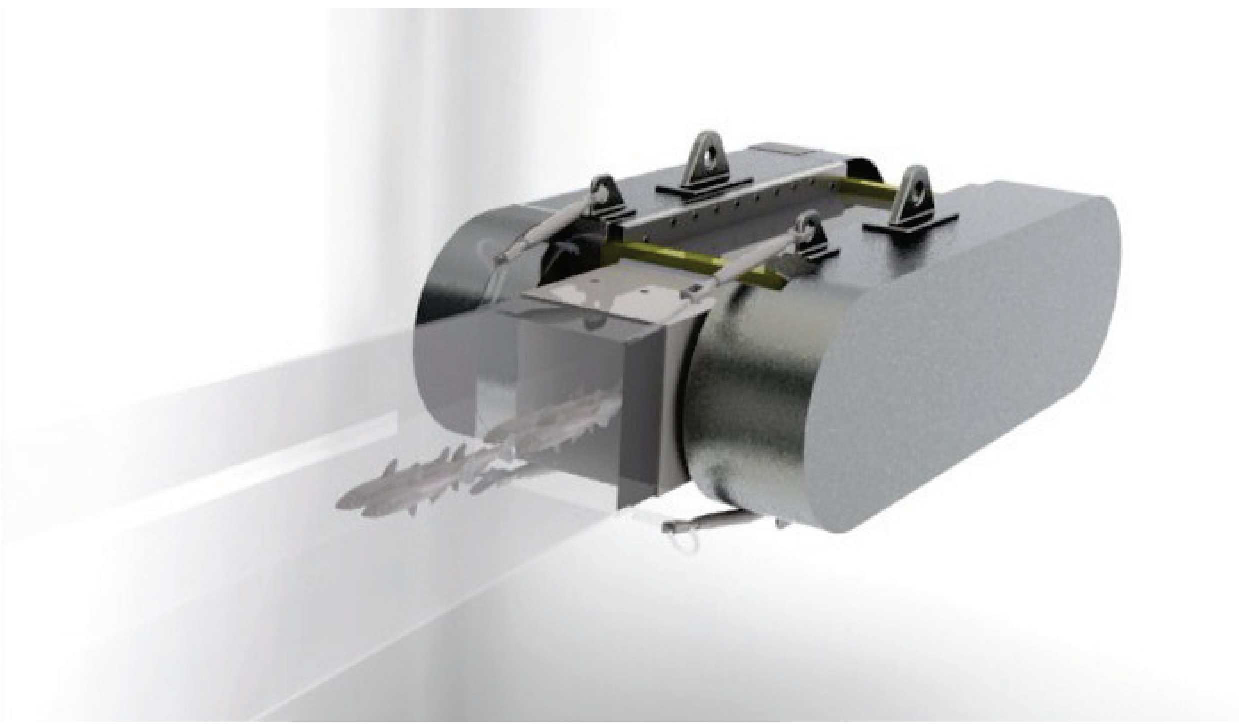
RECLAMATION
Managing Water in the West

Fiscal Year 2011 Annual Progress Report

SmeltCam: Underwater Video Technology for Identifying and Measuring Abundance of Pelagic Fishes



U.S. Department of the Interior
Bureau of Reclamation
Mid-Pacific Region and
Denver Technical Service Center

April 2012

1. REPORT DATE *(DD-MM-YYYY)*
April 2012

2. REPORT TYPE
Progress Report

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
SmeltCam: Underwater Video Technology for Identifying and Measuring Abundance of Pelagic Fishes

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Donald E. Portz and Darren Odom

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Bureau of Reclamation, Technical Service Center
Fisheries and Wildlife Resources Group
PO Box 25007, Denver, CO 80225-0007

SureWorks, LLc.
1607 Ervine Avenue, Longmont, CO 80501

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Bureau of Reclamation,
Mid-Pacific Region
Sacramento, CA 95825

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Available from the National Technical Information Service (NTIS)
Operations Division, 5285 Port Royal Road, Springfield, VA 22161

13. SUPPLEMENTARY NOTE

14. ABSTRACT
The Bureau of Reclamation, SureWorks LLC, California Department of Fish and Game, and California Department of Water Resources are developing technology to count and identify pelagic fish species in the Delta using an underwater video imaging system enclosed in a towed submersible. Innovative fish identification methods are necessary to provide more accurate population numbers and locations of occurrence, and more importantly to provide a passive, noninvasive technique that will lessen the impact of current fish monitoring practices. Pelagic organism declines have led to concern over lethal "take" by traditional trawling methods in a time when more information about sensitive species is needed to advise management decisions. Underwater fish species recognition technology provides a supplemental method to examine pelagic fish distribution and abundance without inadvertently harming threatened and endangered species. During 2011, the SmeltCam project focused on software enhancements and improvements to the video imaging system for the particular application of identifying and counting delta smelt and other Delta species. Average accuracy of the SmeltCam species classifier was 91% during fall 2011 trawls. Algorithms in the species recognition model were able to positively identify 88% of delta smelt.

