Nearshore habitat use, movements, and survival of Chinook and coho salmon in Puget Sound, final report

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Abstract/Executive Summary

In an effort to obtain information about nearshore habitat use and mortality in salmon, we initiated two acoustic tagging programs: 1) a small-scale (0.2 km^2) study of habitat use and movement of Chinook salmon in northern Puget Sound, and 2) a large-scale study of movements of Chinook salmon from northern Puget Sound and coho salmon from southern Puget Sound into the Straits of Georgia and Juan de Fuca. The small-scale study focused on depths and local habitats used by Chinook, while the large scale study examined major pathways of migration in the region using arrays across choke points in Puget Sound and by linking up with other POST arrays. Our studies of Chinook salmon were challenged by difficulties in capturing Chinook salmon that were of a taggable size and keeping them alive after surgery, and both studies were able to examine movements in only six fish before being limited by permit restrictions. We were able to mark 85 (35 wild, 50 hatchery) coho salmon and thereby were able to monitor both movements and survival in Puget Sound. Data from the small-scale study are currently being analyzed. The large scale studies await the full retrieval of the arrays, which is over 60% completed and will be finished when weather permits. In the meantime, we are examining tagging mortality in Chinook salmon smolts in the lab in order to improve survival when we repeat our study in the summer of 2006.

Introduction

Despite several decades of scientific interest, the factors affecting post-freshwater life stages of salmon remain an enigma (Groot and Margolis 1991). Evidence from a number of salmon species suggests that nearshore marine mortality of salmon may be one of the most important limitations on population recovery (Beamish et al. 2000, Kareiva et al. 2000, Friedland et al. 2003, Greene and Beechie 2004). The likely sources of this mortality are osmotic challenges, a diverse array of predators, and competition for limited rearing and refuge habitats in nearshore waters (Thorpe 1994). Unfortunately, mortality in this life stage has been extremely difficult to quantify or address because of the challenges of disaggegrating nearshore mortality from earlier and later stages. Evidence from experiments (Bax 1983, Hargreaves and LeBrasseur 1986), predator diet studies (Beauchamp et al. 1992), and broad population trends (Beamish and Mahnken 2001) suggest that mortality is probably size-dependent, yet quantitative estimates of the effect of size on mortality are lacking (McGurk 1996). Poor return rates of salmon in recent years strongly suggest lower marine survival (Beamish et al. 2000), but whether these findings are due more to local effects (Magnuson and Hilborn 2003) or regional processes (Beamish et al. 2004) remains unclear. Resolving this uncertainty is critical for prioritizing millions of dollars spent on estuarine and nearshore habitat restoration.

Parallel with the problems of characterizing mortality are the challenges in monitoring residency and movement of young salmon. Evidence from field studies suggest that the duration of the nearshore phase is extensive for some species (Levings 1994) and represents a period of large growth potential (Korman et al. 1997), but we have little knowledge of how fish actually use nearshore habitats due to the difficulty of monitoring individual fish through this stage. In the Puget Sound region, these issues are of critical importance, not only because the nearshore waters of Puget Sound may serve as key rearing habitats for salmon (Simenstad et al. 1982), but also because these areas may be under great threat from habitat modification and degradation (PSAT 2004).

We proposed to examine mortality and movements of Chinook and coho salmon in the nearshore by setting up hydroacoustic receiver arrays across key straits in Puget Sound, and by initiating tagging studies of juvenile coho and Chinook salmon in north and south Puget Sound. This program would tie into existing efforts to monitor salmonids in Puget Sound, as well as the POST (Pacific Ocean Shelf Tracking) program, an international effort to monitor long-range migration of fish through Washington, Canadian, and Alaskan waters (Welch et al. 2003). Tagging both Puget Sound Chinook and coho salmon would enable us to determine the extent to which these fish rear in Canadian waters. In addition, it would enable us to examine whether fish marked in Canadian waters in conjunction with other POST tagging projects use Puget Sound for rearing, an intriguing finding suggested by captures of coded-wire tagged Fraser River salmon in Puget Sound (K. Fresh, unpublished data). This information would help inform scientists and administrators charged with managing mixed stocks covered by the Pacific Salmon Treaty.

