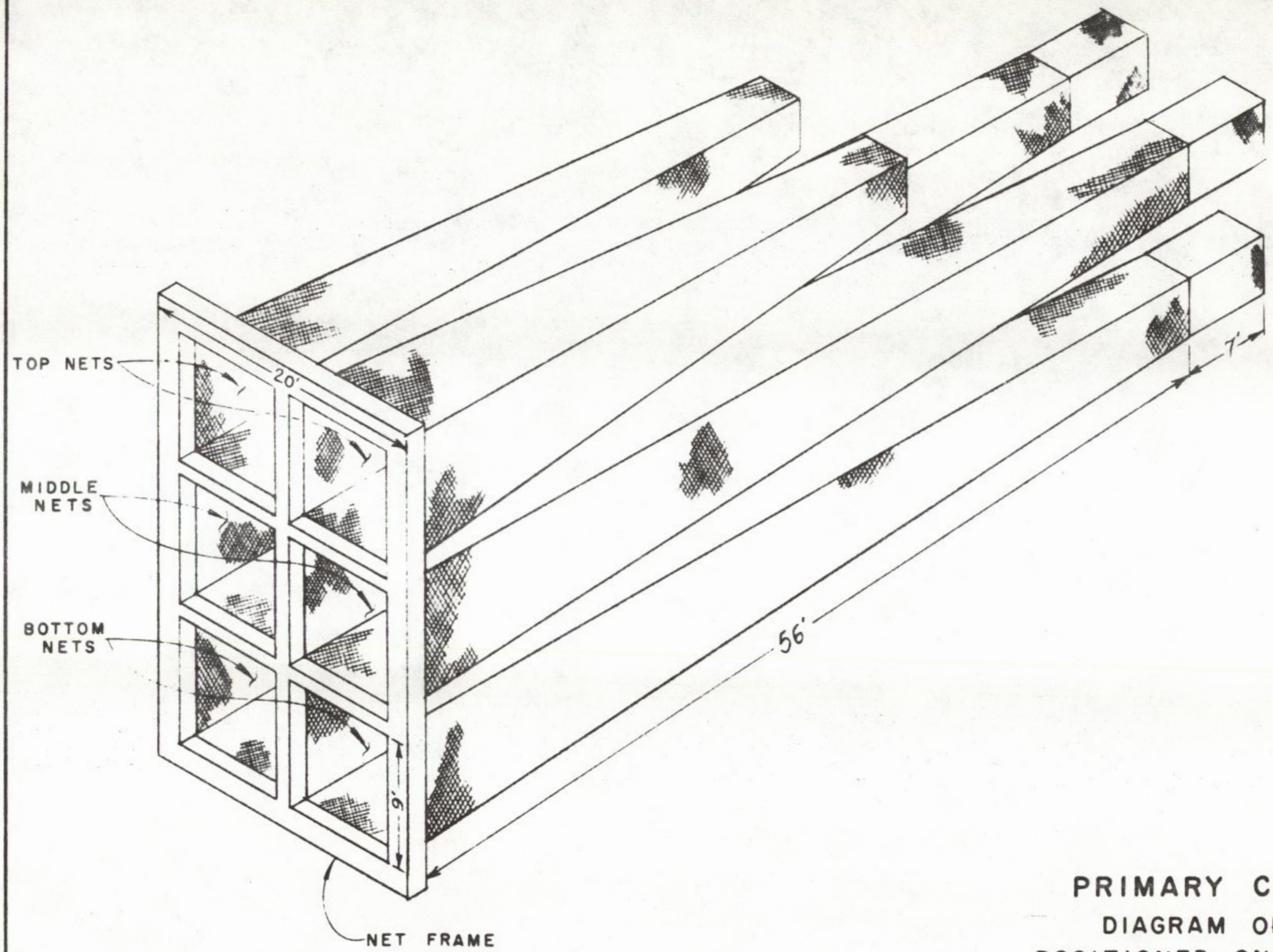
APPENDIX C

PLATES



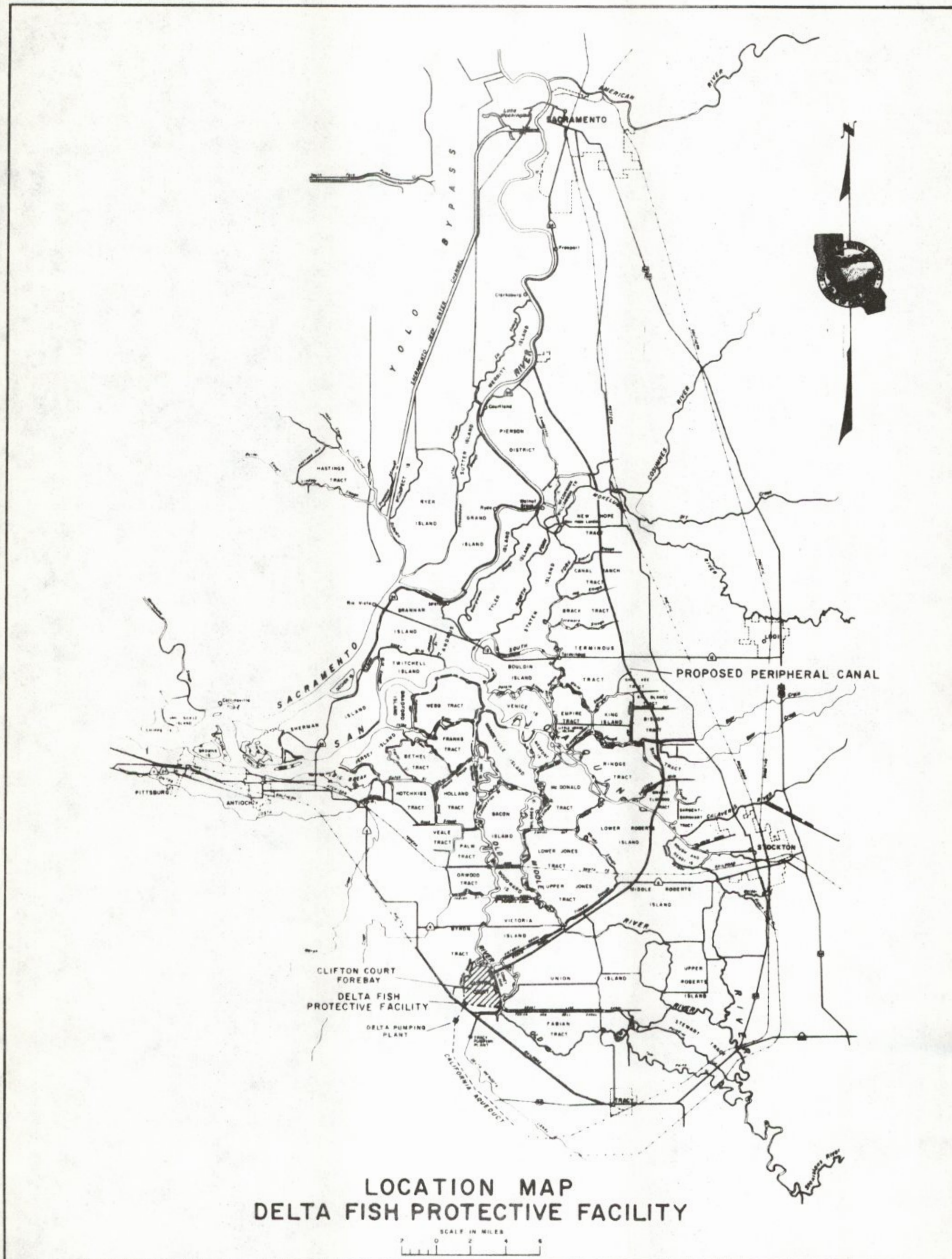
PRIMARY CHANNEL
DIAGRAM OF NETS
RELATION TO
FLOATING PLATFORM

PLATE 3



PRIMARY CHANNEL
DIAGRAM OF NETS