15. SUBJECT TERMS
SmeltCam, delta smelt, underwater video, mid-water trawl, submersible, IEP

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Donald E. Portz, Ph.D.
a. REPORT	b. ABSTRACT	a. THIS PAGE		24	19b. TELEPHONE NUMBER *(Include area code)*
					303-445-2220

SmeltCam Research and Development

SmeltCam: Underwater Video Technology for Identifying and Measuring Abundance of Pelagic Fishes

Fiscal Year 2011 Annual Progress Report

by

Donald E. Portz, PhD[1] and Darren Odom[2]

[1] Bureau of Reclamation
Denver Technical Service Center
Fisheries and Wildlife Resources Group, 86-68290
PO Box 25007
Denver, CO 80225-0007

[2] SureWorks, LLc.
1607 Ervine Avenue
Longmont, CO 80501

U.S. Department of the Interior
Bureau of Reclamation
Denver Technical Service Center **April 2012**

MISSION STATEMENTS

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

DISCLAIMER

TABLE OF CONTENTS

Tables

Figures

EXECUTIVE SUMMARY

Much is still unknown about actual numbers, trends in abundance, and geographic distribution of rare and patchy pelagic fishes in the San Francisco Estuary and Sacramento-San Joaquin River Delta (Delta). Delta fish species and aquatic organisms are in constant flux and have seen recent declines. To learn more information about these fishes in their natural environment, the Bureau of Reclamation, SureWorks LLC, California Department of Fish and Game, and California Department of Water Resources are developing technology to count and identify pelagic fish species in the Delta using an underwater video imaging system enclosed in a towed submersible. Innovative fish identification methods are necessary to provide more accurate population numbers and locations of occurrence, and more importantly to provide a passive, noninvasive technique that will lessen the impact of current fish monitoring practices. Trawls presently form the foundation of Interagency Ecological Program (IEP) fish monitoring in detecting pelagic organism decline (POD) and population trends for pelagic Bay-Delta fishes. While these long term sampling data have been exceptionally useful in monitoring population trends and abundance, additional sampling is necessary to gain further understanding of the distribution and life histories of rare and patchy pelagic fish species, their ecosystem requirements, and factors that may be correlated with their declines. Pelagic organism declines have led to concern over lethal "take" by traditional trawling methods in a time when more information about sensitive species is needed to advise management decisions and attempt to rescue these organisms in peril. Underwater fish species recognition technology provides a supplemental method to examine pelagic fish distribution and abundance without inadvertently harming or handling threatened and endangered species.

During 2011, the SmeltCam project focused on software enhancements that were tested under both laboratory and field situations. Laboratory testing occurred at the Bureau of Reclamation's Hydraulic Laboratory, Denver, Colorado and field testing in the Delta aboard California Department of Fish and Game Research Vessel *Scrutiny.* Improvements to the video imaging system engineered for the particular application of identifying and counting delta smelt and other Delta species in turbid water are ongoing. The user interface, tracking algorithm, and species recognition algorithms were greatly improved. The average accuracy of the SmeltCam species classifier was 91% during trawls performed in fall 2011. Algorithms in the species recognition model were able to positively identify 88% of delta smelt.

INTRODUCTION

While delta smelt (*Hypomesus transpacificus*) abundance in 2011 was greater than it has been since 2001 (DFG 2011 delta smelt abundance index), much is still unknown about actual numbers, trends in abundance, and geographic distribution. Other fish species (*i.e.*, longfin smelt *Spirinchus thaleichthys*, juvenile striped bass *Morone saxatilis*, and threadfin shad *Dorosoma petenense*) and aquatic organisms in the San Francisco Estuary and Sacramento-San Joaquin River Delta (Delta) are in constant flux and have seen recent declines. To learn more information about these fishes in their natural environment, the Bureau of Reclamation, SureWorks LLC, California Department of Fish and Game, and California Department of Water Resources are developing technology to count and identify pelagic fish species in the Delta using an underwater video imaging system enclosed in a towed submersible. Innovative fish identification methods are necessary to provide more accurate population numbers and locations of occurrence, and more importantly to provide a passive, noninvasive technique that will lessen the impact of current fish monitoring practices. Trawls presently form the foundation of Interagency Ecological Program (IEP) fish monitoring in detecting pelagic organism decline (POD) and population trends for pelagic Bay-Delta fishes. While these long term sampling data have been exceptionally useful in monitoring population trends and abundance, additional sampling is necessary to gain further understanding of the distribution and life histories of rare and patchy pelagic fish species, their ecosystem requirements, and factors that may be correlated with their declines. Pelagic organism declines have led to concern over lethal "take" by traditional trawling methods in a time when more information about sensitive species is needed to advise management decisions and attempt to rescue these organisms in peril. Underwater fish species recognition technology provides a supplemental method to examine pelagic fish distribution and abundance without inadvertently harming or handling threatened and endangered species.

SMELTCAM FIELD DEPLOYMENTS

Field testing and data collection were performed during September and October 2011 aboard the California Department of Fish and Game's research vessel *Scrutiny* (Figure 1). The SmeltCam was connected to the cod-end of a Fall Midwater Trawl (FMWT) net with 12 ft x 12 ft mouth dimensions and graduated net mesh sizes from 8-inch mesh at the mouth to 0.5-inch mesh at the cod-end (Figure 2). The four corners of the net mouth were connected to planing doors that function to keep the net mouth open by drag on the doors spreading the net in opposing directions while towed through the water. The trawl net funnels fishes through the SmeltCam and a camera captures video information of passing fish as they freely exit the device. A 12 minute or longer tow was performed at several sampling locations that correspond to sites used for Delta monitoring by the California Department of Fish and Game (Figure 3). Field data from multiple independent trawl samples in the Delta were collected to build an image database. These images form the foundation of the recognition algorithms training data and statistical model from known images of Delta fishes under natural conditions (Figure 4). In addition, the crew measures water temperature, electrical conductivity (specific conductance), Secchi depth, and turbidity. The FMWT is mandated by the Delta Smelt Biological Opinion for the coordinated operation of the Central Valley Project and the State Water Project.

