IMPROVING FISH SCREEN DESIGN AND OPERATION FOR NATIVE SACRAMENTO-SAN JOAQUIN WATERSHED FISHES

Amount Requested $2,073,391(at 48.5% federal overhead rate, or $1,554,062 at 10% state overhead rate) for two years (08/1/03-07/31/05)

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A. PROJECT DESCRIPTION: PROJECT GOALS and SCOPE OF WORK

1. Problem

Installation of fish screens and improvements to existing fish screen facilities have been identified by CALFED as activities that provide direct benefits to fish resources and the ecosystem by reducing stressors associated with water diversions (e.g., Restoration Priority SR-6). The Ecosystem Restoration Program Plan (ERPP, Vol. 1, p. 425) contends that a "well-designed fish screen based on proven technology is effective in reducing entrainment and impingement losses of many species of juvenile fish." However, for most native fishes of the Sacramento-San Joaquin system, including priority listed species like delta smelt and splittail, there is no "proven technology." For these species (and others of concern), present fish screen regulatory criteria and screening technologies, developed from limited studies with salmonids and non-native fishes, may be inadequate and confer no protection from entrainment and impingement or, alternatively, overly protective and thus unnecessarily costly to water diverters.

What is needed are data to evaluate and improve aspects of fish screen design and operation with specific applications to improving protection of native priority species that reside in and migrate through the Sacramento-San Joaquin Delta and greater watershed. The Fish Treadmill project was designed to provide these data and, for the past several years, has been providing scientifically-based, quantitative data on the effects of flow and other environmental conditions on the responses of native Delta fishes exposed to a simulated fish screen. In the coming two years, we propose to build on the results of this successful program and determine the specific effects of alternative methods (including pilot studies) to facilitate fish passage past these screens, including use of: a) very high sweeping velocities that greatly minimize exposure duration and the potential for screen contact; b) "fish friendly" physical crowding devices to push fish past the screen; and c) visual stimuli to encourage volitional movement downstream (i.e., linkages A and B shown in the Figure 1 conceptual model). We also propose to determine the effects of debris loading on fish screen function (i.e., near-screen flow fields and "hot spots") and resultant fish responses (i.e., linkages C, D, and E shown in the Figure 1 conceptual model). Finally, we propose to incorporate within these experiments a series of complementary studies determining the role of non-visual sensory abilities (e.g., mechanoreception using the lateral line) of Delta fishes in the detection of fish screens and their associated turbulent flow fields.

The results of the proposed studies are particularly critical to inform and guide progress on CALFED's planned retrofits of fish screens at the State Water Project (SWP) and Central Valley Project (CVP, including the Tracy Fish Test Facility, TFTF), as well as for other proposed fish screen facilities (e.g., Through-Delta Facility, Clifton Court Forebay modifications).

2. Justification

The proposed studies emanate from multiple discussions with federal and state agency engineers and fisheries biologists tasked with developing the fish facilities needed to implement the California Bay-Delta Authority's programs and protect California's fisheries resources and water supply. The Fish Treadmill project is an ongoing targeted research program that directly addresses the uncertain impacts of water diversions and fish screens on fishes. The project is presently providing rigorous, quantitative data on effects of flow (i.e., combinations of approach and sweeping velocities) and environmental conditions (temperature, day vs night) on the behavior and survival of priority species, including delta smelt, splittail, chinook salmon, steelhead, and sturgeon, near a fish screen. In addition, the project has already submitted reports to state and federal fish screen engineers and biologists that document examples of potential applications of Fish Treadmill results for the development of fish screen design and operational criteria (copies of these reports are presented in Appendix IV). With this proposal, we request next-phase funding to build upon this applied research and redirect our efforts towards those environmental and biological factors now known to significantly affect fish responses near fish screens and that will have the greatest applications for improved fish screen design and operation.

The importance of fish screen flow and design criteria and their potential differential impacts on survival and passage of anadromous and Delta fishes is already indicated by preliminary and, for some species, final results from the Fish Treadmill project (most recently described in a final technical report submitted to CALFED in November 2001: Swanson et al. 2001; and in a series of "Research Findings" submitted to the Anadromous Fish Screen Program, and attached as Appendix IV). Results collected thus far have been regularly communicated to engineers and biologists (e.g., at scientific and informal meetings, workshops, and during visits to the laboratory) to solicit their input and apply our research results to current and anticipated fish screen-related problems[1].

The Fish Treadmill research program began with the conceptual model shown in Figure 1, which identified the hypothesized effects of flow, environmental, and biological factors on fish performance and behavior near a fish screen. During the past few years, results of Fish Treadmill experiments with a number of priority species have identified and quantified significant effects for a number of the hypothesized linkages and, importantly, illustrated the variable responses among different species. Table 1 summarizes some of these results for delta smelt, chinook salmon, and splittail, and relates them to linkages shown in the conceptual model (Figure 1).

These results show that flow (i.e., approach and sweeping velocities) influences screen contact rates in these three species but that the responses are substantially different among them,

[1] Recent meetings include April 18, 2003 (UC Davis Hydraulics Laboratory), March 27, 2003 (Department of Water Resources, Environmental Services Office), February 19, 2003 (Federal Building, Sacramento).

with contact rates decreasing with increases in flow for chinook salmon and splittail while, for delta smelt, increases in flow result in higher contact frequency and severity (as measured by screen impact velocity)[2], impingement, injuries rates and severity, and ultimately significantly reduced survival. In contrast, flow effects on passage show a different pattern and pose potential design conflicts for screens intended to reduce contact and mortality. For example, for all three species, use of intermediate sweeping velocities (i.e., 1 foot/second, fps) to stimulate passage was generally ineffective because most species responded by sustained swimming against the flow with little net movement downstream. Higher sweeping velocities resulted in net downstream movement but, for the delicate delta smelt, significantly higher mortality. Recently these Fish Treadmill results for chinook salmon screen passage were validated in the field, comparing the performance and behavior of the laboratory-tested fish with that of juvenile chinook salmon released and videotaped near two operational screened diversions (Glenn-Colusa Irrigation District diversion on the Sacramento River and Parrot-Phelan diversion on Butte Creek). Preliminary analysis confirms that, for this species, downstream passage at diversions with intermediate sweeping velocities is problematic.[2] In addition, for all of species tested to date, there are substantial differences in both screen contact rates, passage and, for delta smelt, resultant survival, at different time of day/light levels, illustrating the importance of both visual and non-visual cues in shaping the performance and behavior of Delta fishes near fish screens.

These early Fish Treadmill results have been reported and discussed widely among California Bay-Delta Authority member agencies engaged in fish facility development and improvement (including U.S. Bureau of Reclamation, USBR, Department of Water Resources, DWR, Department of Fish and Game, DFG, U.S. Fish and Wildlife Service, USFWS, and NOAA Fisheries), as well as interagency groups such as the Central Valley Fish Facilities Review Team (CVFFRT) and the Anadromous Fish Screen Program Technical Team, and reported at numerous scientific and technical meetings (see Appendix III). Based on collective recommendations of these experts, we propose studies to address three objectives:.

Objective 1. Determine the specific effects of alternative methods (including pilot studies) thought to facilitate passage, including use of: a) very high sweeping velocities that greatly minimize exposure duration and the potential for screen contact; b) "fish friendly" physical crowding devices to push fish past the screen; and c) visual stimuli to encourage volitional movement downstream (i.e., linkages A and B shown in the Figure 1 conceptual model).

Objective 2. Determine the effects of debris loading (including pilot studies) on fish screen function (i.e., near-screen flow fields and "hot spots") and resultant fish responses (i.e., linkages C, D, and E shown in the Figure 1 conceptual model).

Objective 3. Determine the role of non-visual sensory abilities (i.e., mechanoreception using the lateral line system) on the performance and behavior of selected Delta fishes exposed to a simulated fish screen, with an emphasis on the examining the effects of lateral line inactivation on screen contact rates (i.e., the ability of the fish to avoid contact with the screen) and screen passage.

The experiments addressed by the above objectives will complete a comprehensive

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[2] Results of these studies were reported at the CALFED Science Conference (January, 2003) and the Annual Meeting of the American Fisheries Society, Western Division (April, 2003).

exploration of Delta fish responses to vertical wedgewire screens. For future studies, with minor modifications to the versatile Fish Treadmill, fish responses to other types of fish screens (e.g., profile bar, punch plate, woven mesh) and associated variables (e.g., mesh open area, mesh opening size, or different types of screen cleaning systems) could be readily conducted.

Figure 1. Conceptual model identifying relationships among those factors and mechanisms hypothesized to influence near-field water diversion and fish screen impacts on fish populations. See Table 1 and Justification section for further description of linkages identified by numbers or letters.

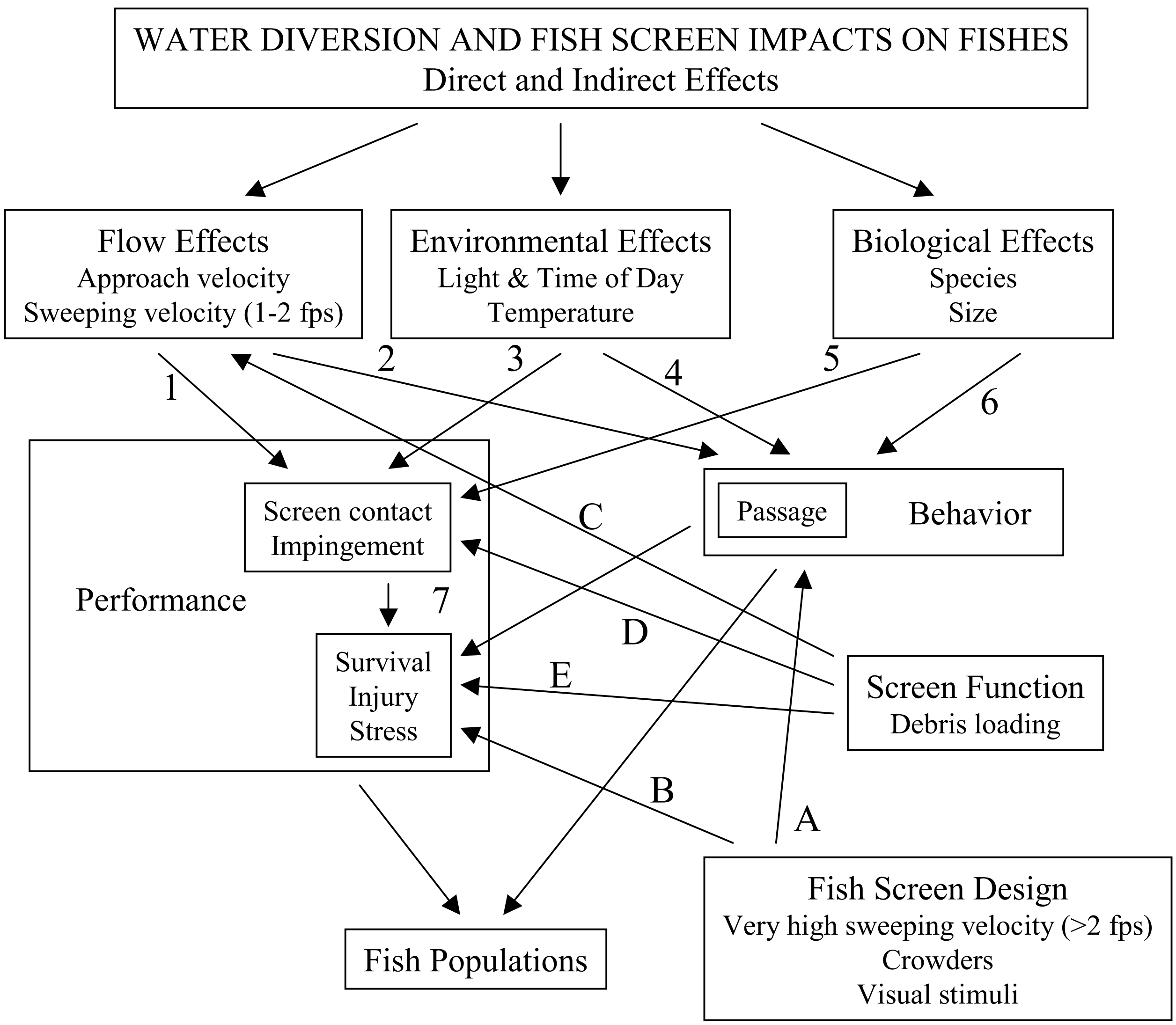

Table 1. Summarized results from selected Fish Treadmill experiments. In the "Response" column, numbers in parentheses relate the result to linkages in the conceptual model shown as Figure 1.

SPECIES	VARIABLE	RESPONSE
Delta smelt	Approach and Sweeping velocity	Screen contact rate, impingement rate, injury, stress, mortality increase with increases in both flow vectors (1, 7).
	Sweeping velocity	Passage is directly related to sweeping velocity (3).
	Exposure duration	Screen contact rate and mortality increase with exposure duration (i.e., time).
	Day vs Night	Screen contact and impingement are higher at night (3). Survival is lower at night (3, 7).
Chinook salmon	Sweeping velocity Day vs night	Screen contact rates decrease with increases in sweeping velocity during the day but are unaffected by flow at night (1, 3). Stress and survival are not related to screen contact rate or flow.
	Size (or life history stage, e.g., parr vs smolt)	Passage is related to sweeping velocity and fish size, particularly at intermediate (1 fps) sweeping velocities (3, 6).
Splittail	Sweeping velocity	Screen contact rates decrease with increases in sweeping velocity during the day but are unaffected by flow at night (1, 3). Stress and survival are not related to screen contact rate or flow.
	Day vs Night	Passage is not affected by sweeping velocity during the day (1, 4). Passage is directly related to sweeping velocity at night (4).

3. Approach

Experimental variables, summarized in Table 2, have been developed in consultation with fish screen engineers and biologists to "bracket" current ranges of fish screen design and operational criteria and to explore more innovative approaches that may ultimately revolutionize fish screens. Experimental measurements are summarized in Table 3. During the period for which funding is requested, we will conduct experiments with the following species[3]:

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[3] Pending availability of adequate numbers of wild-caught or hatchery produced experimental fishes. For some species, use of hatchery produced fish is necessary because the large numbers of fish required for adequately replicated experiments cannot be collected. Analysis and interpretation of results of experiments with these fish will include discussion of the possible differences associated with their hatchery origins, compared with those of wild fish.

- **delta smelt**, juveniles and adults, collected from Sacramento-San Joaquin estuary;
- **steelhead**, parr, collected from state and federal hatcheries;
- **splittail**, young-of-the-year (YOY), collected from Sacramento-San Joaquin estuary and state and federal fish facilities;
- **chinook salmon**, parr and smolts, collected from state and federal hatcheries;
- **green sturgeon**, YOY, hatched and reared at UC Davis, fertilized eggs provided by Yurok Tribe, Trinity and Klamath Rivers; and
- **white sturgeon**, YOY, hatched and reared at Sacramento Valley sturgeon farms.

All experimental fish will be of appropriately small sizes (4-6 cm, 6-8 cm), typically the most sensitive life stages.

The Fish Treadmill is a 6.1-m diameter epoxy-coated steel tank with fixed (2.7-m diameter, wedgewire) and movable (4-m diameter perforated plate) screens, with independently controllable approach and sweeping velocities. It is situated over a 245 kl, temperature-controlled underground reservoir, from which unchlorinated well water is circulated through the device. Although the reservoir's walls are constructed of concrete, there are no concrete walls in the Fish Treadmill (see Hayes et al. 2000 for complete description). Three types of experiments using the Fish Treadmill are proposed.

All Fish Treadmill experiments will be conducted using groups of naive fish. Visual and videotaped observations (see Table 3) will be made throughout the experiment. Analyses will be conducted using measurements made on individual fish and results will be expressed as experimental means and in relation to time (i.e., exposure duration). Subsequent analyses of the effects of environmental variables and experimental manipulations (e.g., mechanoreceptor inactivation) (see Table 2) will be conducted using these reduced data. General linear statistical models relating various performance and behavioral responses to the environmental and biological factors that significantly affect fish responses will be constructed and applied to assist engineers and biologists in the design and operation of new or reconfigured fish screens.

For the mechanoreceptor inactivation experiments, fish will be held in tanks containing the proper concentration of either antibiotics or cobalt salts for 4 d prior to the experiment to remove the functional component in the fish's lateral line system. Results of these experiment will be compared to those using non-mechanoreceptor-inactivated fish in similar environmental conditions (see Table 2) to establish and quantify the lateral line's role in detection and avoidance of fish screens under low light conditions. Treated fish will used in the experiments before mechanoreceptor function recovers (typically 10 d post-chemical treatment).

a. Effects of Fish Passage Enhancement Alternatives: Effects of three alternative methods to facilitate passage (i.e., downstream movement away from the fish screen or into a fish bypass) on fish performance and behavior near a fish screen will be tested. The three methods, 1) very high sweeping velocities (3 and 5 fps); 2) crowding (e.g., a moving barrier of "fish friendly" chain or other weighted flexible material); and 3) visual stimuli (e.g., alternating areas of appropriate-wavelength light and darkness moving downstream), will be tested (including pilot studies) with the range of other environmental and biological conditions shown in Table 2 using methods and measurements already proven effective in earlier Fish Treadmill experiments (see Table 3). Results of these studies will be compared to those from "regular" Fish Treadmill experiments at similar flow and environmental conditions to quantify the effects of the passage treatments.

Hypotheses:

< Very high sweeping velocities will significantly increase downstream passage velocities

and therefore decrease screen exposure time for delta smelt, steelhead, splittail, chinook salmon, green sturgeon and white sturgeon (A, in conceptual model, Figure 1).

- Very high sweeping velocities will significantly decrease screen contact rates for steelhead, splittail, chinook salmon, green sturgeon and white sturgeon; and significantly increase screen contact rate for delta smelt (A in conceptual model).
- Physical crowding will significantly increase downstream passage velocities and decrease screen exposure time and screen contact rates for all tested species (A in conceptual model).
- Visual stimuli will significantly increase downstream passage velocities and decrease screen exposure time and screen contact rates for all tested species (A in conceptual model).
- Very high sweeping velocities will significantly decrease injuries and increase survival for steelhead, splittail, chinook salmon, green sturgeon and white sturgeon; and significantly increase injuries and decrease survival for delta smelt (B in conceptual model).
- Physical crowding will significantly decrease injuries and increase survival for all tested species (B in conceptual model) .
- Visual stimuli will significantly decrease injuries and increase survival for all tested species (B in conceptual model).

b. Effects of Debris/"Hot Spots": Effects of debris loading and resulting approach velocity "hot spots" on fish screen function and fish behavior and performance at selected flow and environmental conditions will be tested. Data from these experiments will be compared with that from "regular" Fish Treadmill experiments at similar flow and environmental conditions.

Hypotheses:

- Presence of debris will significantly decrease screen contact rates at the occluded sections and will significantly increase contact rates at the "hot spots" (high-velocity areas next to the occluded sections) for all tested species (C, D in conceptual model).
- Presence of debris and associated "hot spots" will significantly increase injuries and decrease survival for all tested species (E in conceptual model).

c. Role of the lateral line in performance and behavior near fish screen: Effects of chemical lateral line inactivation on the performance (e.g., screen contact and impingement rates) and behavior (e.g., screen passage velocities) will be tested at selected flow (based on species) and environmental conditions (e.g., day v night). Results of these studies will be compared to those from "regular" Fish Treadmill experiments at similar flow and environmental conditions to examine the role of non-visual sensory abilities in screen avoidance and passage.

Hypotheses:

- Delta fishes use both visual and mechanoreception (e.g., the lateral line system) to detect flow and the fish screen. Inactivation of the lateral line will significantly increase contact rates during both the day and night (5 in the conceptual model).
- Inactivation of the lateral line will significantly increase passage velocities during the night (6 in the conceptual model).

4. Feasibility

The proposed studies have been developed based on a series of discussions with federal and state agency engineers and fisheries biologists responsible for developing the fish facilities needed to implement the California Bay-Delta Authority's programs and protect California's fisheries resources and water supply. This proposal requests next-phase funding for continuation and expansion of a successful, ongoing research program that addresses uncertainties associated with a major CALFED-identified stressor, water diversions. The Fish Treadmill project uses the most appropriate and comprehensive approach to address questions relating to specific aspects of fish screen design, flow criteria, and operation. This cooperative project, with the versatile, fully operational Fish Treadmill apparatus, highly qualified staff, and associated fish collection and maintenance facilities, is the only large-scale fish screen research program capable of testing delicate, high priority native species like delta smelt under wide ranges of realistic, controlled flow and environmental conditions, including very high sweeping velocities (up to 5 fps), and repeatable debris loading/approach velocity "hot spot" conditions. The project has already produced detailed quantitative data that will be used to develop fish screen flow and operational criteria that protect native priority fishes of the Sacramento-San Joaquin watershed. There are no alternatives presently available or in place to meet the stated objectives within the California Bay-Delta Authority's short time frame or to provide needed information for the development and/or evaluation of other CALFED-sponsored programs like the Tracy Fish Test Facility, the Through-Delta Facility, and Clifton Court Forebay modifications.

The targeted research outlined in this proposal is feasible, independent of the outcomes of other projects, and (generally) independent of natural conditions (e.g., weather, although inadequate supplies of wild or hatchery-reared test fishes could affect the rate of research). The Fish Treadmill apparatus has proved to be both versatile and durable with few technical or mechanical failures during the past four years of operation. The project will occur in a laboratory setting and requires no CEQA, NEPA, or other environmental compliance documents. Permits required to continue this project (e.g., DFG/USFWS/NOAA Fisheries collection permits, water discharge permits, and UCD animal care protocols) are approved or have been submitted. A detailed Biological Monitoring/Research Plan (attached as Appendix II) and a Quality Assurance Project Plan have been approved. No zoning regulations, planning ordinances or other constraints that could impact the schedule and implementability of the project are known.

Table 2. Experimental variables and monitoring parameters used in the Fish Treadmill experiments.

PASSAGE EXPERIMENTS		
VERY HIGH	*Approach*	*Sweeping*
SWEEPING VELOCITY	0 (control)	0 (control)
(will be tested	0.2 (6 cm/s)	3.0 (93 cm/s)
at these flows,	0.33 (10cm/s)	3.0
based on results	0.5 (15 cm/s)	3.0
of pilot studies)	0.2	5.0 (155 cm/s)
	0.33	5.0
	0.5	5.0
CROWDER	0 (control)	0 (control)
and	0.2 (6 cm/s)	1.0 (31cm/s)
VISUAL STIMULI	0.33 (10cm/s)	1.0
(will be tested	0.5 (15 cm/s)	1.0
at these flows,	0.2	2.0 (62 cm/s)
pending	0.33	2.0
pilot studies)	0.5	2.0
DEBRIS LOADING/"HOT SPOT" EXPERIMENTS		
DEBRIS LOAD	25% screen occlusion	
FLOW	0 (control)	0 (control)
(selected	0.2 (6 cm/s)	0
based on the	0.33 (10cm/s)	0
results of	0.5 (15 cm/s)	0
pilot studies)	0.2	1.0 (31 cm/s)
	0.33	1.0
	0.5	1.0
INACTIVATED MECHANORECEPTOR EXPERIMENTS		
FLOW	0 (control)	0 (control)
(selected	0.33 (10 cm/s)	0
based on the	0.5 (15cm/s)	0
results of	0.33	1.0 (31 cm/s)
pilot studies)	0.5	1.0
	0.33	2.0 (62 cm/s)
	0.5	2.0
OTHER VARIABLES		
SPECIES	Chinook salmon, Steelhead, Delta smelt, Sturgeon, Splittail	
TEMPERATURE	12°C: winter and spring (delta smelt, chinook salmon, steelhead) 19°C: summer and fall (splittail, chinook salmon, sturgeon)	
TIME OF DAY/ LIGHT LEVEL	Day, light level: 200-300 lux Night, light level: 0-1 lux	
FISH SIZE	small: <6.0 cm SL, medium: 6.0-8.0 cm SL	
NUMBER OF FISH PER EXPERIMENT	20 fish (All fish used only one time in the Fish Treadmill experiments, 3 replicates per treatment.)	
EXPERIMENT DURATION/EVALUATION	30 min - 2 hours/48 hours post-experiment	

Table 3. Measurements made during each Fish Treadmill experiment.

Measurement type	*Definition*	*Method*
FLOW and ENVIRONMENTAL CONDITIONS		
Approach and Sweeping velocity	ft/s and cm/s	3-D acoustic doppler velocimeter, Measured at beginning and end of each experiment
Temperature	°C each	Measured at beginning and end of experiment
Dissolved oxygen	mg/l	Measured at beginning and end of each experiment
Light level	lux	Measured at beginning of each experiment
Debris load	% occlusion	Measured one time at calibration
PERFORMANCE		
Impingement	prolonged (>5 min) screen contact	Measured visually throughout experiment
Screen contact	temporary screen contact	Measured visually throughout experiment
Survival	--------------	Measured at 0 and 48 h post-experiment
Injury	damage to skin, scales, fins, eyes	Measured 48 h post-experiment
BEHAVIOR		
Swimming velocity		
over the ground	cm/s, velocity past screen	,
through the water	cm/s, swimming velocity	*measured using computer-assisted
Orientation (rheotaxis)	orientation relative to resultant flow	*motion analysis of video tapes
Distance from screen	distance (cm) from inner fish screen	-
Schooling	distribution of fish in swimming channel	measured visually throughout experiment

5. Performance Measures

See Section 7, Expected Products and Outcomes, for planned publications, presentations, data reports, and Newsletter articles.

