unit could service many cages and might even be shared among a number of farms. The company is aware of a possible market in commercial culturing and is very interested in cooperative ventures with industry. The company address is on Table 5 and the person to contact is Steven Oura ((604)-276-2497) .

The recommendations here are, at a minimum, to monitor these technologies and encourage research and development in these areas by others. A step up, that would still be relatively inexpensive, would be to set up the conditions attractive to Biometrix, or any other company, to operationally test their developmental and prototype equipment in a commercial context in the New England area. This would be mutually advantageous and be an important factor in promoting technical development along practical lines. There would be a number of fringe benefits. The equipment would be targeted for real requirements rather than a set of mysteriously derived specifications, commercial users would have feedback on actual experience and current status rather than marketing propaganda, and the possibility of all around good communications and relations. Commercial culturists would have to take a more extended time view of possible problem solutions. Typically in developing a new technology, the first hardware systems are rarely, by themselves, of any practical use. It may take several test and redesign cycles to evolve into commercially practical equipment.

For the longer term, it may be necessary to recognize that many management functions, in addition to counting and measuring, are getting much more difficult as the size of culture units increases and sites become more distant and exposed to nature. Operating techniques closer to those used in feed lots and stock yards might be worth examining., Many types of fish can be induced to enter ducts or tunnels by use of properly placed collimated light sources, mild water currents and/or physical crowding. Tunnels are already being used to transfer fish between cages. “Ducting” of fish can be combined with on-line feeding, counting, measuring, visual inspection, prophylactic treatment, grading and harvesting. Ducting makes the counting and measurement a much simpler unidirectional process and large numbers of fish from many culture units can be processed through a single unit. This can be accomplished by opening and closing “stock gates” and turning stimuli on and off. Under these conditions, even a rather expensive in-line processing unit might be economically justifiable. Since all operations are conducted in water, the stress on the fish would be minimal. Research and development efforts in this direction should be encouraged but realizing that practical applications could be sometime into the future. This approach would require some fundamental reevaluation of present procedures and practices to meet the changing requirements of the future.

The recommendations are summarized on Table 6. With a little care, most could be accomplished at relatively little cost. A lot might be done by just encouraging good communications and cooperative projects between industry, commercial fish culturists and academia in specific areas of development. In the past, each group has tended to operate independently, with little appreciation of the requirements, problems and constraints of the other groups. There is a strong need to provide an opportunity to test prototype and developmental equipment in a realistic commercial context. This need is much broader than just counting and measuremmt. Unfortunately, extensive testing, with its associated requirements, can sometimes negatively impact commercial production objectives. The perfect long-term solution is a fish farm halfway between a commercial farm and a research

TABLE 6 RECOMMENDATIONS SUMMARY

* Buy, subsidize or arrange for the close monitoring **of** a SIMRAD FCM 160 Fish Cage Monitoring System to be operated in a commercial-culturing context somewhere in North America.

* Encourage and possibly fund design and development efforts to modify proven above water unidirectional approaches for *in situ* use.

* Arrange for “dialog” between culturists and developers of emerging technologies (particularly, LIDAR and advanced sonar systems) . As an aid to the process, culturists should define their requirements in terms of necessary accuracy, frequency of use, personnel and other resource constraints, conditions of use, and some ideas of acceptable initial and operating cost targets. Arranging for equipment testing opportunities in a commercial culturing context would also do a great deal towards meeting these requirements. A meeting ***or*** Conference on this subject, including commercial culturists, industrial sensor manufacturers and academics, would also be beneficial in both meeting information transfer requirements and as a stimulus to development.

* Encourage and possibly fund a graduate student project to test the feasibility of myoelectric sensors for counting fish in seawater.

* Encourage and possibly fund a system’s design effort for a futuristic-culturing system to meet future requirements. “Culturing System 2020”. This would have to have operational needs, such as *in situ* counting and measuring, included as an integral part of the initial design. The benefit is, starting with a clean sheet of paper, this systematic process would probably surface new ideas and approaches, with possibly nearer term use. If provided with realistic input information and guidance, this could easily and cheaply be done in a cooperative effort with a design course at a University.

station. This would be similar to the USDA agricultural experiment stations and good models already exist in Northern Europe and Japan.

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APPENDIX A: FISH FEED MONITORING TECHNIQUES

TABLE A-1

FUNCTION	REFERENCES	COMMENTS
Detection of uneaten feed	J. Juell, 1991	Hydroacoustic technique for monitoring uneaten feed dropping through the bottom of sea cages
Detection of feed ingestion by fish	M. Walsh, et al., 1987	Extremely small amounts of microencapsulated fluorescent tracers in feed can directly monitor feed ingestion. Tests done with channel cat fish, but should also work with marine fish. Appears sufficiently economical for possible use in commercial culturing
Detection of feed ingestion by fish	C. Talbut & P. Higgins. 1983	X-raying of fish fed feed spiked with iron powder. Used in nutritional studies with Juvenile Atlantic Salmon. May be adaptable to commercial culturing.
Detection of feed ingestion by fish	T. Storbakken, et al., 1981	Rainbow trout fed feed spiked with radioisotopes in nutritional studies. Not likely to be useable in commercial culturing.
Monitoring of demand feeder	W. Hastings, et al., 1972	Electronics used to monitor use of demand feeder by channel catfish. Information may be useful in a commercial context.
Acoustic feed detector used to control demand feeder	J. Juell,et al., 1993 B	Hydroacoustic detection of uneaten feed pellets used to terminate feeding of caged salmon. Fish grew faster than control group feed by conventional schedules. Fish appetite shown to be highly variable.