Methods

The proposal consisted of two linked projects – a small-scale study of local habitat use, movement and survival of Chinook salmon within an enclosed embayment, and a much larger-scale study of habitat use, movement and survival of coho and Chinook salmon in Puget Sound, through the Straits of Georgia and Juan de Fuca, and up through Queen Charlotte Strait (Table 1). The small-scale study focused on fish from north Puget Sound, and the large-scale study included fish from both north and south Puget Sound with the goal of examining how fish from very different regions of Puget Sound utilize marine habitat during the juvenile migration.

We examined several spatial scales of movement using two different acoustic tagging technologies. Acoustic tagging is a highly effective method for reliably tracking individual fish in marine waters (Moser et al. 1991). Hydroacoustic Technology, Inc. (HTI) produces tags that can be used for fish as small as 100 mm, which allow for three-dimensional, fine resolution (position to 1-

m) telemetry in a gridded array of receivers as well as for presence/absence from a linear array. VEMCO Inc. produces tags that can be used for fish as small as 120 mm to detect presence/absence in a linear array. VEMCO transmitters have been used successfully by POST for large-scale studies of movement in salmon and green sturgeon across the west coast. We used HTI tags in the small-scale study to examine habitat use and survival for smaller fish over a two to four week time frame. We used VEMCO tags in the large-scale study to observe movements throughout Puget Sound and north through Georgia Strait and up through the Queen Charlotte Islands over a four-month to two-year time frame. These observations were accomplished via listening lines across Deception Pass, SW Skagit Bay, Possession Sound, Hood Canal, and Admiralty Inlet, existing POST lines in Washington and British Columbia, plus nodes used by the Army Corps of Engineers (ACOE) to study bull trout (Fig. 1).

Table 1. Project design

	Small-scale study	**Large-scale study**		
Region	North	South	North	
Release Site	Similk Bay	Hammersby Inlet	Skagit River	Similk Bay
Species	Chinook	Coho	Coho	Chinook
Number proposed	50	50	50	100
Number tagged	6	35 wild 100 hatchery	0*	6

*A check of the 2005 outmigration revealed that most coho smolts were too small to tag, so we focused all tagging on Chinook salmon.

Small-scale Study

The goal of this study was to examine habitat use of juvenile Chinook salmon smolts within a 1-km^2 area of shoreline, and to track nearshore movement and mortality within this area over a short time frame. Fish detections with the HTI system require that a fish be detected on multiple hydrophones. Through field testing, we discovered that in Similk Bay, hydrophones needed to be within 100 m of each other, which meant we did not have near enough hydrophones to construct a grid that was 1-km^2. However, we were able to obtain additional equipment (cable, hydrophones, receivers) through USGS and the USACE. Consequently, we were able to construct a 5 x 4 hydrophone grid (0.2 km^2). We deployed the grid in late July and had it running from July 20 through August 10.

The second challenge of this study was to capture 50 Chinook salmon smolts and tag them. We tried several techniques for capture, including beach seining, surface trawling, and setting a lampara net, but with the exception of the lampara net, our efforts were hampered either by lack of fish that were large enough to be tagged or fish mortality. Our efforts produced a total of six tagged Chinook salmon.

Our surgeon implanted tags (HTI model 795M, 6.8x16.5 mm) in anesthetized fish (100 -160 mm fork length), a process involving stringent quality control standards. We allowed fish to recover for 24 hours in a 1 x 1 x 1 m tank prior to release within the array. We then monitored fish movement (individual fish tracks) and habitat use within the receiver array over the next two weeks (the expected battery life).

We are currently examining the data collected by in this study. We proposed to address two general questions with the small-scale study: 1) how is nearshore habitat use correlated with environmental variation and 2) what is the survival of fish in the nearshore at a small temporal and spatial scale? Because of the small sample size of tagged fish, neither question can be answered definitively, and our project must be considered a pilot study for these questions. We are examining the first question by correlating movement trajectories of fish with environmental data collected during the period of study. Due to the small sample size, we are not addressing the second question with the data obtained in this study.

Large-scale Study

The goal of this study was to examine large-scale movements and mortality of Chinook and coho salmon across Puget Sound and north into British Columbia. To achieve this, we needed to use acoustic receiver arrays that detected passage of tagged fish during their migration. We therefore capitalized on POST's existing lines in south Puget Sound, Strait of Juan de Fuca, Georgia Strait, Queen Charlotte Strait, and along western Vancouver Island. To these we added existing receiver nodes in shoreline areas in Northern Puget Sound currently operated by ACOE to monitor bull trout movements, as well as five additional POST listening lines to subdivide Puget Sound, plus additional nodes to monitor movements out of local release sites (Fig. 1). All lines were successfully deployed in April, although the Hood Canal line covered shoreline areas only.