Biological studies with the Fish Treadmill are ongoing and, for the period of February 2000 through July (funding)/October (reports) 2001, supported by CALFED (Project # 99-N02, Program Manager: Jonathan Evans, National Fish and Wildlife Foundation). Currently, experiments are supported by CVPIA/Anadromous Fish Screen Program (Cooperative Agreement No. 114201J075) funding, sponsored jointly by the U.S. Bureau of Reclamation and the U.S. Fish and Wildlife Service. The experimental approach, design, methods, and analyses have already been subjected to rigorous discussion and review. Descriptions of the work and preliminary and final results for delta smelt, splittail, and chinook salmon have been reported in several technical reports (Velagic et al., 1998; Swanson et al. 1998a, 1999; Hayes et al., 2000; Swanson et al., 2001), IEP Newsletter articles, several "Research Findings" submitted to the Anadromous Fish Screen Program (attached as Appendix IV), and presentations at technical and scientific meetings. The purpose of these reports (along with the meetings, workshops, and laboratory visits mentioned, above) is to efficiently transmit our current findings to the engineers and biologists, who are charged with designing and building fish screens, and developing suitable screen criteria to protect native fishes. See Appendix III for a complete list of published articles and presentations resulting from the Fish Treadmill project. One manuscript describing project results has been submitted for peer-reviewed publication and another is nearing completion. Detailed descriptions of all aspects of the project are provided in the Fish Treadmill Quality Assurance Project Plan (QAPP, Swanson et al., 1998b) and the Biological Monitoring/Research Plan (BM/RP) submitted to CALFED in 2000 and attached as Appendix II. This document will be updated to incorporate information and monitoring/assessment protocols required for the new types of studies (e.g., research with previously untested species, investigations of effects of debris loading and mechanoreceptor inactivation) proposed for this next-phase research program.

6. Data Handling and Storage

Data handling and storage are described in the Fish Treadmill Biological Monitoring/Research Plan, attached as Appendix II. These protocols will be updated as necessary for this next-phase research program. All data will be stored by the Principal Investigator for a minimum of five years after project completion.

7. Expected Products and Outcomes

Quarterly reports will include financial status, activities during the quarter, tasks completed, deliverables produced, problems encountered, and a description of modifications to the contract.

Technical reports describing results of the two proposed types of studies will be submitted within three months of completion of that study or, at a minimum, annually. A final technical report will be submitted by November 31, 2005. Status and results of the project will also be presented and discussed at periodic workshops, workgroup meetings of the Interagency partners, UC Davis research staff, outside consultants, and other interested parties, especially to inform the engineers designing the screens and the fisheries agencies determining the criteria.

Results of these studies have been and will continue to be presented at scientific and technical meetings. For example, reports on Fish Treadmill project results for several species were presented in the Fish Passage Symposium at the Ann. Meeting of the California-Nevada Chapter of the American Fisheries Society (March, 2001, Santa Rosa, CA), the State of the Estuary Conference (October, 2001, San Francisco, CA), Fish Screen Symposium at the Ann. Meeting of the California-Nevada Chapter of the American Fisheries Society (April, 2002, Tahoe City, CA), Fish Migration and Passage: Physiology and Behavior Symposium at the Biennial Meeting of the International Congress on the Biology of Fishes (July, 2002, Vancouver, BC), and the Bioengineering Symposium, Ann. Meeting of the American Fisheries Society (August, 2002, Baltimore MD), CALFED Science Conference (January, 2003, Sacramento, CA) and Ann. Meeting of the American Fisheries Society, Western Division (April, 2003, San Diego, CA). In addition to any intermediate presentations of Fish Treadmill results, we will sponsor a workshop to thoroughly describe and explain our final results and to interactively explore their potential applications for developing fish screen design and operational criteria, to be held within three months of the end of the contract period

Results of these studies will also be described in IEP Newsletter articles (one or two articles per year), and in manuscripts submitted for publication in peer-reviewed scientific journals (e.g., Transactions of the American Fisheries Society, North American Journal of Fishery Management, Environmental Biology of Fishes, Copeia, Journal of Experimental Biology, Conservation Biology, Hydrobiologia, and Water Research). One manuscript, based on results of Fish Treadmill studies with chinook salmon, has been submitted for publication in the Transactions of the American Fisheries Society. Another on the hydraulics and fish responses to simulated multiple fish screen exposures is being reviewed on the UC Davis campus. Several others describing Fish Treadmill results with splittail and delta smelt are in preparation.

8. Work Schedule

Funding for this next-phase targeted research is requested for a two-year period beginning August 1, 2003 (July 31, 2003 is the end date for the extended CVPIA/AFSP project). Although the Fish Treadmill project is labor-intensive[4], the proposed work and schedule outlined below are based on year-round Fish Treadmill operation and research, successful completion of an average of 4.5 experiments/week (a work rate consistent with that achieved during the past five years of Fish Treadmill studies), and contingent on adequate funding, personnel, and fish availability. For this period, four tasks are identified (Table 4, and see F. Cost, for specific activities involved in these tasks).

Unlike field-based studies that are subject to unpredictable and variable seasonal conditions, the Fish Treadmill is capable of year-round operation and active research (Tasks 1 and 2). The schedule of experiments for each species is determined by seasonal availability (most species are available in the appropriate sizes during limited seasonal periods, see Table 2), species priority rank (e.g., delta smelt have high priority because they are difficult to collect and maintain in the laboratory), and the numbers and types of experiments required to complete experimental datasets defined in this proposal. In general, experiments with delta smelt and steelhead will be conducted during the winter and spring months while experiments with splittail and sturgeon will be conducted during the summer and fall. Experiments with chinook salmon will be conducted year-round in order to test both small parr-size fish as well as larger smolts.

Preliminary data analysis is conducted concurrently with the experiments. Final data analyses and preparation of the final technical report(s) will be completed as specified in Section

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[4] Data collection of a single Fish Treadmill experiment requires four biologists and two engineers for fours hours, each (=three person days). Subsequent data entry, data analysis (including computer-assisted motion analysis of video tape records made during each experiment), interpretation, and preparation of reports and manuscripts require a minimum of three person-days per experiment. Fish collection is seasonal but requires a minimum of six person days per collection trip. Experimental fish require daily care (one person day). On a yearly basis, the Fish Treadmill project requires a minimum of 1565 person days or 6.26 full-time biologists and engineers.

7. Expected Products and Outcomes above. Fish collection (Task 3) is conducted on an "as needed" basis for each species.

Table 4. Tasks and schedule for proposed Fish Treadmill project.

TASK	SCHEDULE
Task 1. Operation, Maintenance, and Calibration of the Fish Treadmill	Aug. 2003 - July 2005
Task 2. Biological Experiments Using the Fish Treadmill	Aug. 2003 - July 2005
Task 3. Fish Collection	Aug. 2003 - July 2005

B. APPLICABILITY TO CALFED ERP AND SCIENCE PROGRAM GOALS AND IMPLEMENTATION PLAN AND CVPIA PRIORITIES

1. ERP, Science Program and CVPIA Priorities

The Fish Treadmill project addresses a major stressor, water diversions, that has uncertain impacts on fishes in the Sacramento-San Joaquin watershed. The project is specifically designed to produce the scientific information necessary for the California Bay-Delta Authority, the Science Program, and CVPIA to understand, quantify and reduce the adverse impacts of the stressor on at-risk species and to advance the scientific basis of regulatory activities associated with water diversions and fish screen design and operation.

By developing the data and technology to reduce water diversion impacts, the project has links to other ecosystem elements and **CALFED Goals**, including:

a) native species recovery and conservation, with an emphasis on listed species like delta smelt, splittail, chinook salmon, and steelhead trout (**CALFED Goal 1**); and

b) improving recreational and commercial fisheries (e.g., chinook salmon, steelhead trout) (**CALFED Goal 3**).

The proposed targeted research specifically addresses several **CALFED ERP Stage 1 Priorities** including:

a) **MR-6**: Ensure recovery of at-risk species by developing conceptual understanding and models that cross multiple regions. Results of the Fish Treadmill project are particularly relevant to salmonid fishes that utilize wide ranges of habitats within the watershed at several biologically and ecologically different life history stages. Results of ongoing studies with chinook salmon (reported in a manuscript presently in review by members of the Central Valley Fish Facilities Review, CVFFRT) have already illustrated important differences in the responses of parr and smolts to screened water diversions.

b) **SR-2**: Restore fish habitat and fish passage particularly for spring-run chinook salmon and steelhead trout and conduct passage studies. The studies proposed directly address downstream passage of juvenile salmonids past screened water diversion. In addition, some of the information from these studies can be applied to address the issue of the effectiveness of screening for the purposes of fish protection.

c) **SR-6**: Continue major fish screen projects and conduct studies to improve knowledge of implications of fish screen for fish populations. The Fish Treadmill is presently the only operational experimental platform for fish screen studies. Results of ongoing and future Fish Treadmill studies have been identified by CALFED, the CVPIA Anadromous Fish Screen Program (AFSP), and the CVFFRT as essential to inform and guide CALFED-sponsored retrofits and replacements of existing fish screens at the CVP and SWP, as well as for other planned fish screen projects such as the Through-Delta Facility.

d) **SR-7**: Develop conceptual models to support restoration of river, stream and riparian habitat. In addition to information on steelhead and chinook salmon life histories, needs and responses to restoration (i.e., installation of fish screens), the Fish Treadmill project will provide similar information on delta smelt, splittail, and sturgeon.

e) **SJ-3**: Improve rearing and spawning habitat and downstream fish passage on tributary streams and the main-stem San Joaquin River, particularly for chinook salmon, steelhead trout and splittail. Results of the Fish Treadmill project have direct and critical application to facilities improvements and fish passage program, as described for the other priorities above.

f) **DR-7**: Protect at-risk species in the Delta using water management and regulatory approaches; Minimize the effects of diversions on fish. The Fish Treadmill project objective is to provide scientifically based comprehensive information to improve design and operation of screened water diversions in the Delta (and elsewhere within the watershed), activities that are presently regulated based on incomplete and minimally applicable data from a limited number of fish species. The objective of the proposed research is to build upon results of ongoing studies that have illustrated potential fish screen design conflicts for the diverse species that use the Delta and test alternative screen design and operational approaches for optimizing multi-species protection.

By providing critical information on the effects of the design and operation of water diversions and fish screens, including at the CVP, on CVPIA priority fish species (including chinook salmon, steelhead, sturgeon, as well as delta smelt and splittail), the Fish Treadmill project addresses all of the **CVPIA Goals**:

a) Protect, restore, and enhance fish, wildlife, and associated habitats in the Central Valley and Trinity River basins of California (especially priorities 3402a, b, c; and 3406(b)(I) which authorizes the AFRP to make all reasonable efforts to double anadromous fish by 2002;

b) Address impacts of Central Valley Project on fish, wildlife and associated habitats; and

c) Contribute to the State of California's interim and long-term efforts to protect the San Francisco Bay and Sacramento-San Joaquin Delta.

The Fish Treadmill project is a comprehensive experimental program designed specifically to quantify the effects of screened water diversions on virtually all of CALFED's priority fish species under a wide range of environmental and biological conditions. The project has been, and will continue to be, developed and guided by rigorous scientific peer review and associated adaptive management. Results of ongoing and proposed studies are essential to guide development of a number of large and high-priority CALFED fish facilities programs, including retrofit and /or replacement of CVP and SWP fish screens in the Delta, design of the proposed Through-Delta Facility, and design and construction of a number of fish screens scheduled for installation throughout the watershed in the coming years. As such it is an excellent example of **targeted research designed to advance the scientific basis of regulatory activities**, as outlined in the **CALFED Science Program Goals**.

2. Relationship to Other Ecosystem Restoration Projects

The proposed targeted research using the Fish Treadmill continues and expands upon a successful research program that has been supported previously by Department of Water Resources and U.S. Bureau of Reclamation (contracts B-58719 and B-80898, 1994-1998, for Fish Treadmill final design, construction, and preliminary biological studies; and B-81622, 1998-2000, for continuation of the biological studies; results of these early Fish Treadmill studies are reported in Velagic et al., 1998, Chen et al., 1998; Swanson et al., 1998a, 1999; and Hayes et al., 2000), CALFED (Project # 99-N02, Fish Treadmill-developed Fish Screen Criteria for Native Sacramento-San Joaquin Watershed Fishes, J. J. Cech, Jr., Principal Investigator), and the CVPIA Anadromous Fish Screen Program (August 2001 - October 2002, Cooperative Agreement No. 114201J075). The project also builds upon work by DFG using a smaller circular flume with a fish screen (Kano, 1982) and upon which present fish screen flow criteria are based. The design of the biological studies using the Fish Treadmill was also based on results of previous work by the UCD Fish Physiology Group on environmental biology and behavior of native Delta and upstream fishes (e.g., delta smelt, Swanson and Cech, 1995, Swanson et al., 1996, 1998a and c; splittail, Young and Cech, 1996; chinook salmon, Young et al., 1998).

Results of this work are already being applied to guide development of the physical design and planned experimental program of the Tracy Fish Test Facility and have been identified as critical to inform further development of planned improvements to fish screens and facilities at the CVP and SWP, as well as CALFED's proposed Through-Delta Facility. Until the Tracy Fish Test Facility is completed and operational, the Fish Treadmill is the only research platform capable of conducting the kinds of detailed research on priority species (including delta smelt and green sturgeon) needed to support development of new fish screens and the regulations that guide their design and operation.

3. Request for Next-Phase Funding

The Fish Treadmill biological studies were originally designed with a three-year study schedule and an emphasis on native Delta fishes (delta smelt, splittail, chinook salmon) and American shad (to produce data more directly comparable to Kano, 1982). By the end of the CALFED contract funding (CALFED project # 99-N02, July 2001, see above), these original biological studies had been mostly completed as well as additional experiments with other priority species, including green sturgeon and steelhead. A final technical report describing and interpreting this work was submitted to CALFED in November 2001. During the period funded by the CVPIA AFSP (August 2001-July 2003), additional experiments with all of these species, as well as experiments investigating the effects of variable flow fields (e.g., to simulate encounters with multiple screens), are being conducted, a series of "Research Findings" reports have been submitted to AFSP, and several manuscripts are being prepared and/or have been submitted for publication. This proposal requests next-phase funding to build upon the results of this large, comprehensive body of work (more fully described in previous sections) to examine: 1) alternative approaches to facilitate fish passage, 2) the effects of suboptimal fish screen flow conditions related to debris, a serious concern in both riverine and Delta regions on fish performance and behavior, and 3) the role of non-visual sensory abilities in fish performance and behavior near fish screens, using the conceptual model (Figure 1) and the specific hypotheses described above.

4. Previous CALFED Program and CVPIA Funding

CALFED Bay-Delta Program:

CALFED Project # 99-N02, February, 2000 - July (funding)/October (reports), 2001
Fish Treadmill-developed Fish Screen Criteria for Native Sacramento-San Joaquin Watershed Fishes. J. J. Cech, Jr., Principal Investigator.
Current status: Final Technical Report submitted in November 2001.

CVPIA AFSP:

Anadromous Fish Screen Program, Cooperative Agreement No. 114201J075, Aug. 2001 - Oct. 2002
Fish Treadmill-developed Fish Screen Criteria for Native Sacramento-San Joaquin Watershed Fishes. J. J. Cech, Jr., Principal Investigator.
Current status: Work began August 2001, and an extension is being sought to continue work until July, 2003.

5. System-wide Ecosystem Benefits

Results of the Fish Treadmill project, when applied to improve fish screen design and operation and thus reduce the adverse impacts of water diversions, will have broad, system-wide ecosystem benefits, affecting

- **habitats** (e.g., both Delta and upstream habitats, including tidal perennial aquatic habitat, instream aquatic habitat, and shaded riverine habitat);
- **species**, with an emphasis on priority, listed native species like delta smelt, steelhead, splittail, chinook salmon, and sturgeon; and
- **ecological processes** (e.g., reducing losses of juvenile fishes at water diversions will improve Bay/Delta and upstream food webs).

Fish Treadmill project results obtained for listed native fishes, species that can affect operation of large water diversions (e.g., by take limits), have direct and timely application for development, design, and operation of several large fish facilities integral to non-ecosystem related CALFED objectives like **water supply reliability**. These include the improvements to the SWP and CVP fish screens, proposed fish screens at upstream diversion(s) for off-stream storage, and the proposed Through-Delta Facility.

C. QUALIFICATIONS

1. Organization of Staff

The project will be under the direction and supervision of the principal investigator, Dr. Joseph J. Cech, Jr., Professor in the Department of Wildlife, Fish, and Conservation Biology, University of California, Davis (Biological Studies, Task 2) and the co-investigator, Dr. M. L. Kavvas, Professor, Department of Civil and Environmental Engineering, University of California, Davis (Fish Treadmill Operation, Task 1). G. Aasen (DFG Biologist) will provide additional management and support for fish collection (Task 3). Day to day project management, implementation, data analysis, interpretation and report writing will be provided by two post-doctoral researchers, co-investigators Drs. Paciencia S. Young (Task 2) and Z. Q. Chen

(Task 1). Additional assistance with fish collection, fish care, fish management, experiment implementation, data collection, data entry, preliminary data analysis, and data quality control and assurance will be provided by full and part-time post-graduate researchers, student research assistants, and DFG researchers and scientific aides.

2. Collaborating Scientists

Dr. Joseph J. Cech, Jr. has been a professor at UCD since 1975 and was Chair of the Department of Wildlife, Fish, and Conservation Biology during 1992-1997. He has published more than 100 peer-reviewed articles in the fields of physiology and physiological ecology of fishes, and has won numerous awards, honors, and grants. He has completed eight contracts with state agencies for studies of the physiological ecology of fishes of the Sacramento-San Joaquin system. He is presently Principal Investigator on the Fish Treadmill Project. Relevant publications include:

Myrick, C.A. and J.J. Cech, Jr. (2000) Swimming performance of four California stream fishes: temperature effects. Env. Biol. Fish. 58:289-295.

Moyle, P. B. and Cech, J. J., Jr. (2000) Fishes: an introduction to ichthyology. 4th edition, Prentice Hall, Englewood Cliffs, New Jersey.

Cech, J. J., Jr., Bartholow, S. D., Young, P. S., and Hopkins, T. E. (1996) Striped bass exercise and handling stress in fresh water: physiological responses to recovery environment. Trans. Am. Fish. Soc. 125:308-320.

Dr. M. Levent Kavvas has been a professor in the Department of Civil and Environmental Engineering since 1985 and Director of the UCD Hydraulics Laboratory since 1991. He is the author of more than 75 journal and proceedings publications in the areas of hydraulic and hydrologic engineering. His areas of specialization include: physical hydraulic modeling of environmental fluid flows, pollutant and sediment transport, and modeling of hydrologic processes such as overland flow, erosion, and infiltration. He is presently co-investigator on the Fish Treadmill project. A recent relevant publications is:

Hayes, D. E., S. D. Mayr, M. L. Kavvas, Z. Q. Chen, E. Velagic, A. Karakas, H. Bandeh, E. C. Dogrul, J. J. Cech, Jr., C. Swanson, and P. S. Young. (2000) Fish screen velocity criteria development using a screened, circular swimming channel. In *Advances in Fish Passage Technology*, (M. Odeh, ed.). American Fisheries Society: Bethesda, MD. pp. 137-147.

Velagic, E., M. L. Kavvas, W. Summer, and others (1996) Fish Screen test apparatus with variable two-vector flow conditions: hydraulic model. Final Report for California Department of Water Resources contract B-58719.

Dr. C. Swanson is a postdoctoral researcher in Dr. Cech's laboratory. She is an expert in the environmental physiology of fishes and has spent the past eight years studying the environmental tolerances, swimming performance, and behavior of Delta fishes, with an emphasis on delta smelt, chinook salmon, and splittail. She was a managing researcher on three successfully completed state contracts and is presently one of the managing biologists on the Fish Treadmill project. Recent relevant publications include:

Swanson, C., T. Reid, P.S. Young, and J.J. Cech, Jr. (2000) Comparative environmental tolerances of threatened delta smelt (*Hypomesus transpacificus*) and introduced wakasagi (*H. nipponensis*) in an altered California estuary. Oecologia 123:384-390.

Swanson, C., P.S. Young, and J.J. Cech, Jr. (1998) Swimming performance of delta smelt: maximum performance, and behavioral and kinematic limitations on swimming at submaximal velocities. J. Exp. Biol. 201:333-345.

Swanson, C., R. C. Mager, S. I. Doroshov, and J. J. Cech, Jr. (1996) Use of salts, anesthetics, and polymers to minimize handing and transport mortality in delta smelt. Trans. Am. Fish. Soc. 125:326-329.

Dr. Z. Q. Chen is a Research Engineer and the manager of the UCD Hydraulics Laboratory. He has worked on various hydraulic modeling studies for more than ten years, and currently is the lead hydraulic engineer for the Fish Treadmill Project. Dr. Chen specializes in physical hydraulic models, hydraulic engineering, and hydrological modeling. A recent relevant publication is:

Hayes, D. E., S. D. Mayr, M. L. Kavvas, Z. Q. Chen, E. Velagic, A. Karakas, H. Bandeh, E. C. Dogrul, J. J. Cech, Jr., C. Swanson, and P. S. Young. (2000) Fish screen velocity criteria development using a screened, circular swimming channel. In *Advances in Fish Passage Technology*, (M. Odeh, ed.). American Fisheries Society: Bethesda, MD. pp. 137-147.

Chen, Z. Q., E. Velagic, A. Karakas, E. Dogrul, H. Bandeh, W. Summer, and M. L. Kavvas (1998) Performance, behavior, and physiological responses of Delta fishes in two-vector flows in a fish treadmill. Part 1. Hydraulics Studies. Final Report, California Department of Water Resources. 42 pp.

Geir Aasen is a biologist with the Bay/Delta division of DFG and has been working with the Fish Treadmill project since January 2000. He will serve as primary Interagency liaison for fish collection, and assist the UCD staff in experimental design, implementation, and data analysis, and data quality control and assurance for the Fish Treadmill experiments.

D. COST

1. Budget

CALFED next-phase funding is requested for a two-year period to support continued operation of the Fish Treadmill (Task 1, UC Davis Hydraulics Laboratory), implementation of the biological studies (Task 2, UC Davis Fish Physiology Group), and DFG assistance for fish collection (Task 3). Cost of the project depends on funding source: $1,554,062 if funded through a State agency and $2,073,391 if funded through a federal agency. Details of the budget are provided in the web forms and are not included in the body of this proposal.

Salaries and benefits are figured from regular University of California, Davis rates. The contributions of many undergraduate students (both those working for student salaries and those earning internship credit hours) significantly reduce the costs of these experiments (i.e., compared with career salaries of regular biologists and engineers). Each experiment involves at least 6 people (2 engineers, 4 biologists) for approximately 4 hours time and, to enable rigorous statistical analyses of the results, many experiments need to be conducted (and replicated) to understand the roles of seasonal temperatures, diel changes in light intensity (lighted during daytime experiments, dark during night experiments), fish life history stage (2 body sizes), and the relative and combined effects of approach and sweeping velocities (10 velocity combinations), in the 6+ species of native Delta fishes. Depending on duration of availability of priority species (e.g., most species are available in the appropriate size range for a limited period), as many as 8 experiments/wk are conducted, underlining the need for multiple part-time, as well as full-time, participants. Further, the water quality tests and Fish Treadmill maintenance (engineers) and the post-experimental fish inspections and data analyses (including motion analysis of video tapes) occupy many hours of the full-time, part-time, and student participants. The number of hours paid to senior level staff on the project (Co-P.I. Prof. M.L. Kavvas) only amounts to 2 months per year. The bottom line is that the Fish Treadmill project produces scientifically based results that are immediately useful to agency biologists and engineers charged with designing and operating fish screens, which will protect our threatened and endangered native fishes.

Recent meetings have clarified the working relationships among fiscal and accounting personnel at UC Davis and cooperating agencies, regarding CALFED grants. The resulting, renewed understanding should minimize difficulties concerning fiscal documentation.

2. Cost Sharing

From its inception in 1994 to February 16, 2000 when CALFED support began, the Fish Treadmill project, including design, construction, modification, and calibration of the apparatus, upgrades to the UC Davis fish holding facilities, fish field collection, and all aspects of the hydraulic and biological studies conducted using the apparatus, has been funded by DWR and USBR. DWR also provided funding to DFG to offset their costs for participation in the project (i.e., assistance with fish field collection). For the period for which next-phase funding is requested from CALFED in this proposal, UC Davis will contribute a percentage of the Principal Investigator's salary (J. J. Cech, Jr., 10%) plus benefits for a total of $31,088. This proposal was only submitted to CALFED.

E. LOCAL INVOLVEMENT

The Fish Treadmill project is an ongoing University-based, laboratory program. All required notifications and approvals (e.g., water discharge permit) to UC Davis, local governments, landowners, environmental groups, and other interested organizations are in place. Public outreach to interested parties (including academics, state and federal agency personnel, local and state media, and the general public) is accomplished through periodic workshops, workgroup meetings, and scientific and technical meetings, IEP Newsletter articles, journal articles in the scientific and technical press, and related UC Davis press releases.

F. COMPLIANCE WITH STANDARD TERMS AND CONDITIONS

The University of California, Davis, and the California Department of Fish and Game are public organizations of the State of California. Both organizations comply with the standard terms and conditions of non-discrimination and non-collusion. There are no conflicts of interest.

G. LITERATURE CITED

Chen, Z. Q., E. Velagic, A. Karakas, E. Dogrul, H. Bandeh, W. Summer, and M. L. Kavvas (1998) Performance, behavior, and physiological responses of Delta fishes in two-vector flows in a fish treadmill. Part 1. Hydraulics Studies. Final Report, California Department of Water Resources. 42 pp.

Hayes, D. E., S. D. Mayr, M. L. Kavvas, Z. Q. Chen, E. Velagic, A. Karakas, H. Bandeh, E. C. Dogrul, J. J. Cech, Jr., C. Swanson, and P. S. Young. (2000) Fish screen velocity criteria development using a screened, circular swimming channel. In *Advances in Fish Passage Technology*, (M. Odeh, ed.). American Fisheries Society: Bethesda, MD. pp. 137-147.

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Swanson, C. and J. J. Cech, Jr. (1995) Environmental tolerances and requirements of the delta smelt, *Hypomesus transpacificus*. Final Report, California Department of Water Resources. 71 pp.

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Swanson, C., T. Reid, P. S. Young, and J. J. Cech, Jr. (2000) Comparative environmental tolerances of threatened delta smelt (*Hypomesus transpacificus*) and introduced wakasagi (*H. nipponensis*) in an altered California estuary. Oecologia 123:384-390.

