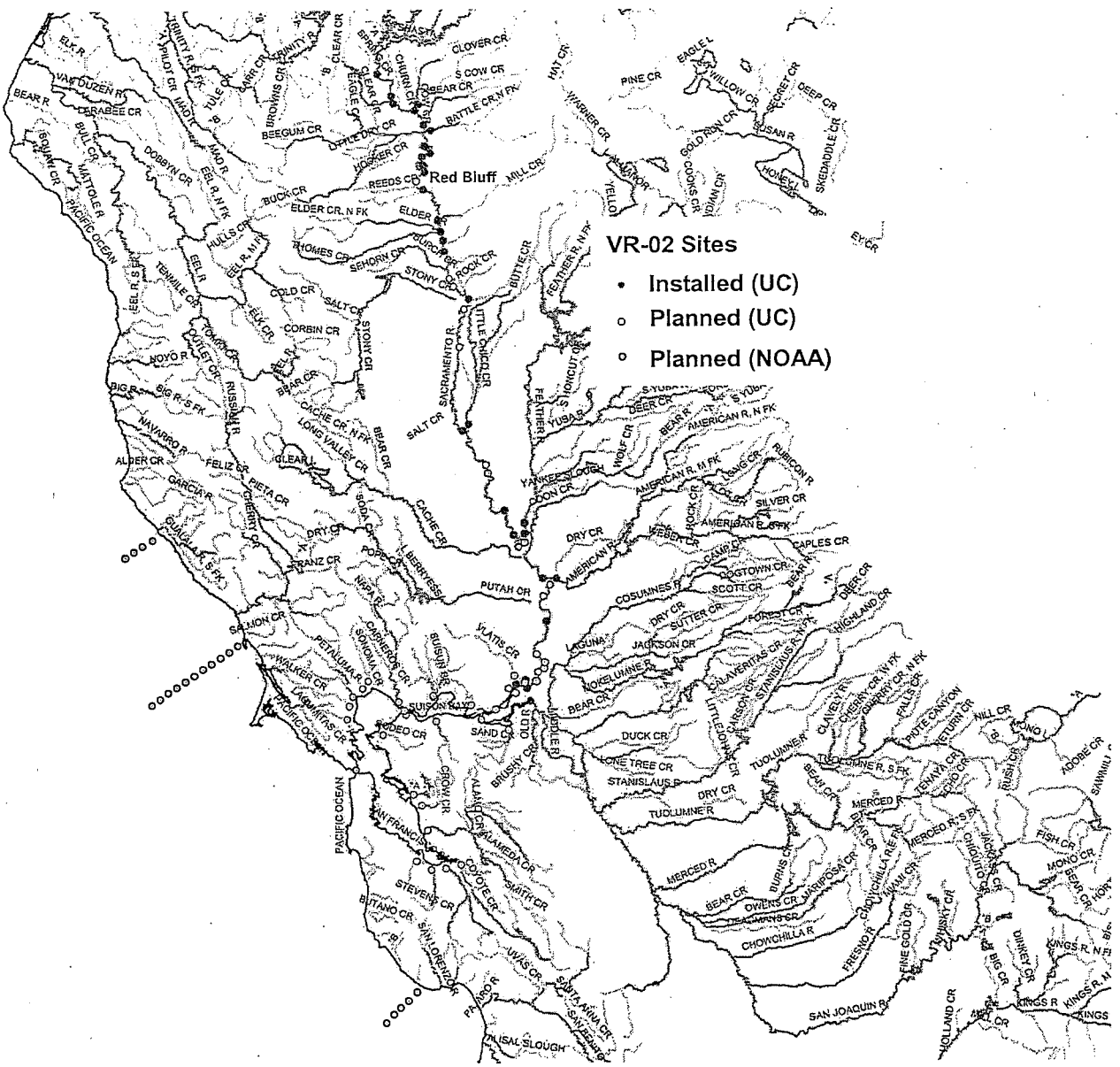
2. Scope of Work

Task 1. Expansion and Maintenance of Array of Tag-detecting Monitors in Sacramento River and San Francisco Estuary