All receivers in these arrays were VEMCO VR-2 receivers, which detect presence or absence of acoustic tags in a 500-m radius. Listening lines spanning the passages of Puget Sound can be created by positioning receivers such that their detection radii overlap (Welch et al. 2003). In addition, single nodes can be used to monitor particularly narrow passages or focal points of migration such as points and spits. Building upon experience from past research efforts, we used a combination of methods for deployment and recovery of acoustic receivers. In deepwater areas (>30m), receivers were anchored to an acoustic release device and accompanying flotation so that upon receiving a release signal the equipment will detach itself and float to the water surface. In other instances, receiver deployment and subsequent recovery were facilitated through the use of SCUBA divers, GPS technology, surface markers, and fixed structures such as navigation buoys, mooring buoys, pilings, and docks. We have currently retrieved 60% of the receivers, but have not been able to complete the retrievals due to cut ground lines, acoustic release malfunctions, and inclement weather. Array retrieval will continue once the weather improves.

We used acoustic tags manufactured by VEMCO (V7 and V8 tags). We implanted these tags in two groups of juvenile coho salmon (120-210 mm fork length), captured in May either at smolt traps on Goldsborough Creek (South Sound) or taken from a group of net-pen raised hatchery fish (tags were obtained through matching funding from local sources). After being held in recovery tanks for 24 hours, we released fish near their capture site.

We also attempted to tag 150 Chinook salmon smolts (120-230 mm fork length) captured in Skagit Bay via beach seining and trawling in August. These methods were largely unsuccessful because most fish were too small to tag. Even fish of the length recommended by VEMCO often surpassed our 5% tag:body weight threshold. In addition, captured fish often suffered high mortality despite our best efforts to reduce handling stress. We obtained better success in capturing fish of the right size by using a lampara net, but had our best success in September using a purse seine. Unfortunately, we reached our mortality limit specified by our federal permit well before we were able to use all the tags. In fact, we were able to release only 6 fish. We are currently performing some studies under controlled conditions to examine whether particular tagging strategies can be used to minimize mortality.

Once we obtain the remaining hydrophones in the arrays, we will focus on two types of analyses: 1) what are the primary movement patterns of coho and chinook salmon, 2) what is the

mortality of fish during migration. The first question involves screening data for relocations from different arrays (Goetz et al. 2004). The detection scheme should allow us to 'acoustically compartmentalize' the Puget Sound region, which can then be further expanded by incorporating relocations form POST listen lines in British Columbia. The second question involves using relocations as evidence of continued survival through different periods to time, and modeling individuals' relocation histories in mark-recapture models to estimate mortality over the time span in which fish can be detected.

Project Schedule

Table 2 compares our proposed schedule with our progress to date. We proceeded according to our proposed schedule in all but the last three tasks. Tagging of Chinook salmon was delayed until the fish we captured were reliably the correct tagging size.

Table 2. Proposed and actual schedule of project activities.

Action	**Proposed date**	**Finished date**
Order acoustic tags and receivers	January	March
Deploy and test acoustic receivers	March - May	April 28
Tag and release **Chinook** salmon for small-scale study	July - August	August 31
Tag and release **coho** salmon for large-scale study	May - June	May 20
Tag and release **Chinook** salmon for large-scale study	July - August	September 22
Recover hydrophones	November	Not complete
Process acoustic data	December	Not complete

Results

Our proposal had four stated objectives:

1) Establish acoustic listening lines across key straits in Puget Sound.
2) Examine the relationship of environmental variation upon habitat use and movements of juvenile coho and Chinook salmon at small spatial scales.
3) Identify the long-range migration paths of coho and Chinook salmon from Puget Sound and examine whether fish from Canada use Puget Sound for rearing.
4) Estimate nearshore mortality of juvenile coho and Chinook salmon, and the effects of body size on nearshore mortality.