Swanson, C. P. S. Young, S, Chun, T. Chen, T MacColl, L. Kanemoto, and J.J. Cech 2001. Fish treadmill-developed fish screen criteria for native Sacramento-San Joaquin Watershed fishes. Part 2 Biological Studies. Final Report to CALFED. Sacramento, California (in prep).

Velagic, E., Z. Q. Chen, A. Karakas, E. Dogrul, H. Bandeh, W. Summer, M. L. Kavvas, C. Swanson, P. S. Young, and J. J. Cech, Jr. (1998) Performance, behavior and physiology of Delta fishes in variable two-vector flows. Progress Report, California Department of Water Resources, Contract B 80898. 93 pp.

Young, P. S. and J. J. Cech, Jr. (1996) Environmental tolerances and requirements of splittail. Trans. Am. Fish Soc. 125:664-678.

Young, P. S., C. Swanson, and J. J. Cech, Jr. (1998) Performance, behavior, and physiological responses of Delta fishes in two-vector flows in a fish treadmill. Part 2. Illumination and photophase effects on swimming performance and behavior of Delta fishes. Final Report, California Department of Water Resources. 57 pp.

Appendix I

CURRENT PROJECT STATUS SUMMARY (AFSP #114201J075)

The Fish Treadmill project is a cooperative, multi-agency, targeted research program that addresses the uncertain impacts of water diversions and fish screens on priority fish species (e.g., delta smelt, splittail, chinook salmon, steelhead). The project, begun in 1994 with funding and/or support from DWR, DFG, NMFS and USBR, was intended to build upon the pioneering work by DFG (Kano, 1982) by providing comprehensive and rigorous data on fish-fish screen interactions for newly listed priority species like delta smelt. Fish Treadmill project results are being, and will continue to be, applied to evaluate and improve aspects of fish protective facility design and operation at the State Water Project (SWP), Central Valley Project (CVP, including the Tracy Fish Test Facility, TFTF), and other existing and proposed fish screen facilities (e.g., Red Bluff Diversion Dam, Glenn-Colusa Irrigation District, Through-Delta Facility).

Research with the Fish Treadmill focuses on near-field effects (i.e., near-screen effects), evaluating fish screen and flow impacts on fish survival, injury, stress, and passage and correlating them with screen design, and regulatory and operational criteria (i.e., approach and sweeping velocity, allowable exposure duration), species and life history stage, and environmental conditions (e.g., temperature, day vs night). The conceptual model (Figure 1 in the proposal), hypotheses, and experimental design used in the studies were developed with input and collaboration from participating agencies, the Interagency Ecological Program's Central Valley Fish Facilities Review Team, outside consultants (e.g., Ken Bates, Washington State Department of Fisheries, and Ned Taft, Alden Research Laboratories), and other interested parties (e.g., Metropolitan Water District).

Biological studies using the Fish Treadmill began in late 1997 with experiments with splittail and delta smelt. Since then, more than 663 "regular" experiments, with delta smelt, splittail, chinook salmon (fall- and winter-run), steelhead, green sturgeon and American shad, and more than 22 simulated multiple screen exposure experiments on detla smelt, splittail and winter-run chinook salmon have been completed. CALFED support of Fish Treadmill research activities began February 16, 2000 and was concluded July 31, 2001, with a final technical report submitted in November 2001 (CALFED project #99-NO2). Table AI-1 (following page) outlines the status of the studies at the end of the period supported by CALFED (i.e., through July 31, 2001). Results of these studies have been presented in several technical reports (Velagic et al., 1998, Chen et al., 1998; Swanson et al., 1998a, 1999; and Hayes et al., 2000; Cech et al., 2001, IEP Newsletter articles, and as oral and poster presentations at scientific and interagency technical meetings (see Appendix III for a complete list of published reports and articles, and presentations of Fish Treadmill results).

Beginning August 2001, Fish Treadmill research was supported by the CVPIA Anadromous Fish Screen Program (AFSP, Cooperative Agreement No. 114201J075). This funding will support Fish Treadmill research through October 2002. During this period, the few remaining studies on the effects of approach and sweeping velocities, environmental conditions, and fish size on the performance and behavior of flow with chinook salmon, delta smelt, and splittail will be completed, as well as further experiments with steelhead and sturgeon. In addition, a series of studies examining the effects of variable flows (e.g., after an initial period of no flow, approach and/or sweeping velocity are increased to specified target levels, to more realistically simulate conditions experienced by a fish moving into the area of influence of a screened water diversion) are conducted. For this CVPIA-funded component of the Fish Treadmill project, in addition to descriptive technical reports, results will be explicitly applied to develop species- and environment-specific recommendations for fish screen flow criteria. For example, recommendations for fish screen flow criteria (e.g., approach and sweeping velocity, exposure duration) for juvenile chinook salmon, based on results with fall- and winter-run parr-size fish, were submitted to AFSP in September 2001.

Table AI -1. Status of Fish Treadmill biological studies ("regular" Fish Treadmill experiments on the effects of constant flow, environmental conditions, and fish size on fish performance and behavior near a screen, only).
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Species	**# of Experiments Required**	**# of Experiments conducted**	**% Complete as of September 2002**
Delta smelt	150	134	89
Splittail	180	168	93
Chinook salmon (fall-run)	180	158	88
Chinook salmon (winter-run)	40	41	102
Steelhead	180	120	67
Green sturgeon	90	25	28
American shad	90	17	19

The Fish Treadmill project is presently staffed with a highly trained team of University and DFG researchers, research assistants, and engineers. The project is further supported by the University of California, Davis, office and facilities management, and information resources (e.g., libraries, online databases). Facilities and equipment for collecting and maintaining the large numbers of fishes needed for the studies are available. All necessary permits and approvals are in place.

FISH TREADMILL-DEVELOPED FISH SCREEN CRITERIA FOR NATIVE SACRAMENTO-SAN JOAQUIN WATERSHED FISHES

CALFED Project #: 99-N02

Biological Monitoring/Research Plan

based on the Quality Assurance Project Plan prepared by

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Ted Frink
Environmental Services Office
California Department of Water Resources

for

Department of Water Resources and the **Interagency Ecological Program**, 1998

I. Introduction and Background

This Biological Monitoring/Research Plan (BM/RP) is based the Quality Assurance Project Plan (QAPP, Swanson et al. 1998) developed for Interagency Ecological Program-supported studies using the Fish Treadmill (Performance, Behavior and Physiology of Delta Fishes in Two-Vector Flows in a Fish Treadmill, M. L. Kavvas and J. J. Cech, Jr., principal investigators). The objective of these documents is to describe and define objectives, experimental design, methods, personnel training requirements, data quality objectives and acceptability criteria, data reduction and analyses methods, and standard operating procedures for all aspects of the biological studies using the Fish Treadmill.

A. Project History

The fisheries resources of the Sacramento-San Joaquin Delta system have been recognized as valuable state resources for several decades. A number of fish species, including the endangered winter-run chinook salmon and threatened delta smelt have been jeopardized by the increased water demand by agriculture, domestic, municipal, industrial, and recreational users of California (Kawasaki and Raquel 1995). State law provides the California Department of Fish and Game (CDFG) the authority for installation of fish screens on water diversions to reduce fish losses. Kano (1982) described pioneering efforts to examine survival of fishes exposed to controlled flow regimes and fish screens like those at water diversions. However, many technical, biological, and environmental problems related to diversion design and operation in the Delta have not been resolved. To address these questions, the Fish Facilities Technical Committee of the Interagency Ecological Program proposed the Fish Treadmill Project in order to determine:

- how Delta fish species of various sizes and swimming abilities might behave if subjected to a screened barrier adjacent to the river; and
- the suitable approach velocity and screen exposure duration for various fish species.

In 1994, the Hydraulics Laboratory of the University of California, Davis (UCD), headed by M. L. Kavvas, was contracted to design and construct a small-scale fish treadmill model as well as a full-scale fish treadmill prototype. The apparatus was designed to provide controlled, relatively uniform flow regimes, at levels similar to those currently required for screened water diversions, in a relatively large volume, annular flume or swimming chamber in which fish could be confined and their responses to the flow and screen observed and quantified. Upon completion of the Fish Treadmill prototype, the UCD Fish Physiology Group, headed by J. J. Cech, Jr., began biological studies to evaluate the performance and behavior of selected Delta fishes in the apparatus under a range of biological and environmental conditions. This Quality Assurance Project Plan (QAPP), developed during the first year of biological testing using the Fish Treadmill, describes the activities associated with the biological studies using the Fish Treadmill with the understanding that the UCD Hydraulics Laboratory will operate and maintain the Fish Treadmill, provide detailed flow velocity and vector maps of the swimming channel within the Fish Treadmill for each of the experimental flow regimes to the Fish Physiology Group, and maintain stable flow regimes and water quality throughout the experimental periods at levels defined as acceptable in this QAPP.

B. Project Objectives

Biological studies will be conducted to evaluate Delta fishes' swimming performance, and behavioral and physiological responses to exposure to a two-vector flow field with a screened barrier.

Objective 1: Evaluate and quantify the performance (i.e., survival, impingement) of selected Delta fishes exposed to two-vector flow regimes and environmental conditions (e.g., temperature, light level) similar to those that occur near fish screens in the Delta and local riverine systems.

Objective 2: Evaluate and quantify the behavior (e.g., swimming velocities, orientation to screen and water flows, distance traveled, etc.) of Delta fishes exposed to two-vector flow regimes and environmental conditions similar to those that occur near fish screens in the selected Delta and local riverine systems.

Objective 3: Evaluate and quantify the physiological stress responses of Delta fishes exposed to two-vector flow regimes and environmental conditions similar to those that occur near fish screens in the selected Delta and local riverine systems.

Objective 4: Compare the performance, behavior, and physiological responses of the tested fish species to determine differential vulnerability to entrainment and impingement at fish screens.

Objective 5: Compare results from these studies with those of Kano (1982).

Objective 6: Compare results from these studies with present fish screen and flow criteria specified for the Delta and local river systems (NMFS, 1997; CDFG, 1997; USFWS, 1994).

Objective 7: In collaboration with state and federal agency personnel, suggest refinements for present fish screen flow and operational criteria for each of the tested species.

C. Determination of Success

The project is successful when complete, statistically testable data sets have been generated, analyzed, interpreted, and documented in a Final Report to the funding agency.

D. Use and Users of Information

Results of these studies will be provided to CALFED as quarterly and final reports for their use in evaluating and revising present fish screen flow and operational criteria to better protect fishes in the Delta and riverine systems and reduce losses due to entrainment and impingement. Results will also be reported in IEP Newsletter articles, presented at interagency workshops and scientific meetings, and will be submitted for publication in peer-reviewed scientific and management journals for wide dissemination.

II. Project Organization

A. Responsibilities

Task 1: Fish Treadmill Operation, Maintenance and Calibration

Prof. M. Levent Kavvas,
Department of Civil and Environmental Engineering, University of California, Davis, CA 95616, (530) 752-2518, mlkavvas@ucdavis.edu.

Supervise operation of the design, construction, testing, calibration, and operation of the Fish Treadmill apparatus; ensure the completion of high-quality projects within established budgets and time schedules; provide guidance and technical advice to those assigned to projects by evaluating performance, implement corrective actions and provide professional development to staff; review preparation of project deliverables; interact with technical reviewers and agencies to assure technical quality requirements are met in accordance with contract specifications.

Task 2: Biological Studies

Prof. Joseph J. Cech, Jr.
Department of Wildlife, Fish, and Conservation Biology, University of California, Davis, CA 95616, (530) 752-3103, jjcech@ucdavis.edu

Supervise and participate in all research activities as needed; ensure the completion of high-quality projects within established budgets and time schedules; provide guidance and technical advice to those assigned to projects by evaluating performance, implement corrective actions and provide professional development to staff; review preparation of project deliverables; interact with technical reviewers and agencies to assure technical quality requirements are met in accordance with contract specifications.

Task 3: Fish Collection

Geir Aasen, Department of Fish and Game, 4001 North Wilson Way, Stockton, CA 95205.
Collection and transport of field collected fishes to UC Davis fish holding facilities, record keeping for fish collection results and reporting threatened and endangered fishes take.

Tasks 4, 5, and 6: Biological Monitoring/Research Plan, Quarterly Reports, Final Technical Report

Prepare BM/RP, quarterly reports and final technical report as scheduled in the Scope for Service.

B. Other Personnel

QA Officer:

Ken Bates, P. E.
Consultant to California Department of Water Resources
5211 Blvd. SE, Olympia, WA 98501.
(306) 902-2545, bateskmb@dfw.wa.gov.

Reports to the principal investigators and is independent of research staff; reviews QA/QC plans and reports for completeness and content, and signs off on the QAPP and reports, responsible for monitoring QC activities to determine compliance, distributing quality related information.

Hydraulics Laboratory Research Engineers:

Design, modification, operation, maintenance of Fish Treadmill; develop hydraulics designs and protocols; conduct hydraulics experiments; analyze and interpret results; prepare reports and journal articles.

Post-doctoral Biological Researchers:
Develop experimental designs and protocols; supervise research assistants and student assistants; conduct experiments; analyze and interpret results; prepare reports and journal articles.

State Agency Biologists:
Collaborate and assist team leaders in the development of experimental designs and protocols, supervision of research assistants, implementation of experiments, analyses and interpretation of results, preparation of reports and journal articles; act as liaison between UCD researchers and various state and federal Agencies.

State Agency Engineers:
Collaborate and assist team leaders in the development of experimental designs and protocols; provide technical assistance in the design and construction of research equipment and accessories; assist with Fish Treadmill modifications and improvements; act as liaison between UCD researchers and various state and federal Agencies.

Hydraulics Laboratory Technicians:
Perform manufacturing and installing modifications to the Fish Treadmill; maintaining Fish Treadmill apparatus.

Research assistants:
Assist in the construction of fish holding facilities, fish collection, fish care, facilities maintenance, preparation, implementation and termination of experiments, data collection, entry and preliminary analyses of data, preparation of reports and journal articles, and supervision of student assistants.

Student assistants:
Assist in fish collection, fish care, facilities maintenance, preparation, implementation and termination of experiments, data collection, entry and data analyses.

C. Training Requirements for Project Personnel

Training will be provided for all research staff, including state agency biologists, UC Davis research assistants, and student assistants. While many of the personnel involved in the project have background in fish biology, fish handling and care, experimental protocols and methods, and specific data collection techniques applicable to this project, no one will be allowed to work independently on the project until trained to the satisfaction of the principal investigator (biological research) or post-doctoral researchers. Training will be provided by the principal investigator, post-doctoral researchers, and when appropriate, state and federal agency biologists. It will be conducted on-site and on an individual basis. It will include background information on the project objectives, rationale, and overall methods as well as information and hands-on practice for specific project activities. Specific topics include:

- fish collection techniques and protocols
- fish care and feeding techniques and protocols
- fish handling techniques and protocols
- basic maintenance and operation of the fish holding facilities
- water quality measurements
- experimental protocols
- data collection techniques and protocols
- data entry and preliminary analyses

- laboratory safety

A training checklist will be used to verify training completeness and provide a written record of training. Performance of all staff and student researchers will be evaluated and discussed weekly at the project staff meeting and additional training provided as required. Evaluation will include: observation and feedback by principal investigator and post-doctoral researchers; comparison of results obtained by individual researchers with those obtained by other researchers and trainers.

III. Measurement And Data Acquisition

A. Experimental Apparatus

All two-vector flow field experiments will be conducted using the Fish Treadmill prototype located at the UC Davis Hydraulic Laboratory. The Fish Treadmill is designed to produce a relatively uniform flow field (similar to that typical near large, flat-plate fish screens) within an annular swimming chamber in which fish can be confined. The outer ring of the swimming chamber consists of perforated plate-type fish screen and the inner ring, which is intended to simulate the flat plate fish screen, consists of vertical wedgewire-type fish screen. Other types of fish screens (e.g., horizontal wedgewire) may be installed in the inner ring for additional tests at a later date. Water depth in the swimming channel, approach velocity, and sweeping velocity of the water in the swimming channel are controlled collectively by the rotation rate of the outer screen and flow rates through the inflow control valve and the outflow control valve. The approach velocity is the velocity component perpendicular to the screen. The sweeping velocity is the velocity component parallel to the inner screen. Viewed from the top, the outer screen rotates in a counter-clockwise direction.

Water for the Fish Treadmill is supplied from a dedicated well. During treadmill operation water, a total volume of 60,000 gal circulates (circulation rate: up to 10,000 gal/min) between the treadmill and an underground sump tank. During operation there is no flow-through or make-up water from the well into the treadmill/sump system. Water temperature is controlled by a 30 HP combination heating and chilling system plumbed to circulate water in the sump tank (circulation rate: 200-350 gal/min). Water in the treadmill/sump system will be partially replaced (50%) with well water every two months or more frequently if necessary to maintain acceptable water quality. Immediately after water replacement, dissolved gases (e.g., oxygen, nitrogen) in the water in the treadmill/sump system will be equilibrated with atmospheric conditions, and water temperature adjusted to required experimental levels by circulating water between the sump, treadmill, and the heating/chilling system for at least 24 h prior to experiments.

To ensure a clear visual field for both visual observers and video cameras, the Fish Treadmill is equipped with plexiglass view plates that are attached to the inner screen at the water surface at four locations. One of these view plates covers the water from the inner screen to approximately 5 cm from the outer screen (large view plate), the other three view plates extend approximately 15 cm from the inner screen. Five video cameras are positioned at selected locations above the Fish Treadmill swimming channel (four cameras) and underwater (one camera, positioned downstream of the inner screen to view through the inner screen into the swimming channel). An additional large view plate is equipped with infra-red light emitters and each of the three small view plates used during day/light experiments can be equipped with a portable infra-red emmitter array to enhance video and visual observations during the night experiments.

B. Experimental Variables

1. Units

For most biological and environmental variables defined in the following sections, measurements are expressed in metric units. However, since water diversion flow criteria are commonly expressed in English units, flow velocities from the Fish Treadmill will be initially defined and expressed as feet per second (f/s). During data reduction and analysis, these values will be converted into metric units. In all preliminary and final reports, velocity measurements will be expressed using both metric and English units.

2. Fish Species

While a number of Delta fish species are thought to be adversely affected by artificial flow regimes and screened barriers, priority for the Fish Treadmill experiments will be:

1. delta smelt (*Hypomesus transpacificus*) juveniles and adults,
2. Splittail (*Pogonichthys macrolepidotus*) young-of-the-year (YOY),
3. fall-run chinook salmon (*Oncorhynchus tshawytscha*) parr and smolts,
4. steelhead trout, *Oncorhynchus mykiss* parr and smolts, and
5. other small size and/or juvenile Delta fishes (e.g.,American shad (*Alosa sapidissima*) YOY*;* striped bass, *Morone saxatilis*; longfin smelt, *Spirinchus thaleichthys*) depending on time and availability of adequate supplies of fish.

This priority order is based on the threatened status of delta smelt, and the "candidate" status of splittail, the endangered status of winter-run chinook salmon, and the threatened status of steelhead trout. American shad are included in these experiments to allow direct comparisons with previous experiments (Kano, 1982), and because American shad are reported to be "weak"swimmers (Kano, 1982).

3. Fish Size

For each species, two size classes will be used in the experiments, <6 cm standard length (SL) and $\geq$6 cm SL. Size class for each experiment is defined by the mean size, SL, of the fish used in that experiments. Fish smaller than 3-4 cm in length, depending on species, may be too small to use in the experiments for several reasons: small fish may be able to escape and/or become entangled in the holes in the perforated plate outer ring screen (Young and Cech, 1997); fish this size may be difficult to collect from the field in adequate numbers (e.g., delta smelt); and/or these fish may be too small to be clearly visible in the Fish Treadmill swimming chamber using either video or visual observations. However, if fish <3-4 cm SL are obtained in sufficient numbers and preliminary experiments indicate that they cannot escape the swimming channel and can be observed effectively, these fish will be included in the experiments. Fish >8 cm SL will not be used in the experiments because fish of this size are presumed to be less vulnerable to entrainment and impingement at water diversions.

4. Flow Regime

The ten flow regimes, derived from combinations of four approach flow velocities and three sweeping flow velocities, to be tested using the Fish Treadmill are listed in the table below. Velocities are expressed as f/s and cm/s (in parentheses). "E" designates an experimental flow regime. "C" designates a control flow regime.

Flow Treatment	Approach	Sweeping
C-1	0	0
E-1	0.2 (6 cm/s)	0
E-2	0.33 (10 cm/s)	0
E-3	0.5 (15 cm/s)	0
E-4	0.2	1 (31 cm/s)
E-5	0.33	1
E-6	0.5	1
E-7	0.2	2 (62 cm/s)
E-8	0.33	2
E-9	0.5	2

5. Temperature

Experiments will be conducted at two seasonally appropriate temperature levels, 12°C in the winter and spring (approximately December-May) and 19°C in the summer and fall (June-November). For all of the fishes we plan to use in the Fish Treadmill experiments, size, season and temperature are closely linked. Therefore, not all species-size-temperature combinations will be tested.

6. Light and Time of Day

Experiments will be conducted under two light level/photophase (time of day) conditions: light conditions during the day and dark conditions during the night. Daytime light levels will be 100-350 lux. Nighttime light levels will be 0-3 lux. Day experiments will begin no earlier than 1 h after sunrise and end no later than 1 h before sunset. Night experiments will begin no sooner than 1 h after sunset and end no later than 1 h before sunrise. Unless preliminary results indicate that large size class fish (>6 cm SL) perform poorly relative to smaller fish, night experiments will be conducted using the small size class of each species only.

7. Number of Fish

All experiments will be conducted using 20 fish from a single species and size class (size class is defined by mean SL of the 20 fish used in the experiment). All fish will be used only one time in the treadmill experiments.

8. Experiment Duration

Duration of experiments will be two hours. A limited number of additional experiments with a six hour duration will be conducted with chinook salmon and American shad only and at flow regime E-4 and E-5 only, in order to provide data which are more directly comparable with Kano (1982).

9. Experiment Scheduling

Experiments and experimental conditions (e.g., temperature, species, flow regime) are

scheduled based on several factors that are listed in order of priority below.
Season: Experimental temperature is determined by season; 12°C in the winter and spring (approximately December-May) and 19°C in the summer and fall (June-November).
Species Availability: Experiments with a particular species are conducted only if enough fish of that species are available (minimum number: 220 fish, enough for one experiment at each of the ten flow regimes) and in acceptable condition (i.e., fully acclimated, healthy). A lower minimum number of fish may be acceptable if the fish are required to complete a replicate or set of experiments from earlier in the season, the previous season and/or to replace experiments excluded from the data set because of errors or unacceptable conditions (see Data Acceptability).
Species Priority: If adequate numbers of more than one species is available, the fish will be used in order of priority (see Fish Species).
Fish Size: If more than one size class of a particular species is available in adequate condition and numbers, experiments will be conducted with the small size class fish first.
Flow Regime: Experiments are generally conducted in sets of ten, one experiment for each of the ten flow regimes, or one complete replicate. Within each replicate, the order in which the flow regimes are tested is random. Under certain circumstances, the flow regime schedule within a single replicate may depart from the randomized order.

- Specific flow regimes may be selected to replace experiments excluded from the data set because of errors or unacceptable conditions.

- Certain flow regimes require more researchers to optimally conduct the experiment (e.g., in the high velocity approach/low sweeping velocity flow regimes, the camera view plates require periodic cleaning to remove small bubbles which accumulate in order to maintain adequate visibility for visual observers and video cameras). Flow regime schedule may be modified to accommodate personnel availability.

C. Fish Collection
Delta smelt: Delta smelt will be collected from three sources, the Sacramento-San Joaquin estuary, the state and federal fish salvage facilities in the south Delta, and from the laboratory of S. I. Doroshov, Department of Animal Science, UC Davis. Field collected fish will be captured using methods described in Swanson et al. (1996). For all fish, handling and transport protocols will also be done according to Swanson et al. (1996).
Splittail: Sacramento splittail young-of-the-year (YOY) will be collected from the Sacramento River and Sacramento-San Joaquin estuary by seine net and/or from state and federal fish salvage facilities. Handling and transport protocols will be according to methods described in Swanson et al. (1996).
Chinook salmon and Steelhead trout: Fall-run chinook salmon parr will be collected from state and federal fish hatcheries on the Sacramento and tributary rivers. Handling and transport protocols will be similar to those used for delta smelt.
American shad: American shad YOY will be collected from the Sacramento-San Joaquin estuary and/or the state and federal fish salvage facilities using methods described in Swanson et al. (1996). Handling and transport protocols will be similar to those used for delta smelt.
Other Delta fishes: Other Delta fishes will be collected from the Sacramento-San Joaquin estuary, state and federal fish salvage facilities, and/or state, federal, and private fish hatcheries using methods for collection, handling, and transport similar to those described above

D. Fish Care

1. Fish holding facilities

Three fish facilities will be used to hold fish used in the Fish Treadmill experiments, two at the UC Davis Aquatic Center and one at the UC Davis Hydraulics Laboratory.

The Aquatic Center fish holding facilities consist of 14 1 m round tanks located in Rm #129 and nine 1.7 m round tanks located in a semi-enclosed outdoor shelter. All tanks are equipped with non-chlorinated, air-equilibrated, temperature-controlled, continuously flowing well water. Fish collected from the field and hatcheries will be initially held in Rm #129 for quarantine and prophylactic treatments.

The Hydraulics Laboratory fish holding facility consists of six 1 m round tanks and eight 0.5 m round tanks located within the laboratory building. All tanks are equipped with non-chlorinated, air-equilibrated, temperature-controlled, continuously flowing well water. This facility is primarily for holding fish immediately prior to and after use in the Fish Treadmill experiments.

2. Fish care

All fish in all facilities will be cared for according the UC Davis Aquatic Center Animal Care Protocols. Some specific aspects of the fish care relevant to use of the fish in the treadmill experiments are outlined below.

Stocking density: <2g fish/l.

Flow rates: 500-1000ml/min (minimum: 500 ml/min) generating a flow velocity in the tank of <6 cm/s.

Diet: Silver Cup (Stirling H. Nelson & Sons, Murray, UT), BioKyowa Fry feed (BioKyowa, Inc., Cape Girardeau, MO), and live *Artemia* nauplii freshly hatched from brine shrimp cysts (Argent Chemical Co., Redmond, WA).

