Initial Species Discrimination Experiments with Riverine Salmonids

Jae-Byung Jung*, James H. Jacobs, George A. Dowding, Patrick K. Simpson*
*Scientific Fishery Systems, Inc.
P.O. Box 2420565
Anchorage AK 99524
www.scifish.com

Abstract— The primary objective of this study is to determine if there is sufficient information in broadband sonar echoes from the live tethered animals to determine their species. This study is focusing on two species: chinook salmon (Oncorhynchus tshawytscha) and sockeye salmon (Oncorhynchus nerka). In addition to determining the species discrimination efficacy of the broadband sonar system, a comparison of these results with the seminal work of Burwen & Fleischman will be made as they have presented a firm baseline for species discrimination in this riverine environment using a traditional narrowband split-beam hydroacoustic sonar system.

I. Introduction

Scientific Fishery Systems, Inc. (SciFish) was invited by the Alaska Department of Fish and Games Sport Fishing Division (ADF&G) to collect broadband sonar echoes from tethered fish in the Kenai River in South Central Alaska. The primary objective of this study was to determine if there was sufficient information in broadband sonar echoes from the live tethered animals to determine their species. In prior work in marine [9][10][2], lake[8], and riverine[3][4][5][6] environments, SciFish has demonstrated the ability to identify species and size using features extracted from broadband sonar returns.

This study was focusing on two species that SciFish had not worked with to date: chinook salmon and sockeye salmon. In addition to determining the species discrimination efficacy of the broadband sonar system, a comparison of these results with the seminal work of Burwen & Fleischman[1] bwill be made as they have presented a firm baseline for species discrimination in this riverine environment using a traditional narrowband split-beam hydroacoustic sonar system.

Using the data collected on Day Two, a classifier was built that was able to correctly classify 97% of the sockeye and 83% of the chinook. If we aggregate the classifications from a classifier built to discriminate the individual salmon from both days, the overall classification performance for chinook and sockeye are 87% and 92%, respectively. We also found that the classifier is able to easily separate clutter and shore from fish echoes.

This report describes the location where the sonar data was collected, it reviews the data collection methodology, it summarizes the echo extraction process, it provides a brief analysis of the echoes that were collected, and it works through the construction and analysis of two classifiers built to iscriminate one species from another. This report concludes with a discussion of the results, a comparison with the prior results of Burwen & Fleischman [1], and an enumeration of possible next steps.

II. Methods

A. Tethered Data Collection (The Burwin-Fleischman Method)

Ten salmon were tethered and placed perpendicular to a side-looking broadband sonar in the Kenai River over a two day period in early July. The sonar unit was the first generation prototype broadband sonar built by SciFish from a modified RD Instruments BBADCP 150 VM. Data was collected over three different pulse widths (2m, 4m, and 8m).

Ten live fish were tethered in front of a broadband side-looking sonar. Four of the fish were chinook salmon and the remaining six were sockeye salmon. The sonar data was collected July 5-6, 2000 at kilometer 14 of the Kenai River. The sonar data was collected using the tethered methodology first described in Burwin & Fleischman [1] as illustrated in Fig. 1. Paraphrasing from Burwen & Fleischman, the tethering methodology is as follows:

> "Live chinook and sockeye salmon were captured with gill nets and held in totes until they could be placed on the tether. A cable tie was inserted through a small hole punched in the lower jaw. The cable tie was then attached to about 10m of Dacron fishing line that led to two 1.4Kg downrigger weights that were used to anchor the fish to the bottom. Another section of Dacron line (about 6m in length) led from the weights to a buoy on the surface. The buoy, in turn, was attached to a polypropylene line to an anchor upstream. Using this technique, we were able to isolate the fish from other scattering surfaces such as lead weights and the buoy."