POSITIONED ON NET FRAME

PLATE 4

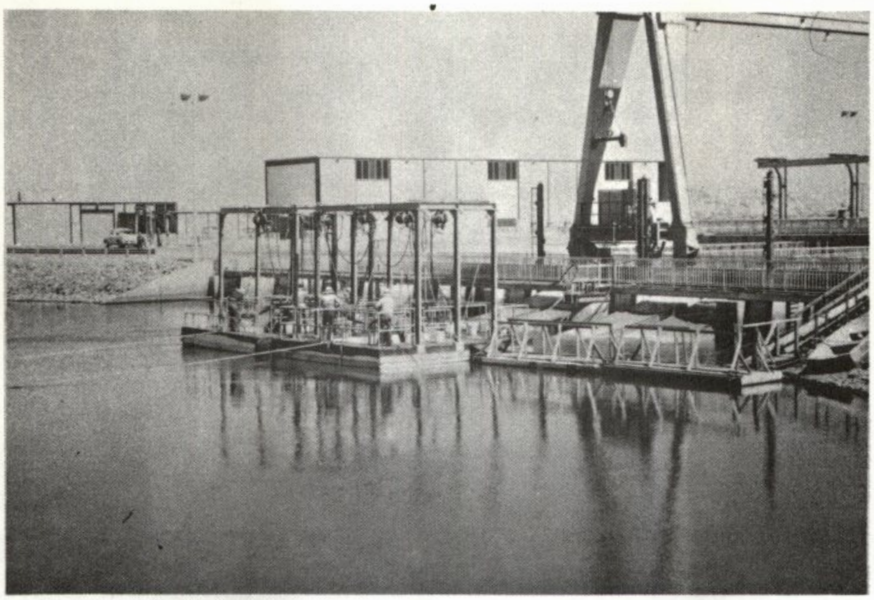


LOCATION MAP
DELTA FISH PROTECTIVE FACILITY

PLATE 6

APPENDIX D

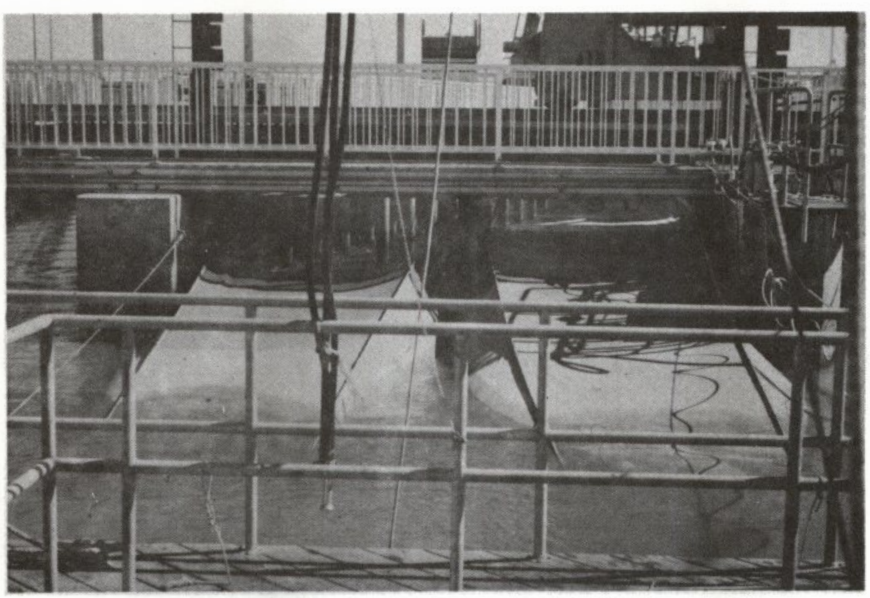
PHOTOS