Feeding Rate: *Ad libitum* for artificial diets using automatic feeders which dispense food hourly during daylight hours. *Artemia* nauplii once or twice per day, depending on species and fish size.

Photoperiod: All fish will be maintained on natural (e.g., Aquatic Center outdoor facility) or simulated natural (e.g., both indoor facilities) photoperiod regimes.

Light Intensity: 30-300 lux at 5 cm above water surface.

Temperature: ± 1°C of target acclimation temperature, measured daily.

Temperature acclimation: All fish will be acclimated to the appropriate acclimation temperature for a minimum of seven (7) days prior to use in the experiments.

Dissolved oxygen: >70% air-saturation, measured weekly.

pH: 7.0-9.0, measured weekly

Ammonia: <0.5 mg/l (as total N), measured weekly.

Alkalinity: measured monthly.

Hardness: measured monthly.

Disease treatment and prophylaxis: Fish will be treated within 2 days of collection and/or as necessary for bacterial infection using a nitrofurazone solution (dose: 10 mg/l) and for fungal infections using a formaldehyde solution (dose: 0.1 ml/l). No fish from a particular tank will be used in the experiments if they show evidence of disease or have been treated for disease within the previous 10 d.

Mortality: All mortalities and incidents of possible disease among fish held in any of the fish holding tanks at each of the fish holding facilities will be recorded and, if necessary samples will be sent to the UC Davis Fish Pathology Laboratory (Dr. R. P. Hedrick, School Of Veterinary Medicine) for necropsy and diagnosis. Fish from a particular tank will not be used in the experiments if mortalities from that tank exceed 10% during the five days prior to the experiment. The batch history and source will be available and documented for all fish used in the experiments.

3. Pre- and Post-test Fish Care

All fish used in the Fish Treadmill experiments will be transported from the UCD Aquatic Center fish holding facility to the UCD Hydraulics Laboratory fish holding facility a minimum of three (3) days prior to use in the experiments. Transport water temperature will be $\pm$1°C of acclimation temperature. At the Hydraulics Laboratory fish holding facilities, all fish will be maintained at the appropriate acclimation temperature and fed the same quantity and quality diet as at the Aquatic Center. All fish that have completed a Fish Treadmill experiment will be held at the Hydraulic Laboratory fish holding facility for a 48-h post-test survival evaluation period and post-test health assessment and/or sampling for measurement of blood and plasma parameters prior to transport back to the Aquatic Center fish holding facility and use in other experiments (i.e., experiments other than Fish Treadmill experiments) and/or release.

E. Experimental Protocol

The schedule and brief descriptions of activities associated with each treadmill experiment is outlined below.

Pre-test activities

Establishment of experimental flow regime in Fish Treadmill: Conducted by Hydraulics Laboratory personnel. Fish will be introduced into the Fish Treadmill when the flow regime is within the acceptable flow velocity parameters (see Data Acceptability). Pre-test flow measurements (see Measurements) will made no more than 20 min prior to introduction of fish into treadmill.

Fish Treadmill water quality assessment: Conducted by Hydraulics Laboratory personnel. Fish will be introduced into the Fish Treadmill when water quality variables are within acceptable parameters (see Data Acceptability). Pre-test water quality measurements (see Measurements) will made no more than 20 min prior to introduction of fish into treadmill.

Placement of camera view plates: The large camera view plate will be installed along the inner screen frame of the Fish Treadmill and the positions of small view plates (left in place between successive experiments) adjusted as necessary.

Light level measurement: Light level (lux) measured at 5 cm above the water surface at the large view plate observation station.

Pre-test health assessment of experimental fish: See Measurements.

Transport of fish to treadmill: After the flow regime and water quality parameters are determined to be within the acceptable range, the experimental fish will be placed in the Fish Introduction Container and carried to the Fish Treadmill, and the container partially submerged in the swimming chamber.

Experimental activities

Introduction of fish into treadmill: After a period of >2 min and <10 min, the Fish Introduction Container will be opened and the fish released into the treadmill. This is the beginning of the

experiment, e.g., time 0 min.
Video tape recording: At time 0 min, each of the four video cameras will be activated (and proper operation verified) to begin recording the activity of the fish in the treadmill.
Visual observations of fish swimming behavior and performance: See Measurements.

Post-test activities

Post-test flow measurements: See Measurements. These measurements will be made <5 min prior to the end of the experiment and cessation of flow in the treadmill.
Post-test water quality measurements: See Measurements. These measurements will be made <5 min prior to the end of the experiment and cessation of flow in the treadmill.
Video tape recording ended: Video cameras turned off at the end of the experiment and cessation of flow in the treadmill.
Removal of large view plates: Large view plate is removed to allow fish collection from the treadmill.
Fish collection and transport: Fish crowding device is installed and fish crowded and collected into holding container using dip nets and beakers. Fish are carried to designated Hydraulics Laboratory tank and released for post-test holding period.
Blood sampling for physiological measurements: In those experiments where physiological responses are being measured, eight randomly selected fish will be euthanized immediately after collection or at selected times post-experiment and blood collected by caudal transection (see Measurements). The remaining 12 fish will be carried to designated Hydraulics Laboratory tank and released for post-test holding period.
Post-test fish health assessment: See Measurements.
Data sheets: Complete data sheets and records, preliminary review of data sheets and records for accuracy by the principal investigator (research) or post-doctoral researcher..

F. Measurements

1. Types, Frequency, and Numbers of Measurements

Pre-test Health Assessment: Pre-test health assessments will be made on 20 fish randomly selected from the Hydraulics Laboratory pre-test holding tanks and anesthetized with MS222 (tricaine methanesulfonate; 70-100 mg/l) at least once for each group of fish of a single species, size class, temperature level and light level treatment. Measurements will include identification to species, fish size and weight (standard, fork, and total length in cm, wet weight in g), visible anatomical abnormalities, damage to skin, scales, fins, and eyes, and evidence of disease. An additional pre-test assessment, made on each group of 20 fish selected for use in each experiment as they are collected for use in the experiment, includes identification to species, approximate size (length in cm), visual health assessment without anesthesia (e.g., visible anatomical abnormalities or evidence of disease), and information on duration of laboratory holding (weeks), and acclimation temperature, mortality, disease, and treatment history from the tank(s) in which the fish have been held.
Water Quality: Measured treadmill water quality parameters are temperature, dissolved oxygen, pH, ammonia, alkalinity, and hardness. Measurements and/or water samples will be taken from the treadmill swimming chamber during treadmill operation. Temperature, dissolved oxygen, pH, and ammonia will be measured at the beginning of each experiment (immediately prior to introduction of the fish into the treadmill) and at the end (immediately prior to cessation of the experimental treadmill flow regime and removal of the fish from the apparatus) of all

treadmill experiments. Alkalinity and hardness will be measured every four weeks.

Flow Regime: Two values of the flow velocity components, the average approach velocity perpendicular to the inner screen and the mid-channel sweeping velocity parallel to the inner screen, are the controlling parameters for each flow regime. The average approach velocity will be calculated from the inflow discharge rate (Dynasonics Ultrasonics Flowmeter) and the water depth in the swimming channel at the inner screen (see Measurements, Methodology and Definitions for formulae). The mid-channel sweeping velocity will be measured using an electronic velocity meter (SonTec Acoustic Doppler Velocimeter) in the swimming channel at one location 12 inches from the inner screen and at a depth of 10.2 inches from the bottom. These measurements will be made at the beginning (immediately prior to introduction of the fish into the treadmill) and end (immediately prior to cessation of the experimental treadmill flow regime and removal of the fish from the apparatus) of all treadmill experiments.

Light Level: Light level (lux) will be measured at a height of 5 cm above the water surface <10 min before the start of each experiment.

Fish Behavior and Performance - Visual Observations: Visual observations will be made at a minimum of two locations in the treadmill swimming chamber (visual field each observation station: approximately 6% of the swimming chamber circumference). Measurements will be made for 5-min intervals (e.g., time 0-5 min, time 5-10 min) throughout the two-hour experiment. Measurements will be made on loss of equilibrium (number of incidents during each 5-min interval), screen contacts (tail contacts and body contacts; number of each type of contact during each 5-min interval), impingement (body contact for >5 min; number of fish impinged at each 5 min interval), and fish distribution (number of fish visible at each observation station at 10 min intervals, e.g., time 10 min, time 20 min, etc.). Equilibrium loss rates (equilibrium loss/fish*min), screen contact rates (contacts/fish*min), and impingement rates (# fish impinged/20 fish) will be calculated for each 5-min interval and fish distribution (random, regular, or clumped) for each 10-min interval. Mean values for the entire 2-hour experiment will also be calculated. Observations on fish depth strata (bottom, middle, or top third of the swimming channel water column) and general swimming behavior will be made and recorded periodically.

Fish Behavior and Performance - Video Analyses: Video tape from four video cameras suspended 0.5-1.5 m above the swimming chamber and the underwater camera will be analyzed using a computer-assisted, video capture/motion analysis system (Peak Performance Technologies, Inc., Englewood, CO). Measurements will be made on fish spatial position (lateral position, cm from inner screen; and depth, cm from bottom), fish orientation (degrees; angle to the screen, measured, and angle to water flow, calculated using Fish Treadmill flow vector profiles), swimming direction and rheotaxis (swimming with or against the sweeping flow), swimming velocity (cm/s; velocity over the ground, measured, and through the water, calculated from swimming direction, velocity over the ground, and Fish Treadmill flow velocity profiles), and distance traveled (cm; distance over the ground, measured, and through the water, calculated) for five fish at times 0, 5, 10, 20, 40, 60, 80, 100, 110, and 120 min in the experiment. Swimming velocity (cm/s; velocity over the ground, measured, and through the water, calculated from swimming direction, velocity over the ground, and Fish Treadmill flow velocity profiles), stroke (i.e., tail beat) frequency, stroke amplitude, stride length (calculated; distance traveled per stroke), and swimming behavior (i.e., discontinuous vs continuous stroking, steady vs burst swimming), will be measured for selected fish (minimum: 5 fish each experiment, selection based on swimming direction and behavior) in each experiment (day/light conditions only).

Post-test Health and Survival Assessment: Post-test observations and measurements will include survival (up to 48 h post-test in holding tanks with minimal handling), fish size and weight (length; cm, standard, fork and total length; wet weight, g), health assessment (visible anatomical damage to skin, scales, fins, eyes, signs of diseases, etc.). Survival will be measured at 0 h and 48 h post-test. During the 48-h post-test period survival will be assessed every 12 h (minimum). Fish size, weight, and health assessment will be measured for all surviving fish 48 h post-test and, for any fish which die during the experiment, within 12 h of death. For fish which are sacrificed for physiological measurements, these measurements will be made immediately after death.

Physiological Responses: In selected experiments from all 10 flow regimes with large size class fish (minimum: 2 of 3 replicate experiments), eight fish will be sacrificed at selected times after the end of the experiment (0 min or immediately after collection, and 30 minutes, 2 hours, and 24 hours after the end of the experiment; two fish each sample) and blood collected by caudal transection for measurements of blood hematocrit, and plasma [cortisol], [lactate], [glucose], [Cl^-] and pH. A minimum of two of the remaining 12 fish used in the 48 hour post-test survival assessment will be sampled similarly 48 hours after the end of the experiment. Control (i.e., resting) samples will be collected from a minimum of 2 fish randomly selected from Hydraulics Laboratory pre-test holding tanks. Samples from fish (collected as above) used in the C-1 flow regime (0 f/s approach/0 f/s sweeping) will be the handling control. Because of the expected volume of blood required to perform these tests, blood from the two fish at each sampling interval will be pooled for analyses.

2. Methods and Definitions

The following sections briefly outline how each of the measurements described above will be made.

Pre-test Health Assessment

Species identification: Visual inspection, comparison using appropriate fish key(s) (Miller and Lea, 1972; Moyle, 1976; Wang, 1986, 1991; Sweetnam, 1995) and laboratory fish care log book.

Acclimation conditions: Aquatic Center and Hydraulics Laboratory fish care log books.

Duration of laboratory holding: Fish collection data sheets and Aquatic Center fish care log books.

Approximate size: Visual inspection during collection for use in experiments.

Length and weight: Measured on anesthetized fish as standard, fork, and total length, and wet weight in g.

Health assessment: Visual inspection on anesthetized fish and during collection for use in experiments.

Mortality and disease history: Aquatic Center fish care log book.

Water Quality

All measurements will be made according to American Public Health Association et al. (1995).

Temperature: Calibrated electronic temperature sensor and/or certified mercury thermometer.

Dissolved oxygen: Electronic dissolved oxygen meter (Royce Model 900CE, Royce Instrument Co.)

pH: Hand-held electronic pH meter (Model pHep2; Hanna Instruments, Woonsocket, RI)
Ammonia: Hach ammonia test kit
Alkalinity: Aquatic Toxicology Laboratory, UCD
Hardness: Aquatic Toxicology Laboratory, UCD

Flow Regime

Approach and sweeping flow velocities: Measured using a SonTec Acoustic Doppler Velocimeter in f/s at 131 locations (3 sections in the circular swimming channel, 3 lateral locations in each section, 10-11 depths in each location, and an additional 35 measurements near the inner screen) for each experimental flow regime. These measured values are used to generate detailed flow velocity profiles.

Average approach flow velocity: This value is used as a controlling parameter for establishing the specified flow regime in each experiment. It is calculated as:

V_a(f/s)=Q(gpm)/(12684 x H(ft))

where

Q = inflow discharge rate measured with Dynasonics Ultrasonic Flowmeter in gallons per minute (gpm); and

H = water depth in the swimming channel at the inner screen measured with an A. B. McIntyre Hydraulics Instruments micrometer in feet (f).

Mid-channel sweeping flow velocity: Measured using a SonTec Acoustic Doppler Velocimeter in f/s at one location 12 inches from the inner screen and at a depth of 10.2 inches from the bottom. This value is used as a controlling parameter for establishing the specified flow regime in each experiment.

Resultant flow velocity: Calculated from approach and sweeping flow velocities at selected lateral and vertical locations within the swimming channel using from flow velocity profiles for each flow regime.

Resultant flow velocity = sqrt[(approach^2)+(sweeping^2)]

Resultant flow vector: Calculated from approach and sweeping flow velocities at selected lateral and vertical locations within the swimming channel using flow velocity profiles for each flow regime.

Resultant flow vector = arctangent(approach flow velocity/sweeping flow velocity)

Light Level

Light level (lux) measured using a photometer (Model LI-185A; LI-COR Inc.)

Fish Behavior and Performance - Visual Observations

Fish depth strata: Estimated as location in the bottom, middle, or top third of the water column.
Loss of equilibrium: Visual observation of lateral or longitudinal rolling by the fish to at least 90° from vertical, detected by observation of the fish's light colored ventrum.
Tail contact: Contact with the inner screen by the fish's caudal fin or <50% of the posterior body length.
Body contact: Contact with the inner screen by >50% of the fish's body length.
Impingement: Prolonged body contact, >5 min duration, with the inner screen by the fish.
Fish distribution: Number of fish visible in the observation area of the swimming channel defined by the view plate between the inner and outer screens.

Fish Behavior and Performance - Video Analyses

Motion analysis: Video tapes from one of the cameras will be analyzed manually and using a computer assisted, video capture/motion analysis system (Peak Performance Technologies, Inc., Englewood, CO) which tracks fish position, angle of orientation, and distance from selected reference points in an XY coordinate system for each frame of selected video tape. For each section of video tape analyzed (e.g., 0.5 seconds or 30 frames), a mean value for each variable described below will be calculated for each fish analyzed.
Fish spatial location: Distance from inner screen, calculated using calibrated, scaled coordinates of the fish and the inner screen at the point closest to the fish. Depth, cm from the bottom, will be measured manually from video tapes from the underwater camera concurrently with the motion analyses of video tape from the same experiment.
Swimming direction and rheotaxis: Measured from fish orientation relative to the resultant flow vector or relative to the counter-clockwise direction for experiment in which sweeping flow=0 f/s as swimming with the flow (negative rheotaxis) or swimming against the flow (positive rheotaxis).
Swimming velocity: Swimming velocity over the ground calculated from scaled XY coordinates and time (automatic calculation by the Peak Performance software). Swimming velocity through the water calculated from swimming velocity over the ground and water velocity in the region of the swimming channel in which the fish is swimming. Swimming velocity through the water is calculated for the X and Y axes and as resultant swimming velocity.
Distance traveled: Calculated as the product of swimming velocity (cm/s, either over the ground or through the water) and time interval duration (e.g., in 1 min, 1 h, or 2 h).
Fish orientation: Fish orientation relative to the inner screen, measured in degrees for a single frame of the section of taped analyzed for motion analysis. Fish orientation relative to the resultant flow vector will be calculated from motion analysis measurement of fish orientation in the XY coordinates and flow vector profiles.
Stroke frequency: Measured as strokes/sec for single fish. Resultant swimming velocity through the water is also measured (as above) for the same fish from the same section of video tape.
Stroke amplitude: Maximum lateral displacement of the caudal peduncle, measured from scaled XY coordinates using the motion analysis system. Resultant swimming velocity through the water and stroke frequency are also calculated (as above) for the same fish.
Stride length: Distance (cm and as proportion of SL) traveled by the fish per stroke. Calculated as swimming velocity divided by stroke frequency.
Swimming behavior: Identified as low velocity discontinuous (“stroke and glide”), continuous, or high velocity discontinuous (i.e., burst) swimming based in swimming velocity, and stroking pattern.
Loss of equilibrium: Same as visual observations.
Tail and body contacts: Same as visual observations.

Post-test health Assessment
Survival: Assessed as number of fish alive out of 20 fish at the end of each experiment (0 h post-experiment) and at 48 h after the end of the experiment. Mortality is defined by cessation of ventilation or opercular movement for >1 min in non-swimming fish, lack of response to constant prodding, rigor mortis.
Size: Wet weight ($\pm$0.01 g) and standard, fork, and total lengths ($\pm$0.1cm).

Health Assessment: Visual observation for evidence of disease, morphological abnormalities, and physical damage to skin, scales, fins, and eyes (e.g., abrasion, scale loss, hemorrhaging).

Physiological Responses
Hematocrit: Measured using an IEC micro-hematocrit reader after centrigugation of capillary tubes with blood samples at 11,000 x gravity for 3 min.
Cortisol: Measured using radioimmunoassay (Brown et al., 1987).
Lactate and Glucose: Measured simultaneously using a YSI 2700 Select Biochemistry Analyzer (Yellow Springs Instruments, Inc., Yellow Springs, OH).
Osmolality: Measured using a Wescor 5100B Vapor Pressure Osmometer (Wescor, Inc., Logan, UT).
pH: Measured using an Orion Model SA 720 pH meter.

G. Data Quality Objectives

The following section describes the data quality objectives (DQOs) of the variables or characteristics which will be measured or recorded as part of the experiments. Data quality objectives are quantitative and qualitative statements describing the accuracy, precision, representativeness, comparability, and completeness goals for the measuring or classifying systems used (USEPA, 1996). These DQOs specify the quality of the data needed to meet the goals of the biological experiments. Generally, all measurements or observations should be:

- representative of the typical conditions found in the test chamber in the immediate vicinity of the location monitored at the time the measurement is taken;
- representative of the performance, behavior, and physiology of fish exposed to the above conditions.
- “True values” refer to properly measured variables based on the proper calibration procedures and standards of the instrument.

All measurements of a variable should be comparable to each other, and should be comparable to similar data collected by other researchers in North America. At least 90% of the measurements collected should meet the data quality objectives of the project. The accuracy and precision objectives for variables measured during the routine biological experiments are discussed below.

1. Pre- and Post-Test Health Assessments

Species Identification: No accuracy objective is available for this variable. Fish identification by two trained personnel should agree. Any fish that can not be identified using keys found in Moyle (1976), Miller and Lea (1972), Wang (1986, 1991), and Sweetnam (1995) with certainty will not be used in the experiments.
Health Assessment: No accuracy objective is available for this variable. At least 80% of the health assessments made by two trained personnel should agree.
Fish Weight (Wet): Measured values should be within 0.1 g of the true values. Replicate measurements should be within 0.15 g each other. Fish weight will be reported as wet weight (g).
Fish Length: Measured values should be within 0.1 cm of the true values. Replicate measurements should be within 0.15 cm each other. Fish length will be reported as standard length (SL), total length (TL), and fork length (FL) in cm.
Survival/Mortality: No accuracy objective is set for this parameter. At least 90% of the

observations regarding the determination of mortality made by two trained personnel should agree. Personnel will use multiple criteria to determine death of the test organism (e.g., lack of gill movement, lack of response to constant prodding, rigor mortis).

2. Water Quality

Water Temperature: Measured values should be within 0.5ºC of the true values (based on calibrations using certified thermometer). Replicate measurements should be within 0.3ºC of each other. During the biological experiments, the mean water temperature should not deviate more than 1.0ºC from the target experimental temperature. Measurements of water temperature in the Fish Treadmill will be made at least once every 60 min during experiments.

Dissolved Oxygen: Measured values should be within 0.5 mg/l of the true values. Replicate measurements should be within 0.25 mg/l of each other. A reading will be taken twice during each experiment, at the start and end of the experiment.

pH: Measured values should be within 0.3 pH units of the true values. Replicate measurements should be within 0.5 pH units of each other. A reading should be taken twice during each experiment, at the start and end of the experiment.

Total Ammonia: Measured values should be within 0.1 mg/l as N or 10% of the true values. Replicate measurements should be within 0.05 mg/l as N or 15% of the true values. Measurements will be recorded at the start and end of each experiment.

Alkalinity: No accuracy objective is available for this parameter. Replicate measurements should be within 5 mg/l as $CaCO_3$ or 5% of each other. Measurement will be recorded for each set of experiments using the same water from the sump.

Total Hardness: Measured values should be within either 3 mg/l as $CaCO_3$ or 3% of the true values. Replicate measurements should be within 5 mg/l as $CaCO_3$ or 5% of each other. Measurement will be recorded for each set of experiments using the same water from the sump.

3. Flow Regime

Inflow discharge rate: Measured values should be within 0.5 cfs of the true values. Replicate measurements should be within 0.4 cfs of each other.

Water depth: Measured values should be within 0.5 in of the true values. Replicate measurements should be within 0.3 in of each other.

Sweeping flow velocity: Measured values should be within 2.0 cm s^{-1} (0.066 f/s) of the true values. Replicate measurements should be within 2.0 cm s^{-1} (0.066 f/s)of each other.

Approach flow velocity: Measured values should be within 1.0 cm s^{-1} of the true values. Replicate measurements should be within 0.5 cm s^{-1} of each other.

Mid-channel sweeping flow velocity: Measured values should be within 2.0 cm s^{-1} (0.066 f/s) of the true values. Replicate measurements should be within 2.0 cm s^{-1} (0.066 f/s)of each other.

4. Light Level

Measured values should be within 10 lux of the true values (based on calibration procedures). Replicate measurements should be within 5 lux of each other or have a relative percent difference (RPD) $\leq$ 5%.

5. Fish Behavior and Performance - Visual Observations

Depth strata**:** No accuracy objective is set for this parameter. Because of the difficulty in estimating fish depth, observations will be limited to classifying fish depth in three strata (e.g., surface, mid-depth, bottom). At least 80% of the observations regarding location of fish in

depth strata made by two trained personnel should agree.
Loss of equilibrium: No accuracy objective is set for this parameter. At least 80% of the observations regarding the determination of the loss of equilibrium made by two trained personnel should agree.
Tail contact: No accuracy objective is set for this parameter. At least 80% of the observations regarding numeration and description of tail contact made by two trained personnel should agree.
Body contact: No accuracy objective is set for this parameter. At least 80% of the observations regarding numeration and description of body contact made by two trained personnel should agree.
Impingement: No accuracy objective is set for this parameter. At least 80% of the observations regarding numeration and description of impingement made by two trained personnel should agree.
Fish distribution: No accuracy objective is set for this parameter. At least 80% of the observations regarding numeration of fish visible in the observation area at the designated time made by two trained personnel should agree.

6. Fish Behavior and Performance - Video Analyses
Fish Spatial Position: Calculated coordinate values for distance from inner screen should be within 3.0 cm of the true values. Replicate measurements should be within 2.0 cm of each other. Manual estimation of depth should be within 5.0 cm of the true values. Replicate measurements should be within 3.0 cm of each other.
Swimming direction, rheotaxis, and fish orientation: Measured values should be within 10 degrees of the true angles. Replicate measurements should be within 5 degrees of each other.
Swimming velocity (over the ground): Calculated values for swimming velocity (over the ground) should be within 3 cm/s of true values. Replicate measurements should be within 2.0 cm/s of each other.
Swimming velocity (through the water): Calculated values for swimming velocity (over the ground) should be within 6 cm/s of true values. Replicate measurements should be within 3.0 cm/s of each other.
Stroke frequency: Counts of stroke number per unit time should be within 1 stroke of true values. Replicate counts should be within 1 stroke of each other.
Stroke amplitude: Calculated values should be within 0.5 cm of true values. Replicate measurements should be within 0.5 cm of each other.
Stride length: Calculated values should be within 1.0 cm of true values. Replicate measurements should be within 1.0 cm of each other.
Swimming behavior: No accuracy objective is set for this parameter. At least 80% of the replicate observations regarding identification of swimming behavior made by two trained personnel should agree.
Loss of Equilibrium: No accuracy objective is set for this parameter. At least 80% of the replicate observations regarding identification of loss of equilibrium made by two trained personnel should agree.
Tail contact: No accuracy objective is set for this parameter. At least 80% of the observations regarding numeration and description of tail contact made by two trained personnel should agree.
Body contact: No accuracy objective is set for this parameter. At least 80% of the observations

regarding numeration and description of body contact made by two trained personnel should agree.

7. Physiological responses

Blood Hematocrit: Measured values should be within 1.0% volume red blood cells of true values. Replicate measurements should be within 10% of each other.

Plasma Cortisol: Measured values should be within 0.1 ng ml^{-1} of the true values. Replicate measurements should be within 0.05 ng ml^{-1} of each other.

