Testing the Feasibility of Counting Salmon in the Lower Copper River Delta with Imaging Sonars

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Executive Summary

Three imaging sonar systems were deployed in the Copper River in June 2015 to test their ability to count migrating salmon: a 720 kHz Tritech Gemini, a 500 kHz Picosonar PicoFLS, and a 260 kHz Imagenex 965. The sonars were first tested alongside a DIDSON sonar operated by the Alaska Department of Fish & Game at Miles Lake (~35 miles from the ocean). In those tests the Gemini and PicoFLS sonars both imaged fish effectively, with much clearer images obtained by the Gemini. Counts of fish passage by the Gemini were similar to those of the DIDSON. Short term deployments of the Gemini sonar at sites near Bridge 339 (~ 23 miles from the ocean) of the Copper River Highway and in the mouth of the Clear Martin River (~13 miles from the ocean) also observed fish passing. Estimating the size of passing fish proved challenging, because the sonar returns were highly variable and noisy.

Background/Rationale

The Copper River salmon fishery is managed in part with an acoustic weir operated by the Alaska Department of Fish and Game (ADF&G) at the Million Dollar Bridge/Miles Lake at mile 50 of the Copper River Highway. ADF&G operates two sonar systems at the site (one on each bank), and fish are counted by technicians from 10 minute subsets done at two frequencies (high frequency for short range observations, and low frequency for longer ranges). The sonar systems used by ADF&G are highly specialized imaging multibeam sonars that produce a video-like image by scanning at high frequencies. This allows individual fish to be counted as the pass the sonar, which results in very good estimates of escapement.

The ADF&G sonar site is located at the first point above the Copper River delta where the river is confined to a single channel, and is approximately 35 miles from the nearest ocean entry point to the Copper River Delta at Kokenhenik Bar. Direct measurement of the swimming velocity of up-migrating salmon has not been done in the Copper River, but estimates from matching up abundance peaks between the fishery, a site at Flag Point (~15 miles from the ocean) and the Miles Lake site suggest that it takes at least 3 to 5 days for salmon to transit through the delta (Degan et al., 2005). The lag between the time when the fish enter the river (and are no longer available to the fishery) and when they pass the counters at Miles Lake complicates timely management of effort by the fishery, and can lead to escapements in excess of expectations.

The main channel of the Copper River has been transitioning from having the bulk of the flow through the western side of the delta at Flag Point (mile 27 of the Copper River Highway), towards the east (Brabets and Conaway, 2009). Those changes in flow regime lead to significant damage to a number of the bridges of the Copper River Highway in the early 2000’s. After being almost completely undermined by the new main channel, bridge 339 at mile 37 was closed in 2011 and became the new terminus of the Copper River Highway. In the years since the channel has continued to migrate eastward, and there is now a gap of several hundred yards from the end of the bridge and the opposite bank.

Presently, during periods of low discharge, essentially all the water in the river passes through the main channel at bridge 339; as discharge increases and water levels rise, other channels begin to come on-line (Jeff Conaway, USGS Hydrologist, personal communication). Landsat imagery also suggests that during low water, the river is confined to a relatively small number of channels until a point near where the Clear Martin River enters the delta (~10 miles from Kokenhenik Bar), and is heavily braided below that (fig. 1).

The use of multibeam imaging sonars for counting salmon has been pioneered by Sound Metrics Inc. in their DIDSON (Dual frequency Identification SONar) line of sonars. The DIDSON system uses acoustic lenses to focus the sonar beams into different geometries that may be changed to match the bottom topography. Numerous acoustic weirs in Alaska use DIDSON sonars. DIDSON systems are not inexpensive (~$80K each), and there have recently been a number of smaller, simpler multibeam systems developed in recent years that may produce similar results to the DIDSON, at lower cost.