B. Data Collected

Full pings were stored during the study to allow complete replay of all the data collected in the river. Data was collected using four different pulse widths (2m, 4m, and 8m). Of the ten fish that were tethered over the two days, only eight of the fish provided useful data. Fish number 5, a 48Cm sockeye, could not be found in the beam. Fish number 6, a 60Cm sockeye, was dead on retrieval. Pings on Fish 1-3 were collected on Day One (7/5/00) and pings

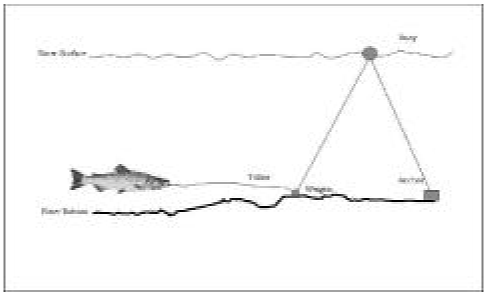

Fig. 1. Illustration of Tethered Fish Configuration Used in these Experiments.

on Fish 4-10 were collected on Day Two (7/6/00). TABLE I shows data collection log.

III. Data Analysis

The processing steps that convert pings into species identifications are the following. Echoes are extracted from the pings. The extracted echoes are converted into spectra and analyzed. These spectra are then used to create features for classification. The features are used to develop a classifier. The classifiers performance is then evaluated.

A. Echo Extraction

Echoes are detected using a matched filter process similar to that used in radar. A coded waveform is sent into the water column in a long pulse and the returning pings are matched against the transmitted waveform to locate echoes from targets. A perfect match produces a correlation value of 1.0. Correlation values near zero represent uncorrelated returns. When a target is located in the water column, a spike in the correlation is seen. Correlation values that exceed a user-defined threshold are declared as echoes from a target. An example of this detection process is shown in the Oscilloscope view of Ping #50 from the second Chinook salmon that was tethered during the first day (Fig. 2). In this figure the red line show the traditional echo energy display in db Volts. Below the red line you see the correlations with respect to range. Just past 24 m in range, the correlation value is nearly 0.4, denoting a target at that location. This is the tethered chinook salmon being detected.

The echo extraction process is highly automated in SciFish 2000. These echoes are then extracted from database and placed into a echo extraction viewer that allows the user to select those echoes of interest. Each detected echo has the range, target strength, correlation, and spectra stored with it.

The features extracted from each echo create an exemplar that can be used for classification. Extracted echoes are processed using the Exemplar Set Editor. Using the Exemplar Set Editor, it is possible to select exactly what parameters you would like to export for building the classifier. Exemplars can be exported in either Matlab format or in tab-delimited ASCII files.

TABLE I

SciFish Data Collection Log - Ping Series Listing

ADF&G Fish #	Notes	No. of Pings
1	Testing Sonar, No Fish	9
1	Testing Sonar, No Fish	21
1	Tethered fish King; first collection.	80
1	Tethered fish King; 2nd collection.	36
1	Tethered fish King; 3rd collection.	152
1	Tethered fish King; collection.	560
1	Tethered fish King; collection.	716
1	Tethered fish King; collection.	638
2	Tethered fish sockeye; collection.	511
2	Tethered fish sockeye; collection.	1487
2	Tethered fish sockeye; collection.	211
2	Tethered fish sockeye; collection.	208
3	Tethered fish chinook 2; collection.	1024
3	Tethered fish chinook 2; collection.	627
4	7/6/00 Chinook #1, Day 2	222
4	7/6/00 Chinook #1, Day 2	321
4	7/6/00 Chinook #1, Day 2	219
5	7/6/00 Sockeye #1, Day 2	1176
6	7/6/00 Sockeye #2, Day 2	508
6	7/6/00 Sockeye #2, Day 2	283
6	7/6/00 Sockeye #2, Day 2	211
7	7/6/00 Chinook #2, Day 2	330
7	7/6/00 Chinook #2, Day 2	275
7	7/6/00 Chinook #2, Day 2	266
8	7/6/00 Sockeye #3, Day 2	364
8	7/6/00 Sockeye #3, Day 2	297
8	7/6/00 Sockeye #3, Day 2	0
8	7/6/00 sockeye #3, Day 2	223
9	7/6/00 sockeye #4, Day 2	257
9	7/6/00 sockeye #4, Day 2	235
9	7/6/00 sockeye #4, Day 2	1
9	7/6/00 sockeye #4, Day 2	338
10	7/6/00 sockeye #5, Day 2	245
10	7/6/00 sockeye #5, Day 2	219
10	7/6/00 sockeye #5, Day 2	280