Grantee has established an array of tag-detecting monitors within the Sacramento River to detect the migratory movements of green sturgeon (Klimley, pers. commun.). Thirty-two monitors are currently in place at the junctions between the mainstem and tributaries over a 500 km reach of the Sacramento River from Rio Vista at the mouth of Grizzly Bay to the headwaters at the base of Keswick Dam (Fig. 4). Grantee will be placing eight more monitors during fall 2004 at additional sites along the river such as along the Yolo Bypass and at the junction to the San Joaquin River. A goal of this grant proposal is to expand the geographic extent of this array and increase the density of monitors to enable us to describe the migration of juvenile Chinook salmon and steelhead down the Sacramento River and through the San Francisco Estuary. Grantee will upgrade the array of monitors in the following ways. More monitors will be installed at critical points in the Sacramento River, where juvenile salmon may be diverted from their normal migratory route, such as entrances and exits to the Delta, Sutter Bypass, and the Deep Water Ship Channel, at the Glenn Colusa Irrigation Ditch intake, and at the two water project intakes. Secondly, monitors, each separated by 250 m, will be installed at the mouth of the Sacramento River at the northernmost end of Grizzly Bay to detect the arrival of juveniles to Grizzly and Suisun Bays. Thirdly, monitors separated by a similar distance will be installed across the Carquinez Straits to detect the arrival of juveniles at the entrance to San Pablo Bay. Fourthly, monitors will be placed at the mouths of the sloughs and rivers leading into Grizzly, Suisun, San Pablo, and San Francisco Bays to ascertain whether juveniles might stray from their path directly through the bay, and become stranded in rivers during the strong reverse flows occurring from slack to high tide during the periods of full and new moons. Finally, monitors have been placed across the mouth of San Francisco Bay at the Golden Gate to detect the egress of juveniles from the San Francisco Estuary.

The river monitors will be deployed 1.5 m above the bottom in the main channel (Fig 5). Each river mooring will consist of an 18 kg, pyramid-shaped, lead anchor with a galvanized eye at the vertex of the pyramid. Attached to the eye will be a 1.5 m nylon line leading to a subsurface buoy. A steel plate, holding the monitor, will be affixed to the line using plastic tie wraps and its signal-detecting PZT will be oriented upward in the water column. Attached to the monitor will be a small temperature logger (Onset, HOBO). These low-cost devices can be programmed to record water temperature at hourly intervals during the deployment period of the monitor. Also attached to eye is a 10-m length of ¼" stainless steel cable, which is unraveled so that it lies on the river bottom and leads to the bank where the cable is looped and attached to itself with a stainless steel crimp. These moorings are small and inconspicuous with all of the components being underwater, and hence there should be little loss of equipment due to vandalism or theft. All of the monitors, to which we have returned to interrogate as part of the green sturgeon study, have remained in place. Recently, 29 of 30 monitors were relocated after a deployment period of six months by biologists of the Department of Fish and Game studying the migratory behavior of white sturgeon in the Delta region of Sacramento/San Joaquin watershed (Derek Stein, pers. commun.). The monitors within the bays will be of similar design to the river monitors, but will not be connected to a structure on shore. Instead, they will be

connected to each other by a lead line that will he along the bottom. Attached to the eyes of the pyramid anchors at the beginning and end of each lead line will be a polypropylene line with a buoy at its end that will release from the bottom when activated by a signal from an ultrasonic transducer. Grantee will interrogate all


VR-02 Sites
Installed (UC)
Planned (UC)
Planned (NOAA)
Red Bluff
PACIFIC OCEAN
SAN FRANCISCO
SAN JOAQUIN R
SACRAMENTO R
STANISLAUS R
TUOLUMNE R
MERCED R
CHOWCHILLA R
FRESNO R
KINGS R
MOKELUMNE R
CALAVERAS R
AMERICAN R
YUBA R
FEATHER R
BUTTE CR
PUTAH CR
CACHE CR
SALT CR
STONY CR
CORBIN CR
COLD CR
ELDER CR
BEAR CR
DRY CR
SUTTER CR
JACKSON CR
COSUMNES R
DUCK CR
LONE TREE CR
SAND CR
RODEO CR
SUISUN BAY
ALAMEDA CR
COYOTE CR
SMITH CR
STEVENS CR
BUTANO CR
SAN LORENZO R
PESCADERO CR
PETALUMA R
SONOMA CR
NAPA R
CARQUINEZ STRAIT
SUISUN SLOUGH
MUSAL SLOUGH
SAN JOAQUIN R
HOLLAND CR
KINGS R
BIG CR
DINKEY CR
FISH CR
MONO CR
ADOBE CR
RUSH CR
MERCED R
BEAR CR
OWENS CR
MARIPOSA CR
CHOWCHILLA R
FINE GOLD CR
CHOWCHILLA R
FRESNO R
SAN JOAQUIN R
MOKELUMNE R
CALAVERAS R
STANISLAUS R
TUOLUMNE R
MERCED R
BEAR CR
DUCK CR
LONE TREE CR
STANISLAUS R
DRY CR
TUOLUMNE R