Plasma Lactate: Measured values should be within 0.1 mM l^{-1} of the true values. Replicate measurements should be within 0.05 mM l^{-1} of each other.

Plasma Glucose: Measured values should be within 0.1 mM l^{-1} of the true values. Replicate measurements should be within 0.05 mM l^{-1} of each other.

Plasma Osmolality: Measured values should be within 1.0 mOsm kg^{-1} of the true values. Replicate measurements should be within 1.0 mOsm kg^{-1} of each other.

Plasma pH: Measured values should be within 0.3 pH units of true values. Replicate measurements should be within 0.3 pH units of each other.

H. Calibration Procedures and Frequency

1. Flow Regime

The Fish Treadmill will be calibrated and detailed flow profiles developed for the nine experimental flow regimes every six months. Calibrations will be conducted at the two test temperatures (12 and 19°C, one temperature every six months). The SonTec Acoustic Doppler Velocimeter used to measure flow velocity and direction in the Fish Treadmill will be calibrated according to manufacturer's specifications as defined in the user's manuals.

2. Light Level

Light level and light placement will be calibrated and adjusted as necessary using light level measurements made at 24 locations (8 sections, 3 lateral locations each section; near inner screen, mid-channel, and near outer screen) twice per year.

3. Analytical Equipment

All analytical equipment (e.g., dissolved oxygen meter, pH meter, osmometer, etc.) will be calibrated according to manufacturers' specifications as defined in the user's manuals.

4. Motion Analysis

Calibration and scaling of video images, to convert computer/monitor pixel dimensions into linear metric units, will be conducted for each camera using procedures outlined in the operator's manual and the program's online help manual. The scaling rod will consist of two permanent markers of retro-reflective tape placed on the upper surface of the large view plates. Distance between the markers will be checked using a standard linear scale at monthly intervals, although it is not expected that the marker's positions will change. Motion analysis of each videotape will begin with this calibration/scaling procedure and all motion analyses from that tape will incorporate the scaling factor for measurements and calculations.

I. Data Documentation

All laboratory and field activities will be documented at the time they are conducted. Documentation type (e.g., data sheets, laboratory log books) will vary depending on activity. Specific documentation is described below.

Fish Collection: Data sheets from each collection will include information on personnel, location, species, collection conditions (e.g., temperature and salinity), weather conditions, number of fish collected, and general notes on fish condition and other relevant information as necessary.

Fish Care: Laboratory log books for each fish holding facility will include information recorded daily on personnel, feeding, cleaning, water quality (e.g., temperature), all prophylactic and anti-disease treatments, mortality and health assessments, other relevant information on fish and/or fish holding facility status.

Fish Treadmill Experiments: Data collected from treadmill experiments will be documented on separate data sheets for various aspects of the experiment and experimental conditions. All data sheets will include information on date, time, species, experimental flow regime, temperature, light level, and personnel. Separate data sheets will be used for:

- water quality and flow regime;
- pre- and post-test fish health assessments;
- visual observations of fish in the treadmill;
- data recording and analyses from video tape records of the treadmill experiments;
- post-test physiological measurements.

All treadmill experiments will also be video recorded using five video cameras mounted above the treadmill swimming chamber and underwater (see Experimental Apparatus, and Measurements). Video tapes will be stored at the UC Davis Hydraulics Laboratory or Academic Surge Building, Rm 1331, prior to analysis and data collection on fish swimming performance and behavior. After analyses, video tapes will be archived at the Fish Physiology Laboratory (UCD Academic Surge building) and available for follow-up analyses for data checking purposes and/or additional analyses.

IV. DATA REDUCTION, ANALYSES, AND REPORTING

A. Data Reduction and File Management

1. Pre- and Post-test Health Assessments

Pre- and post-test health assessment data and reduced physiological response data (see Physiological Responses below) will be compiled into a Fish Status data file. Summarized data from this file (e.g., duration of laboratory holding pre-test, survival, blood parameters) will be included in other data files (e.g., Fish Performance, see below) for incorporation into subsequent statistical analyses (see Statistical Methods). Fish size data (e.g., mean standard lengths) will also be included in the Fish Performance and Fish Behavior data files (see below) in order to allow calculation of relative swimming velocities and distance values and to test for effects of fish size on performance and behavior.

2. Water Quality, Flow Regime, and Light Levels

Data on fish treadmill water quality, flow regime, and light levels will be incorporated into an Flow and Environmental Conditions data file and will be analyzed to assess the variability of the experimental conditions. Reduced data from some variables (e.g., water temperature) will also be included in Fish Performance and Fish Behavior data files.

3. Fish Behavior and Performance

a. Visual Observations

Data from visual observation data sheets will be included in Fish Performance data files.

b. Video Analysis

Data on fish spatial position, velocities, distances, and orientation collected using motion analysis will be incorporated into Fish Behavior data files. Data on swimming kinematics (e.g. stroke frequency, stride length) collected using motion analysis will be incorporated into a Kinematics data file.

c. Fish Performance

A Fish Performance data file will include data on species, experimental conditions (e.g., temperature, flow regime, light level), visual observation data, video analysis data, and reduced data from the Fish Status data file (e.g., survival rates, physiological responses). It will be generated using data from visual observation data sheets, manual video analysis, reduced motion-analysis data, reduced data from the Flow and Environmental Conditions data file (e.g., temperature) and Fish Treadmill flow profiles.

d. Fish Behavior

A Fish Behavior data file will include data on species, fish size (from Fish Status data files) experimental conditions (e.g., temperature, flow regime, light level, etc., from Flow and Environmental Conditions data files), water velocity at the specified location (from Fish Treadmill flow profiles) and swimming behavior (e.g., spatial position, velocities, etc., from motion analysis data sheets).

e. Physiological Responses

Data from the measured physiological responses (e.g., plasma cortisol, etc.) and data from the Fish Status data files (e.g., survival, size) and experimental conditions (e.g., temperature, flow regime, light level, etc., from Flow and Environmental Conditions data files) will be incorporated into a Physiological Response data file.

B. Statistical Methods

Results compiled in the files described above will be analyzed using Sigmastat and Systat software. Statistical analyses will include: comparisons among appropriate treatment groups (e.g., species, flow regime, light level, etc.) made using analysis of variance and two-tailed t-tests; regression analyses and analysis of covariance for examination of the effects of continuous variables (e.g., time, swimming velocity) and categorical covariates (e.g., temperature); nonparametric tests (e.g., Mann-Whitney Rank Sum test) for comparisons of treatment groups for which the data are not normally distributed.

V. DATA ASSESSMENT AND OVERSIGHT

A. Data Quality Control Checks
1. Data Acceptability

Listed below (or referenced in the specified section of this document) are the acceptable ranges of selected biological, environmental, and experimental conditions for the pre-test, test, and post-test periods for the Fish Treadmill experiments. Conditions that deviate from these acceptable ranges may be considered as rationale for a) excluding or postponing the use of selected fish from the experiments; b) canceling a planned experiment; and/or c) excluding some or all of the data collected during an experiment (e.g., if water temperature in the Fish Treadmill is unacceptable, all data collected during the experiment must be evaluated separately and, possibly, excluded from the data set; however, if post-test holding tank temperature is unacceptable, all data from the experiment with the exception of post-test survival and health assessment may be used).

Pre-test Health and Fish Care Conditions
<u>Temperature Acclimation</u>: Minimum 7 days at experimental temperature.
<u>Holding Tank Temperature</u>: <±1.0°C of specified test temperature. If Hydraulics Laboratory tank temperatures deviate from specified test temperature, the temperature will be adjusted 1.0°C/day and the fish held a minimum of one day after the temperature has been adjusted to the correct level before they are used in the experiments.
<u>Disease History</u>: No fish from a holding tank that has been treated for bacterial or fungal infections in the previous 10 d will be used in the experiments.
<u>Mortality History</u>: No fish from a tank that has experienced >10% mortality (excluding transport mortality) in the five days prior to use in the experiments will be used in the experiments
<u>Transport History</u>: All fish will spend a minimum of three days in Hydraulics Laboratory fish holding tanks prior to use in the experiments.

Experimental Variables
Listed below are the acceptable water quality ranges for specific parameters.
<u>Fish Treadmill Water Temperature</u>: ±1.0°C of specified test temperature.
<u>Fish Treadmill Dissolved Oxygen</u>: >70% air-saturation.
<u>Fish Treadmill pH</u>: >7.0 or <9.0 pH units.
<u>Fish Treadmill Ammonia</u>: <0.5 mg/l (as total N).
<u>Flow Regime</u>: ±3 cm/s for the approach flow velocity, ±6 cm/s for the sweeping flow velocity.

Post-test Conditions
<u>Holding Tank Temperature, Dissolved Oxygen, pH, and Ammonia</u>: same range as for the Fish Treadmill.
<u>Fish Size</u>: If data on fish size are lost or unavailable for all fish used in an experiment, estimated size ranges from pre-test log books and data sheets, will be used but data from the experiment will be evaluated separately before possible inclusion in the data set. If data on fish size of <30% of the fish used in the experiment are lost or unavailable, mean fish size values calculated from the remaining fish will be used in the data set.
2. Error Checking of Raw Data

Upon completion, all data sheets will be checked by the research assistant in charge of that particular experiment, any errors or incomplete sections corrected, and the data sheet signed by the research assistant in charge. Completion and error checks will also be made at the time the data are entered into the data files. Any corrections made on data sheets after completion will be signed and dated by the research assistant in charge of the experiment or a post-doctoral researcher. During data entry, a minimum of 10% of the data entered in each data file (e.g., 1 row out of every 10 rows in the data file) will be double checked by a second trained research assistant or a post-doctoral researcher. Any questions or discrepancies will be investigated and corrected by the post-doctoral researchers. Specific data in which questions can not be resolved (e.g., unreadable) will not be included in the data sets.

3. Error checking of Reduced Data and Analyses
Reduced Data and Preliminary Analyses

All reduced data and preliminary analyses (e.g., summary statistics) will be checked by a trained research assistant and/or a post-doctoral researcher for errors, completeness, and correct execution of preliminary statistical tests. After this check, selected components of these data will be entered (and checked as above) in the appropriate data file(s) (see these Data Reduction and File Management) for further analyses.

Statistical Analyses

All statistical procedures will be conducted according to Sokal and Rohlf (1981), Snedecor and Cochran (1967), and other recognized and standard methods. The UCD Statistics Laboratory, which provides consultations with professional statisticians, will be consulted as necessary.

4. Performance and System Evaluation

All field and laboratory activities may be reviewed by the Principal Investigator, QA Officer, and post-doctoral researchers as requested. A QA/QC report summarizing the results of data quality control checks will be submitted to the QA Officer monthly. In the event data quality control objectives are not satisfied, the Principal Investigator, post-doctoral researchers, and State agency representatives will meet to determine the extent of the problem, discuss and develop corrective actions, oversee implementation of the corrective actions, and evaluate their effectiveness.

B. Agency and Peer Review

The Fish Treadmill project will be subjected to agency and peer review at several levels. Agency representatives (i.e., DWR, CDFG; see Project Organization, Responsibilities), in addition to participation in various aspects of the project and experiments, will meet regularly (two times per month) to discuss and evaluate progress, problems, and scheduling. The project will be more formally evaluated by agency representatives, representatives from cooperating agencies, and contract consultants at least once per year. Journal articles describing results of various aspects of the project will be submitted for publication in peer-reviewed scientific, water-related, and management journals (e.g., Transactions of the American Fisheries Society, North American Journal of Fisheries Management, Environmental Biology of Fishes, Copeia, Canadian Journal of Aquatic and Fisheries Sciences, Journal of Experimental Biology, Conservation Biology, Hydrobiologia, and Water Research).

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Appendix III

Publications and Presentations of Results From the Fish Treadmill Project

1. Published Reports and Articles

(listed in reverse chronological order)

Swanson, C., P.S. Young, J. J. Cech, Jr, . R Wantuck, and D. Odenweller. 2003. Performance and Behavior of Juvenile Chinook Salmon Near a Fish Screen: Linking Laboratory and Field Studies. 2003. Annual Meeting, American Fisheries Society, Western Division, April 15-17, 2001. San Diego, CA. Abstr. No. 4307.

White, D., C. Swanson, P.S. Young, J. J. Cech, Jr, Z. Q. Chen, L. Kavvas. 2003. Close Encounters with a Fish Screen: Impingements with Respect to Flow Field Analysis. Annual Meeting, American Fisheries Society, Western Division, April 15-17, 2001. San Diego, CA. Abstr. No. 4306.

Swanson, C., P.S. Young, J. J. Cech, Jr, . R Wantuck, and D. Odenweller. 2003. Close Encounters with a Fish Screen: Linking Laboratory and Field Studies on Juvenile Chinook Salmon. 2003. CALFED Science Conference, January 14-16, 2003. Sacramento, CA. Abstr. p. 164.

White, D., C. Swanson, P.S. Young, J. J. Cech, Jr, Z. Q. Chen, L. Kavvas. 2003. Close Encounters with a Fish Screen: Anatomy of an Impingement. CALFED Science Conference, January 14-16, 2003. Sacramento, CA. Abstr. p. 176.

Swanson, C., P.S. Young, S. N. Chun, T. Chen, T. Mussen, J. J. Cech, Jr, G. Aasen, and R. Fujimura. 2003. Close Encounters with a Fish Screen: Exploring Applications of Laboratory Studies for Developing Fish Screen Criteria. CALFED Science Conference, January 14-16, 2003. Sacramento, CA. Abstr. p. 270.

Young, P. S., C. Swanson, S. Chun, J. J. Cech, Jr. 2003. Delta Smelt Physiology and Behavioral Research: What We Know and What We Need to Know. CALFED Science Conference, January 14-16, 2003. Sacramento, CA. Abstr. p. 285.

Swanson, C., D. V. Baxa, P. S. Young, J. J. Cech, Jr., and R. P. Hedrick. 2002. Reduced Swimming Performance in Delta Smelt Infected with *Mycobacterium* spp. J. Fish Biol. 61:1012-1020.

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Appendix IV

Research Findings

submitted to the

CVPIA/Anadromous Fish Screen Program
(U.S. Bureau of Reclamation and U.S. Fish and Wildlife Service)

The Research Findings reports are designed to summarize relevant Fish Treadmill project results for selected species and illustrate potential applications of the results for development and/or refinement of fish screen flow criteria. Three reports are included in this appendix.

Appendix IV. A.: Chinook salmon (12°C, 4-8 cm SL)

Appendix IV. B.: Delta smelt (12°C, 4-8 cm SL)

Appendix IV. C.: Splittail (19°C, 4-8 cm SL)

Appendix IV. A.

FISH TREADMILL-DEVELOPED
FISH SCREEN CRITERIA FOR NATIVE SACRAMENTO-SAN JOAQUIN WATERSHED FISHES

Anadromous Fish Screen Program, Cooperative Agreement No. 114201J075

Recommendations for Fish Screen Flow and Operational Criteria to Improve Protection

of

Species: Chinook salmon, *Oncorhynchus tshawytscha*

Size (Age): 4-6 cm standard length (SL), “parr”
6-8 cm SL, “smolt”

Environmental Conditions: 12°C, winter and spring
Day (light conditions) and Night (dark conditions)

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Submitted to

The Anadromous Fish Screen Program
U. S. Fish and Wildlife Service
Sacramento, California

September 2001

**Recommendations for Fish Screen Flow and Operational Criteria
Based on Results of Fish Treadmill Studies**

Anadromous Fish Screen Program, Cooperative Agreement No. 114201J075

by

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Species: Chinook salmon, *Oncorhynchus tshawytscha*

Size (Age): 4-6 cm standard length (SL), "parr"
6-8 cm SL, "smolt"

Environmental Conditions: 12°C, winter and spring
Day (light conditions) and Night (dark conditions)

BACKGROUND

The Fish Treadmill project is an ongoing, laboratory-based research program designed to quantitatively evaluate the performance and behavior of native Sacramento-San Joaquin watershed fishes near a simulated fish screen. A complete description of the Fish Treadmill project, including design and operational details of the apparatus, experimental design and protocols, types of measurements, data collection and handling, and quality assurance/quality control, is provided in the Biological Monitoring Plan (submitted with this first recommendation). The Fish Treadmill studies are intended to provide information that can be applied to establish or improve existing fish screen criteria for approach velocity, sweeping velocity, and exposure duration.

RATIONALE AND RELEVANT MEASUREMENTS

These recommendations for fish screen flow criteria are based on the assumption that, for optimal protection, the fish screen should be designed and operated to minimize the occurrence and severity of contact by the fish with the screen. Based on results of the Fish Treadmill studies with a variety of fish species, this depends on two factors:

- ability of the fish to avoid physical contact with the screen; and

- duration that the fish is exposed, or in close proximity, to the screen.

For juvenile chinook salmon (12°C, day and night), the Fish Treadmill experiments tested the effects of constant levels of approach velocity and sweeping velocity, water temperature (or season), day vs night, and fish size (or age/life stage) on fish performance and behavior (see Table 1 for a complete list).

Table 1. Fish Treadmill experiments conducted with juvenile chinook salmon, 12°C.

Species	Temp. (°C) Season	Size (cm SL) Life stage	Day vs Night	Flow treatments (ft/s)	Number of replicates, number of experiments	Comments
chinook salmon	12 winter and spring	4-6 "parr"	Day	10 flow treatments control: 0 approach: 0.2, 0.33, and 0.5 combined with sweeping: 0, 1.0, and 2.0	3-6 replicates each treatment 47 experiments	
chinook salmon	12 winter and spring	4-6 "parr"	Night	10 flow treatments control: 0 approach: 0.2, 0.33, and 0.5 combined with sweeping: 0, 1.0, and 2.0	3-6 replicates each treatment 48 experiments	
chinook salmon	12 winter and spring	6-8 "smolt"	Day	10 flow treatments control: 0 approach: 0.2, 0.33, and 0.5 combined with sweeping: 0, 1.0, and 2.0	3-5 replicates each treatment 37 experiments	Physiological stress responses measured. Results are incomplete and preliminary.

Recommendations for fish screen flow and exposure duration criteria are based on several specific results from these experiments, including:

- screen contact rate (the average number of times a fish contacted the simulated fish screen per min)
- screen contact severity (measured as proportion of contacts in which >50% of the body contacted the screen)
- impingement rate (the number of times a fish experienced continuous contact with the screen for >2.5 min)
- injury rates (number and severity of post-experiment injuries to fins, eyes, scale loss, and abrasions exhibited by the fish 48 h post-experiment, expressed as an index)
- physiological stress responses (including plasma cortisol, lactate, glucose, and pH, measured for 6-8 cm SL "smolts" only)

- survival (at 0 and 48 h post-experiment)
- swimming behavior (including swimming velocity and rheotaxis)
- screen passage velocity (velocity and direction of movement past the fish screen)
- exposure duration (as the effects of time on some of the above responses)

RESULTS

Table 2, Figures 1 and 2, and the general linear statistical models and text descriptions below describe the relevant results of the Fish Treadmill experiments with juvenile chinook salmon at 12°C.

Fish-Fish Screen Interactions:

Juvenile chinook salmon (12°C) experienced frequent temporary contact with the fish screen, with rates dependent on flow, environmental conditions, fish size, and the location of the fish relative to the screen (see Figure 1a and b). For juvenile chinook salmon during the DAY and NIGHT, screen contact rates (contacts/fish*min) are described by the regressions:

Screen contact rate (DAY) = 0.138(SL) - 0.008(SWP) - 0.01(DST)

n = 66, r^2 = 0.7547, standard error of the estimate (SEE) = 0.311

Screen contact rate (NIGHT) = 0.146(SL)

n = 36, r2 = 0.7152, SEE = 0.529

where SL is standard length in cm;

SWP is sweeping velocity is in cm/s; and

DST is distance from screen in cm (i.e., average location of the fish relative to the screen); and

n is the number of experiments.

Screen contact rates were slightly higher during the early period of exposure to the fish screen. The regression below describes screen contact rates for the first 30 min of exposure (DAY only).

Screen contact rate (DAY, 0-30 min) = 0.192(SL) - 0.007(SWP) - 0.018(DST)

$$n = 57, r^2 = 0.6207, SEE = 0.561$$

Screen passage, as velocity past screen in cm/s with negative values indicating downstream movement and positive values indicating upstream movement (relative to the sweeping flow), reflected and integrated the swimming behavior of the fish and sweeping velocity to which the fish was exposed (see Figure 2). For juvenile chinook salmon (12°C), screen passage is described by the regression:

Screen passage = 24.19 - 9.61(DN) - 1.22(SWP) + 0.76(SV) - 0.34(R) + 0.22(DN x SWP)
n = 97, r2 = 0.9028, SEE = 6.15

where: DN is time of day/light level, with day = 1 and night = 2;
SWP is sweeping velocity, cm/s;
SV is swimming velocity through the water, cm/s; and
R is rheotaxis, degrees, with 0° for positive rheotaxis and 180° for negative rheotaxis.

Excluding the behavioral component of swimming velocity and rheotaxis, screen passage velocity is described by the regression:

Screen passage = 20.52 - 8.96(DN) - 0.89(SWP) + 0.18(DN x SWP)
n = 97, r2 = 0.7378, SEE = 10.00

Swimming Behavior:

In high velocity flow regimes, i.e., those with a 2.0 ft/s sweeping velocity, juvenile chinook salmon in 12°C volitionally and consistently swam at velocities comparable to critical swimming velocities (i.e., maximum sustained swimming velocities) measured for similarly sized conspecifics acclimated to similar temperatures in other studies (P. S. Young, C. Swanson, and J. J. Cech Jr., unpublished results). In the 1.0 ft/s sweeping velocity flow regimes, the larger fish (6-8 cm SL, tested during the day only) and the 4-6 cm SL "parr" size fish tested at night swam at lower velocities but, during the daytime, swimming velocities of the smaller fish (4-6 cm SL) were as high as those measured in the 2.0 ft/s sweeping flow regimes. Critical swimming velocity is a measure of the maximum level of activity that can be sustained by the fish through aerobic metabolism.

Table 2. Summarized results of Fish Treadmill experiments with juvenile chinook salmon, 12°C. NS = no significant effect of the specified variable. NA = not applicable (e.g., effect of size on stress is NA because stress was measured for the large fish only).

Response	Approach velocity	Sweeping velocity	DAY vs NIGHT (4-6 cm SL "parr" only)	Size (age) (DAY experiments only)	Time (exposure duration)
Screen contact Figure 1a	NS	Screen contact rate decreased with increases in sweeping velocity during the DAY but not during the NIGHT	Screen contact rates were independent of flow at NIGHT	Large fish (6-8 cm SL, "smolts") contacted the screen more frequently than small fish (4-6 cm SL, "parr")	For large 6-8 cm SL "smolts", contact rates decreased with time; fish contacted the screen 92% more frequently during the first 30min than the final 30 min
Screen contact severity Figure 1b	NS	Contact severity increased with increases in sweeping velocity, DAY and NIGHT	Contact severity was higher during the NIGHT than during the DAY	NS	NS
Impingement	NS impingement = rare	NS impingement = rare	NS impingement = rare	NS impingement = rare	NS
Injuries Figure 1c	NS	NS	NS	NS	NA
Stress	NS	NS	NA	NA	NA
Survival (0 and 48 hour)	>99%	>99%	>99%	>99%	NA
Swimming velocity Figure 2a	NS	Swimming velocity increased with increases in sweeping velocity DAY and NIGHT	Fish swam slower at NIGHT	NS	During the DAY, swimming velocities decreased slightly with time in the 2.0 ft/sec sweeping velocity only
Rheotaxis Figure 2b	NS	Fish exhibited increased positive rheotaxis with increases in sweeping during the DAY	During the NIGHT, fish exhibited consistent and strong positive rheotaxis that was independent of flow	NS	NS
Screen passage Figure 2c	NS	Downstream screen passage directly related to sweeping velocity	NS	NS	NS

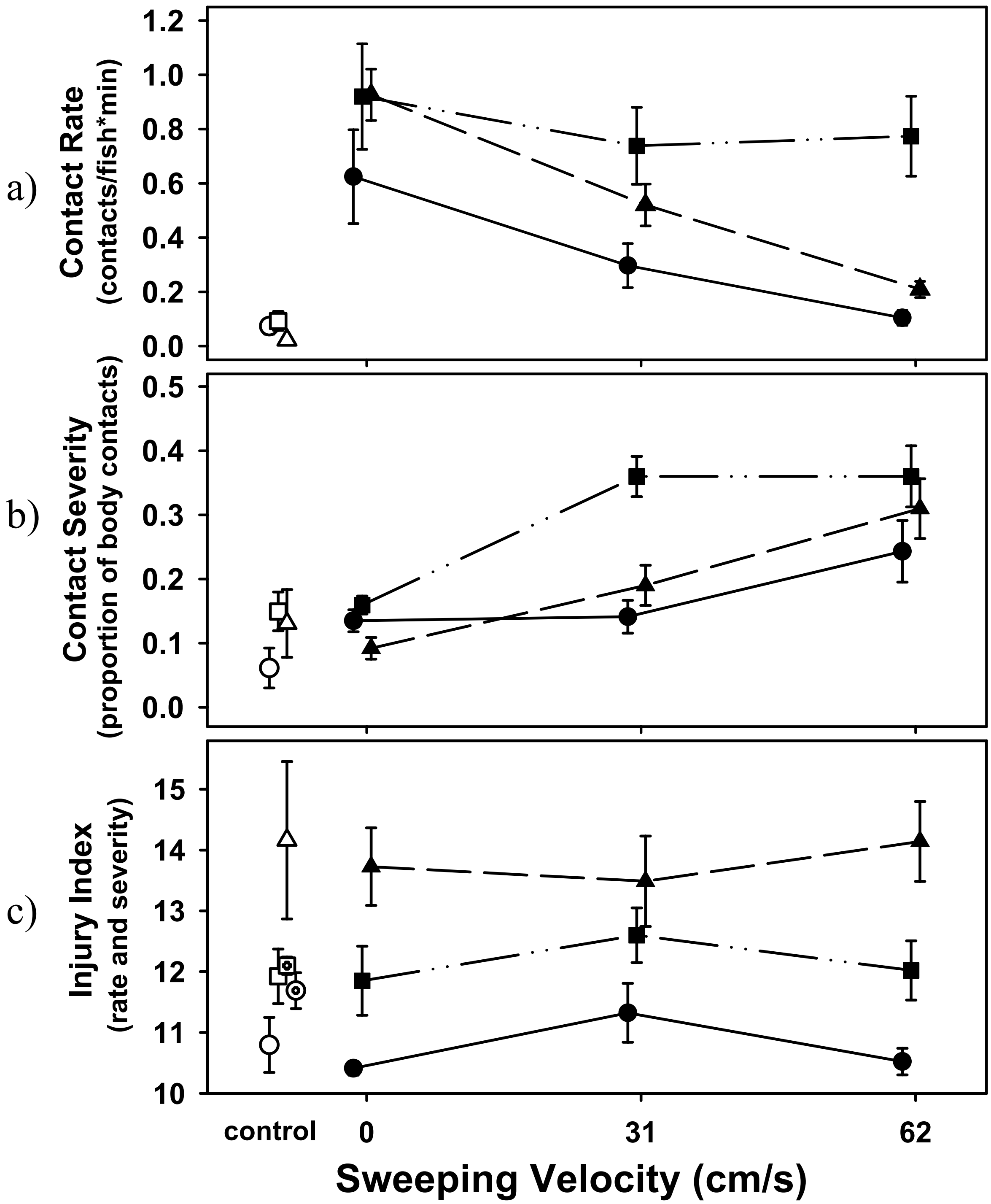

Figure 1. Effects of sweeping velocity on fish-screen interactions for juvenile chinook salmon, 12EC: a) screen contact rate; b) screen contact severity, as proportion of total contacts that were body contacts; c) post-experiment injuries, expressed as injury index that combines injury rates and injury severity, an injury index of 10 = no injuries. Within each sweeping flow treatment, results from the three approach velocities are pooled. Each point is the mean (±SE) of the pooled results from replicate experiments. = 12EC, 4-6 cm SL, "parr", DAY. = 12EC, 4-6 cm SL, "parr", NIGHT. • = 12EC, 6-8 cm SL, "smolts", DAY. Closed symbols are for experimental flow regimes and open symbols are for corresponding controls. Relative to the X axis, points from the three treatment groups have been offset for visual clarity.