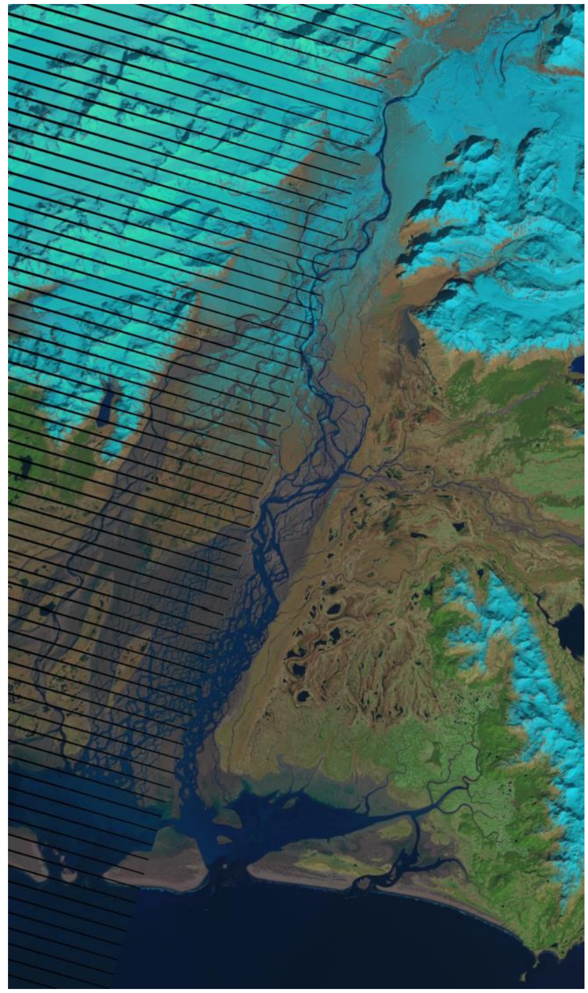

Figure 1: The Copper River Delta, May 2015. Image is a composite from multiple LANDSAT 7/8 images taken on May 3rd and 4th 2015. The black stripes are an artefact found in LANDSAT 7 images caused by a failure in the imager.

The objective of this study was to assess the utility of several loaned multibeam sonar systems at counting Copper River salmon, and to examine the feasibility of counting salmon in the lower portion of the Copper River delta.

Methods

<u>Sonars:</u> Multibeam sonars are phased-array sonars that use beamforming (changing phase and amplitude at multiple transmitters) to produce a 2D sonar image. By sampling at high frequency (10 Hz or more) they are able to produce a video-like representation of the changing sonogram over time. In practice they may be thought of as a stacked series of beams, where each beam is analogous to the single beam produced by a traditional echosounder, arranged into a fan-shaped

series. The specifications among different systems vary, with differing frequencies, fields of view, beam geometry, and sampling rate.

Following product research and speaking with a number of experts, five different commercially available sonar systems were identified as potentially appropriate for use in the Copper River, and the manufacturers were approached about the possibility of borrowing a demonstration system for testing and comparison. Three of the five manufacturers provided systems for testing, and a summary of the specifications of the different sonars is given in table 1.

Table 1: Comparison of imaging sonar systems. Systems with shaded in grey were not available for testing.

System	Frequency	Beamwidth	# of Beams	Beam spacing	Field of view	Approx. cost
DIDSON	1.1 MHz 1.8 MHz	0.4° x 14° 0.3° x 14°	48 96	0.6° 0.3°	29° 29°	$80K
Imagenex 965	260 kHZ	1.5° x 20°	120/240/480	not specified	120°	$20K
PicoSonar PicoFLS	500 kHz	1° x 16°	64	0.7°	42°	$25K
Tritech Gemini	720 kHz	1°/0.5° x 20°	256	not specified	120°	$40K
Blueview M900-2250	900 kHz/ 2.25 MHz	1° x 20°	768	0.18°	130°	$30K
Kongsberg M3	500 kHz	1.6° x 3 – 30°	256	not specified	120°	$45K

The sonar transducers were mounted on 2” aluminum poles with tapped mounts that permitted adjustment of the viewing angle. A simple skiff mount was developed for in-river testing (fig. 2).

Figure 2: Skiff-mounted sonars prior to the first in-river test, June 12th 2015. Sonar systems from left to right are the Imagenex 965, PicoFLS, and Gemini.

Figure 3: Demonstration sonars prior to deployment alongside the ADF&G DIDSON sonar (in water, to left). The steel rails to the right are a legacy deployment system, and are visible in the sonograms. The net weir to the left is to direct salmon in front of the beams.

Sonar intercomparison: On June 16th 2015, the three demonstration sonar systems were deployed alongside the ADF&G DIDSON system at Miles Lake. The sonars were affixed to a frame alongside the DIDSON frame (fig. 3), aimed so to ensonify approximately the same area, and run alongside the DIDSON system for half hour intervals (the DIDSON system runs operationally for ~20 minutes out of every hour, our tests were run during down time).

To compare fish counts between the two sonars, a simple counting program was written which recorded the time a user to clicked a mouse button - one to record an upstream passage by a fish, and a second to record a downstream passage. This gave a measurement of the time of passage that was compared between the sonars. During periods where both records overlapped, the number of upstream and downstream passages through the sonar beams recorded, and each record then broken up into time blocks that could be compared. The number of downstream passes (which were rare) was subtracted from the upstream passes to calculate total fish passage. The geometry of the sonar beams were not the same (the Gemini beam was much wider), and the both sonars were not aimed in exactly the same directions, which probably lead to small differences in the timing of when a "count" was made. Upstream and downstream counts were made on the Gemini sonogram when a fish crossed the centerline of the sonogram; counts on the DIDSON sonogram were made when a fish exited or entered the sonogram on the right hand side. Those points roughly corresponded to the same place in space in both of the sonograms.

Bathymetry survey: The bathymetry of the various sites where the sonars were deployed was surveyed with a vessel mounted Garmin GPSmap 420S sounder, recording at 1 Hz. Survey tracks were generally saw-toothed over the survey site, with additional transects near shorelines. Data from the survey were interpolated onto a ~2.5 x 2.5 m grid with linear interpolation. The fine grid spacing leads to artefacts in the interpolation, which have been left in since the changes in the vicinity of the tracklines show the high frequency variability in bottom topography.