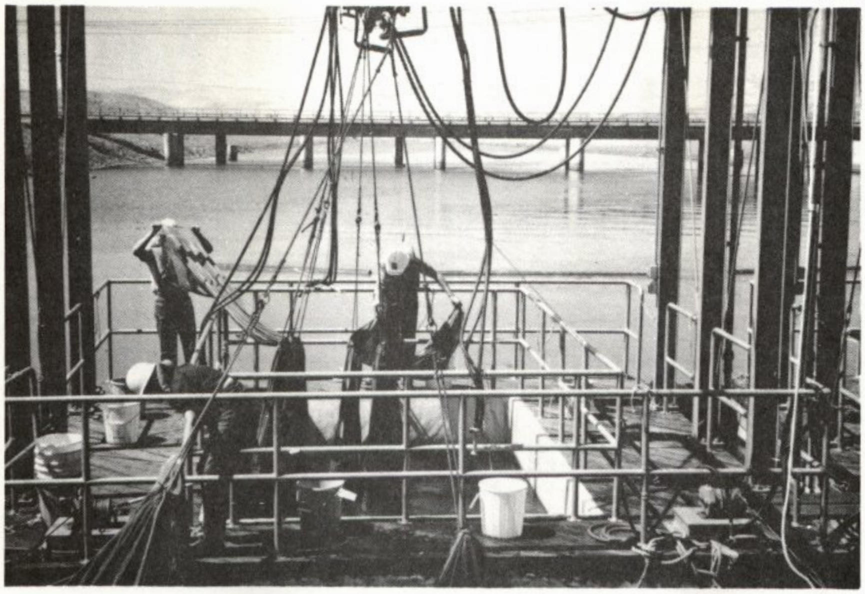
1. Floating platforms and gantry crane from downstream on left bank.

2. Primary net frame suspended from gantry crane. Nets off - two nets hung on handrailing.

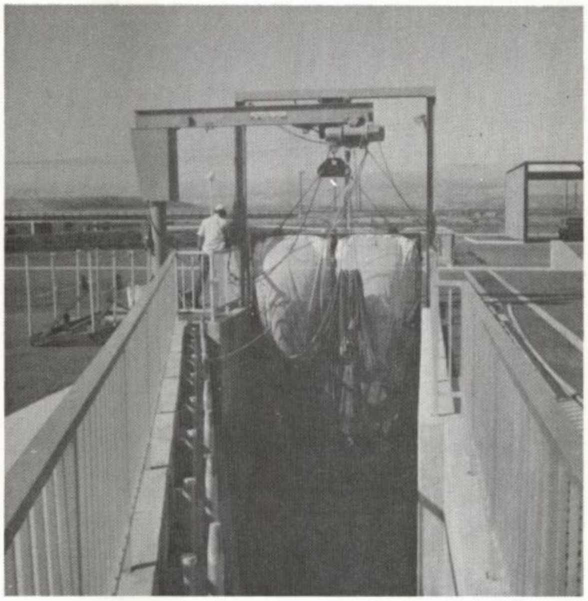