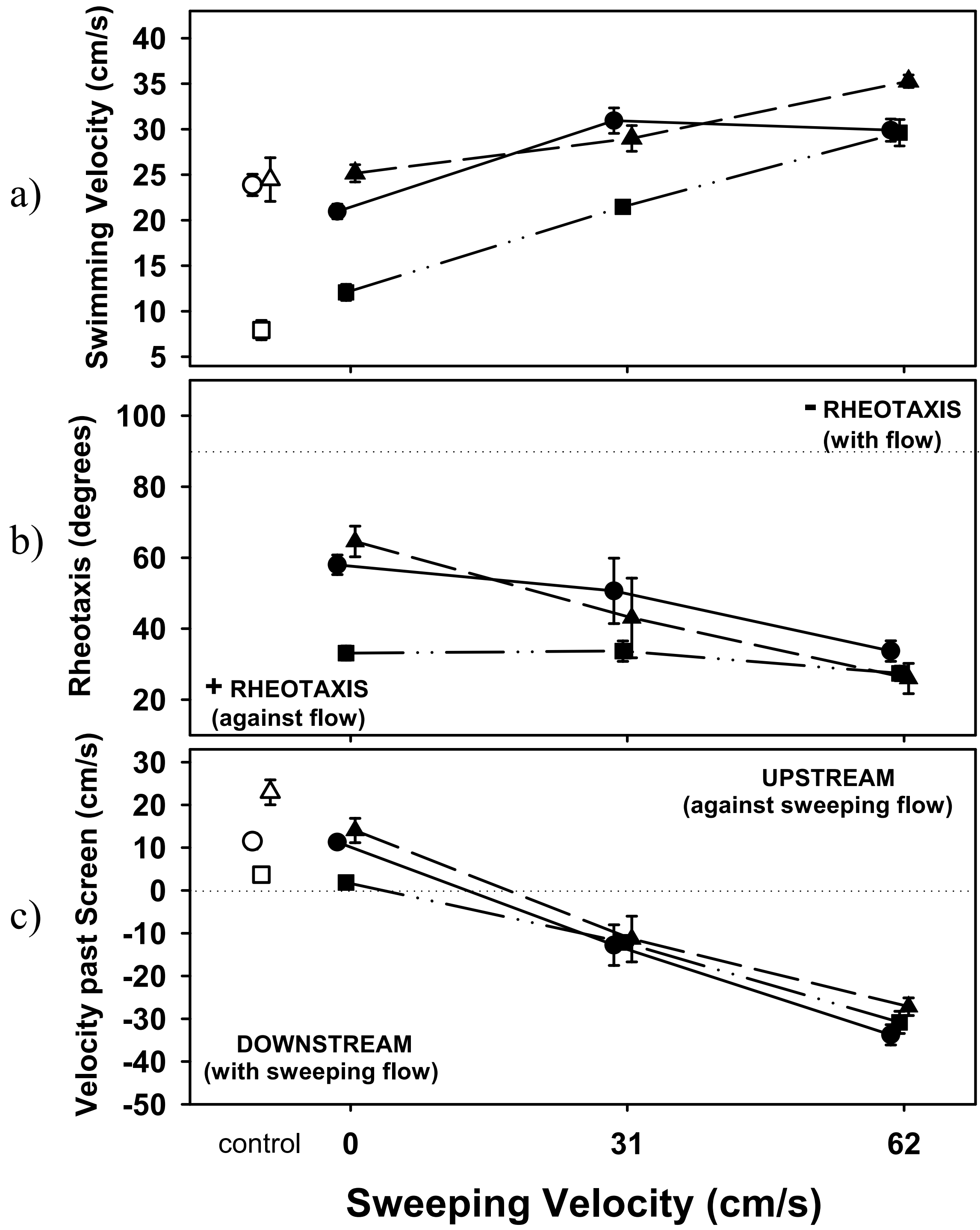

Figure 2. Effects of sweeping velocity on swimming behavior of juvenile chinook salmon, 12EC: a) swimming velocity, through the water; b) rheotaxis, swimming orientation relative to the resultant flow, 0E = positive rheotaxis, 180E = negative rheotaxis, results from control experiments with no flow are not shown; c) screen passage velocity, or velocity over the ground. Positive values are for upstream movement relative to the sweeping flow. Negative values are for downstream movement relative to the sweeping flow. Results for 0 cm/s sweeping flow treatments are absolutes values. Within each sweeping flow treatment, results from the three approach velocities are pooled. Each point is the mean (±SE) of the pooled results from replicate experiments. = 12EC, 4-6 cm SL, "parr", DAY. = 12EC, 4-6 cm SL, "parr", NIGHT. • = 12EC, 6-8 cm SL, "smolts", DAY. Closed symbols are for experimental flow regimes and open symbols are for corresponding controls. Relative to the X axis, points from the three treatment groups have been offset for visual clarity.

APPLICATIONS FOR FISH SCREEN DESIGN

The statistical models in the Results section can be applied to determine optimal screen flow conditions that minimize screen contact and promote passage for juvenile chinook salmon (12°C) and then to quantitatively predict the fish's performance and behavior near a fish screen.

1. During the day, screen contact rates were minimized at screen flows with a high sweeping velocity component (i.e., 2.0 ft/s).

2. During the day and night, downstream screen passage was maximized at screen flows with a high sweeping velocity component (i.e., 2.0 ft/s). Rapid downstream passage correlates with minimized exposure to a fish screen of finite length.

Example: For a 100 ft long flat plate fish screen designed to operate with an approach velocity of 0.33 ft/s approach velocity (the present approach velocity criterion for juvenile chinook salmon) and a 2.0 ft/s sweeping velocity during the daytime, for how long would a 5 cm SL-long, juvenile chinook salmon that swam to within 6 inches from the screen be exposed to the screen and, during that exposure, how many times would the fish contact the screen?

<u>Screen Passage Velocity</u>

= 20.52 - 8.96(1=DAY) - 0.89(62=sweeping velocity, cm/s) + 0.18(1=DAY x 62=sweeping velocity)

= -32.5±10.0 cm/s (=32.5±10.0 cm/s in the downstream direction)

= -1.05 ft/s±0.3 (=1.05±0.3 ft/s in the downstream direction)

<u>Exposure Duration</u>

= 100 ft long screen/(1.05±0.3 ft/s)

= 95±21 seconds exposure = 1.6±0.3 minutes exposure.

<u>Screen Contact During the Exposure</u>

= 0.192(5 cm SL) - 0.007(62=sweeping velocity, cm/s) - 0.018(15=cm from screen)

= 0.26±0.56 contacts per fish per minute

= 0.26 contacts per minute x 1.6 min exposure

= an average of 0.4 contacts per fish per exposure

= on average, 2 fish out of every 5 fish would contact the fish screen one time during the exposure.

Example: At night under the above conditions, screen passage velocity would be similar (e.g., see Figure 2c) but, during the approximately 1.6-min exposure period, on average, the 5 cm SL fish would contact the screen at least one time, or approximately three times as often as during the day.

<u>Screen contact during exposure</u>

= 0.146(5=cm SL)

= an average of 0.73 contacts per minute x 1.6 min exposure

= on average, 1.2 contacts per exposure.

Example: For a similar screen operated with a sweeping velocity of 1.0 ft/s, the fish would move downstream at an average of 10.5 cm/s (0.34 ft/s) and require, on average, 5 min to pass the length of the screen. During that exposure the fish would, on average, contact the screen 2.4 times. During the night, the fish would contact the screen, on average, 3.7 times.

Example: For juvenile chinook salmon during the day, at what sweeping velocity is screen passage velocity effectively zero?

<u>0 cm/s Screen Passage Velocity</u>

= 20.52 - 8.96(1=DAY) - 0.89(sweeping velocity) + 0.18 (1=DAY x sweeping velocity)

= sweeping velocity = 16.3±10.0 cm/s = 0.52±0.3 ft/s

INTERPRETATIONS

In Fish Treadmill experiments, juvenile chinook salmon (12°C) contacted the fish screen frequently, as often as once per minute for some flow treatments. During the day, screen contact rates and severity were significantly influenced by sweeping velocity but were independent of approach velocity. At night, screen contact rates were independent of flow.

However, neither screen contact rates, screen contact severity, nor flow velocity were significantly correlated with injuries, stress, or post-exposure mortality. Impingement was rare and survival was uniformly high, even during the nighttime experiments when fish contacted the screen with maximum frequency and severity.

Therefore, although fish-fish screen contact may be undesirable (e.g., a fish disoriented by unexpected contact with the fish screen could be more vulnerable to predation, a factor not tested in these Fish Treadmill studies), these results provide no direct justifications for establishing or limiting either approach or sweeping velocities on the bases of injuries, stress or reduced survival of the fish.

High velocity sweeping flows (up to 2.0 ft/s) promoted downstream passage of juvenile chinook salmon acclimated to 12°C, with the additional benefit during the daytime of minimizing the frequency of screen contacts by the fish. However, exposure to these high velocity flows was more energetically expensive for the fish, as indicated by high swimming velocities at or approaching maximum sustainable levels, than exposure under similar conditions to lower velocity flows.

RECOMMENDATIONS

Based on the above results and interpretations, we submit the following recommendations for fish screen flow criteria for juvenile chinook salmon in 12°C (or during the winter and spring). These recommendations are limited to the species, flow velocities, environmental conditions, and life stages tested in the Fish Treadmill and do not account for other factors that have been hypothesized to affect the performance and behavior of fishes near a fish screen, for example increased vulnerability to predation.

Approach Velocity: No recommendation.
On the bases of screen contact frequency, screen contact severity, injuries, stress, survival and screen passage, approach velocities between 0.2 and 0.5 ft/s are equally protective.

Sweeping Velocity: Minimum = 1.0 ft/s. Preferred = 2.0 ft/s.
On the bases of reduced screen contact frequency, no adverse effects on injuries, stress or survival, and enhanced screen passage, high sweeping velocities (up to 2 ft/s) provide greater benefit to juvenile chinook salmon than lower sweeping velocities.

Exposure Duration: Maximum: 2 minutes for fish screens that operate during the day and night, or 2-4 minutes for fish screens that operate only during the day, depending on the size (or life stage) of the affected fish.

These recommendations are based on the following conclusions and calculations using the statistical models presented in the Results section.

1. The energetic costs associated with exposure to a fish screen (and its near-screen flow field) should be minimized.

2. While fish-fish screen contact was not injurious, stressful, or lethal in the Fish Treadmill studies, it may have other adverse consequences for the fish not measured in these studies (e.g., increased vulnerability to predation) and should therefore be minimized. Based on this, exposure durations were calculated to allow a maximum

average of 2 contacts per fish per exposure. Results of these screen contact calculations using the statistical models developed from Fish Treadmill results for a juvenile chinook salmon (swimming within 0.5 ft of the fish screen) are shown in Table 3.

3. The allowable linear length of the fish screen should be calculated based on planned sweeping velocities, predicted size(s) and life stage(s) of juvenile chinook salmon needing protection, and planned day/night operations of the diversion.

Table 3. Maximum allowable exposure durations, calculated to result in an average of 2 screen contacts per fish, for juvenile chinook salmon, 12°C, in two sweeping velocities.

Day vs Night	Sweeping velocity (ft/s)	Fish Size (cm SL)	Exposure Duration (min) (calculated to result in an average of 2 screen contacts per fish)
DAY	1.0	5	4.2
NIGHT	1.0	5	2.7
DAY	2.0	5	7.8
NIGHT	2.0	5	2.7
DAY	1.0	7	2.3
NIGHT	1.0	7	2.0
DAY	2.0	7	3.1
NIGHT	2.0	7	2.0

RESEARCH FINDINGS

Interpretations and Potential Applications for Fish Screen Flow and Operational Criteria from the Fish Treadmill Project

Anadromous Fish Screen Program, Cooperative Agreement No. 114201J075

Prepared by

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Species: Delta smelt, *Hypomesus transpacificus*

Size (Age):4-6 cm standard length (SL), "sub-adult"
6-8 cm SL, "adult"

Environmental Conditions: 12°C, winter and spring
Day (light conditions) and Night (dark conditions)

Submitted to

The Anadromous Fish Screen Program
U. S. Fish and Wildlife Service
Sacramento, CA

March 2002
revised April 2002

RESEARCH FINDINGS

Interpretations and Potential Applications for Fish Screen Flow and Operational Criteria from the Fish Treadmill Project

Species: **Delta smelt**, *Hypomesus transpacificus*

Size (Age): 4-6 cm standard length (SL)

6-8 cm SL

Environmental Conditions: 12°C, winter and spring

Day (light conditions) and Night (dark conditions)

Experimental Flow Conditions: 0, 0.2, 0.33, 0.5 ft/s (0, 6, 10, 15 cm/s) **approach velocity**

0, 1.0, 2.0 ft/s (0, 31, 62 cm/s) **sweeping velocity**

BACKGROUND

The Fish Treadmill Project is an ongoing, laboratory-based research program designed to quantitatively evaluate the performance (e.g., screen contact frequency, survival) and behavior (e.g., swimming velocity) of native Sacramento-San Joaquin watershed fishes near a simulated fish screen. A complete description of the Fish Treadmill project, including design and operational details of the apparatus, experimental design and protocols, types of measurements, data collection and handling, and quality assurance/quality control, is provided in the Biological Monitoring/Research Plan (submitted to the Anadromous Fish Screen Program in October 2001) and also provided, in abbreviated form, in the Fish Treadmill Project website, http://wfcb.ucdavis.edu/www/Faculty/Joe/treadmill/index.htm. The Fish Treadmill studies are intended to provide information that can be applied to establish, improve or refine existing fish screen criteria for approach velocity, sweeping velocity, and exposure duration.

All interpretations and any potential applications of the results presented here are <u>limited to the species, flow velocities, environmental conditions, and life stages tested in the Fish Treadmill</u> (listed above) and do <u>not</u> account for other factors that have been hypothesized

to affect the performance and behavior of fishes near a fish screen (e.g., enhanced vulnerability to predation).

RATIONALE AND RELEVANT MEASUREMENTS

Interpretations of these results in the context of their potential applications for fish screen flow criteria are based on the assumption that, for optimal protection, the fish screen should be designed and operated to minimize the occurrence and severity of contact by the fish with the screen. Based on results of the Fish Treadmill studies with a variety of fish species, this depends on two factors:

- ability of the fish to avoid physical contact with the screen; and
- duration that the fish is exposed, or in close proximity, to the screen.

For delta smelt (12°C, day and night, 4-6 and 6-8 cm SL), the Fish Treadmill experiments tested the effects of constant levels of approach velocity and sweeping velocity, day vs night, and fish size on fish performance and behavior (see Table 1 for a complete list). These experiments were conducted during the winter and spring (December-April). Differences in size between the two groups reflect, to a limited degree, differences in age (i.e., larger fish are older) and, because all fish were collected during the fall, laboratory holding duration. However, large variations and overlap in each of these two factors within and between each size class preclude statistical analyses of their effects on performance and behavior.

Table 1. Fish Treadmill experiments conducted with delta smelt, 12°C. (Note: results of experiments with delta smelt at 19°C will be reported later.)

Size (cm SL)	DAY vs NIGHT	Flow treatments (ft/s)	Number of replicates, number of experiments	Comments
4-6	DAY	10 flow treatments control: 0 approach: 0.2, 0.33, 0.5 combined with sweeping: 0, 1.0, 2.0	3-5 replicates each treatment 34 experiments	
4-6	NIGHT	10 flow treatments control: 0 approach: 0.2, 0.33, 0.5 combined with sweeping: 0, 1.0, 2.0	3-5 replicates each treatment 35 experiments	
6-8	DAY	10 flow treatments control: 0 approach: 0.2, 0.33, 0.5 combined with sweeping: 0, 1.0, 2.0	3-4 replicates each treatment 32 experiments	DAY experiments only, 48-h survival was not measured because all fish were sacrificed for physiological stress response measurements at intervals post-experiment.

Analyses and interpretations relevant to fish screen flow criteria are based on several specific results from these experiments, including:

- screen contact rate (average number of times a fish contacted the fish screen per min)
- body contact rate (average number of times a fish contacted the fish screen with >50% of its body per min)
- impingement rate (the cumulative number of incidents of continuous body contact with the screen for >2.5 min)
- injury indices (number and severity of post-experiment injuries to fins, eyes, scale loss, and abrasions exhibited by the fish 48 h post-experiment)

- physiological stress responses (plasma cortisol measured for 6-8 cm SL only)
- survival (at 0 and 48-h post-experiment, 48-h survival measured for 4-6 cm SL only because all 6-8 cm SL fish were sacrificed at intervals post-experiment for physiological stress response measurements)
- swimming behavior (including swimming velocity and rheotaxis)
- screen passage velocity (velocity of downstream passage past the fish screen)

RESULTS

Tables 2 and 3, Figure 1, and the general linear statistical models below describe the relevant results of the Fish Treadmill experiments with delta smelt at 12°C. For the statistical models, variables are identified by abbreviations (see next page for key) and all regressions and coefficients shown are significant at $p<0.05$ unless otherwise noted. In order to facilitate application of these statistical models for fish screen flow and operational criteria, the models presented were selected on the basis of goodness of fit (as described by the r^2 value and the standard estimate of the error, SEE) and simplicity. For some responses (e.g., see screen contact rate and 48-mortality), multiple (or alternative) statistical models are presented. For example, some models emphasize controllable variables (e.g., approach and sweeping velocities) that affect delta smelt responses while others describe the effects of biological factors (e.g., fish size) or the fish's behavior (e.g., distance from the screen, frequency of screen contact) on their responses in the Fish Treadmill.

Variables shown in the general linear models
A is approach velocity in cm/s
SWP is sweeping velocity is in cm/s
SL is standard length in cm
DST is distance from screen in cm (i.e., average location of the fish relative to the screen)
BCR is body contact rate as body contacts/fish*min
SV is swimming velocity through the water, cm/s
DN is day vs night, with DAY = 1 and NIGHT = 2

Fish-Fish Screen Interactions

Delta smelt contacted the screen frequently, with total and body contact rates significantly affected by multiple factors, including approach and sweeping velocity, fish size, distance from screen, and day vs night. Some delta smelt also became impinged on the screen for prolonged periods (>2.5 min).

Screen contact rate (DAY, 4-6 and 6-8 cm SL)

= 0.0305(A) - 0.0047(SWP) + 0.0001(SWP*SWP) + 0.0011(A*A)

n = 66, r^2 = 0.7321, standard error of the estimate (SEE) = 0.108

Screen contact rate (NIGHT, 4-6 cm SL)

= 0.157(A) - 0.024(SWP) - 0.0067(A*A) + 0.0005(SWP*SWP)

n = 35, r^2 = 0.7909, SEE = 0.4512

Screen contact rate (NIGHT, 4-6 cm SL) = 0.0286(A*) - 0.0565(DST) + 0.4058(SL)

n = 27, r^2 = 0.8451, SEE = 0.3633

* p = 0.09 for this coefficient only

Body contact rate (DAY, 4-6 and 6-8 cm SL) = 0.0028(A) + 0.0001 (A*SWP)

n = 66, r^2 = 0.7235, SEE = 0.0551

Body contact rate (NIGHT, 4-6 cm SL) = 0.0111(A) + 0.0001(SWP*SWP)

n = 35, r^2 = 0.6378, SEE = 0.2367

Impingement Rate (DAY, 4-6 and 6-8 cm SL) = -0.0830(SWP) + 0.0126(A*SWP)

n = 66, r^2 = 0.7022, SEE = 1.8124

Injuries, Stress, and Mortality

Screen contact was harmful; injury indices, physiological stress responses, and post-experiment mortality were directly related to approach and sweeping velocities and screen contact rates.

Injury Index (4-6 cm SL only) = 7.7695 + 0.1017(A) + 1.3457 (DN) +0.0008(SWP*SWP)

n = 64, r^2 = 0.5240, SEE = 1.5734

Injury Index (4-6 cm SL only) = 10.733 + 7.3479(BCR)

n = 64, r^2 = 0.5836, SEE = 1.4477

Physiological stress responses (plasma cortisol concentrations measured at the end of the experimental exposure period in the Fish Treadmill) were significantly higher than control and resting levels in several flow combinations (Table 2).

Table 2. Changes in plasma cortisol concentrations of delta smelt (12°C, 6-8 cm SL, day only) in relation to sweeping and approach velocities in the Fish Treadmill. NS = no significant effect.

Sweeping Velocity (cm/s)	**Approach Velocity** (cm/s)	**Changes in plasma cortisol ($p<0.05$)**
0 (0 ft/s)	0 (0 ft/s) 6 (0.2 ft/s) 10 (0.33 ft/s) 15 (0.5 ft/s)	control NS NS NS
31 (1.0 ft/s)	6 (0.2 ft/s) 10 (0.33 ft/s) 15 (0.5 ft/s)	NS NS significantly elevated
62 (2.0 ft/s)	6 (0.2 ft/s) 10 (0.33 ft/s) 15 (0.5 ft/s)	NS significantly elevated significantly elevated

48-h Mortality (DAY, 4-6 cm SL) = -0.069(SWP) + 0.0121(A*SWP)

n = 31, r^2 = 0.7284, SEE = 1.8711

48-h Mortality (DAY, 4-6 cm SL) = -0.529 + 40.06(BCR)

n = 31, r^2 = 0.6626, SEE = 1.7079

48-h Mortality (NIGHT, 4-6 cm SL) = 0.1482(A) + 0.0109(A*SWP)

$n = 35$, $r^2 = 0.8234$, SEE = 2.6949

<u>Swimming Behavior and Screen Passage</u>

Delta smelt (12°C, 4-6 cm SL) swam significantly faster during the day than during the night ($p<0.05$) but exhibited consistent positive rheotaxis in all flows with >0 ft/s sweeping velocity. Swimming velocities increased with approach and sweeping velocities and, in the high velocity treatments, were comparable to critical swimming velocities (i.e., maximum sustained swimming velocities) measured in other studies with this species (Swanson et al., 1998).

Swimming Velocity (cm/s, DAY, 4-6 and 6-8 cm SL)

= -5.48 + 0.33(A) + 0.07(SWP) + 3.70(SL)

$n = 61$, $r^2 = 0.3431$, SEE = 4.0478

Swimming Velocity (cm/s, NIGHT, 4-6 cm SL) = 6.77 + 0.54(A) + 0.13(SWP)

$n = 27$, $r^2 = 0.8537$, SEE = 1.9462

Screen passage, as velocity past screen in cm/s with negative values indicating downstream movement and positive values indicating upstream movement (relative to the sweeping flow), was strongly related to sweeping velocity.

Screen passage (DAY, 4-6 and 6-8 cm SL) = -10.62 - 0.92(SWP) - 0.23(A) + 1.38(SV)

$n = 61$, $r^2 = 0.9720$, SEE = 3.77

Screen passage (DAY, 4-6 and 6-8 cm SL) = 12.57 - 0.81(SWP)

$n = 61$, $r^2 = 0.9031$, SEE = 6.89

Screen passage (NIGHT, 4-6 cm SL) = 3.82 - 0.8381(SWP)

$n = 27$, $r^2 = 0.9523$, SEE = 5.06

Table 3. Summarized results of Fish Treadmill experiments with delta smelt, 12°C. NS = no significant effect of the specified variable. NA = not applicable (e.g., effect of size on stress is NA because stress was measured for the large fish only).