Image processing: thresholding video frames to estimate salmon size:

There is considerable interest in being able to estimate the size of passing fish, to be able to discriminate between the more abundant Sockeye and less abundant Chinook (Chinook populations appear to be in decline state-wide, and management decisions often center around the likelihood of intercepting Chinook). In order to effectively size salmon, the echo return in the sonograms must be removed from the background and identified (a technique known as thresholding in the machine vision field). Several background removal and thresholding techniques were applied to video frames, including a fixed threshold, the "triangle" algorithm of Zack et al. (1977), and the minimum error method of Kittler and Illingworth (1986).

Results

Sonar intercomparison:

The sonars deployed at Miles Lake had a wide range of frequencies, and crosstalk among the sonars was minimal when the DIDSON was operating at its high frequency setting (1.1 MHz), allowing all to be operated at the same time and ensonifying the same fish. The Imagenex 965 sonar did not image fish well, the PicoFLS did image some fish, but cannot be directly compared to the DIDSON (it was operated with a tablet computer which was returned to the manufacturer, PC software is in development but not yet available). The Gemini sonar clearly showed the concrete base of the ADF&G sonar platform, and fish were clearly imaged in passing (fig. 4). The field of view of the Gemini is considerably wider than that of the DIDSON (120° vs 29°), which made discriminating multiple targets easier in some cases (the fish were observed for longer, which gave more time for multiple targets to resolve). The included DVD appendix includes footage of the DIDSON, Gemini, and 965 operating simultaneously, and separate video

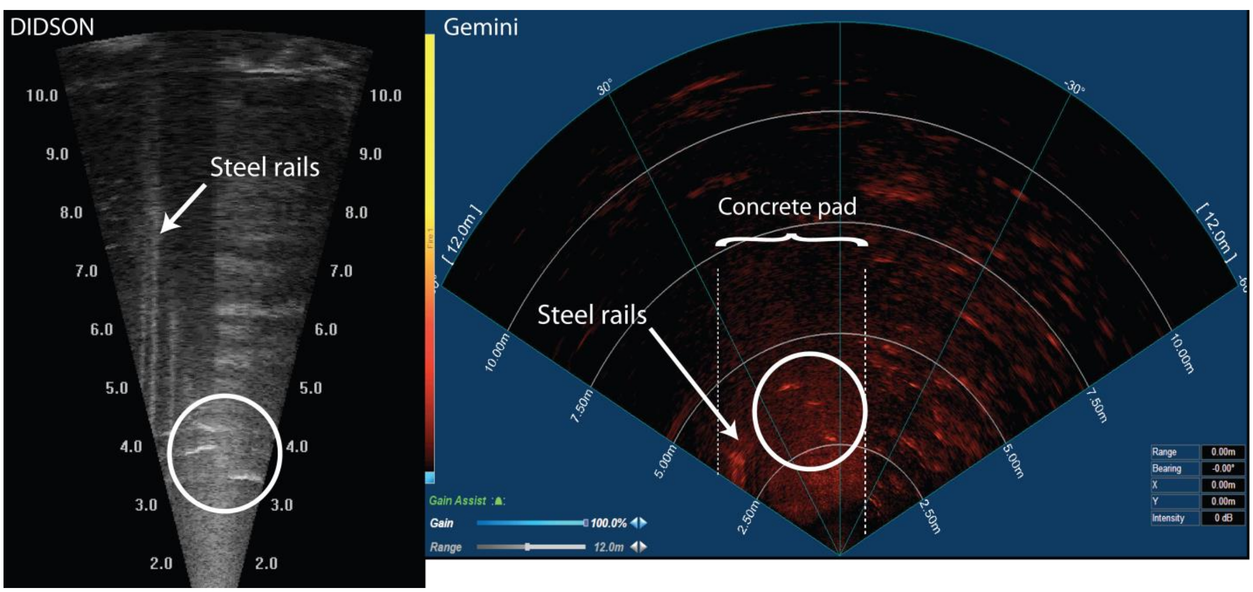

Figure 4: Images of passing fish (circled) in the DIDSON (left panel) and Gemini (right panel) sonograms taken at the Miles Lake acoustic weir.

of the PicoFLS.

Fish passage counts from the DIDSON and Gemini sonograms (during times when they overlapped), showed that the Gemini returned similar counts to the DIDSON system (fig. 5), with small differences in either direction among counts (plus or minus about 3 fish per time bin).