3. Primary nets being attached to net frame.



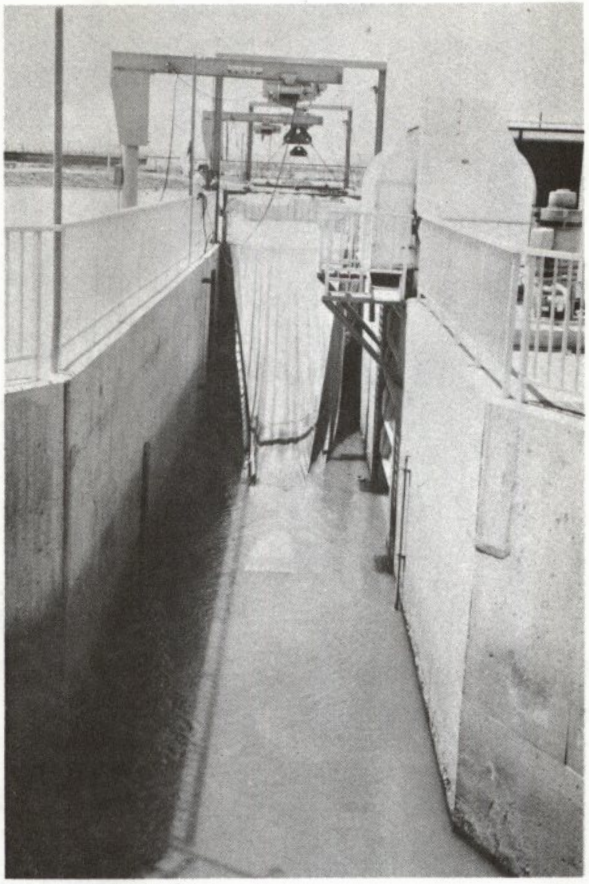
4. Top primary louver nets in fishing position. Separation of nets due to no flow in adjacent bays.