Implanting ultrasonic tags and releasing fish. Each year for three years (2007-2009), grantee will implant coded ultrasonic tags into 200 late-fall Chinook salmon smolts (about 150 mm FL) and 200 steelhead smolts

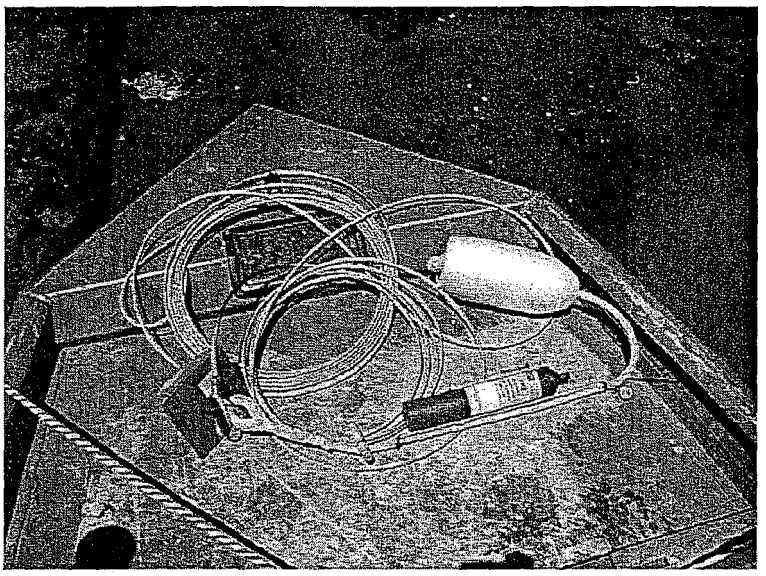


Fig. 5. Mooring for VR-02 used to deploy monitors in the channel of the Sacramento River.

(about 190 mm FL). The fish will be released during January into the headwaters of the Sacramento River to monitor rate of movement and mortality during their downstream migration. The fish will be raised at the Coleman National Fish Hatchery (CNFH), situated on Battle Creek, and released into the reach below the hatchery. The CNFH raises late-fall juveniles spawned from adults migrating up to CNFH in December and January. Some of these juveniles are kept for one year, after which they are 130-150 mm FL and released into the river during January (Hamelberg, pers. commun.). The CNFH also raises juvenile steelhead (160-200 mm FL) spawned from adults that migrate up Battle Creek in January to February of the previous year (Hamelberg, pers. commun.). We have made formal request to CNFH to provide us with the above-mentioned number of juveniles. Scott Hamelberg, the Hatchery Manager, and Kevin Niemela, U.S. Fish & Wildlife Service Hatchery Evaluation Program Leader, have approved our request.

Grantee chose to use late-fall run Chinook salmon and steelhead because *(1) they are candidates for listing (late fall Chinook) or listed as threatened (steelhead) under the U.S. Endangered Species Act, (2) are important ecological and socioeconomic resources to California and (3) are large enough at the time of smolt outmigration to carry an ultrasonic tag.* In addition, late-fall run Chinook yearlings can be considered as surrogates for the ESA-listed threatened spring-run because of their overlapping early life history. Fish from CNFH were selected because of (1) availability, (2) ease of conducting the tagging and evaluation of tagged fish, and (3) the hatchery's location at the northern end of the Sacramento River system, thus encompassing the entire migratory corridor for anadromous salmonids. Although we would prefer to also implant tags into wild late-fall Chinook salmon and steelhead juveniles, they are not caught in enough numbers at juvenile monitoring sites, due to their size and ability to avoid traps, to make statistically valid comparisons - less than six fish/year are captured in January at Red Bluff Diversion Dam Rotary Screw Traps (Bill Poytress, pers. comm.).

When using any experimental technique to monitor animal behavior it is essential that the technique itself does not modify behavior or affect survival (Moore *et al.,* 1990). With respect to implantation of a tracking device into a fish, the main consideration is the size of the device that can be implanted into a fish without modifying that fish's behavior. Several technical advances in electronic miniaturization and transmitter configuration (pulsed and coded signals) have resulted in very small tags with extended battery life and the ability to monitor many tags in the same area. Some very small ultrasonic tags are available (-0.5 g), but the tradeoff in reducing tag size is reduced battery life and power output. The estimated transit time of up to 60 days from Battle Creek to the Golden Gate for juvenile late-fall Chinook salmon requires a tag with battery life at least that long and preferable much longer so that monitoring in the ocean will also be possible.