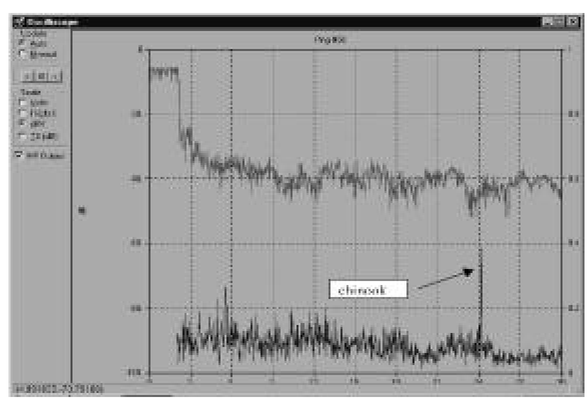

Fig. 2. Oscilloscope view of a ping #50 showing echo energy and correlations with respect to range.

TABLE II

Echoes Extracted From 4m Pulses

Fish #	Species	Size (L/W/G)	# Echoes
1	Chinook	1100/675/141	244
2	Sockeye	624/370/81	448
3	Chinook	780/510/97	88
4	Chinook	700/470/98	310
5	Sockeye	485/305/63	0
6	Sockeye	600/405/99	0
7	Chinook	960/610/136	99
8	Sockeye	630/370/73	259
9	Sockeye	575/340/71	227
10	Sockeye	580/355/74	159
Clutter	-	-	3435
Shore	-	-	777

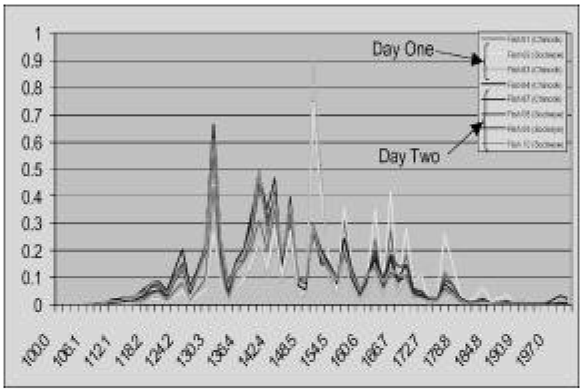

Fig. 3. Comparison of spectra from each of the eight salmon.

Pings were collected at three pulse widths for each tethered fish: 2m, 4m, and 8m. An initial review of the number of pings associated with each fish revealed that there were no echoes available at 2m for Fish 3 and 7, so our initial classification evaluation was done using the 4 m pulses. TABLE II lists the number echoes extracted from each fish. All echoes extracted using 0.30 Correlation value and TS>-30dB. Note that Fish 5 and 6 had no echoes extracted, reducing the sample size to eight fish four chinook and four sockeye. In addition, echoes were also extracted from the clutter that was seen immediately surround each fish and echoes were extracted from the far shore detections at 70 and 90m.

B. Spectral Analysis

The first step in developing a classifier is to analyze the spectra (Fig. 5). Immediately we see that the spectra from those fish during Day One have a significant difference from those collected during Day Two. In particular, the Day One data shows the carrier frequency quite clearly at 154KHz, but the Day Two data does not include this carrier. Typically this type of interference is indicative of the inclusion of significant clutter with the targets, indicating that the beam included a great deal of the bottom with the echoes from the fish.

Finally, a review of the echograms for each of the fish illustrated a significant amount of clutter for the Day Two

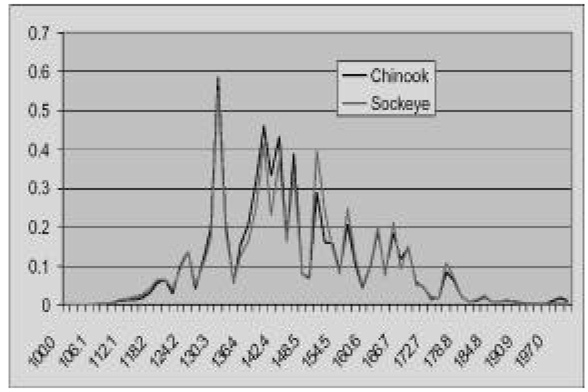

Fig. 4. Comparison of spectra from chinook and sockeye salmon from Day Two.