5. Primary louver nets being emptied. Note yoke on the hoist line and connection to splitting strap.

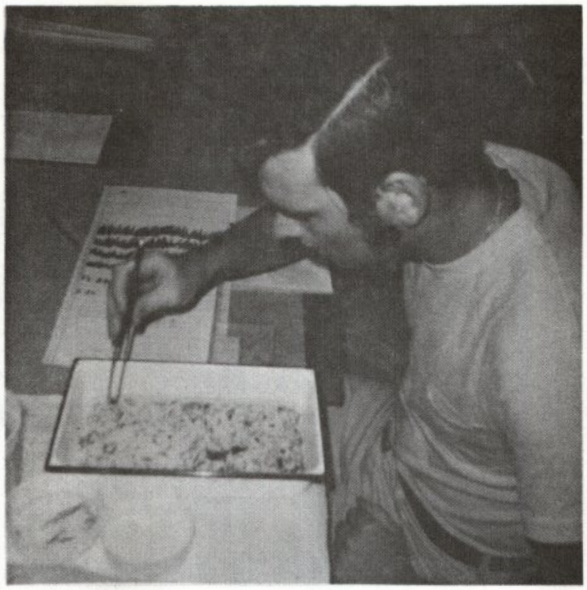


6. Primary bypass nets in elevated position. Note splitting strap on cod sections of nets.