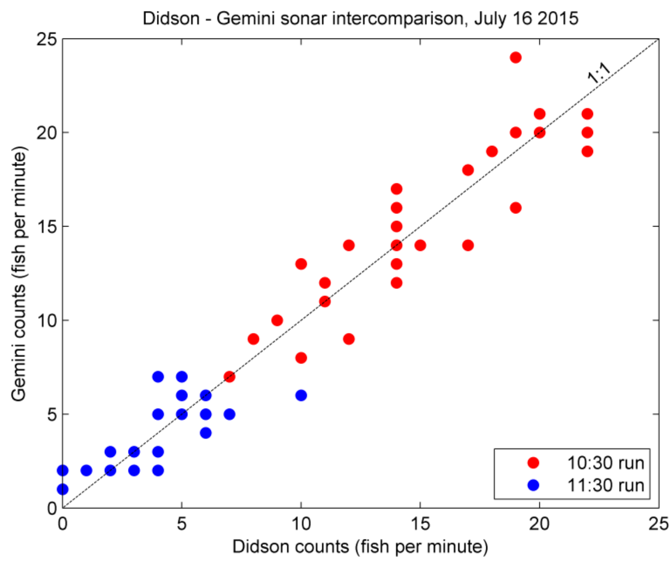

Figure 5: Comparison between counts made from the DIDSON sonogram versus counts made from the Gemini sonogram for the same period. The dashed line is the 1:1 line.

Site surveys:

Bathymetric surveys were done in front of the Miles Lake sonar site (fig. 6), an area immediately south of Bridge 339 (fig. 7), and in the vicinity of the Clear Martin River where it enters the Copper (fig. 8). The Gemini sonar system was deployed at multiple locations south of Bridge 339 and the clear Martin, during most deployments the sonar was run for approximately 10-15 minutes. Fish were observed passing at most of the deployments. A relatively small number of fish were observed near Bridge 339, and the highest count was at the southernmost site at the Clear Martin River, at the beginning of the cutbank (fig. 9).

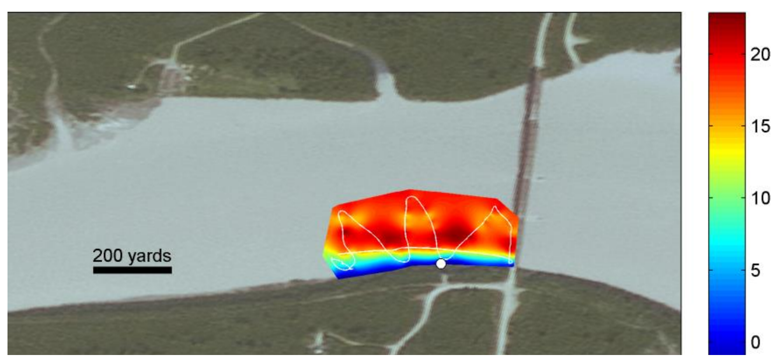

Figure 6: Bathymetry (in feet) in the vicinity of the Miles Lake sonar site (denoted with a white dot). The white line is the trackline from the survey vessel. Depths within the colored area were interpolated via linear interpolation. Base image source: UAF-GINA/SDMI http://alaskamapped.org/bdl

Image processing: thresholding video frames to estimate salmon size:

Applying automated image analysis techniques to video frames from the Gemini sonar gave mixed results. The bed surface in the Copper River is acoustically bright: the hard substrate (cobbles and concrete at Miles lake, smaller gravel in the lower delta) results in high spots in the background, which can obscure the acoustic returns from fish. The amount of suspended material (some of considerable size) entrained in the river also scatters sound, which results in a very noisy sonogram. Standard methods of background subtraction and thresholding were not

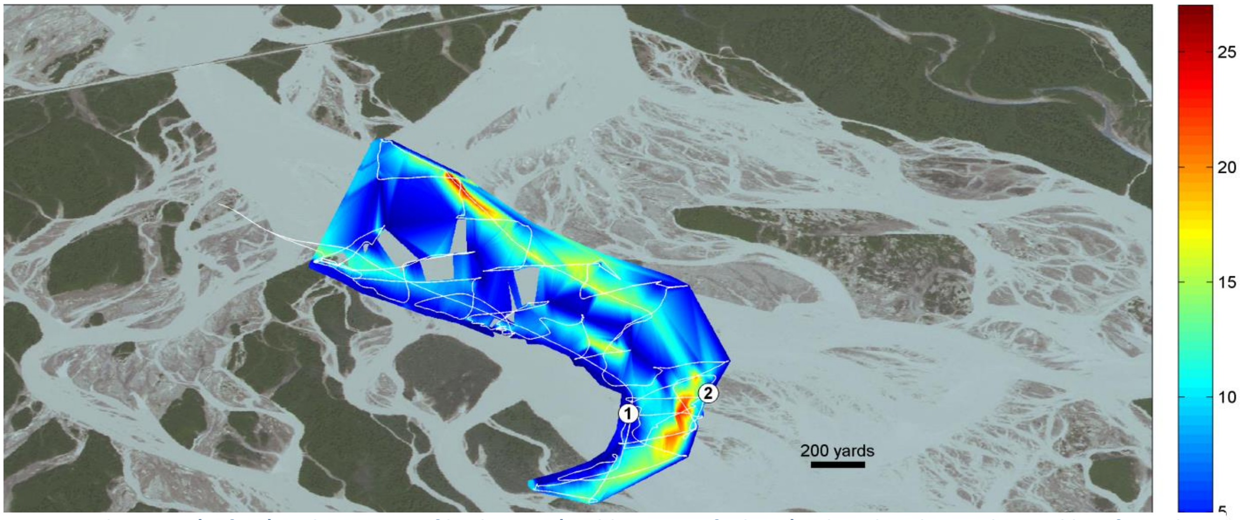

Figure 7: Bathymetry (in feet) in the vicinity of bridge 339 (visible at top of photo). The white line is the trackline from the survey vessel, and the numbered dots correspond to the survey sites. Depths within the colored area were interpolated via linear interpolation. Base image source: UAF-GINA/SDMI http://alaskamapped.org/bdl