Figure 1.— SmeltCam being deployed from the *Scrutiny* in the San Francisco Estuary and Sacramento-San Joaquin River Delta by Reclamation, SureWorks, and California Department of Fish and Game staff.

Figure 2.— SmeltCam attached to a modified cod-end of the Fall Midwater trawl net as it is being deployed from the *Scrutiny*.

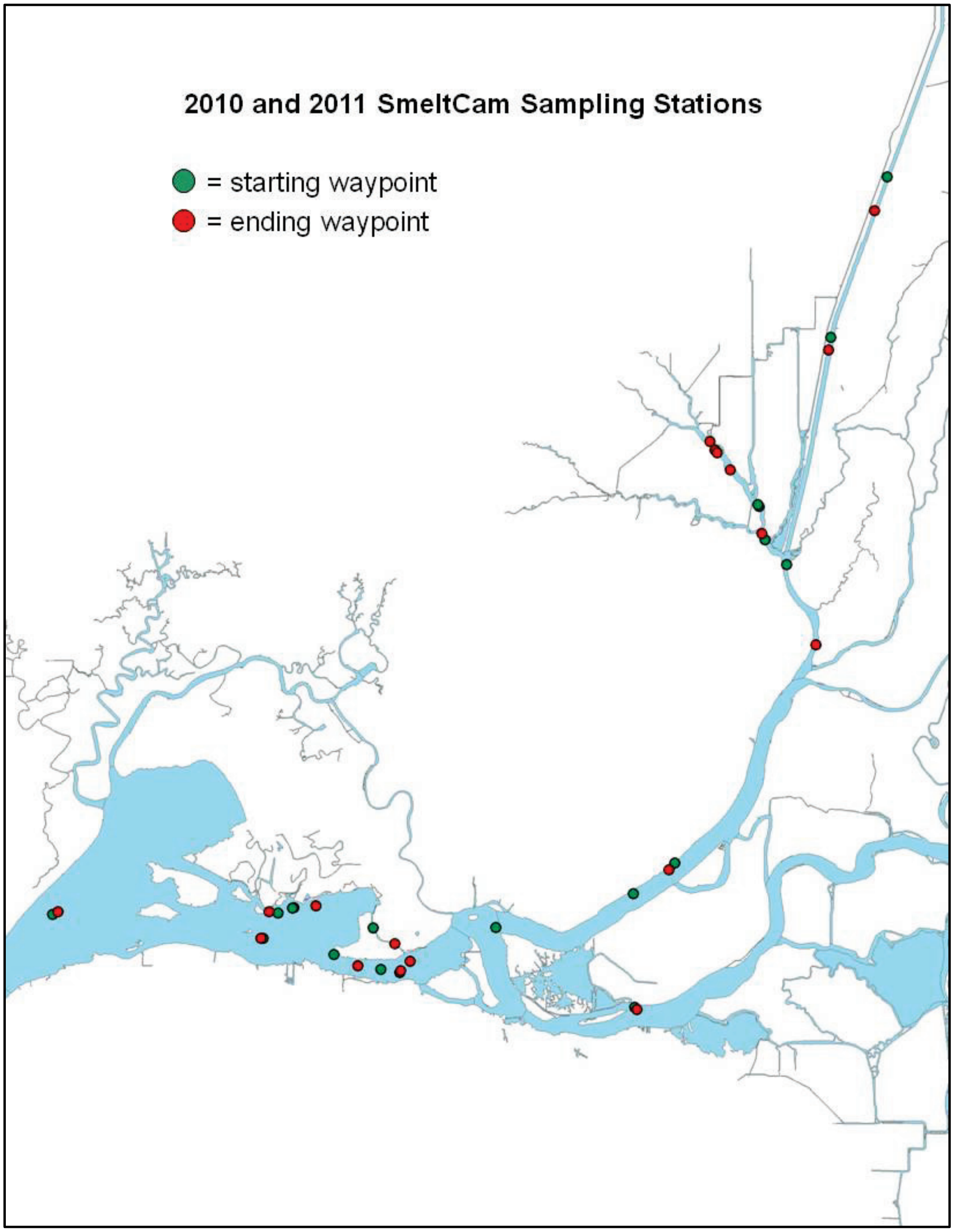
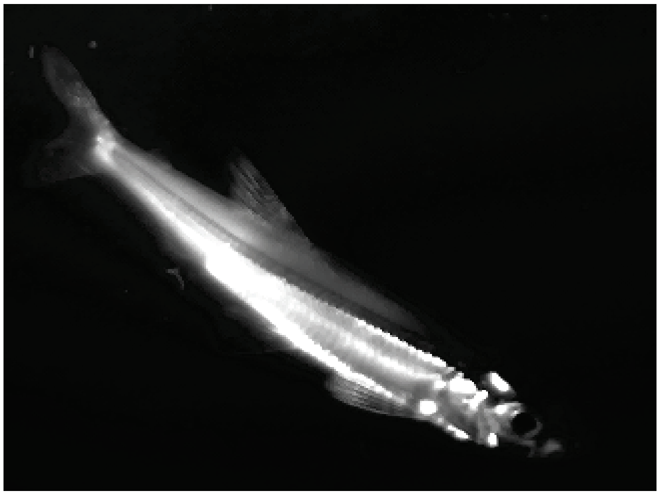
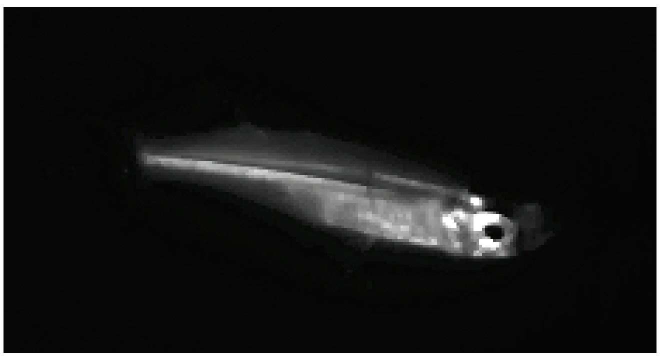