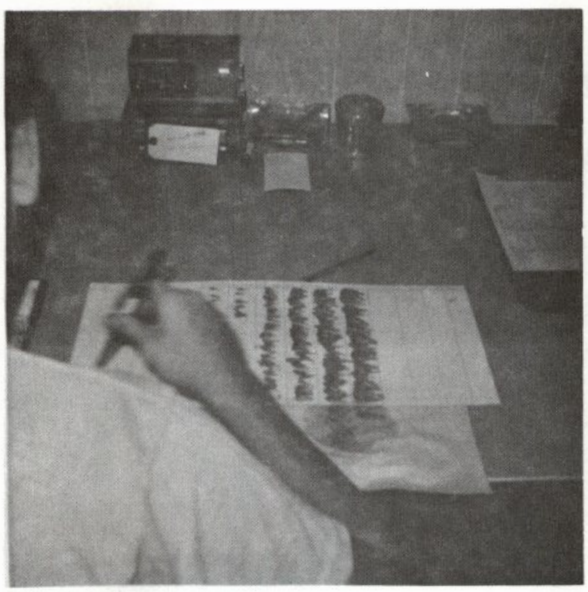


7. Secondary louver net in elevated position.

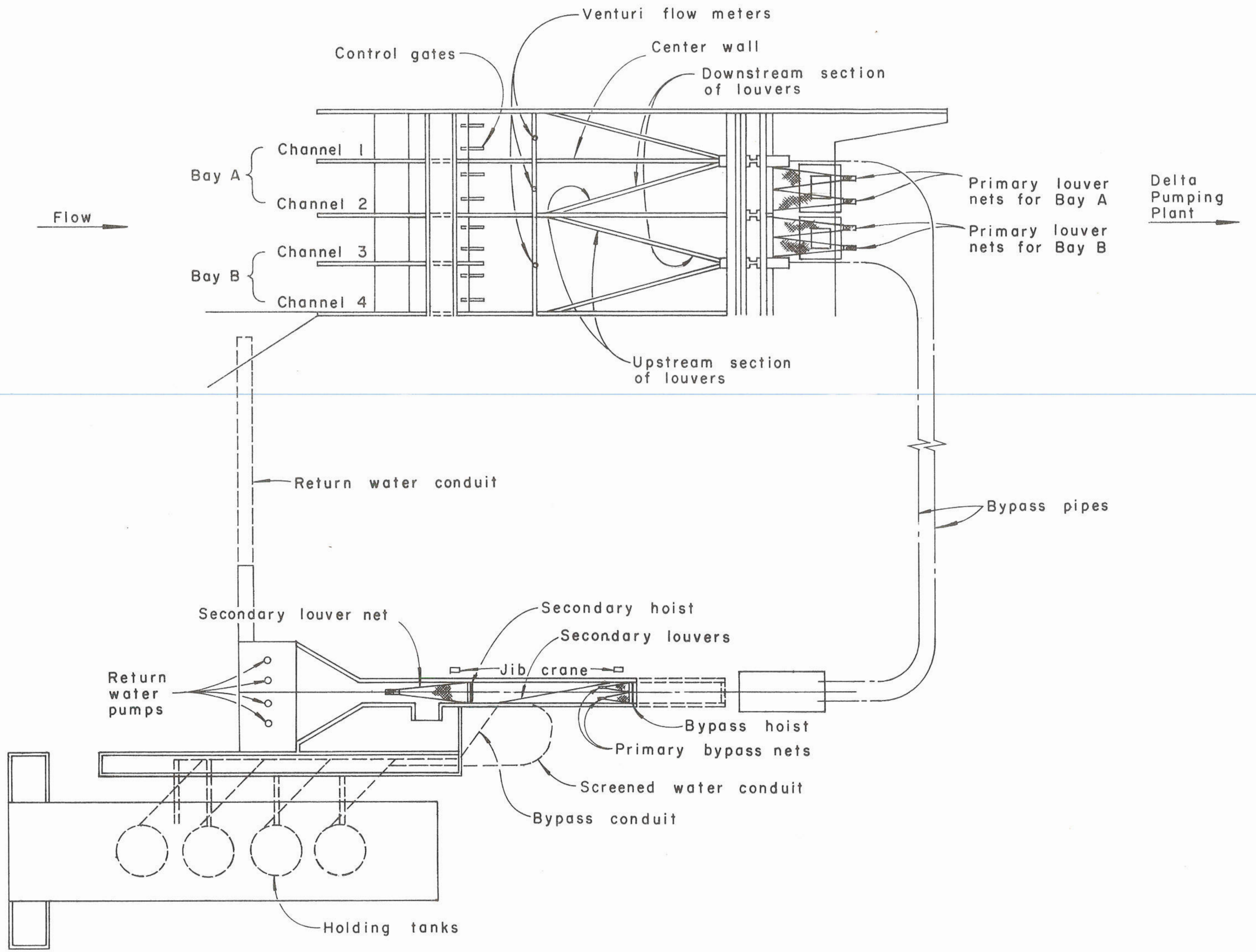
8. Plastic tray with lattice divider for subsampling large samples.