We have made progress on each of these objectives, as detailed below:

Objective 1. We deployed a total of 33 hydrophones in 9 lines across straits in Puget Sound (Fig. 1). Deployment of arrays consisted of either weighted groundlines, or single nodes attached directly to substrates or on retrievable anchor lines. Of these, a total of 17 have been retrieved, with the remaining retrievals scheduled for the spring contingent on fair weather. Data collected from hydrophones in the arrays indicate that we were able to relocate tagged fish from each tagged population. In addition, our arrays recorded fish tagged by numerous other researchers. Species recorded include bull trout, steelhead, green sturgeon, and six-gill sharks. As a result, the researchers are extremely interested in having us continue the deployment of the arrays

Objective 2. We are just beginning to examine our recaptures to address this objective at two spatial scales. The first scale is based on six fish tagged in Skagit Bay and placed in the 0.2 km^2 HTI array. The second scale is based on movements of VEMCO-tagged fish in Puget Sound. This will be based on six Chinook salmon tagged in Skagit Bay as well as coho tagged in south Puget Sound.

Assuming the data we have collected on a few individuals are representative of the larger populations, we can make two generalizations about movement of salmon in Puget Sound. First,

coho salmon from south Puget Sound do not rear or migrate in Whidbey Basin, but appear to migrate through Admiralty Inlet. We had no relocations of south Sound fish migrating through any of the hydrophones retrieved from arrays in Whidbey Basin. Second, Chinook salmon from the Skagit River appear to migrate out of Puget Sound both through Deception Pass and south through Saratoga Passage. This conclusion is based on detections associated with each area. Both conclusions should remain tentative until most of the hydrophones are retrieved and larger sample sizes of wild fish are monitored.

Objective 3. Checks with detections in the POST array indicate that none of our marked fish have been detected passing other arrays in the Straits of Georgia and Juan de Fuca and Pacific Ocean shelf. At this point, the data are extremely limited to draw any strong conclusions, but several alternative hypotheses consistent with these results exist: 1) all marked fish died in Puget Sound, 2) all fish reared in Puget Sound or the southeastern Salish Sea for periods longer than the life of the acoustic tags, or 3) arrays in the Salish Sea failed to detect migrating fish. POST reports a 98% detection of tags in their arrays, so one of the first two possibilities or a combination seem much more likely.

Objective 4. Estimating survival is possible only with a sufficiently large sample size and with a reliable series of detections. At this point we have sufficient data to assess survival only in coho salmon in South Sound. We tagged 35 coho in Goldsborough Creek and subsequently captured only two near the outlet of Hammersley Inlet Goldsborough Creek into Puget Sound proper, a distance of approximately 6 miles. This suggests a very low survival rate of 6% (2 of 33 that made it to marine waters), which may have been influenced by the small tagging size of wild fish. Hatchery coho did appreciably better, with a survival of 35% measured from net pens near Goldsborough Creek to nearest passages into south Sound proper. Survival through Puget Sound will await analysis until more hydrophones have been collected. We plan to repeat our study in 2006 with the tags we dedicated to Chinook salmon but did not use. At that point we should have sufficient data to analyze survival of Chinook salmon.

Discussion

Our study, while not completely finalized, indicates we have made progress toward completing two of our four objectives (#1 and #2), and one remaining (#4) will be addressed when we have retrieved the remaining hydrophones. At this point, several conclusions can be drawn about the project.

1) Our array system in Puget Sound is serving numerous tagging studies and should be continued to facilitate the research. The arrays support studies of six salmonid populations, and more are planned for 2006. In addition, the array supports studies of six- and seven-gilled sharks, green sturgeon, rockfish, cod, and squid.
2) We will continue using the array to monitor Pacific salmon populations. In 2006, we intend to follow through with our studies of Chinook salmon from the Skagit River, and will continue with studies of coho salmon in South Sound pending funds to purchase additional tags.
3) Small-scale studies using the HTI system in the nearshore are probably not cost effective without a significant budget. The tidal flux in the nearshore created strains on the electrical cables, and resulted in over 3000 feet of damaged line. These represent our only significant cost overrun, which will be covered by reducing money allocated for our intern. In the future, we suggest such studies utilize mobile tracking.

References

Bax N. 1983. Early marine mortality of marked juvenile chum salmon (Oncorhynchus keta) released into Hood Canal, Puget Sound, Washington, in 1980. Canadian Journal of Fisheries and Aquatic Sciences 40:426-435.

Beamish RJ, Noakes DJ, McFarlane GA, Pinnix W, Sweeting R, King J. 2000. Trends in coho marine survival in relation to the regime concept. Fisheries Oceanography 9:114-119.