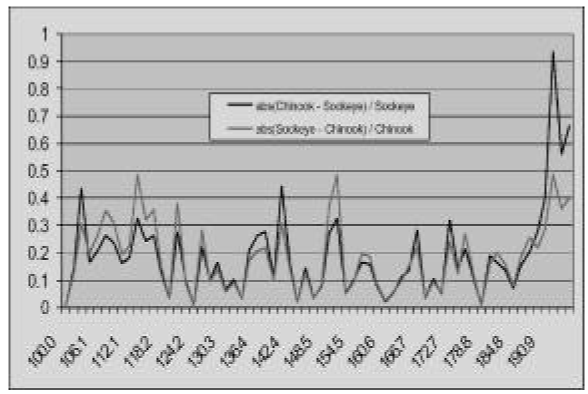

Fig. 5. Comparison of relative difference in spectra from Day Two.

fish that was not present during the first day. Given these differences, it was decided to work primarily with the fish from Day Two.

C. Classifying Fish Species

Using only five salmon from Day Two (three sockeye, two chinook), the average spectra from each were compared (Fig. 4). As the figure shows, there is not a significant difference between the two salmon, but their physiological similarity would support this observation. However, we also see that there are differences at 143KHz, 153KHz, and 178KHz.

To compare the relative difference between one spectra and the other, the absolute value of the difference between the two spectral values are normalized by the spectral value of one and then the other spectral value. This comparison provides the percentage of difference relative to the spectral values. As the plot shows, there is an 18% average difference between the spectra, with as much as 95% difference at the highest frequencies. This analysis indicates that there should be enough difference between the spectra to provide species discrimination.

A running average of the spectra from ten consecutive echoes was used to create the exemplars. The averaging is a critical element of the process as it removes a great deal of the variability that is present in an individual echo.

TABLE III
Training Set Composition Day Two Data

Target	Species	Total	Train	Percentage
Fish 04	Chinook	310	33	10.7%
Fish 07	Chinook	99	7	7.1%
Fish 08	Sockeye	259	28	10.8%
Fish 09	Sockeye	227	16	7.1%
Fish 10	Sockeye	209	18	8.6%
Total Chinook	Chinook	409	40	9.8%
Total Sockeye	Sockeye	695	62	8.9%
Clutter	-	159	23	14.5%
Shore	-	81	20	24.7%

A subset of the extracted data was used to train a neural network classifier to discriminate sockeye from chinook (TABLE III). Overall, the percentage of data used to train the neural network was just under 10% of the total number of patterns. In addition to the salmon, the clutter echoes and the shore echoes were also included as separate classes. These are included to create decision boundaries between fish and non-fish, a technique that provides improved classification in high-clutter environments like that experienced during Day Two.

A Probabilistic Neural Network was used as the classifier. This neural network has demonstrated superior classification performance with reduced data sets. If there are a large number of training exemplars, the Multilayer Perceptron is a preferred neural network classifier [7].

The neural network classifier trained to an overall performance of 97% correct. The remainder of the data was used to evaluate the classifiers performance. The results are shown in TABLE ??. The classifier was able to correctly classify 97% of the sockeye and correctly classify 83% of the chinook. There were 111 chinook exemplars that were misclassified as sockeye, but only 27 sockeye exemplars misclassified as chinook. One of the two chinook salmon were 780 cm in length, which is relatively close to the size of the sockeye and most of the misclassification of the chinook as sockeye were associated with this fish. The clutter and shore classes were very separable from the fish, with only 10 sockeye exemplars being associated with the clutter class and 6 sockeye exemplars being associated with the shore class.

D. Hold-One-Out Classifications

To test generalization with a small sample size (in our case, only five salmon), hold-one-out experiments were conducted. With hold-one-out, a classifier is built using all but one sample in the data set, and then tests are made against the one sample that was held out. For these experiments, a classifier was built using four of the five salmon from Day Two, and the fifth salmon was then tested. The results are shown below in TABLE IV. Although the classifier trained well with the available data, it was not able to generalize well to the chinook salmon. This is indicative of an insufficient training set. It indicates that the classifier has not been presented with a set of exemplars that are representative of the entire range of values it needs to correctly generalize to new data.