9. Stiped bass being picked and measured from sample.

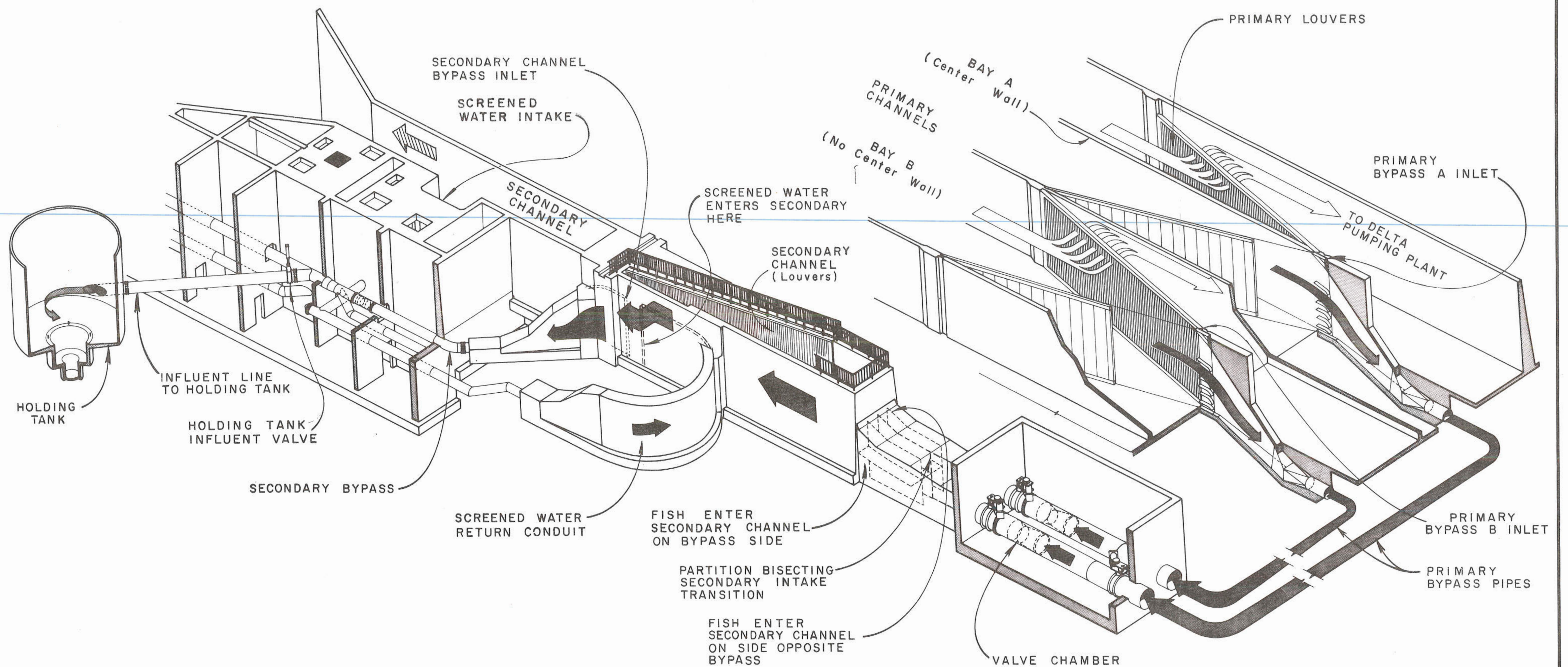


10. Bass of various size groups aligned to facilitate counting.



DELTA FISH PROTECTIVE FACILITY
EVALUATION TESTING AND FISH COLLECTING FEATURES