Beamish RJ, Mahnken C. 2001. A critical size and period hypothesis to explain natural regulation of salmon abundance and linage to climate and climate change. Progress Oceanography 49:423-437.

Beamish RJ, Sweeting RM, Neville CM. 2004. Improvement of juvenile Pacific salmon production in a regional ecosystem after the 1998 climatic regime shift. *Transactions of the American Fisheries Society* 133:1163-1175.

Beauchamp DA, Vecht SA, Thomas GL. 1992. Temporal, spatial, and size-related foraging of wild cutthroat trout in Lake Washington. *Northwest Science* 66: 149-159.

Friedland KD, Reddin DG, McMenemy JR, Drinkwater KF. 2003. Multidecadal trends in North American Atlantic salmon (*Salmon salar*) stocks and climate trends relevant to juvenile survival. *Canadian Journal of Fisheries and Aquatic Sciences* 60:563-583.

Greene CM, Beechie TJ. 2004. Consequences of potential density-dependent mechanisms on recovery of ocean-type chinook salmon (*Oncorhynchus tshawytscha*). *Canadian Journal of Fisheries and Aquatic Sciences* 61: 590-602.

Groot C, Margolis L. 1991. Pacific Salmon Life Histories. Vancouver, UBC Press.

Hargreaves NB, LeBrasseur, RJ. 1986. Size selectivity of coho salmon (*Oncorhynchus kistuch*) preying on juvenile chum salmon (*O. keta*). Canadian Journal of Fisheries and Aquatic Sciences 43:581-586.

Kareiva PM, Marvier M, McClure M. 2000. Recovery and management options for spring/summer chinook salmon in the Columbia River Basin. *Science* 270: 977-79.

Korman J, Bravender B, Levings CD. 1997. Utilization of the Campbell River Estuary by Juvenile chinook Salmon (*Oncorhynchus tshawytscha*) in 1994. Can. Tech. Rep. Fish. Aq. Sci. 2169: 1-45.

Levings CD. 1994. Feeding behaviour of juvenile salmon and significance of habitat during estuary and early sea phase. Nordic J. Freshwtr. Res. 70: 7-16.

Magnusson A, Hilborn R. 2003. Estuarine survival rates of coho (*Oncorhynchus kisutch*) and chinook salmon (*Oncorhynchus tshawytscha*) released from hatcheries on the U.S. Pacific Coast. Estuaries 26 (4B):1094-1103.

McGurk MD. 1996. Allometry of marine mortality of Pacific salmon. Fishery Bulletin 94:77-88.

Parker RR. 1971. Size selective predation among juvenile salmonid fishes in a British Columbia Inlet. Journal of the Fisheries Research Board Canada 28:1503-1510.

Puget Sound Action Team. 2004. 2005-2007 Puget Sound priorities, stategies and results. http://www.psat.wa.gov/Publications/priorities_05/Priorities_05_review.htm.

Simenstad, C.A., K.L. Fresh and E.O. Salo 1982. The role of Puget Sound and Washington coastal estuaries in the life history of Pacific salmon: an unappreciated function. Estuarine Comparisons. V.S. Kennedy. New York, Academic Press: 343-364.

Thorpe JE. 1994. Salmonid fishes and the estuarine environment. Estuaries 17:76-93.

Welch DW, Boehlert GW, Ward BR. 2003. POST – the Pacific ocean salmon tracking project. *Oceanologica Acta* 25:243-253.