E. Classifying Individual Fish

When looking over the data, it was conjectured that the classifier may simply be just classifying individual fish and not actually classifying to the species. To test this hypothesis, a classifier was built that attempted to learn each individual fish as a separate class. TABLE VI lists the data used for training and testing this classifier. In these experiments, we included all of the fish from both days. Like the earlier classifier experiments, the exemplars are created from the average of ten consecutive echoes in range and the training data is approximately 10% of the total exemplars with the remaining 90% being used for evaluation.

TABLE VI
Training and testing data used to build Individual Fish Classifier

Target	Number	Train	Percentage
Fish 01	244	19	7.79%
Fish 02	448	50	11.16%
Fish 03	88	3	3.41%
Fish 04	310	33	10.65%
Fish 07	99	7	7.07%
Fish 08	259	28	10.81%
Fish 09	227	16	7.05%
Fish 10	209	18	8.61%
Clutter	159	23	14.47%
Shore	81	20	24.69%
Totals	2124	217	10.22%

The classifier trained to 90% correct classifications overall. The training process stalled at 90% correct, which would indicate that the decision boundaries between all the available exemplars were overlapping for 10% of the training data. The performance on the remainder of the data is shown below in TABLE VII.

The classifier results were encouraging. As expected, the Day One fish were clearly separated from the Day Two fish, with the exception of 4 Fish 09 being classified as Fish 01. What is more encouraging is the confusion of the Day Two fish. Fish 04 and 07 are both Chinook and Fish 08, 09, and 10 are Sockeye. As shown in TABLE VIII, when looking at aggregates of the species, we see that the confusion between classes occurs primarily within the species, with Chinook and Sockeye being correctly classified 87% and 92% respectively for both days.

IV. Discussion

A. Broadband Performance

Using the data collected on Day Two, a classifier was built that was able to correctly classify 97% of the sockeye and 83% of the chinook. If we aggregate the classifications from a classifier built to discriminate the individual salmon from both days, the overall classification performance for chinook and sockeye are 87% and 92%, respectively. We

TABLE IV

Classification Results Day Two Data

	Actual Clutter	Actual Chinook	Actual Sockeye	Actual Shore	Total
Classified as Clutter	108	-	-	-	108
Classified as Chinook	-	557	27	-	584
Classified as Sockeye	10	111	993	6	1120
Classified as Shore	-	1	-	55	56
Total	118	669	1020	61	1868
True-positive ratio	0.9153	0.8326	0.9735	0.9016	-
False-positive ratio	0	0.0225	0.1498	0.0006	-
True-negative ratio	1	0.9775	0.8502	0.9994	-
False-negative ratio	0.0847	0.1674	0.0265	0.0984	-
Sensitivity	91.53%	83.26%	97.35%	90.16%	-
Specificity	100.00%	97.75%	85.02%	99.94%	-

TABLE V

Classification Results Day Two Data

Fish # Held Out	Species	# Chinook Exemplars	# Sockeye Exemplars	Train Performance	Test Performance	Hold Out Performance
10	Sockeye	790	908	94%	79%	74%
9	Sockeye	790	930	97%	82%	85%
8	Sockeye	790	914	90%	77%	57%
7	Chinook	671	1033	99%	94%	69%
4	Chinook	438	1033	98%	93%	52%