PLAN

PLATE I

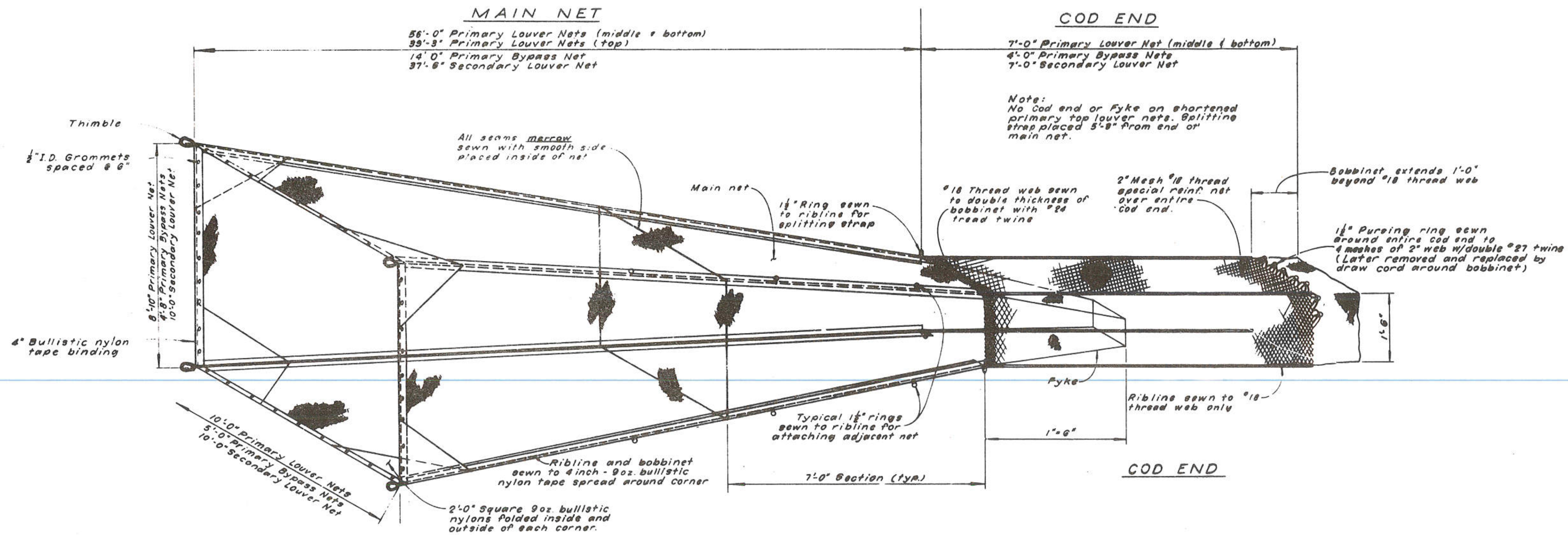


DELTA FISH PROTECTIVE FACILITY

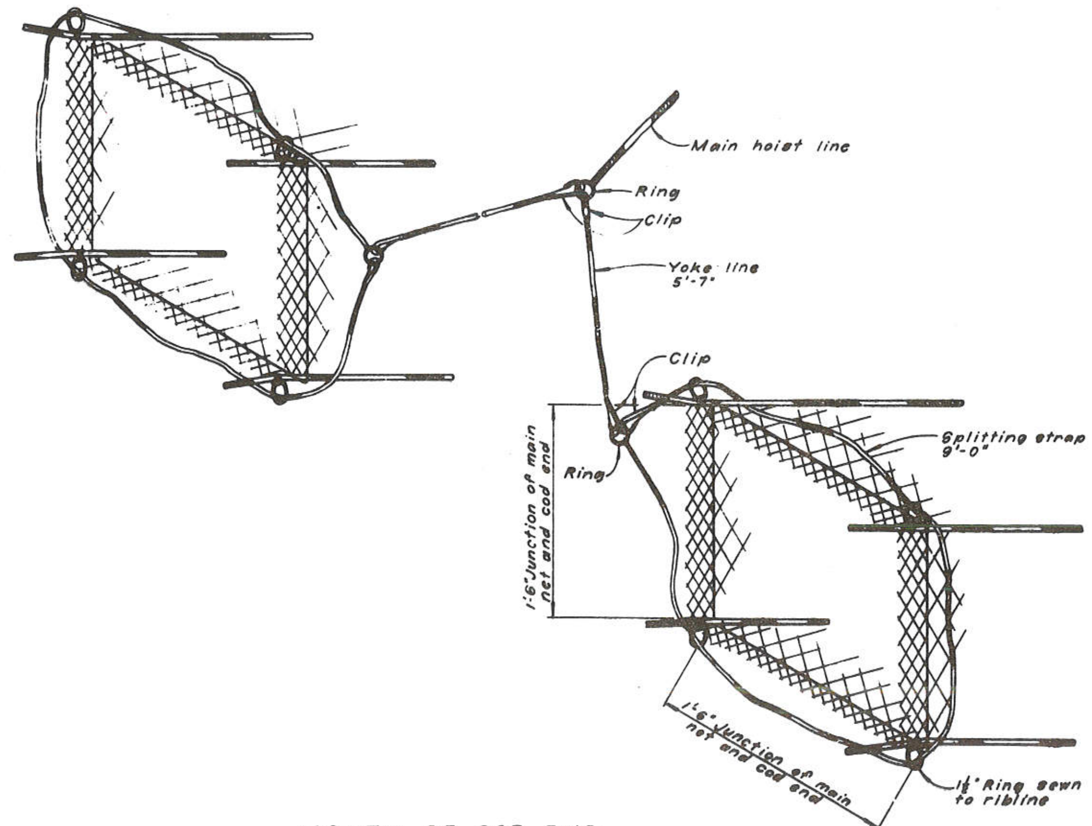
FISH COLLECTING FEATURES

SCHEMATIC

PLATE 2



NETS



MOUTH OF COD END

TEST NETS
DIMENSIONS AND DETAILS