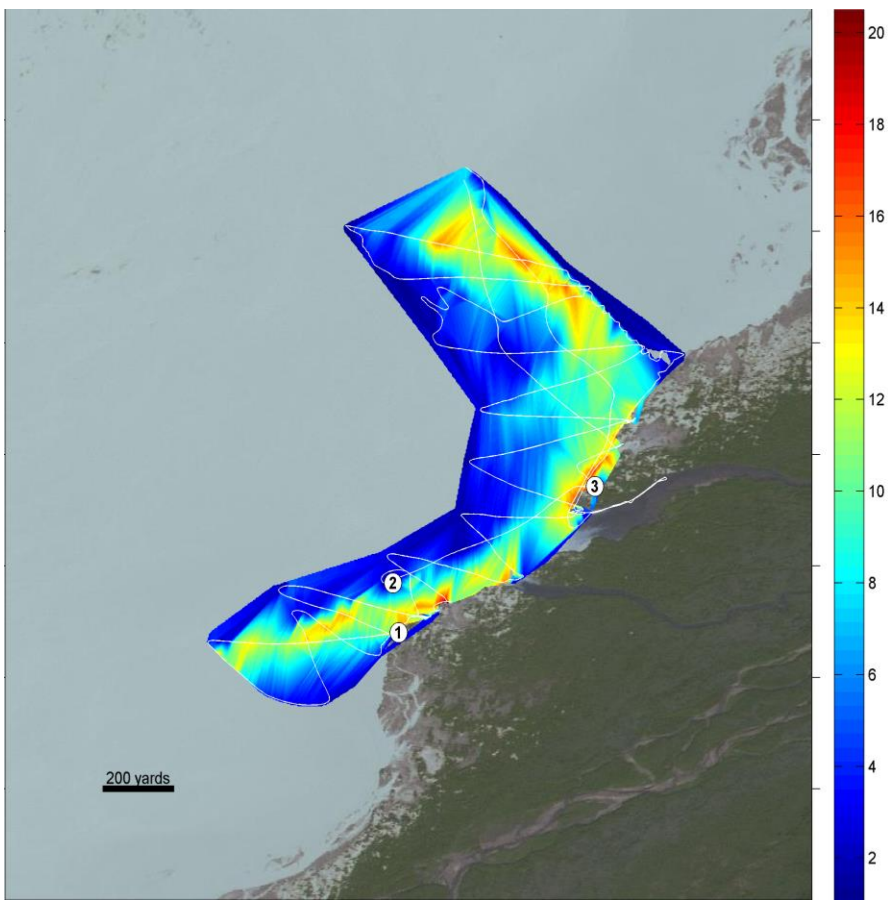

Figure 8: Bathymetry (in feet) in the vicinity of bridge 339 (visible at top of photo). The white line is the trackline from the survey vessel, and the numbered dots correspond to the survey sites. Depths within the colored area were interpolated via linear interpolation. Base image source: UAF-GINA/SDMI http://alaskamapped.org/bdl

very successful, with considerable noise retained in the thresholded images. The size of the fish