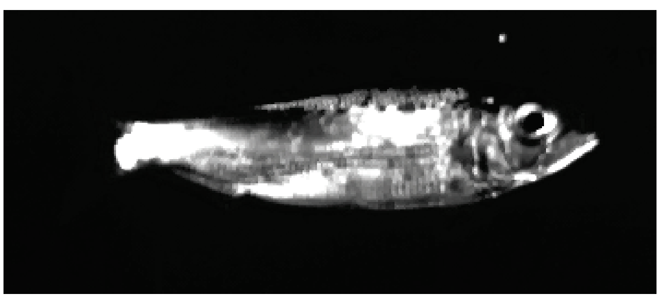
Figure 3.— SmeltCam sampling locations in the San Francisco Estuary and Sacramento-San Joaquin River Delta.



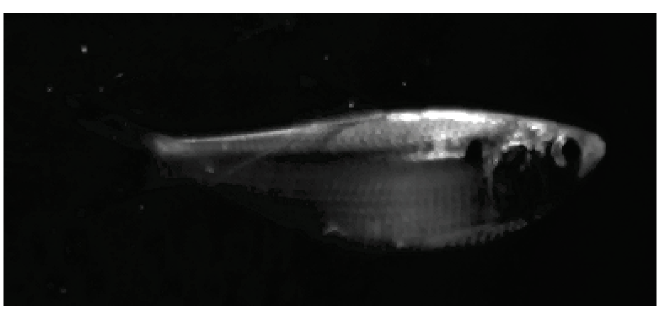
A. Delta smelt (*Hypomesus transpacificus*)



B. Inland silverside (*Menidia beryllina*)



C. American shad (*Alosa sapidissima*)



D. Threadfin shad (*Dorosoma petenense*)

Figure 4.— Images of four Delta fishes (A. delta smelt, B. inland silverside, C. American shad, and D. threadfin shad) taken with the SmeltCam in their natural environment.

2011 SmeltCam Development Activities

During 2011, the SmeltCam project focused almost solely on software enhancements, testing these improvements in both laboratory and field settings. Laboratory testing occurred at the Bureau of Reclamation's Hydraulic Laboratory, Denver, Colorado and field testing in the Delta aboard California Department of Fish and Game Research Vessel *Scrutiny*. Improvements to the video imaging system engineered for the particular application of identifying and counting delta smelt and other Delta species in turbid water are ongoing. Below are 2011 SmeltCam research developments.

User Interface:

The user interface has been greatly improved to be intuitive for scientist to manipulate the settings and follow the tracked objects as they arrive from the SmeltCam. Figure 5 is one of the main screens on the user interface and shows a list of every image that is sent to the computer as the images are collected. The user can click on an object, select multiples, and scrub through all cropped-in stills of an object through its entire trajectory. The user interface is still a work in progress and is versatile where it can be customized for displaying data important to the scientist.