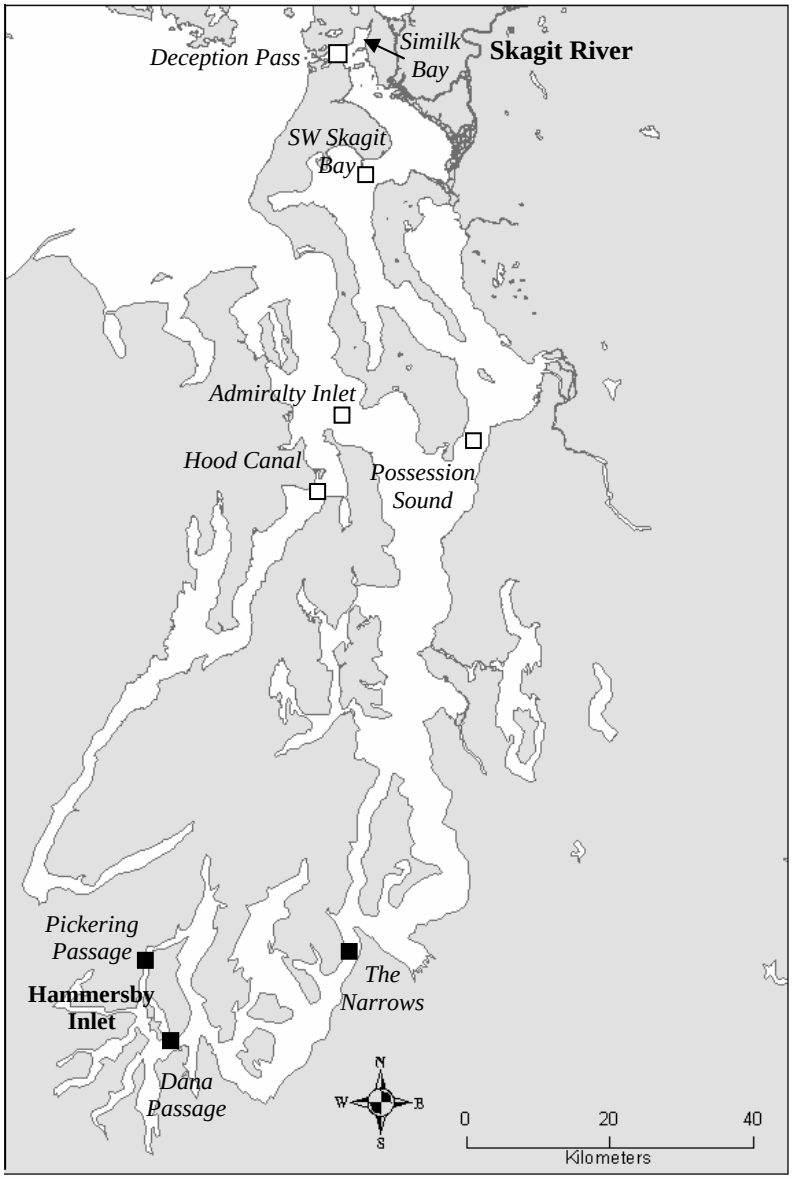

Figure 1. Map of arrays and sources of salmon in this study. Hydrophone arrays are indicated by boxes (white = north Sound, black = south Sound), sources of coho salmon (south Sound) and chinook salmon (north Sound) are indicated by boldface, and location of small scale HTI array is noted by the arrow.

Appendix 1. Financial Statement of Expenditures

Below is our total budget, showing both how we proposed to use in-kind and PSC funds as well as how we actually spent them. Most items were near to our proposed amounts or less, with several important exceptions. First, we required several additional contracts with groups with expertise and facilities for equipment deployment, array retrieval and data analysis. These costs were offset by significant reductions in our other subcontracts. Other costs not in the original budget included additional money spent on acoustic tags due to a delay in the in-kind support, and work required to repair a boat motor. However, the largest cost overrun resulted from repair and replacement of cable for the HTI array. Because our costs were offset by savings in subcontracts, we remained within our proposed total budget. We will use the final 10% of our budget for technician assistance on data analysis and continued retrieval of hydrophones.

Acoustic Tagging Budget

	Proposed		Actual	
Labor	**In-kind**	**PSC**	**In-kind**	**PSC**
Wages and salaries	10,272	10,272	19,800	
Employer costs		5,639	10,890	
Volunteer labor			200	
Subcontractors				
POST		25,000		10,192
Postdoc		40,000		
Boat operators	10,400	0	10,400	
Field technicians (+insurance)		21,450	15,000	40,340
Field crews	116,656	12,544	90,000	
Surgeon	3,472	3,472	9,000	
Admiralty Underwater Services		17,790		17,790
HTI				2,717
City of Seattle				4,500
Moorage and other port contracts				3,461
Site/Project costs				
Travel	17,000	5,000	17,000	2,325
Tools and Equipment		5,100		4,616
Work and safety gear		500		328
Repairs and maintenance		500		3,148
Permits		20		12
Training		600		300
Capital costs	334,975	37,675	320,680	52,973
Repair/replacement of damaged HTI cable				24,330
Total	**492,775**	**185,562**	**492,970**	**167,031**

This budget accurately reflects expenses incurred during the course of this project.

Tom Hom, Financial Officer

3/23/06
Date