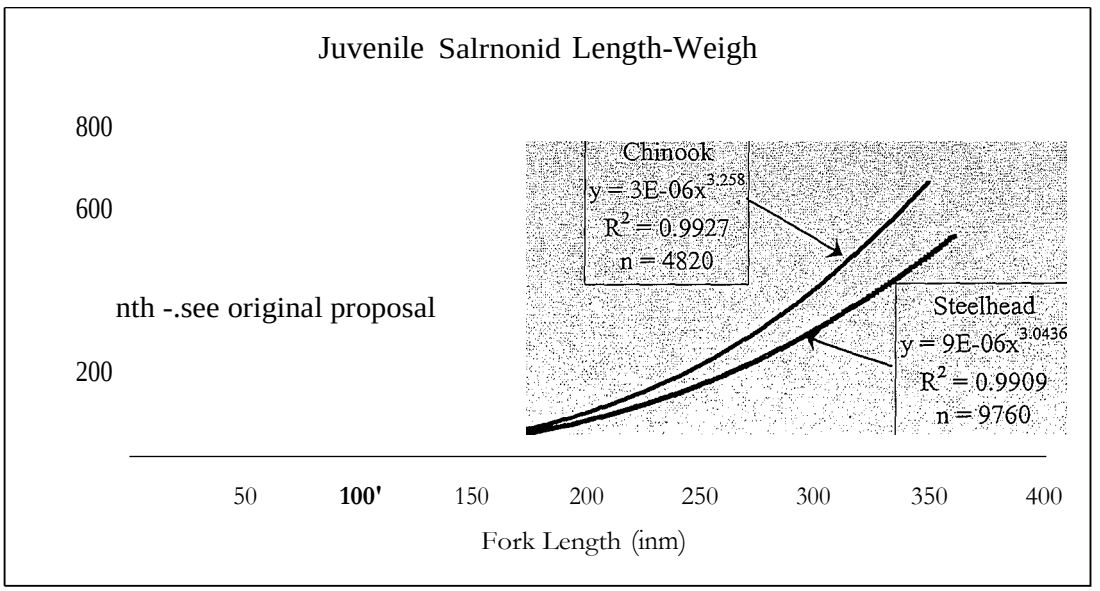
Several studies have examined the effect of implanted radio or ultrasonic tags on swimming performance, growth, and vulnerability to predation of juvenile salmonids. These studies comprise

experiments with juveniles of various sizes and tags of various sizes, both with and without an external antenna. The characteristic that seems to best indicate the magnitude of effect in these studies is the tag weight to fish weight ratio. Studies that implanted a tag that weighed less than 8.0% of the fish's weight did not find any significant difference in swimming performance between tag, sham tag (if done), or control treatments (Moore *et al.,* 1990; Peake *et at.,* 1997; Adams *et at.,* 1998b; Brown *et at.,* 1999; Robertson *et at.,* 2003; Anglea *et al.,* 2004; Lacroix *et al.,* 2004).

In studies that examined growth rates, three studies using surgically implanted tags of less than 6% of the fish's weight found no effect on growth rates compared to controls (Moore *et al.,* 1990; Adams *et al.,* 1998a; Martinelli *et al.,* 1998). Another study demonstrated a negative effect of surgically implanted tags on growth rates compared to controls, but the tag weighed about 8.5% of the fish's weight (Lacroix *et at.,* 2004). Two studies suggested that surgical intraperitoneal tag implantation was superior to gastric implantation (Adams *et at.,* 1998a; Martinelli *et at.,* 1998). Two studies that tested predator avoidance had contrasting results. Juvenile Chinook salmon implanted with tags representing 4.6-10.4% of the fish's weight and having a 31 cm long trailing antenna were eaten in significantly greater numbers than controls, probably because of the affect of the antenna (Adams *et at.,* 1998b). In contrast, predation on juvenile Chinook salmon implanted with tags representing 4.2% of the fish's weight and not having an antenna was not significantly different from controls (Anglea *et at.,* 2004). The results of these studies indicate that the *optimum methodology would be ' surgical intraperitoneal implantation of tags without antennae (i.e., ultrasonic) and keeping the tag weight to less than 8% of the fish's weight.*

Given the requirement of tag battery life of at least 60 d (to at least migrate through the Golden Gate) and an approximate fish weight of 37 g for a 150 mm FL Chinook smolt and 78 g for a steelhead smolt (Fig. 6), the most appropriate tag under the 8% limit is the Vemco V7-4L. This tag is 7 mm dia by 20.5 mm in length and weighs 1.8 g in air. The tag would comprise 4.9% of juvenile Chinook weight and 2.3% of juvenile steelhead weight. With an average pulse interval of 60 s (range 30-90 sec) and R4K coding, this tag will have an estimated minimum 160 d of life according to Vemco Ltd. Data from Vemco for battery life is typically conservative; it is expected that the tags will be substantially longer than 160 d, perhaps twice as long.