TABLE VII

Classification Results Classifying Individual Fish

	King Actual Fish 01	Sockeye Actual Fish 02	King Actual Fish 03	King Actual Fish 04	King Actual Fish 07	Sockeye Actual Fish 08	Sockeye Actual Fish 09	Sockeye Actual Fish 10	Total
Classified as "Fish 01"	195	16	8	-	-	-	-	-	219 King
Classified as "Fish 02"	24	382	-	-	-	-	-	-	406 Sockeye
Classified as "Fish 03"	-	-	77	8	-	-	-	-	85 King
Classified as "Fish 04"	-	-	-	244	4	1	1	1	251 King
Classified as "Fish 07"	-	-	-	7	55	8	5	-	75 King
Classified as "Fish 08"	-	-	-	3	4	177	35	41	260 Sockeye
Classified as "Fish 09"	-	-	4	2	2	10	131	10	159 Sockeye
Classified as "Fish 10"	-	-	-	8	1	19	11	139	178 Sockeye
Total	223	398	85	272	66	215	183	191	1633
True-pos. ratio	0.8744	0.9598	0.9059	0.8971	0.8333	0.8233	0.7158	0.7277	-
False-pos. ratio	0.017	0.0194	0.0052	0.0051	0.0128	0.0585	0.0193	0.027	-
True-neg. ratio	0.983	0.9806	0.9948	0.9949	0.9872	0.9415	0.9807	0.973	-
False-neg. ratio	0.1256	0.0402	0.0941	0.1029	0.1667	0.1767	0.2842	0.2723	-
Sensitivity	87.44%	95.98%	90.59%	89.71%	83.33%	82.33%	71.58%	72.77%	-
Specificity	98.30%	98.06%	99.48%	99.49%	98.72%	94.15%	98.07%	97.30%	-

TABLE VIII

Classification Results Aggregating Individual Classifications By Species

Day Two		Chinook	Sockeye	% Correct
Chinook	Fish 4 & 7	310	36	88%
Sockeye	Fish 8-10	36	573	94%
Day One		Chinook	Sockeye	% Correct
Chinook	Fish 1 & 3	280	40	86%
Reds	Fish 2	40	382	90%
Both Days		Chinook	Sockeye	% Correct
Chinook	Fish 1,3,4,7	590	76	87%
Sockeye	Fish 2,8-10	76	955	92%

also found that the classifier is able to easily separate clutter and shore from fish echoes.

The sample size of eight fish is too small to make any stronger claims than the performance looks encouraging. A much larger sample size would be needed to fully evaluate the broadband sonars performance. A sample size of 100 fish would provide a more representative evaluation of the discrimination capability of the sonar. The abrupt change in clutter between Day One and Two needs to be examined in more detail. It is conjectured here that the clutter is the result of pointing the sonar more toward the bottom on Day Two than Day One. It is also possible, however, that there was an introduction of noise into the system that reduced the dynamic range. This would look similar to the clutter and could have been caused by water penetrating the extension cable on the sonar or some additional noise in the River. A hydrophone sample should have accompanied each days data to quantify the background noise in the river and allow that noise to be separated from the system noise.

Averaging consecutive echoes from the same fish were necessary to create a spectral representation that was stable enough for classification. The variability in a single ping was too extreme to create a classifier that provided a reasonable level of performance. In the results presented herein a ten echo average was utilized. A preliminary experiment with only a five echo average was found to give similar classification performance to the ten echo average. What this indicates is that a tracking component will be needed in the sonar. Consecutive echoes from the same track can be averaged to create the exemplars for the classifier.

B. Comparison With Prior ADF&G Classification Results

Burwen & Fleischman (1998) have performed a set of seminal experiments that explored the discrimination potential of various narrowband sonar parameters that were collected on 93 tethered salmon. The broadband sonar data was collected using the same tethering methodology and with the guidance of Burwen, so the sampling approach is very similar.

When comparing the results between the Burwen & Fleischman results and those reported here, there are two important differences. First, the sample size of the Burwen & Fleischman study was an order of magnitude larger. Second, the number of echoes used to create the exemplars was considerably greater with the Burwen & Fleischman work than that reported here. A summary comparison of the two studies is found in TABLE IX. It does appear that the broadband sonar is able to provide better classification performance than the narrowband sonar, and warrants further study.

C. Future Works

There are several areas that deserve further study and examination. The following is a suggested list of future activities that would lead toward fully evaluating the broadband sonars potential use for species discrimination in the Kenai River.