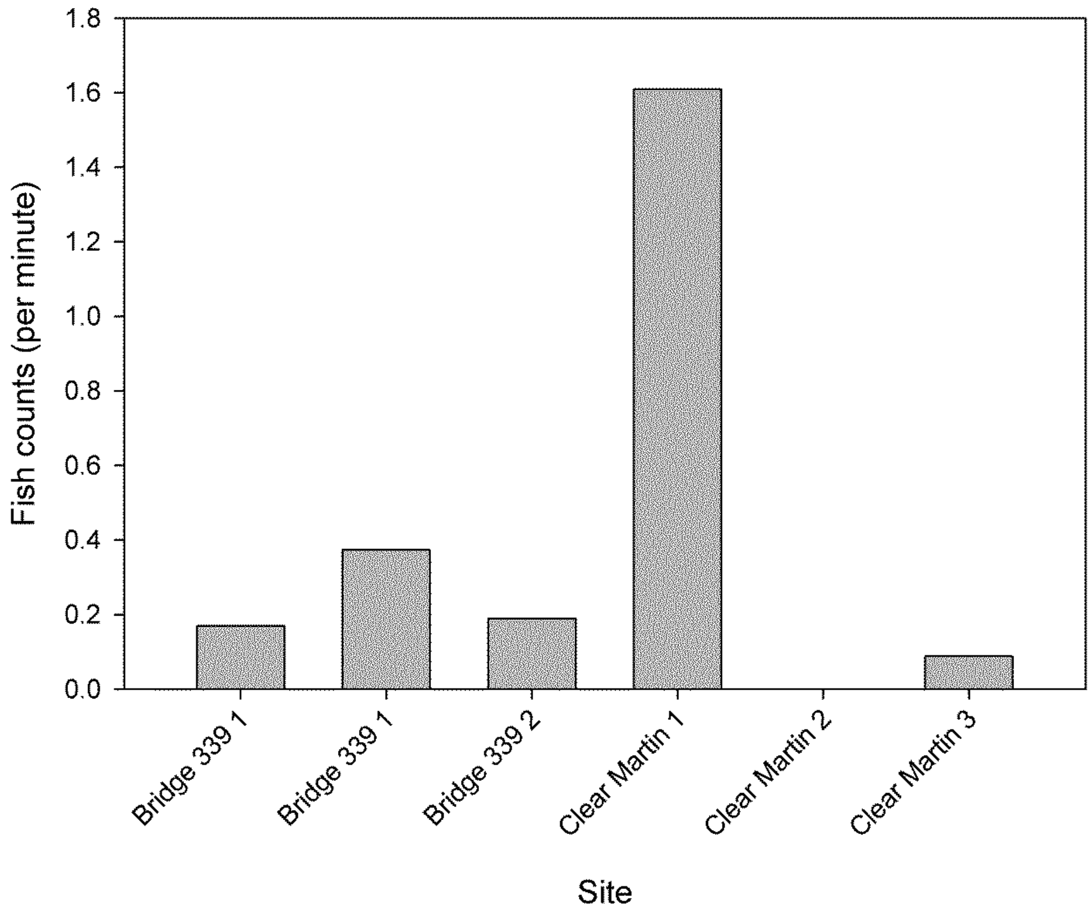

Figure 9: Fish passage rates recorded at sites in the lower Copper River delta. Numbering corresponds to the numbered sites in fig. 7 and fig. 8.

targets also varied considerably as they moved through the sonar beam. Video analysis does not lend itself well to a written format, a detailed explanation of the image analysis methods used and their results is included in the DVD appendix that accompanies this report (the "Image analysis of sonar videos" tab).

Discussion/Conclusions

The intercomparison study done at Miles Lake showed that of the three sonars tested, the highest frequency sonar, the Tritech Gemini, gave the best returns. The PicoFLS did register fish as well, but in the absence of software to create real-time videos it was not possible to directly compare it to the DIDSON or other sonars. The Imagenex 965 sonar did not register fish well in any of the tests, it appears that the background noise and fairly large beam angle, along with its low frequency, did not lead to good returns from fish targets.

The Gemini also returned similar count results to the DIDSON, with the some of the differences likely being attributable to differences in the beam geometery (i.e. sometimes the Gemini sonar imaged fish that the DIDSON did not, and vice-versa). Some differences were also likely due to the discretization of count events by time. Count times likely did not line up perfectly within each 5 minute block because the sonars were ensonifying slightly different volumes of water. The videos were also difficult to keep lined up over time. It is likely that one or both of the sonars occasionally dropped frames, or there were subtle differences in the frame rate that put them slightly out of synchronization. Test deployments done at potential choke points below the Copper River Highway with the Gemini sonar system did indicate that the Gemini sonar is able to image fish in those areas as well. Counts were lower than at Miles Lake, but that is not surprising given the time of the year the surveys were done (mid June) and the stage height of the river at that time (~140 feet, about 10 feet higher than in mid-May); there were many other channels available for fish to pass.

Investigations into the feasibility of thresholding salmon targets out from the background of the video sonograms to take measurements were not very successful. The sonograms were extremely noisy, with noise that was both highly variable in space and time, and of very high magnitude (equivalent to the return from fish targets. The size of the fish targets also varied as they passed through the beams. Part of the difference in return was simply from the motion of the fish: they undulate as they swim, which changes how sound is scattered and returns to the sonar. It is possible that more elaborate methods (filtering in the frequency domain), and a semi-automated approach (using human operators to discriminate targets) will be more fruitful. Following the time spent with the sonograms done here, it can be concluded that size measurements of fish targets is nontrivial, and will need considerably more work done.

Recommendations and considerations for operationally counting fish in the lower Copper River Delta

The test deployments done in this study suggest that it may be possible to operationally count fish in the lower part of the delta during the early part of the Copper River salmon run. In the early season, when water levels are low, it appears that the main channel of the river is well defined, and passes along the mouth of the Clear Martin (fig. 10). The bottom topography in that area is variable, with some deep areas , but also with a number of shallower alluvial fans near the river mouths (fig. 8).   The water depths at those areas were well within the geometry of the Gemini and DIDSON sonars (fig. 11) when they were measured in mid-June (~ 12 – 15 feet) so it can be expected that sonars deployed in in May when water levels are much lower will also be able to cover most of the water column.