Response	**Approach velocity**	**Sweeping velocity**	**DAY vs NIGHT (4-6 cm SL only)**	**Size (age) (DAY experiments only)**
Screen contact	Screen contact rate increased with increases in approach velocity during the DAY and NIGHT	Screen contact rate increased with increases in sweeping velocity during the DAY but not during the NIGHT	Screen contact rates were higher during the NIGHT than during the DAY	NS
Body Contact Rate	Body contact rates increased with increases in approach velocity during the DAY and NIGHT	Body contact rates increased with increases in sweeping velocity during the DAY and NIGHT	Body contact rate was higher during the NIGHT than during the DAY	NS
Impingement	Impingement rate increased with increases in approach velocity (measured DAY only)	Impingement rate increased with increases in sweeping velocity (measured DAY only)	no comparison possible because of limited ability to view entire Fish Treadmill channel at NIGHT	NS
Injuries	Injury indices increased with increases in approach velocity (4-6 cm SL only)	Injury indices increased with increases in sweeping velocity (4-6 cm SL only)	Injury indices were higher at NIGHT than during the DAY	Injuries were not assessed for the large fish because all were sacrificed for physiological stress response measurements at intervals post-experiment
Stress	Plasma cortisol concentrations increased with increases in approach velocity (DAY, 6-8 cm SL only)	Plasma cortisol concentrations increased with increases in sweeping velocity (DAY, 6-8 cm SL only)	Effect of size on stress is was not measured because stress responses were measured for the large fish during the DAY only	Effect of size on stress is was not measured because stress responses were measured for the large fish only
Survival (48 hour)	Survival decreased with increases in approach velocity (4-6 cm Sl only, DAY and NIGHT)	Survival decreased with increases in sweeping velocity (4-6 cm Sl only, DAY and NIGHT)	Survival was lower at NIGHT	48-h survival was not measured for the large fish because all were sacrificed for physiological stress response measurements at intervals post-experiment
Swimming velocity	Swimming velocity increased with increases in approach velocity DAY and NIGHT	Swimming velocity increased with increases in sweeping velocity DAY and NIGHT	Fish swam slower at NIGHT	Large 6-8 cm SL fish swam faster than smaller 4-6 cm SL fish
Screen passage velocity	Downstream screen passage increased with increases in approach velocity (DAY only)	Downstream screen passage increased with increases in sweeping velocity (DAY and NIGHT)	Downstream passage was faster at NIGHT	Downstream passage of small 4-6 cm SL fish was faster than that of larger 6-8 cm SL fish

INTERPRETATIONS AND CONCLUSIONS

The results summarized above indicate that delta smelt (12°C, 4-6 and 6-8 cm SL) exposed to ranges of approach and sweeping velocity within those tested in these studies may be vulnerable to flow and time of day-dependent screen related mortality. Both flow vectors, approach and sweeping, influence screen contact rate and severity, injury rates, physiological stress, and ultimately survival. The effects of these flow-related fish-screen interactions on mortality are exacerbated during the night under dark conditions.

Five broad conclusions can be identified.

1. The frequency and severity of screen contact by delta smelt (12°C, 4-6 and 6-8 cm SL) are directly related to a) approach velocity; b) sweeping velocity; and c) time of day (light level). Screen contact rate and severity are minimized at low velocity flow combinations, particularly those without a sweeping flow component.
2. Repeated screen contact is injurious, stressful and lethal for delta smelt (12°C, 4-6 and 6-8 cm SL).
3. Under similar flow conditions, screen contact rates and the associated injury and mortality are higher at night than during the day.
4. Screen passage velocity is directly related to sweeping velocity. Therefore, screen exposure duration is negatively correlated with sweeping velocity.
5. Approach and sweeping flow combinations that minimize screen contact and severity, and thus minimize injury, stress and mortality, do not facilitate screen passage. Therefore, under these flow conditions, screen exposures are potentially of long duration. Flow conditions that promote rapid downstream passage also result in high rates of screen contact, injury, stress, and mortality, particularly at night.

EXAMPLES OF POTENTIAL APPLICATIONS FOR FISH SCREEN DESIGN

Using the statistical models developed to describe the effects of approach and sweeping velocities on 48-h mortality, Figure 2 was generated. For daytime and nighttime, each plotted line depicts selected levels of average mortality, expressed as % of the exposed fish, at the various combinations of approach velocity and sweeping velocity. Using these graphs, average mortality rates can be predicted for any flow combination within the range tested in the Fish Treadmill experiments.

Example 1: For delta smelt exposed for 2 h during the day to a fish screen with a 0.33 ft/s (10 cm/s) approach velocity and a 1.0 ft/s (31 cm/s) sweeping velocity, an average of 5-10% of the fish would be expected to die within 48 h after exposure, under conditions used in the Fish Treadmill experiments.

Example 2: During the night under these flow conditions, an average of slightly more than 20% of the fish would die within 48 h, under conditions used in the Fish Treadmill experiments. Additional calculations can be made using other statistical models developed from the Fish Treadmill results with delta smelt (12°C, 4-6 and 6-8 cm SL).

Additional analyses using other statistical models presented in the preceding sections provide alternative examples for applications of these results for developing fish screen criteria specific for delta smelt (12°C).

Example 3: Post-exposure mortality of delta smelt was strongly correlated with injuries and body contact rates. The lowest mortality occurred in low approach velocities without a sweeping flow component. Extrapolating the mean body contact rate for 0.2 ft/s (6 cm/s) approach velocity at 0 ft/s sweeping velocity (0.023±0.0095 (SE)) to a 2-h exposure period yields a cumulative number of body contacts of 2.76±1.14. For the purpose of establishing allowable exposure duration or allowable screen length that results in zero or very low post-exposure mortality, the lower range of this value (1.6 body contacts per exposure) could be interpreted to represent the maximum allowable number of body contacts per exposure. Therefore, for a screen operated at 0.2 ft/s (6 cm/s, the present approach velocity criterion for delta smelt) and a sweeping velocity of 1.0 ft/s (31 cm/s), the following estimates can be made:

Note: For the calculations below, the most conservative estimate of each parameter, based on the range defined by the standard errors, has been used.

For a daytime exposure duration that allows <1.6 body contacts:

Body Contact Rate = 0.0028(6 cm/s) + 0.0001(6 cm/s *31 cm/s)

= 0.035±0.0551 body contacts/fish*min

Allowable exposure duration = 1.6 body contacts per exposure/0.035±0.055 body contacts/fish*min

= 45±27 min (18-72 min, range based in SE)

During that exposure and assuming an average swimming velocity of 13 cm/s, average screen passage velocities would be:

Screen Passage Velocity (downstream) = -10.62 - 0.92(31 cm/s) - 0.23(6 cm/s) + 1.38(22 cm/s)

= -10.16±3.77 cm/s

= 10.16±3.77 cm/s downstream (relative to sweeping flow)

Therefore, a 18-min allowable exposure period would require a screen length no longer than 226 feet.

= 6.39 cm/s x 18 min x 60 s/min

= 6901 cm

= 226 feet

Example 4. Exposure to the same screen for a period of 18 min during the night, when the body contact rate would be expected to be higher, would result in 2.93±4.32 body contacts, greater than the maximum allowable level of 1.6 body contacts (see Example 3 above) established based on zero or very low mortality. Statistical models developed from the nighttime results can be used to estimate allowable exposure durations and screen lengths.

Body Contact Rate (NIGHT) = 0.0111(6 cm/s) + 0.0001 (31 cm/s x 31 cm/s)

= 0.163±0.24 body contact/fish*min

Allowable Exposure Duration = 1.6 body contacts per exposure/0.163±0.24 body contacts/fish*min

= 10±6 min (4-16 min, range based on SE)

Screen Passage Velocity = 3.82 - 0.8381(31 cm/s)

= -22.16±5.06 cm/s

= 22.16±5.06 cm/s downstream (relative to sweeping flow)

Therefore, a 4-min allowable exposure period would require a screen length no longer than 135 feet.

= 17.1 cm/s x 4 min x 60s/min

= 4104 cm

= 135 ft

LITERATURE CITED:

Swanson, C., Young, P. S., & Cech, J. J., Jr. (1998) Swimming performance of delta smelt: maximum performance, and behavioral and kinematic limitations on swimming at submaximal velocities. *Journal of Experimental Biology* 201:333-345.

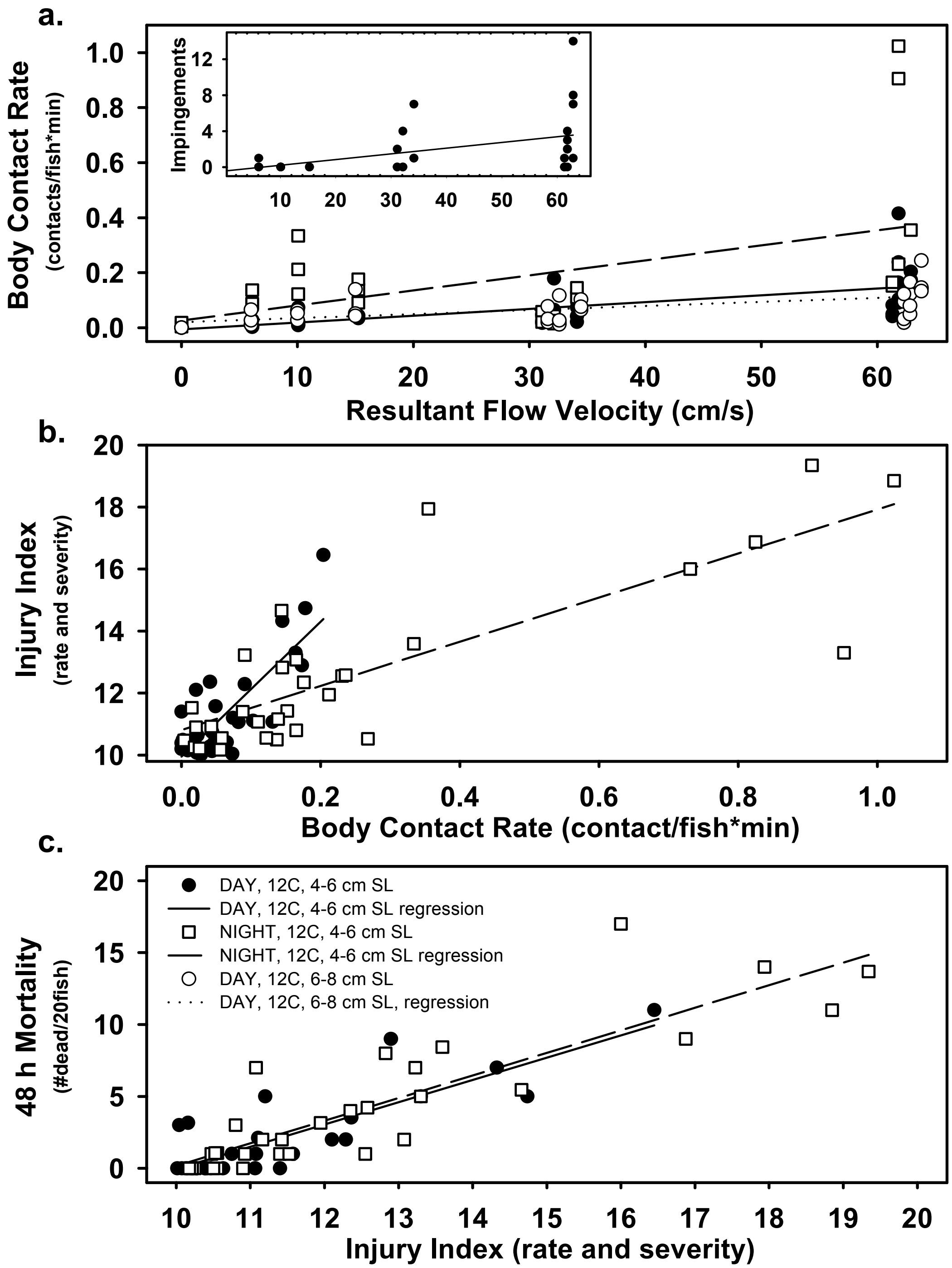

Figure
1. Effects of flow (as resultant velocity, cm/s, calculated as the sqrt[approach velocity^2 + sweeping velocity^2]) on delta smelt (12°C) fish-screen contacts, injuries, and mortality 48-h post-experiment: a) effects of resultant water velocity on body contact rates, inset graph shows effects of resultant velocity n the number of impingements observed during the 2-h experiment; b) effects of body contact rates on post-experiment injuries, expressed as the injury index; and c) effects of injuries on 48-h post-experiment mortality (# fish dead/20 fish). Each point is the mean from a single experiment. Legend is presented on the bottom graph panel.

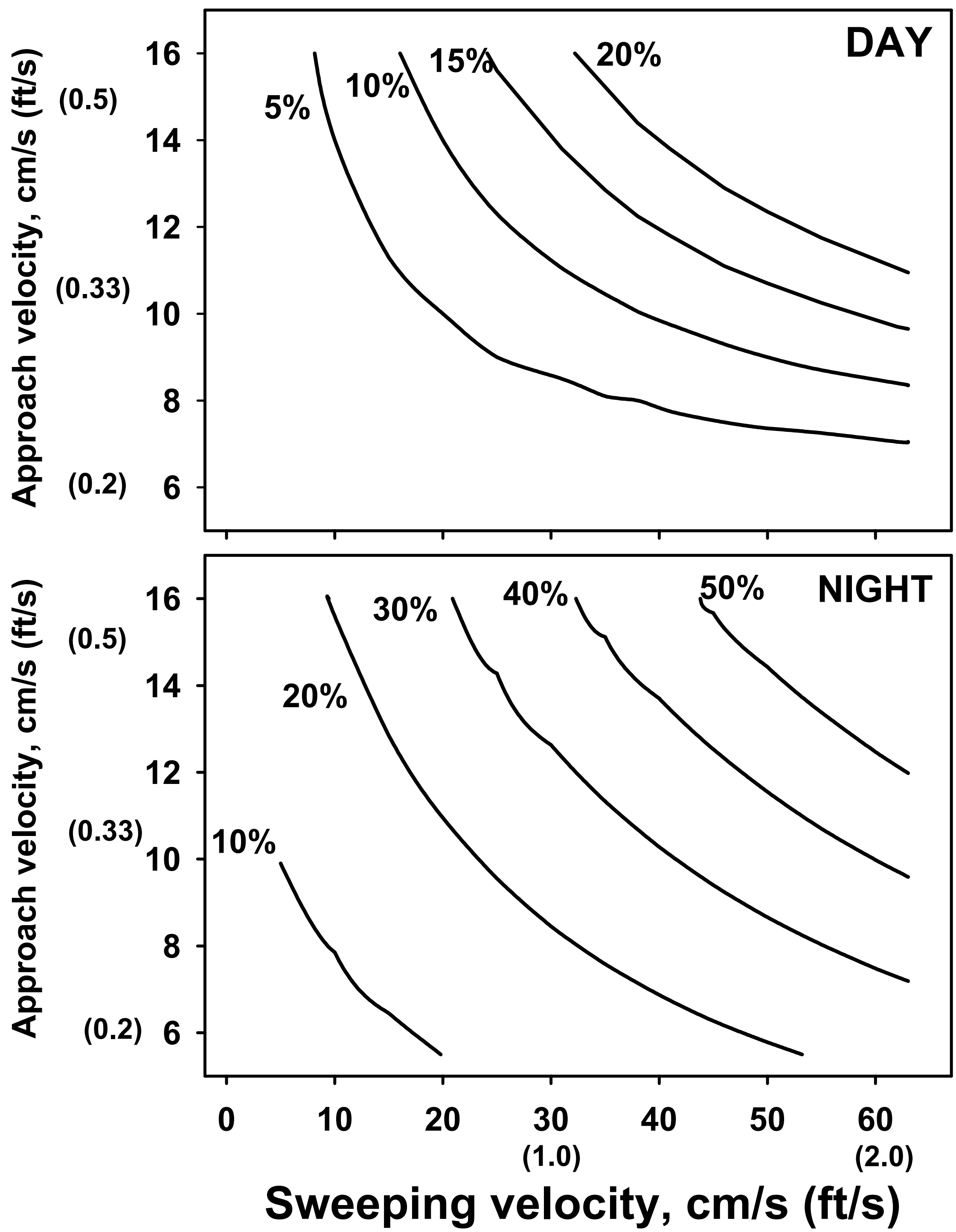

Figure 2. Effects of approach and sweeping velocity on 48-h post-experiment mortality of delta smelt (12°C, 4-6 cm SL). Each isopleth depicts selected levels of mortality, expressed as % of exposed fish, at the various combinations of approach and sweeping velocity. Plots were derived from general linear statistical models describing the effects of approach and sweeping velocities on 48-h mortality (see text). Slight irregularities in the lines do not represent real differences from the "smooth" relationships shown.

RESEARCH FINDINGS

Interpretations and Potential Applications for Fish Screen Flow and Operational Criteria from the Fish Treadmill Project

Anadromous Fish Screen Program, Cooperative Agreement No. 114201J075

Prepared by

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University of California, Davis, CA 95616

Species: Splittail, *Pogonichthys macrolepidotus*

Size (Age): 4-6 and 6-8 cm standard length (SL), "young-of-the-year"

Environmental Conditions: 19°C, summer and fall
Day (light conditions) and Night (dark conditions)

Submitted to

The Anadromous Fish Screen Program
U. S. Fish and Wildlife Service
Sacramento, CA

June 2002
revised July 2002

RESEARCH FINDINGS

Interpretations and Potential Applications for Fish Screen Flow and

Operational Criteria from the Fish Treadmill Project

Species: **Splittail**, *Pogonichthys macrolepidotus*

Size (Age): 4-6 and 6-8 cm standard length (SL), "young-of-the-year" (YOY)

Environmental Conditions: 19°C, summer and fall

Day (light conditions) and Night (dark conditions)

Experimental Flow Conditions: 0, 0.2, 0.33, 0.5 ft/s (0, 6, 10, 15 cm/s) **approach velocity**

0, 1.0, 2.0 ft/s (0, 31, 62 cm/s) **sweeping velocity**

BACKGROUND

The Fish Treadmill project is an ongoing, laboratory-based research program designed to quantitatively evaluate the performance and behavior of native Sacramento-San Joaquin watershed fishes near a simulated fish screen. A complete description of the Fish Treadmill project, including design and operational details of the apparatus, experimental design and protocols, types of measurements, data collection and handling, and quality assurance/quality control, is provided in the Biological Monitoring/Research Plan (submitted to the Anadromous Fish Screen Program in October 2001) and also provided in the Fish Treadmill Project website, http://wfcb.ucdavis.edu/www/Faculty/Joe/treadmill/index.htm. The Fish Treadmill studies are intended to provide information that can be applied to establish, improve or refine existing fish screen criteria for approach velocity, sweeping velocity, and exposure duration.

All interpretations and any potential applications of the results presented here are <u>limited to the species, flow velocities, environmental conditions, and life stages tested in the Fish Treadmill</u> (listed above) and do <u>not</u> account for other factors that have been hypothesized to affect the performance and behavior of fishes near a fish screen (e.g., enhanced vulnerability to predation).

RATIONALE AND RELEVANT MEASUREMENTS

Interpretations of these results in the context of their potential applications for fish screen flow criteria are based on the assumption that, for optimal protection, the fish screen should be designed and operated to minimize the occurrence and severity of contact by the fish with the screen. Based on results of the Fish Treadmill studies with a variety of fish species, this depends on two factors:

- ability of the fish to avoid physical contact with the screen; and
- duration that the fish is exposed, or in close proximity, to the screen.

For splittail (YOY, 19°C, day and night), the Fish Treadmill experiments tested the effects of constant levels of approach velocity and sweeping velocity, day vs night, and fish size (or age) on fish performance and behavior (see Table 1 for a complete list).

Table 1. Fish Treadmill experiments conducted with splittail, 19°C.

Size (cm SL) Life stage	Day vs Night	Flow treatments (ft/s)	Number of replicates, number of experiments	Comments
4-6 YOY	Day	10 flow treatments control: 0 approach: 0.2, 0.33, 0.5 combined with sweeping: 0, 1.0, 2.0	3-4 replicates each treatment 31 experiments	
4-6 YOY	Night	10 flow treatments control: 0 approach: 0.2, 0.33, 0.5 combined with sweeping: 0, 1.0, 2.0	3-4 replicates each treatment 36 experiments	
6-8 YOY	Day	10 flow treatments control: 0 approach: 0.2, 0.33, 0.5 combined with sweeping: 0, 1.0, 2.0	3-4 replicates each treatment 31 experiments	Physiological stress responses measured.

Analyses and interpretations that are relevant to fish screen flow criteria are based on several specific results from these experiments, including:

- screen contact rate (the average number of times a fish contacted the simulated fish screen per min)
- screen contact severity (measured as proportion of contacts in which >50% of the body contacted the screen)
- impingement rate (the cumulative number of incidents of continuous body contact with

the screen for >2.5 min)

- injury indices (number and severity of post-experiment injuries to fins, eyes, scale loss, and abrasions exhibited by the fish 48 h post-experiment)
- physiological stress responses (blood hematocrit, plasma cortisol, lactate, glucose measured for 6-8 cm SL only)
- survival (at 0 and 48 h post-experiment)
- swimming behavior (including swimming velocity, rheotaxis, and the proportion of fish exhibiting positive rheotaxis)
- screen passage velocity (velocity of downstream passage past the fish screen)

RESULTS

Table 2, Figures 1 and 2, and the general linear statistical models below describe the relevant results of the Fish Treadmill experiments with YOY splittail at 19°C. For the statistical models, variables are identified by abbreviations (key shown below) and all coefficients shown are significant at $p<0.05$ unless otherwise noted. In order to facilitate application of these statistical models for fish screen flow and operational criteria, the models presented below were selected on the basis of goodness of fit (as described by the r^2 value and the standard estimate of the error, SEE) and simplicity.

Variables shown in the general linear models
A is approach velocity in cm/s
SWP is sweeping velocity is in cm/s
SL is standard length in cm
DST is distance from screen in cm (i.e., average location of the fish relative to the screen)
TIME is exposure duration in 30-min intervals (i.e., for 0-30 min TIME = 1, for 31-60 min TIME = 2, etc.)
RHEO is rheotaxis in degrees, with 0° for perfect positive rheotaxis (i.e., swimming into the flow) and 180° for perfect negative rheotaxis (i.e., swimming with the flow)
SV is swimming velocity through the water, cm/s
DN is day vs night, with DAY = 1 and NIGHT = 2

Fish-Fish Screen Interactions

Splittail contacted the screen frequently during the nighttime (under dark conditions) but infrequently during the daytime (lighted conditions) (see Table 2 and Figure 1). Most screen contacts (on average, 70% of all daytime contacts and 72% of all nighttime contacts) were minor "tail contacts" (i.e., contact by the caudal fin and/or <50% of the fish's posterior body length). Contact severity increased slightly with increases in sweeping velocity during the night, from 23% of total contacts recorded as "body contacts" in which the head and/or >50% of the fish's body length contacted the screen in flow regimes without a sweeping flow to 34% of total contacts recorded as body contacts in the high velocity (2 ft/s) sweeping flow regimes. Contact severity was unaffected by flow during the daytime. At night, screen contact rates were significantly affected by both approach and sweeping velocities, decreasing with increases in both flow vectors. During the daytime, screen contact rates were affected by sweeping velocity, decreasing with increases in the velocity of this flow vector, but not approach velocity (although in multiple regression models, approach velocity was a statistically significant parameter, see equation below). Other significant factors included fish size and distance between the fish and the screen (see Table 2). Of the nearly 2000 YOY splittail tested, only one fish (<<0.1% of the fish tested) in one experiment (0.33 ft/s approach velocity combined with 1.0 ft/s sweeping velocity) was observed to become impinged on the screen for a prolonged period (i.e., >2.5 min).

Screen contact rate (DAY, 4-6 and 6-8 cm SL)

$= 0.093(SL) - 0.004(DST) - 0.024(A) + 0.0001(SWP^2) + 0.0005(A*SWP) - 0.002(SL*SWP)$

$n = 52$, $r^2 = 0.7211$, standard error of the estimate (SEE) = 0.093

Screen contact rate (NIGHT, 4-6 cm SL only)

$= 1.80 - 0.053(A) - 0.024(SWP) + 0.0002(SWP^2)$

$n = 33$, $r^2 = 0.6017$, SEE = 0.2814

Screen contact rates decreased with exposure duration (i.e., time) during nighttime experiments (4-6 cm SL only) and for the larger fish (6-8 cm SL) during daytime experiments.

Screen contact rate (DAY, 6-8 cm SL only)

$= 0.818 - 0.146(TIME) - 0.041(A) - .0122(SWP) + 0.0001(SWP^2) = 0.01(TIME*A)$

$n = 112$, $r^2 = 0.3456$, standard error of the estimate (SEE) = 0.2108

Screen contact rate (NIGHT, 4-6 cm SL only)

$= 2.331 - 0.252(TIME) - 0.042(A)) - 0.026(SWP) + 0.0003(SWP^2)$

$n = 140$, $r^2 = 0.5162$, SEE = 0.4043

Injuries, Stress and Survival

Contact with the Fish Treadmill screen during the 2-h exposure was apparently neither injurious nor stressful to YOY splittail (19°C). Injury rates and severity were consistently low and unrelated to approach velocity, sweeping velocity, or screen contact rates. Physiological stress responses (e.g., blood hematocrit, plasma cortisol, lactate, glucose, measured for 6-8 cm SL only) were not significantly affected by flow, screen contact rates, or screen contact severity. Post-experiment survival was uniformly high (100% survival at 48-h post-experiment in all experiments).

Swimming Behavior and Screen Passage

YOY splittail (19°C) swam significantly faster during the day than during the night, with daytime swimming velocities comparable to critical swimming velocities (i.e., maximum sustained swimming velocities) measured for this species in other studies (Young and Cech 1996). Swimming velocities increased with increases in fish size (as SL, daytime experiments only) but were not significantly affected by either approach or sweeping velocities under any conditions (see Table 2 and Figure 2). Splittail did not exhibit consistent positive rheotaxis. During the daytime, average rheotaxis values of 80-120 degrees (see Figure 2) reflected high variability in swimming direction, with most fish oriented either strongly upstream (i.e., against the sweeping flow) or strongly downstream (i.e., with the sweeping flow), rather than failure of the fish to orient to the resultant flow. During the day, in flow regimes with a sweeping flow component, the majority of the fish swam downstream, with the resultant flow (i.e., negative rheotaxis, or rheotaxis$90°, by 77% of the fish in 1 ft/s sweeping velocities and 58% of the fish in 2.0 ft/s sweeping velocities). At night, positive rheotaxis (i.e., rheotaxis<90°) was somewhat enhanced with 37% of the fish swimming upstream in the 1.0 ft/s sweeping velocity and a significantly larger proportion, 75% of the fish, swimming upstream in the 2.0 ft/s sweeping velocity. Screen passage, as velocity past screen in cm/s (with negative values indicating downstream movement and positive values indicating upstream movement, relative to the sweeping flow), was strongly related to sweeping velocity and swimming orientation of the fish.