- ADF&G Review. Repeat the analyses and results presented herein with ADF&G. This would provide valuable additional scientific perspectives and it would provide ADF&G with a better understanding of how SciFish processes its data.
- Larger Sample Size. Repeat the data collection experiment with a much larger sample size, possibly as many as 100 total salmon.
- Narrowband / Broadband Co-sampling Evaluation. Repeat the data collection experiment using both the current narrowband sonar and the SciFish broadband sonar. Compare the species discrimination accuracy of each using the same fish to provide the greatest opportunity for performance evaluation.
- Aspect Angle. Burwen & Fleischman (1998) had performed a set of aspect angle measurements that evaluated the affect of lateral movement on species discrimination. Repeating those studies with the broadband sonar would be beneficial as well. Specifically, it would be useful to understand how well the correlation process performed for detection as the aspect angle is varied. Again, this should be done in conjunction with narrowband sonar to provide a performance comparison.
- Other Species. Repeat the data collection experiment with additional species such as coho and/or pink salmon.

Acknowledgment

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References

[1] Burwin, D. & Fleischman, S. (1998). Evaluation of side-aspect target strength and pulse width as potential hydroacoustic discriminators of fish species in rivers, Can. J. Fish. Aquat. Sci., Vol. 55, pp. 2492-2502.

[2] Denny, G. & Simpson, P. (1998). Broadband sonar fish identication, 1998 Annual Meeting of the acoustical Society of America, June 26, 1998, Seattle, WA.

[3] Denny, G., deVilleroy, K. & Simpson, P. (1999). The Advantages of Broadband Sonar for Riverine Fish Stock Assessment, ADF&G Riverine Sonar Workshop, UW Applied Physics Laboratory, Seattle, WA, February 15-17.

[4] Denny, G., Chapman, D., Fairchild, J., & Jacobson, R. (1999). Assessment of a broadband acoustic fish identification system in the Missouri River, Report on USGS-CERC Research Project, June.

[5] Denny, G., Chapman, D., Fairchild, J., & Jacobson, R. (2000). Assessment of a broadband acoustic fish identification system in the Missouri River, ERIMs Marine and Coastal Environments Conference, South Carolina (Invited by Dr. Laura Kracker, NOAA/NOS), May.

[6] Denny, G., Chapman, D., Fairchild, J., Jacobson, R., and Simpson, P. (2000). Preliminary assessment of a broadband acoustic fish identification system for use in the Missouri River, American Fisheries Society Annual Meeting, St. Louis MO, August.

[7] Simpson, P. (1990). Artificial Neural Systems: Foundations, Paradigms, Applications, and Implementations, Pergamon Press, New York.

[8] Simpson, P. and Tuohey, M (1996). Broadband Freshwater Fish Identification, Report No. SFS-95-05, National Biological Service, Great Lakes Science Center, Work Order No. 84080-6-0584, December.

[9] Simpson, P. & Penvenne, J. (1996a). Automated Broadband Bottomfish Identification, Report No. SFS-95-04, Phase I SBIR Final Report, Dept. of Commerce, Contract No. 50-DKNA-5-00096, 30 January.

[10] Simpson, P. & Penvenne, J. (1996b). Broadband Fish Identification Prototype, Report No. SFS-95-01, Phase I SBIR Bridge Grant Final Report, Alaska Science and Technology Foundation, Award No. 94-4-121R, Anchorage AK, 31 January.

[11] Simpson, P., Tuohey, M., & Fleischer, G. (1997). Experiments with broadband fish identification, special session on fisheries hydroacoustics, International Association of Great Lakes Researchers Annual Meeting, Buffalo, June.

TABLE IX

Classification Results Aggregating Individual Classifications By Species

Experiment	Source	Sockeye correct	Chinook correct
All Echoes - Univariate (SD12)	ADF&G	100%	81%
All Echoes - Univariate (SD12)	ADF&G	90%	85%
All Echoes - Multivariate (SD12)	ADF&G	84%	88%
All Echoes - Multivariate (SD12)	ADF&G	90%	73%
90 Echo Avg - Multivariate (SD12)	ADF&G	90%	66%
30 Echo Avg - Multivariate (SD12)	ADF&G	90%	57%
10 Echo Avg - Day Two - Sockeye, Chinook, Clutter & Shore	SciFish	97%	83%
10 Echo Avg - Day One & Two - Individual Fish Aggregated to Species	SciFish	92%	87%