It is not known how salmon use the various channels in the delta as water levels rise into the summer. The observations made here suggest that at least some are still using the deeper channels later in the year when many of the shallower channels are filled with water ; deeper channels may provide the best navigation options for migrating fish. Even if not producing a comprehensive count of fish, a sonar station in the lower river could give an indication of fish movement into the delta, and could be more directly compared to catches made by the fishery. Comparing the counts made in the lower delta to the DIDSON counts at Miles Lake will also give a better idea of fish passage times (and how they may vary), and allow Copper River stage heights (at the Million Dollar Bridge) are generally at their lowest in April, and increase through May into late July or August (fig. 12). Although the Clear Martin site might work for the early season, it is not guaranteed that it will be a good site once water levels are high enough that the numerous other channels in the lower delta begin to fill. The best likelihood for success, then, will be to build some flexibility into any field operations that might be undertaken: beginning as low as possible in the delta in the early

Figure 10: Aerial view of the mouth of the Clear Martin during low water. Photo taken 4/11/15 by Troy Tirell.

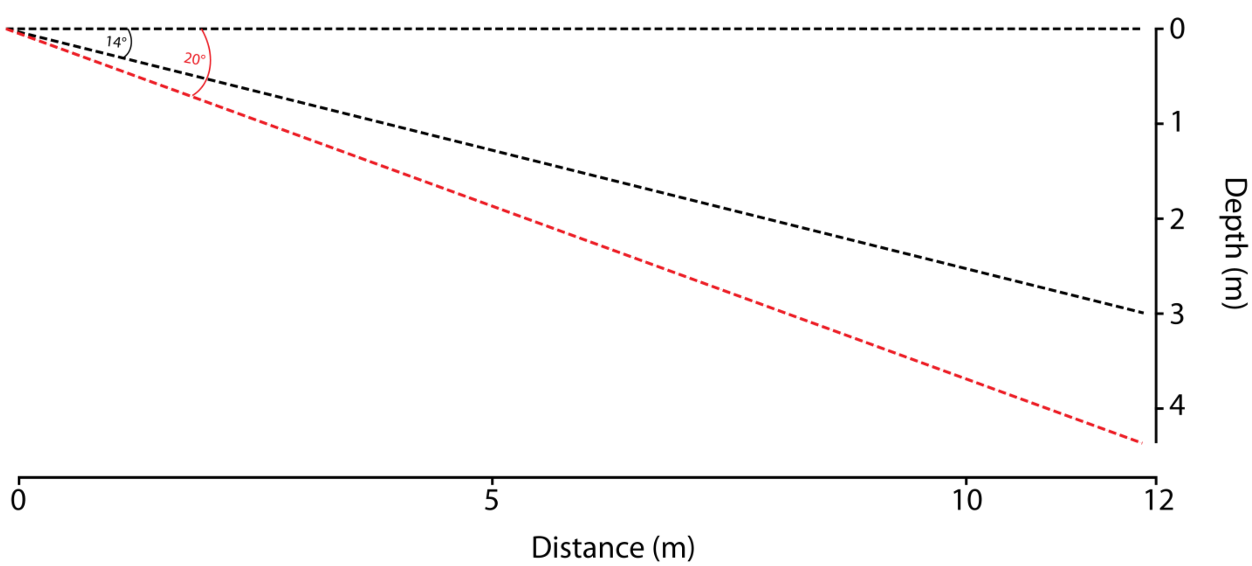

Figure 11: Approximate side-view beam geometry of the the DIDSON (black, 14° beam angle) and Gemini (red, 20° beam angle) sonars.

season, then falling back to more northerly sites as water levels rise. The Clear Martin appears to be a good starting site (the delta is highly braided below it, even in the early season), and a site in the vicinity of bridge 339 could be used later on. There is also potentially a third site between bridge 339 and the Clear Martin. North of the Clear Martin, the river travels due north to the other side of the delta, with the main channel forming a bend on the west side of the delta (at a site known locally as Shangri-la). Most of the river is confined to a single channel at that site, with a small bypassing channel to the east. Further comments on the utility of that site (or any other) at this time would be speculative.

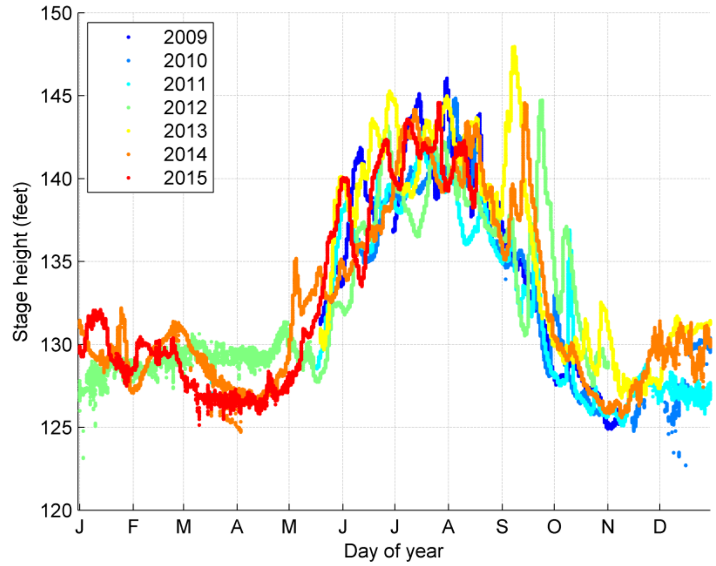

Figure 12: Hydrograph (stage height time series) of the Copper River at the Million Dollar Bridge, 2009-2015. Note that the gauge was not always installed yaer-round in all years. Data source: http://waterdata.usgs.gov/