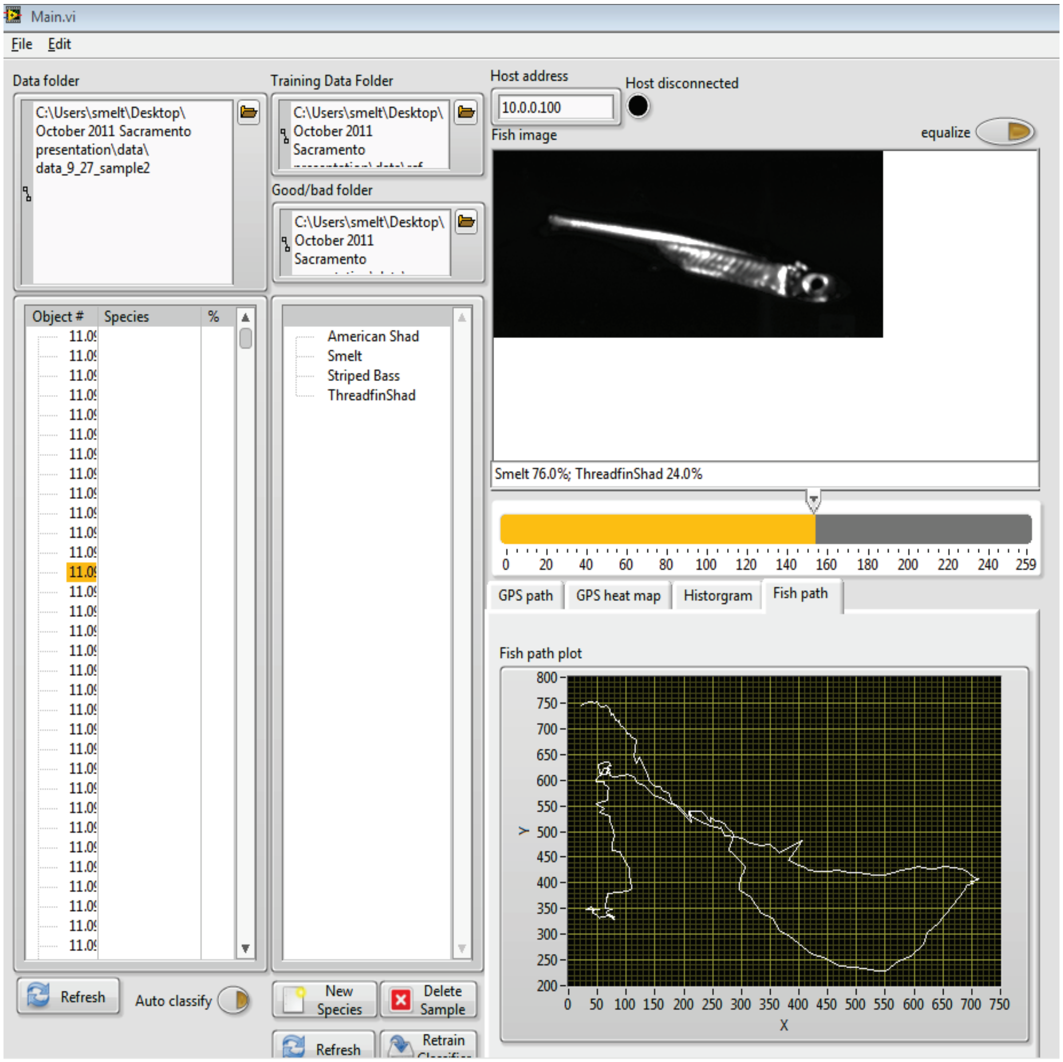


Figure 5.—SmeltCam user computer interface. Interface shows still images from the collected video including tracking and species identification information.

Tracking Performance:

The tracking algorithm receives raw image information from the camera and makes it meaningful by separating the foreground/background and each object from one another as they pass in the camera's field of view. Background model robustness against light changes and rapid background changes have been improved to respond quicker and allow the computer to take on higher priority tasks of image analysis and tracking functions. The prior method used a slow, complex Mixture of Gaussians method that relied on a large amount of memory.

Gradient contour methods were introduced to obtain the shape of the fish and objects more accurately. Due to water turbidity, reflected light backscatters in the water causing a halo effect which obscures fish shapes. Object silhouettes are one of the most valuable indices for species identification. Therefore gradient contours are important to calculate. Figure 6 below shows the shape of the fish image before and after gradient contour detection. Gradient contour samples each object identified in standard blob detection. Objects are filtered for size and passed to the gradient contour method. The algorithm takes the derivative of the value of the pixels contained in the object and determines the contour of the fish from the equipotential lines that result from the gradient function. This allows much more detailed and accurate representations of the outline of the fish, in turn, giving the Identification Algorithm more accurate information.

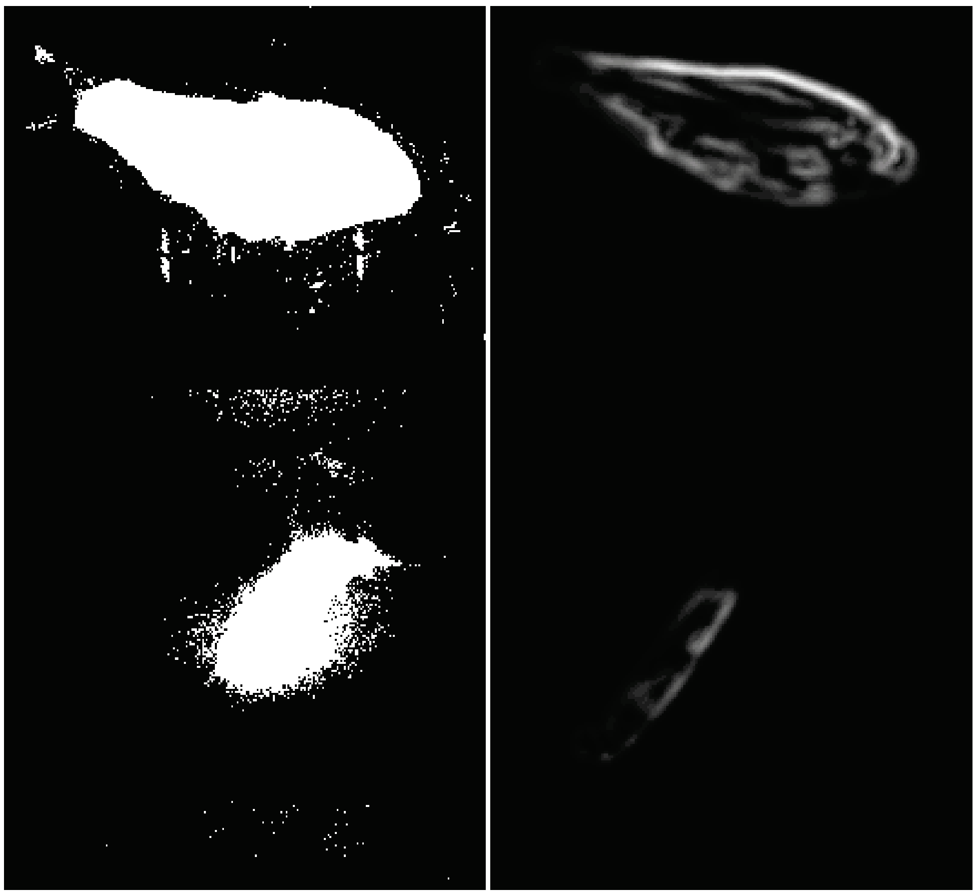


Figure 6.—Gradient contour method refinement of a threadfin shad and a delta smelt. Fish images are before and after gradient contour detection.