Fig. nth -.see original proposal



Grantee will tag individuals following the procedure of (Moore *et al., 1990)* as modified by (Lacroix *et al.,* 2004). Each juvenile will be held initially in a 40-liter cooler with river water and anesthetized with CO_2 (150 g of sodium bicarbonate, a trace of sodium chloride, and acetic acid; for concentration versus fish size, see Peake, 1998). The individual will be removed from the anesthetic solution when it loses equilibrium. The fish's weight and fork length will be recorded. The fish will be placed ventral side up on a surgery cradle, its head covered by wet toweling, and its gills flushed by water of half-strength. anesthetic passed through vinyl tubing from a container using a submersible pump. A short incision (10 mm) will be made parallel to and 3 mm to the side of the ventral midline and 3 mm anterior to the pelvic girdle. We will insert a sterilized, individually coded, cylindrical ultrasonic tag into the peritoneum of the fish. The tag will be positioned so it is lying just under the incision. The incision will be closed with two simple interrupted sutures using 3-0 silicon treated silk. The fish will then be placed into a 40-liter cooler to recover from anesthesia and surgery. Once fully recovered and swimming normally the fish will be transferred to a holding tank for three days. The implanted tag will be checked for proper function using Vemco VR60 manual tracking receiver, then the fish will be released into the river. There will be a VR-02 monitor in place at the release site, which will record when individuals leave the reach and begin their downstream migration.

Tags will be implanted into 10 late-fall Chinook salmon smolts and 10 steelhead smolts each day, 5 days per week, for four weeks in January. Each group will be released after the post-implant holding period. Ten fish of both species will be released each day, 5 days per week, until 200 fish have been released. Releasing fish over a 30 d period will minimize the number of fish moving together through the river system thus reduce potential "tag collisions" (multiple fish pinging at the same time at a given monitor) and increase detection rate. Furthermore, spreading out releases through time will allow for comparisons with varying environmental variables, such as flow rate.

Analysis of tracking data. The basic data produced by our study are detections of tagged fish at various locations between the upper river and ocean monitors. Each fish has a unique "mark" given by its ultrasonic pinger code, and we "recapture" the fish by detecting it with the data-logging hydrophones. We will use standard mark-recapture modeling to reduce the receiver detection data set to estimates of survival (see Burnham *et al.,* 1987, Cormack, 1964), and extend these models to include explanatory variables.

Each fish either exits the study area after completing its migration, or it dies en route to the sea. Along the way, it can be detected as it passes locations where monitors are moored with probability p_i at the i 'th location. At several places, the fish can take either of two paths with probability t_i and 1 - t_i, circumventing the monitors on the other path. Between the i'th and i'th +1 hydrophone locations, the fish survives with probability ϕ_i. It is these survival rates and turning probabilities that are of interest in our study. Using the terms of Burnham *et al.* (1987), the study results can be represented as a capture history matrix or an m-array. The likelihood of the data set is the product *of 2k -3* independent binomial distributions (where k is the number of monitor locations + 1 [for the initial release location]), allowing estimation of the unknown parameters p_i, t_i, and ϕ_i with the maximum likelihood method.

It is a fairly simple extension to treat the reach-specific survival probabilities as functions (logistic, complementary log-log) of various explanatory variables. The analysis proceeds as above, except that rather than finding the maximum likelihood estimates (MLEs) of the survival probabilities, we find the MLEs of the parameters that relate the explanatory variables to the survival probabilities, which in turn influence the expected capture histories.

In addition to reach-specific survival estimates, the. data will allow determination of movement rates between monitors. *This analysis will be useful in 'identining areas of importance to juvenile salmonids, such as holding/nursery areas, etc. that can be subsequently afforded protection to improve recovery. Further, analysis of the data in relation to sites of water projects, diversions, bypasses and Delta entrances, and other anthropogenic structures will provide knowledge on the impacts of these factors to survival and movement rates.* Interannual comparisons of survival and movement patterns in relation to hydrologic variables, including flow dynamics and water temperature, will improve understanding of their effects on survival and migratory patterns. By gathering data in the coastal ocean, the influence of oceanographic conditions on

migratory dynamics and survival can be assessed, which will improve the ability to resolve impacts of water projects on the animals.