<u>What will it cost?</u> There are any number of ways of approaching the problem of counting fish in the lower delta, and any number of trade-offs that could be made to balance information needs with overall costs. What follows is a budget narrative that will outline some of the anticipated costs of such an endeavor.

<u>Up front costs:</u>

Sonars: Sound Metrics DIDSON sonars (and their replacement, the ARIS), remain the gold standard for fisheries acoustics; the up front costs are however very high (~$85K). The Tritech Gemini sonar identified as the best choice of the sonars tested here does not have quite the same range, but has a wider field of view and costs less than half that ($35K). A pan/tilt option can be added for approximately $8K (which permits aiming the sonar remotely). A shore-based mount would also need to be fabricated, as well as a barrier weir (to keep fish far enough away from the sonar that they can be effectively counted).

Support equipment: Includes computers for data logging and transmission (2 laptops), networking equipment for data collection /telemetry, and a cellular data modem and antenna. This would allow near real-time transmission of sonar videos (which could even be sent to a streaming channel, such as youtube.com). Power for the system is best provided as it done at the ADF&G Miles Lake camp: from a battery bank/inverter, which is charged by solar panels and a gas generator as necessary.

Logistics and camp equipment: A jet skiff will be required for mobilizing/demobilizing and supplying the camp (at very low water levels an air boat may be necessary). Camp equipment includes a wind-capable main tent ($3500), individual sleeping tents/pads/bags, cookstove/cookware, and other miscellaneous equipment. A summary of estimated up front costs is given in table 2.

Table 2: Estimated up-front costs.

Item	Cost
Sonar equipment	
Tritech Gemini Sonar	35000
Sonar Pan/Tilt	8000
Sonar rigging	2500
Jet skiff	10000
Laptops	2400
Cellular modem	500
Network equipment	1000
Power - genset	1300
Power - solar	2000
Camp equipment	
Main tent	3500
Sleeping tents/pads	2000
Cooking	500
Other misc equipment	1500
Waders & boots	1200
Total	71400

Operational costs:

Personnel: The ADF&G Miles Lake camp is a 24 hour a day operation staffed by 3 technicians working 8 hour shifts, an effort in the lower delta would require a similar level of effort. Similar work by PWSSC has shown that a camp-type operation such as this is best done with a lead technician who is in charge, and subordinate junior technicians. A senior staff scientist would also be necessary to oversee the entire project. Estimated costs are shown in table 3, and are based on current PWSSC rates, and assuming a 2 ½ month term (~ two months in the field with a week for mobilization/demobilization). Benefits are included in salary costs.

Data telemetry: Cordova Wireless expects to have wireless coverage over most of the delta by late 2015 from flag point; their transmitter on Heney Ridge is also an option with directional antennas. The cost given in table 3 is an estimate.

Supplies: Estimated costs for other supplies is also listed in table 3.

Permits: All of the delta south of the Copper River highway is part of the ADF&G designated Copper River Delta Critical Habitat Area and also falls within the Chugach national forest. ADF&G levies a $100 fee for a fish habitat permit, and the Alaska Department of Environmental Conservation also requires a land use permit ($500 per site, plus a refundable $1000 bond; at least $300K insurance coverage is also required). The US Forest Service charges a cost recovery free for permit processing that is based on the amount of time taken. The amount budgeted for here is an estimate following a phone conversation with Dede Srb in the Cordova office (table 3).

Overhead: The costs shown here are an estimate of actual costs. Nonprofit organizations usually levy an additional overhead charge to cover administrative costs (PWSSC currently has a 30% overhead on direct costs and equipment under $25K). For-profit organizations do not usually have a cited overhead, but charge considerably higher rates for staff time, and have mark-ups for consumbles.

Table 3: Estimaged annual operational costs.

ITEM	QTY	UNIT	RATE	TOTAL
Direct Labor				
Senior Scientist	1.5	mo.	9600	14400
Lead Technician	2.5	mo.	5750	14375
Junior Technician	5	mo.	3680	18400
Subcontracts/Consultants				
Data streaming	1	est.	1000	1000
Supplies				
Food and Incidentals	225	days	20	4500
Camp, truck and boat fuel	1	est.	4000	4000
Waders and Boots	3	ea.	400	1200
Misc. camp supplies	1	est.	2000	2000
Permits				
ADF&G	1	ea.	100	100
ADEC	1	ea.	1500	1500
USFS	1	ea.	500	500
			Total:	**61975**

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