Individual tracking of each object within the field of view was also improved. This is a difficult number to quantify because its accuracy varies for the total number of objects in the frame, but on an average sequence (<10 objects in frame at once), we were able to get 94.5% accuracy in a sample size of 1,853 objects. Figure 7 is an example of the tracking algorithm output. The tracking algorithm was made much more robust to long-term occlusions (more than 5 frames of the object being lost off-screen or lost behind another object) after we experienced fish occlusions under high densities of threadfin shad under field observations. The tracking algorithm uses Kalman statistics to predict the next probable position of the object being tracked. Kalman statistics are based on a physical model and does not allow for accelerations that are too quick. It also helps to address the problem of object permanence, which is where an object has left the visual field or is occluded by another object but is still assumed present for a specified time duration. The algorithm also excludes objects that are non-fish by first passing them through a filter that measures shape features and size range.

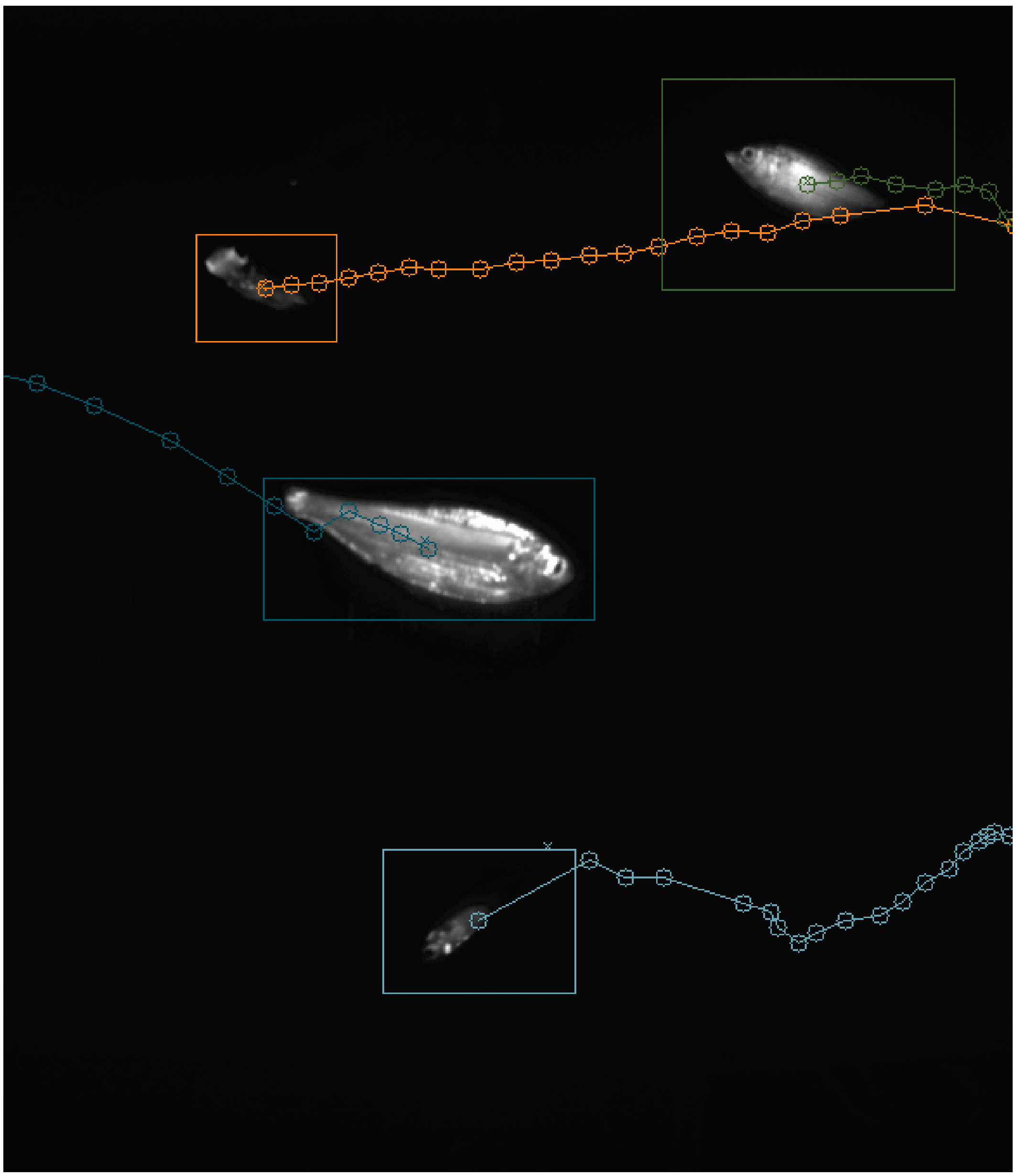


Figure 7.—Tracking of fish objects within the visual field.