Task 3. Project Management and Dissemination of Results

The principle investigator (APK), Grantee, will manage the project. This will involve frequent inspection of the work in progress. Grantee will work with the co-investigators to coordinate completion of tasks, will supervise graduate students, give scientific presentations, and prepare jointly authored publications. Grantee will assemble the semiannual reports, based on reports from the co-principle investigators of the tasks described in this proposal. In addition to conducting the research, the co-investigators will prepare semiannual progress reports, analyze the data, present results in peer-reviewed journals and at national scientific meetings.

Grantee will make a concerted effort to communicate the results of this study to the scientific community, interest and stakeholder groups, and the public concerned with the health of the salmonid runs in the Central Valley. Grantee will present posters, describing the planned studies for juvenile Chinook and steelhead at the beginning of Year 1 of the grant at the 7 th Biennial State of the Estuary Conference, which will be held in October 2005. This meeting is attended by academic and agency scientists, consultants, and the general public. The results of Year 1's studies will be reported at the 6th Biennial CALFED Bay-Delta Conference, which will be held during October 2006. Year 2's results will be presented during the following year at the 8 th Biennial State of the Estuary Conference.

Grantee plans to organize and hold an international symposium at the NOAA Fisheries Santa Cruz Laboratory/UCSC Long Marine Laboratory during September 2008 on survival and migratory patterns of salmonids in North America. This meeting will serve to publicize the results of our studies, and place them in the context of other studies being conducted on the western and eastern coasts of North America. We will invite presentations from scientists, conducting similar studies, from elsewhere in California, Oregon, Washington, Alaska, Maine, and Canada. This meeting will be open to scientists, resource managers, and the interested public. The presenters at this meeting would be asked to produce scientific articles for a book or dedicated journal issue. The contributions would be peer-reviewed, whether they are published in a book or journal.

A website will be created for the research study. The internet site would have two functions. It will make the public aware of our studies of juvenile salmonids and update them on the latest findings. Secondarily, it will provide a coordination interface with other tagging-tracking studies, through which other researchers can learn of our tag codes and the locations of our tag-detecting monitors. They will be able to learn whether one of our tagged fish has been detected by one of their monitors or one of their tagged fish has been detected by our monitors. The potential for collaboration between research groups in this tagging study is very high, increasing the overall benefit of the project for resource management.

3. **Task Table: task summary, schedule and deliverables**

Task ID	Task Name	Start Month	End Month	Personnel involved	Description	Task Products
	Deploy and maintain inland monitor arrays	1	36	Klimley, A. Peter, Ph.D. To be named (1) To be named (2)	Establish and maintain array of tag-detecting monitors in Sacramento River, Grizzly, Suisun, and San Pablo Bay as well in sloughs and rivers flowing into San Francisco Estuary.	Provide records of the passage of juvenile Chinook salmon and steelhead trout every four months; keep database of records.
	Tag juvenile steelhead trout	3	36	Klimley, A. Peter, Ph.D. To be named (1) -To be named (2)	Tag juvenile steelhead trout and analyze data on survival and movement patterns.	Produce scientific publication on survival and movement patterns of juvenile steelhead in San Francisco Estuary.
2b	Tag juvenile Chinook salmon	3	36	MacFarlane, R. Bruce, Ph.D. Lindley, Steven T., Ph.D. Ammann, Arnold J. Szerlong, Glenn To be named (3)	Tag juvenile Chinook salmon and analyze data on survival of movement patterns	Produce scientific publication on survival and movement patterns of juvenile Chinook salmon in San Francisco Estuary.
	Dissemination of Results	3	36	Klimley, A. Peter, Ph.D. Kucich, Jennifer L.	Prepare seminannual and final reports; maintain web site; and attend local scientific meetings.	Produce serninannual and final reports and either give scientific talks or.present posters with results of studies at local meetings..
3b	Dissemination of Results	3	36	MacFarlane, R. Bruce, Ph.D. Lindley, Steven T., Ph.D. Ammann, Arnold J.	Attend local scientific meetings; organize and hold symposium.	Make scientific presentations at local meetings; produce peer-reviewed journal issue devoted to the migratory behavior of salmonids.