Screen passage (DAY) = 77.83 - 1.26(SWP) - 0.66(RHEO)

n = 55, r² = 0.9299, SEE = 12.41

Screen passage (NIGHT) = 24.24 - 0.90(SWP) - 0.28(RHEO)

n = 17, r² = 0.9541, SEE = 5.61

INTERPRETATIONS AND CONCLUSIONS

The results summarized above indicate that splittail (19°C, YOY) exposed to ranges of approach and sweeping velocity within those tested in these studies may be vulnerable to contact with the fish screen, particularly at night under dark conditions, but that such contact is not harmful to the fish, at least in the short term (i.e., 48-h post-exposure). Screen passage, and thus screen exposure duration, was related to sweeping velocities but strongly dependent on the swimming behavior of the fish.

Five broad conclusions can be identified.

1. The frequency of screen contact by splittail was inversely related to sweeping velocity, with the highest rates of screen contact occurring in flow regimes in which the water flowed perpendicularly through the screen rather than at an oblique angle and in which resultant water velocities were low.

2. Under similar flow conditions, screen contact rates were substantially higher at night (dark conditions) than during the day (light conditions).

3. Repeated contact with the Fish Treadmill fish screen, up to the rates measured in these studies, was not injurious, stressful, or lethal for splittail (19°C, YOY).

4. Screen passage velocity was directly related to sweeping velocity and the swimming orientation of the fish. Swimming orientation was unpredictable, although the majority of the fish tended to swim downstream in most flow regimes, a behavior that enhanced screen passage velocities.

5. Approach and sweeping flow combinations that minimized screen contact also facilitated screen passage, on average.

EXAMPLES OF POTENTIAL APPLICATIONS FOR FISH SCREEN DESIGN

Using the statistical models developed to describe the effects of approach and sweeping velocities, fish size, and swimming behavior of YOY splittail (19°C), the following examples illustrate potential quantitative applications of results of the Fish Treadmill studies for designing and operating fish screens for protection of this species.

Example 1: For a 100 ft long flat plate fish screen designed to operate with an approach velocity of 0.33 ft/s (10 cm/s) and a sweeping velocity of 1.0 ft/s (31 cm/s), how long would a 5 cm SL-long juvenile splittail be exposed to the screen during the daytime?

• During the daytime in this flow regime, splittail exhibited positive rheotaxis, averaging approximately 45°, 23% of the time. (Note: negative values for screen passage indicate downstream movement, positive values indicate upstream movement)

Screen passage (DAY) = 77.83 - 1.26(31 cm/s) - 0.66(45°)
= 9.03±12.41 cm/s
= 17.7 ft/min upstream to -6.7 ft/min downstream
= at least 15 min to pass downstream of a 100 ft-long fish screen

Therefore, based on these results, most splittail swimming into the flow under these sweeping velocity and time of day conditions would not be transported downstream, past the fish screen.

• The remaining 77% of the time the fish exhibited negative rheotaxis, averaging approximately 135°.

Screen passage (DAY) = 77.83 - 1.26(31 cm/s) - 0.66(135°)
= -50.3±12.41 cm/s (downstream)
= -98.8±24.4 ft/min (downstream)
= 1-2 min to pass by a 100 ft-long fish screen

Example 2: Under these flow conditions, how long would splittail be exposed to this screen during the night under dark conditions?

• During the nighttime in this flow regime, splittail exhibited positive rheotaxis, averaging approximately 45°, 37% of the time.

Screen passage (NIGHT) = 24.24 - 0.9(31 cm/s) - 0.28(45°)
= -16.26±5.61 cm/s (downstream)
= -31.9±11.0 ft/min (downstream)
= 3-5 min to pass by a 100 ft-long fish screen

• The remaining 63% of the time the fish exhibited negative rheotaxis, averaging approximately 135°.

Screen passage (NIGHT) = 24.24 - 0.9(31 cm/s) - 0.28(135°)
= -41.46±5.61 cm/s (downstream)
= -81.5±11.0 ft/min (downstream)
= 1-2 min to pass by a 100 ft-long fish screen

Example 3: During the above exposures, how many times would a 5 cm SL-long splittail swimming 1.0 ft (31 cm) from the screen be expected to contact the fish screen?

• For a 2-15 min exposure during the daytime:

Screen contact rate (DAY)
= 0.093(5 cm SL) - 0.004(31 cm) - 0.024(10.5 cm/s) + 0.0001(31 cm/s^2)
+ 0.0005(10.5 cm/s x 31 cm/s) - 0.002(5 cm SL x 31 cm/s)
= 0.038 contacts/fish*min
= 0.08 contacts/fish per 2-min exposure and 0.56 contacts/fish per 15-min exposure

• For a 2-5 min exposure during the nighttime:

Screen contact rate (NIGHT) = 1.80 - 0.053(10.5 cm/s) - 0.024(31 cm/s) + 0.0002(31 cm/s^2)
= 0.69 contacts/fish*min
= 1.38 contacts/fish per 2 min exposure and
3.45 contacts/fish per 5 min exposure

Example 4: For a group of 100 fish exposed to this 100 ft-long screen operated at the 0.33 ft/s approach velocity and 1.0 ft/s sweeping velocity, how many fish would contact the fish screen once during the exposure?

• During a daytime exposure, calculating exposure duration based on proportional rheotactic behavior, on average 19 of the 100 exposed fish would contact the screen once during the exposure.

• During a nighttime exposure, calculating exposure duration based on proportional rheotactic behavior, on average each of the 100 exposed fish would contact the screen once during the exposure (i.e., an average of 101 total contacts for the 100 fish exposed to the screen).

REFERENCES

Young, P. S., and J. J. Cech, Jr. 1996. Environmental tolerances and requirements of splittail. Trans. Am. Fish. Soc. 125:664-678.

Table 2. Summarized results of Fish Treadmill experiments with YOY splittail, 19°C. NS = no significant effect of the specified variable. NA = not applicable (e.g., effect of size on stress is NA because stress was measured for the large fish only).

Response	Approach velocity	Sweeping velocity	DAY vs NIGHT (4-6 cm SL only)	Size (age) (DAY experiments only)
Screen contact	Screen contact rate decreased with increases in approach velocity during the NIGHT but not during the DAY	Screen contact rate decreased with increases in sweeping velocity during the DAY and the NIGHT	Screen contact rates were higher during the NIGHT than during the DAY	Large fish contacted the screen more frequently than small fish (DAY only)
Screen contact severity	NS	Contact severity increased with increases in sweeping velocity during the NIGHT but not during the DAY	NS	NS
Impingement	NS and rare	NS and rare	no comparison possible	NS and rare
Injuries	NS	NS	NS	NS
Stress	NS	NS	NA	NA
Survival	NS 100%	NS 100%	NS 100%	NS 100%
Swimming velocity	NS	NS	Fish swam slower at NIGHT	Large fish swam faster than small fish
Rheotaxis	NS	Positive rheotaxis increased with increases in sweeping velocity during the NIGHT but not during the DAY	NS	NS
Screen passage	NS	Downstream screen passage increased with increases in sweeping velocity (DAY and NIGHT)	NS	NS

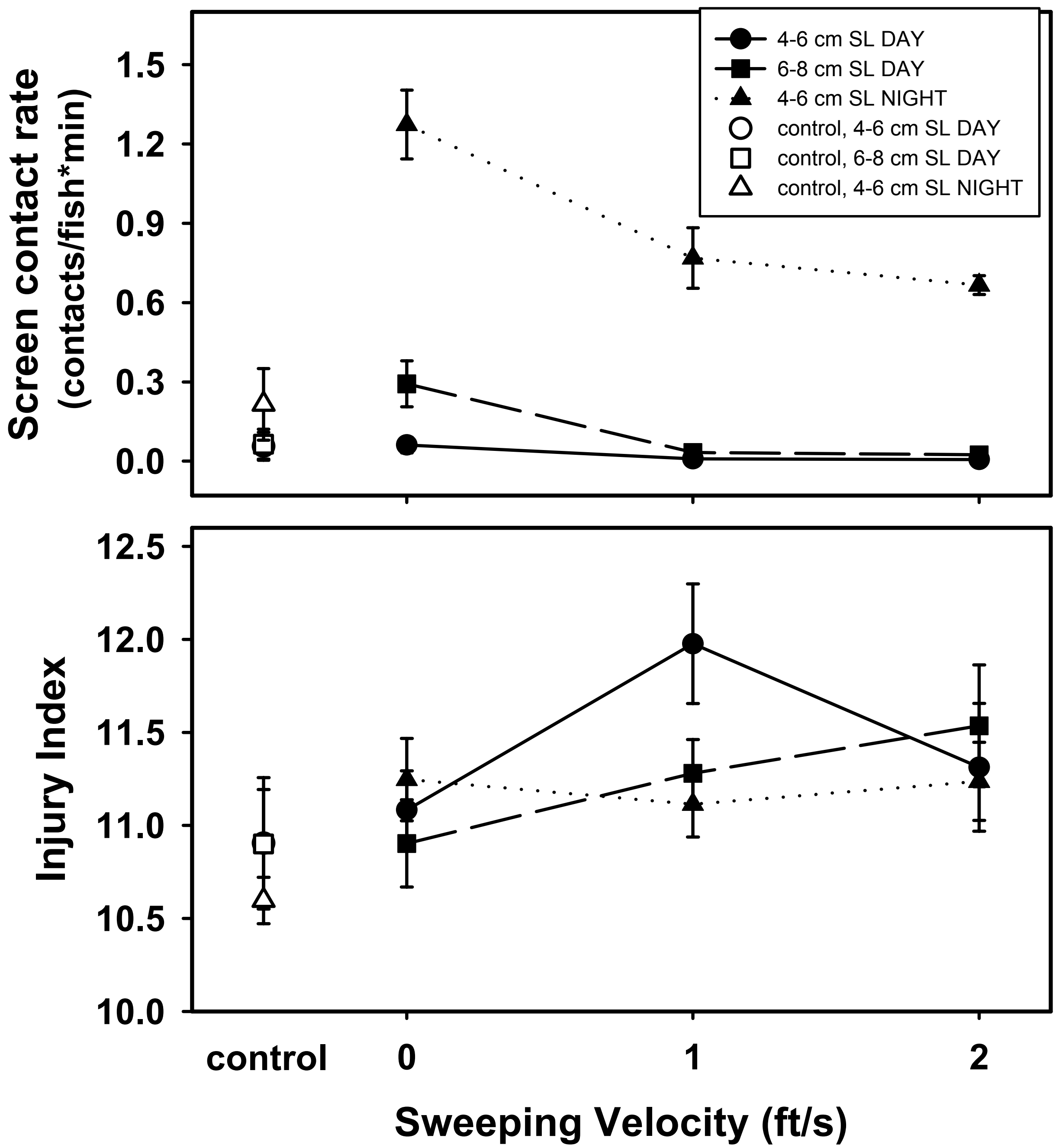

Figure 1. Effects of sweeping velocity on fish-screen contacts (top panel) and injuries (bottom panel) of YOY splittail (19°C).

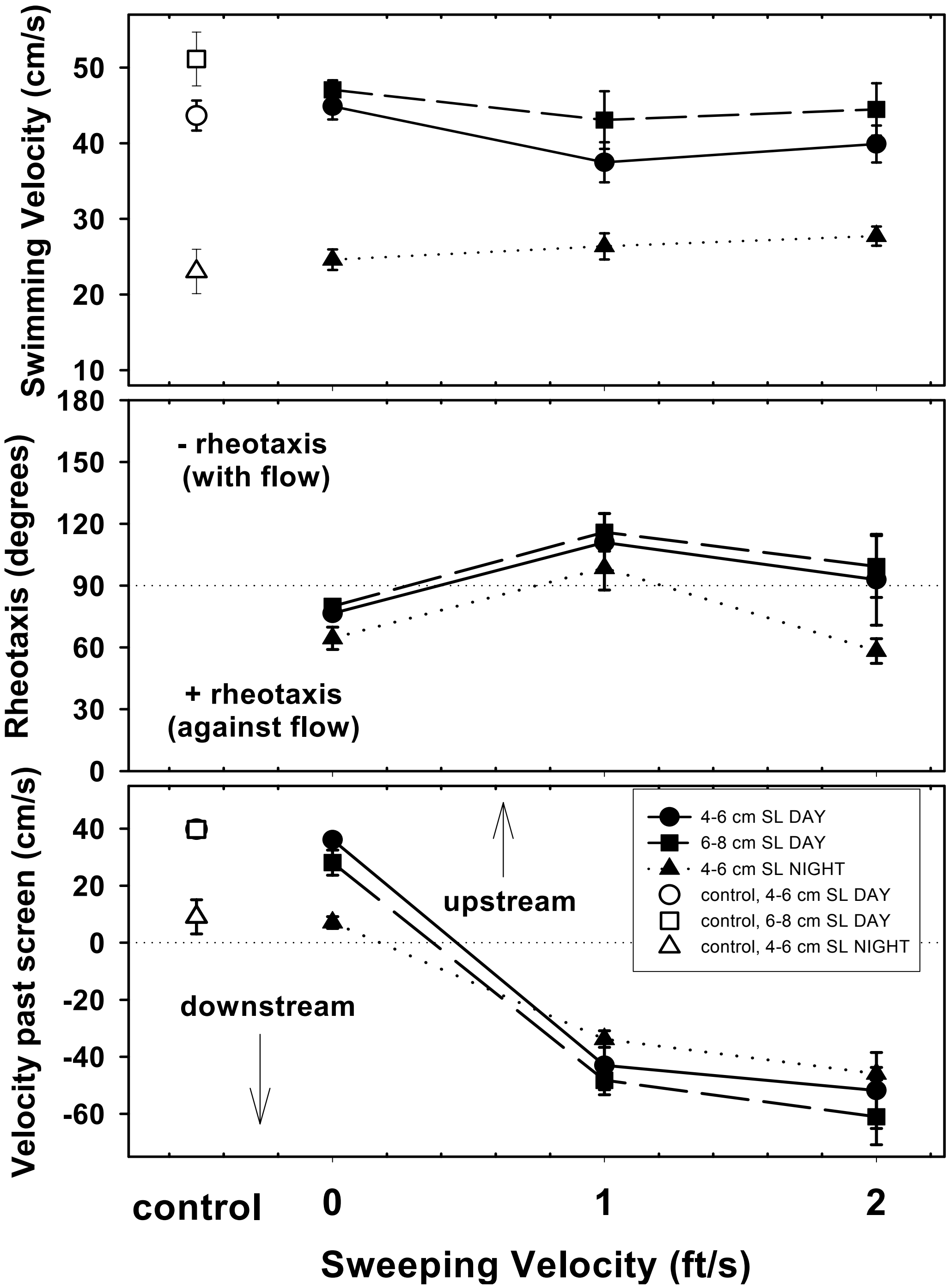

Figure 2. Effects of sweeping velocity on swimming velocities (top panel), rheotaxis (middle panel) and screen passage velocities (bottom panel) of YOY splittail (19°C).

Table 1. Two-year budget for the Fish Treadmill project with 10% (state) overhead rate.

Year	Task	Direct Labor Hours	Subject to Overhead: Salary	Benefits	Travel	Supplies & Expendables	Services and consultations	Agency Overhead (@18.3%)	Total Cost subject to overhead	Overhead (10% for all tasks)	Exempt from Overhead: Equipment	Graduate Student Fee Remission	Total Cost
1	Task 1	8,147	201,924	32,725	4,000	22,500	4,400	0	265,549	26,555	15,700	14,463	322,267
	Task 2	14,025	258,941	45,136	12,000	46,500	9,300	0	371,877	37,188	0	4,928	413,993
	Task 3	343	8,831	2,835	11,000	4,640	0	4,997	32,303	2,500	0	0	34,803
	Task 4	398	10,000	1,378	0	0	0	0	11,378	1,138	0	0	12,516
Total Year 1		**22,913**	**479,696**	**82,074**	**27,000**	**73,640**	**13,700**	**4,997**	**681,107**	**67,380**	**15,700**	**19,391**	**$783,578**
2	Task 1	8,147	212,019	34,929	4,000	17,500	4,400	0	272,848	27,285	0	15,639	$315,772
	Task 2	14,025	258,941	45,136	12,000	40,500	9,300	0	365,877	36,588	0	4,928	$407,393
	Task 3	343	8,831	2,835	11,000	4,640	0	4,997	32,303	2,500	0	0	34,803
	Task 4	398	10,000	1,378	0	0	0	0	11,378	1,138	0	0	$12,516
Total Year 2		**22,913**	**489,791**	**84,278**	**27,000**	**62,640**	**13,700**	**4,997**	**682,406**	**67,510**	**0**	**20,567**	**$770,483**
Total 2 yrs		**45,826**	**969,487**	**166,352**	**54,000**	**136,280**	**27,400**	**9,994**	**1,363,513**	**134,891**	**15,700**	**39,958**	**$1,554,062**

Table 2. Two-year budget for the Fish Treadmill project with 48.5% (federal) overhead rate.

Year	Task	Direct Labor Hours	Subject to Overhead: Salary	Benefits	Travel	Supplies & Expendables	Services and consultations	Agency Overhead (@18.3%)	Total Cost subject to overhead	Overhead (48.5% for all tasks)	Exempt from Overhead: Equipment	Graduate Student Fee Remission	Total Cost
1	Task 1	8,147	201,924	32,725	4,000	22,500	4,400	0	265,549	128,791	15,700	14,463	424,503
	Task 2	14,025	258,941	45,136	12,000	46,500	9,300	0	371,877	180,360	0	4,928	557,165
	Task 3	343	8,831	2,835	11,000	4,640	0	4,997	32,303	12,125	0	0	44,428
	Task 4	398	10,000	1,378	0	0	0	0	11,378	5,518	0	0	16,896
Total Year 1		**22,913**	**479,696**	**82,074**	**27,000**	**73,640**	**13,700**	**4,997**	**681,107**	**326,795**	**15,700**	**19,391**	**$1,042,993**
2	Task 1	8,147	212,019	34,929	4,000	17,500	4,400	0	272,848	132,331	0	15,639	420,818
	Task 2	14,025	258,941	45,136	12,000	40,500	9,300	0	365,877	177,450	0	4,928	548,255
	Task 3	343	8,831	2,835	11,000	4,640	0	4,997	32,303	12,125	0	0	44,428
	Task 4	398	10,000	1,378	0	0	0	0	11,378	5,518	0	0	16,896
Total Year 2		**22,913**	**489,791**	**84,278**	**27,000**	**62,640**	**13,700**	**4,997**	**682,406**	**327,425**	**0**	**20,567**	**$1,030,398**
Total 2 yrs		**45,826**	**969,487**	**166,352**	**54,000**	**136,280**	**27,400**	**9,994**	**1,363,513**	**654,220**	**15,700**	**39,958**	**$2,073,391**

Task 1: Fish Treadmill Operation and Maintenance
Task 2: Biological Studies
Task 3: Fish Collection
Task 4: Project Management

Itemized details:

Task 1: Fish Treadmill Operations and Maintenance

Salary and benefit rate:

Year 1	**Hours**	**Salary**	**Benefits**	Hourly rat	Benefits rate
M. L. Kavvas	347	27,538	2,534	79.44	0.0920
Z. Chen	1,387	48,363	12,216	34.88	0.2526
H. Bandeh	1,387	33,951	8,576	24.48	0.2526
M. Hannum	1,127	25,855	6,552	22.95	0.2534
PGRE1	1,300	20,811	895	16.01	0.0430
PGRE3	1,300	22,703	976	17.46	0.0430
PGRE3	1,300	22,703	976	17.46	0.0430
Total	**8,147**	**201,924**	**32,725**		

Year 2	**Hours**	**Salary**	**Benefits**	Hourly rat	Benefit rate
M. L. Kavvas	347	28,915	2,659	83.41	0.0920
Z. Chen	1,387	50,781	13,160	36.62	0.2576
H. Bandeh	1,387	35,649	9,090	25.71	0.2576
M. Hannum	1,127	27,147	6,550	24.10	0.2584
PGRE1	1,300	21,851	1,083	16.81	0.0430
PGRE3	1,300	23,838	1,181	18.34	0.0430
PGRE3	1,300	23,838	1,181	18.34	0.0430
Total	**8,147**	**212,019**	**34,905**		

Services (for Task 1 per year):	**Total =**	**10,700**
1) Annual acute toxicity test from sump tank		300
2) Annual 3 species toxicity test from sump tank		2,000
Sierra Foothills, Jackson, CA		
3) Detailed annual water quality tests from sump tank		600
4) Quartely water quality analyses from sump tank		7,000
Sequioa Analytical, Sacramento, CA		
4) Water discharge permit fee		800
Water Resource Control Board, Sacramento, CA		

Travel (Task 1 per year)	**4,000**
1) meetings with state and federal agency people	2,000
2) result presentation in workshops, conferences, etc.	2,000

Task 2: Biological Studies

Salary and benefit rate:

Year 1	**Hours**	**Salary**	**Benefit**	Hourly rate	Benefit rate
PDR	605	15,201	1,807	25.13	0.1189
PDR	2,016	50,660	12,827	25.13	0.2532
3 PGR 2	6,048	117,321	22,326	19.40	0.1903
Grad. Stu.	1,260	22,092	442	17.53	0.0200
4 students	2,080	14,560	291	7.00	0.0200
Total	**12,009**	**$219,834**	**$37,694**		

Task 2: Biological Studies

Year 2	**Hours**	**Salary**	**Benefit**	Hourly rate	Benefit rate
PDR	605	15,201	1,807	25.13	0.1189
PDR	2,016	50,660	12,827	25.13	0.2532
4 PGR 2	8,064	156,428	29,768	19.40	0.1903
Grad. Stu.	1,260	22,092	442	17.53	0.0200
4 students	2,080	14,560	291	7.00	0.0200
Total	**14,025**	**$258,941**	**$45,136**		

Task 2: Biological Studies

Services (per year):	**Total =**	**$16,200**
1) Annual acute toxicity test from holding tanks		300
2) Annual 3 species toxicity test from holding tanks		2,000
Sierra Foothills, Jackson, CA		
3) Detailed annual water quality analyses from holding tanks		600
4) Quarterly water quality analyses from holding tanks		7,000
Sequioa Analytical, Sacramento, CA		
5) Water discharge permit fee		800
Water Resource Control Board, Sacramento, CA		
6) Tank rental and water fee		5,000
Center for Aquatic Biology and Aquaculture, UCD		
7) Statistical consultations		500
Dr. Hong Zhou, Statistical laboratory, UCD		

Supplies and expendables (Task 1 per year)	22,500
Office suppies (staples, ink cartridges, paper reams, diskettes, zip disks, binders, folders, pens, pencils, erasers, liquid paper, etc)	2,000
Publication costs	1,000
Machine shop supplies	10,000
Fish Treamill Outer Screen wheels	500
Fabrication of crowder (first year only)	3,000
Fabrication of visual stimuli (first year only)	2,000
Pipes	4,000

Equipment (Task 1)	**15,700**
1) SonTek Velocity Meter	9,500
2) Wastewater discharge flow totalizer system	6,200

Task 3: Fish Collection

Salary and benefit rate:

Year 1	Hours	Salary	Benefits	Hourly rat	Benefits rate
Geir Aasen	343	8,831	2,835	25.75	0.3210
Total	**343**	**8,831**	**2,835**		

Year 2	Hours	Salary	Benefits	Hourly rat	Benefit rate
Geir Aasen	343	8,831	2,835	25.75	0.3210
Total	**343**	**8,831**	**2,835**		

Travel (Task 3)	**Total =**	**11,000**
1) vehicle operations		1,500
2) boat operations		3,000
3) Fuel		6,500

Supplies and expendables (Task 3)	**4,640**

Overhead:

Costs associated with general office requirements such as rent, phones, furniture, general office staff

Travel (Task 2 per year)	**12,000**
1) fish collection (from hatcheries)	3,000
2) meetings with state and federal agency personnel	2,000
3) result presentation in workshops, conferences, etc.	5,000
4) weekly fish transport from CABA to HL	2,000

Supplies and expendables (Task 2 per year)	**46,000**
Office suppies (staples, ink cartridges, paper reams, diskettes, zip disks, blank CDs, binders, folders, pens, pencils, erasers, liquid paper, label tapes)	4,000
Copying costs (for data sheets, reports, instructions, etc)	5,000
Illustration services (slides and transparencies)	3,000
Publication costs	2,000
Fish food (Artemia cysts, Biokyowa special fish diet, etc.)	2,000
Holding tank supplies (feeders, siphons, lights, airstones, air pumps, airline tubings, tank covers, screens, waterproof thermometers, PVC pipes, etc)	2,000
Laboratory supplies (ammonia ampules, pH buffers, batteries for night vision goggles, pH reader, batterries for ammonia reader, DO meter, batteries for red flashlights, air pumps, DO electrolytes, label tapes, videotapes, etc)	12,000
Chemicals (nitrofurazone, malachite green, MS-222) formaldehyde, iodine solution, oxygen gas, etc)	3,000
Video cameras and VCRs replacements or repair services*	6,000
Synthetic debris	1,000
Electrical supplies/repairs (for chillers, heaters, water pumps)	6,000

*** first year only**

Task 4: Project Management

Salary and benefit rate:

Year 1	Hours	Salary	Benefits	Hourly rate	Benefits rate
J. Cech	219	0	0	-	0.0000
L. Kavvas	101	8,000	736	79.44	0.0920
G. Aasen	78	2,000	642	25.75	0.321
Total	**398**	**10,000**	**1,378**		

Year 1	Hours	Salary	Benefits	Hourly rate	Benefits rate
J. Cech	224	0	0	-	0.0000
L. Kavvas	96	8,000	736	83.41	0.0920
G. Aasen	78	2,000	642	25.75	0.321
Total	**398**	**10,000**	**1,378**		

Responsibilities:
1) Inspection of work in progress
2) validation of costs
3) report preparation
4) giving presentations
5) response to project specific questions
6) Benefits