Species Identification:

A set of species recognition algorithms were further developed and species identification was determined based on training data collected from field sampling and laboratory experiments with fish. In the previous year, a texture-based classifier using principal component analysis was employed to try to determine species from textural information on the side of each fish. This approach was very prone to error because of the difficulty in estimating the pose of the individual. In 2011, a Support Vector Machine (SVM) was used which takes several feature vectors, or multiple-dimensional list of numerical features to describe each species uniquely in a mathematical approach. The SVM takes in all of the features (input data) and predicts the species for each given input with confidence intervals though non-probabilistic binary linear classification. The qualities of each object are plotted in N-dimensional space. The inputs include features such as length, shape (as expressed through Hu Moments), size, aspect ratio, texture (binary radial section), and others. The SVM maps those points into 'feature space' where a definitive line exists when comparing two species (Figure 8). Given a set of training examples, each marked as belonging to one of two categories, an SVM algorithm builds a model that assigns new examples into one category or the other. An SVM model is a representation of the examples as points in space, mapped so that the examples of the separate categories are divided by a clear gap that is as wide as possible. New examples are then mapped into that same space and predicted to belong to a category based on which side of the gap they fall on. This process is repeated until all species have been compared to each other and what results is a numerical confidence value. The main advantage to this approach is that the classifier is easily improved-upon by adding increasingly more features to the list to compare. As measurable features were identified and deemed reliable enough over several sample videos, those features were fed into the identification classifier to determine additional benefit. Features that were included were object size, size and shape-independent list of shape moments (Hu moments), aspect ratio, defect from pure ellipse, RMS error (or deviation from) normalized species image, and radial local pattern.

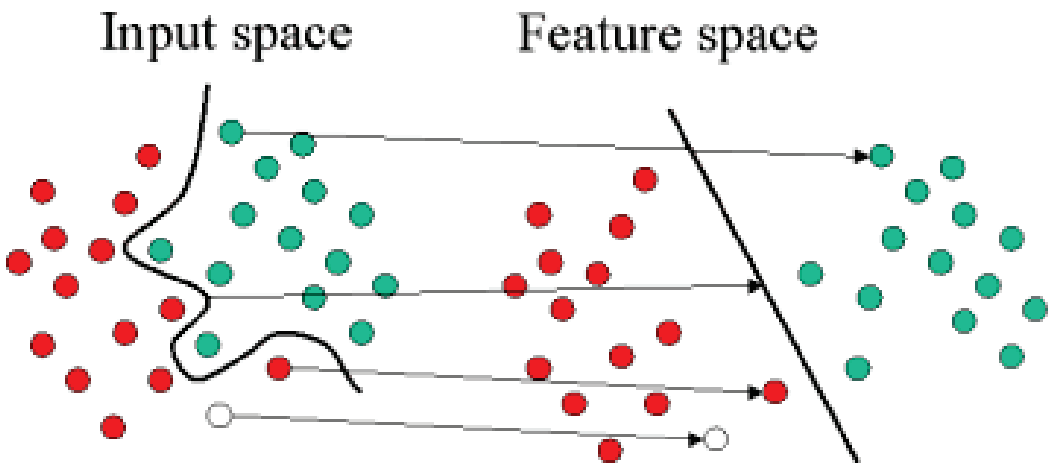


Figure 8.— The standard Support Vector Machine (SVM) takes a set of input data and predicts, for each given input, which of two possible classes forms the input. SVM uses several vectors and maps points into 'feature space' and a regression can be formed between the two to determine probabilities of belonging to either category.

Data from September were annotated (800 samples) by two fisheries biologist and cross validated against the recognition model. The average accuracy of the classifier was 91%. This means of the images that a biologist can positively identify, the algorithm can do 91% as well. October data was interpreted by two biologist (306 samples) and using the data from September as a training set, the algorithms were able to positively identify 88% of delta smelt as such (Table 1). Some confusion still exists in the algorithm when comparing American shad and threadfin shad. Comparing generalized 'shad' and 'smelt' categories, the algorithm was 85% correct for shad and 88% correct for smelt. However, because pristine, side profile images of sampled fish are not always achievable, some are occluded, and some appear hazy due to elevated turbidity, even biologists are challenged by positively identifying all fish that enter the device.

Table 1.— Average accuracy of the classifier for test species of Delta fish. October data was interpreted by two biologists (306 samples) and using the data from September as a training set, the algorithms were able to positively identify each species to the bolded value.

	American Shad	**Delta Smelt**	**Inland Silverside**	**Threadfin Shad**
American Shad	**56%**	15%	0%	28%
Delta Smelt	0%	**88%**	0%	2%
Inland Silverside	0%	0%	**0%**	0%
Threadfin Shad	37%	14%	0%	**47%**

FUTURE NEEDS AND TECHNOLOGY ADVANCEMENT

Hardware Redesign

In order to advance the SmeltCam into the fabrication and production phase, we must gather evidence of system improvements for a few major hardware redesigns that still need to be performed. Each redesigned component will need to be modeled and tested before the changes are introduced to the overall hardware redesign. Computer-aided design modeling, prototyping, and testing are necessary for design and development of the submersible unit. Testing of SmeltCam's ability to tolerate increased pressures, improve stability, handling, and deployability, and overall utility as a fisheries tool will need to be furthered this upcoming year.

Hardware advancements to occur this year include modifications to the lighting system and camera redesign to improve tracking and object recognition. Changes to the SmeltCam lighting system will include infrared lighting that would replace the existing 8000 lumens of white light with high power infrared LEDs. Lighting changes will need to be tested under controlled settings in the hydraulics laboratory. One of the primary goals of the lighting system upgrade is to determine how infrared light or near infrared behave in turbid water when gathering video footage, and how these wavelengths of light are affected by backscattering caused by high turbidity. A possible benefit of the infrared modification is that many fish species are attracted to the current SmeltCam lighting system and by removing the bright lights, less phototactic species will remain in the field of view. Loitering fish species make it difficult to track and count individual fishes, and can overwhelm the software tracking algorithm.

Individual target tracking is anticipated to be improved by tracking in three-dimensional space with a three-dimensional camera. Often overlapping fish cannot be accurately tracked because of occlusion. In three dimensions, because two cameras are involved, there is less occlusion, and calculation of the depth of each fish is possible. This allows a more sophisticated tracking algorithm, and ultimately, an improvement of the accuracy of the device when the water is turbid and there are many fish traveling through the device. Three-dimensional filming also allows calculation of the length and size of each fish passing through, which is currently impossible. Three-dimension correlated cameras calculating a point cloud of three-dimensional data with live fish under simulated flows will need to be set-up in the hydraulics laboratory. This will determine the ability of three-dimension algorithms to correlate pixels between cameras in such short focal length lenses (wide angle lenses), and if a third dimension is able to be calculated accurately enough to improve the tracking algorithm.

The last proposed hardware upgrade is to install opposing cameras in the device to increase the amount of water that can be effectively sampled. This idea to split the device into two devices that mirror each other with a black divider down the middle was derived from discussions during our October 2011 SmeltCam meeting and presentation. This effectively doubles the distance that can be seen through by the camera in turbid water. It was determined after the meeting that the black divider may not be necessary if the lighting is strobed in an alternating pattern where each side is illuminated and sampled briefly.

Software Improvements

Software improvements will need to be orchestrated to follow advancements in hardware and SmeltCam design. The current tracking and object accounting algorithm will need to be redesigned for the use with a three-dimensional camera system. If three-dimensional videography is promising, then three-dimensional algorithms will be integrated into the tracking algorithm replacing most of the algorithmic functions. Similarly, if the opposing camera with alternating strobes design proves feasible, the tracker will need to handle and correlate objects seen by both halves and have to be rewritten. In theory this is a challenging task and will need significant development effort to be successful. The inclusion of three-dimensional functionality may prove critical to the success of opposing, alternating cameras because of the challenges associated with correlation of objects.

Target tracking and accounting needs to be improved this year to manage fish that pass through the field of view, initially counted, and re-enter the recording area where they are counted again. The tracking software needs to account for the probability of these objects and not count them as new, unique objects. Counting the same object multiple times as fish swim in and out of the SmeltCam is problem with the current design.

Finally, if the identification algorithm is made fast enough to be run real-time or the portion of the identification algorithm that determines fish/non-fish be placed in SmeltCam's onboard system to be calculated before the object is sent up to the boat computer, then the required bandwidth of the system will be greatly reduced and would improve the rate of successful message delivery over the cable back to the boat. Placing the entire identification algorithm within the underwater portion of the device to reduce the total amount of data that needs to be transferred and increase reliability of the system would require a significant amount of software development to increase the speed of the identification routine. There are several highly computational routines that can be added to the existing SVM. Some routines have been already written to test their efficacy and determine which measurable object parameters are reliable enough and create the greatest benefit to the system.

Field Testing and Implementation

Additional species recognition and further refinement of currently profiled species could be improved with the collection of more field data. Independent samples of Delta fishes under natural conditions are more useful than flume data to build the image database. SmeltCam field experience, deployment/retrieval, trawl data collections, and unforeseeable challenges that arise in the field aid in the development of the device. We are proposing for this coming year that additional data for algorithm training be collected. While we continue to sample and learn from the current operational prototype, the next generation SmeltCam can be fabricated with the hardware and software improvements previously mentioned. The next generation SmeltCam will require flume tests for hydrodynamic performance and boat time for field deployment and final testing.

We recommend that the SmeltCam be used starting later this summer/early fall to develop a quantitative understanding of environmental factors (e.g., salinity, turbidity, water temperature) directly affecting the location, movement, and distribution of delta smelt. The SmeltCam can provide detection locations using GPS that will pinpoint populations and then can be correlated with location-specific water quality information that is either collecting real-time or from other monitoring data. Traditional trawling practices can only provide information over the 12-minute sampling effort, which provides no certainty of where and when during a trawl captured fish were encountered. This effort will require collaboration with the California Department of Fish and Game, California Department of Water Resources, Bureau of Reclamation and the Interagency Ecological Program. Further research could also focus on heat mapping population densities and distributions of Delta fishes.

ACKNOWLEDGMENTS

Funding for the research and development of the SmeltCam was provided by the Bureau of Reclamation's Mid-Pacific Region in coordination with the Interagency Ecological Program and the Reclamation's Science and Technology Program. We would like to thank Randy Baxter, Davis Contreras, Steve Slater, Brian Delano, Lauren Damon, Jennifer Messineo of California Department of Fish and Game; Nick Van Ark of California Department of Water Resources; David Van Wie and Adam Torgerson of Boulder Labs, and Chuck Hueth of the Bureau of Reclamation for aiding in 2011 data collection. We would like to acknowledge Norm Ponferrada of the Reclamation's Fisheries and Wildlife Resources Group for conducting species identification of SmeltCam fish images.