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Holland, 1980	Acoustic telemetry system using 100-150kHz transmitter to record data on fish such as position depth, temperature, and heart rate	SINTEF research can be used to define fish behavior under culture conditions.
Juell 1991	Hydroacoustic measurements of food waste falling through bottom of fish cages. Small amounts are detectable.	Ability to measure and quantify wasted fish feed critical in feed management. A 200 kHz Furuno MK-11 connected to a SIMRAD QM echo integrator were used.
Lord, et al., 1975	System of 4 buoys with upward looking 120 kHz transducers placed at depth of 46 m count fish and running depth, digital radio link, for high seas salmon assessments. Tested for 3 summers of Alaska.	Operations limited in presence of heavy breaking waves due to air entrainment giving ambiguous echo counts. Usually limited to winds less than 25 knots. Range resolution is 25 cm. Fish found to be at depth of 5 m or less. Considered successful & operational
Lovik, 1987	Counting fish & measuring length through swimbladder resonance. Theoretical & test data presented. Fish lengths of 5-45 cm. Frequencies of 0-10 kHz.	Limited to fish with swimbladders (salmon, trout & cod included). Resonance frequenties in range of 0.5-4 kHz. Being developed for use on caged fish.
Mathisen, 1975	A historical & technical review of acoustical fish stock assessment from WW-11 to 1975. Problems & future prospects discussed.	Discussion of acoustic equipment & signal processing emphasizes importance to advances in biological oceanography
Peterson, et al., 1976	Theoretical model for development of backscattering cross section of single fish from above compared to test data from Lake Michigan using 1.2 msec pings at 50kHz on alewifes.	Data critical for echo-integration data reduction, claim good match between acoustic model & test data. Emphasizes importance of reducing transducer side lobes.
Shibata, et al., 1971 (pp.99-l03)	Discusses status of research in Japan with 3 approaches to acoustic fish stock assessment: echo counting single fish, echo counting fish schools & optical integration of each echograms	Test data, relative advantages/ disadvantages & suggestions for future research are presented

Shibata, 1971 (pp.104-108)	Experimentally measured target strength & backscattering pattern of wild goldfish at 50 & 200 kHz from top, side & front. Fish tested alive but under anesthesia, dead without swim-bladder & dead without swim-bladder or viscera.	Acoustic properties of other species also discussed
Smith, 1990	Describes a dual beam echo sounder produced by Seastar Industries of Dartmouth, N.S. A 6.5 degree beam is transmitted and returned to both the 6,5 and a coaxial 26 degree transducer. The unit is built into a towed fish and is used for fish stock assessment.	Signal processing advantages for counting & measuring are claimed. Neither the frequencies used or the sensor orientation are stated.
Terazono, et al., 1990	Acoustic system to count from below fish ascending and descending fishway	Only abstract and figure captions in English, the rest is in Japanese
Thorne, 1980	Describes two stationary systems 1 using a 105-kHz Ross Lab 200A at a coastal power plant intake & the other a 70 kHz SIMRAD EY-M at an under ice intake in Alaska purpose of both are fish behavior studies. .	A number of advantages of fixed systems over vessel mounted units are described.

APPENDIX B: Fish Counting / Measurement Literature

Table B-2 Conductivity - Resistivity

References	Type/Characteristics	Comments
Appleby, et al., 1991	Tests of Smith-Root SR-1600 & NW Marine Technology FC-3 counters with smelts of various trout species, conditions of tests & factors effecting performance are discussed.	Counters produce accurate counts with little stress on the fish. Electronic and hand counts were generally within 3% and averaged less than 1.5%. In 2 way mode to reduce errors from multi-pass, numbers were within 1.4% and averaged 0.4%.
Dilley, 1985	Field tests of Northwest Marine Technology FC-1 Fish Counter with small Chum (409/lb) & Coho (64/lb) salmon and steelhead (18/lb) trout at rates up to 167,000/hr.	Comparison of electronic and hand counts at times produced high electronic counts due to multipass. Fish behavior and conditions required to get good counts are discussed.
Dunkley, et al., 1981	A resistivity fish counter for counting Atlantic salmon in open channel situations.	Also measured fish into two groups (above & below 50 cm in length). Counts compared to video taped TV numbers. Found instances of multipass counts.
Joyce, et al., 1988	A NW Marine Technology FC-1 fish counter was used to count eyed Pink & Coho Salmon fish eggs, at rates of over 10,000/minute.	Electronic counts were within 1% of hand counts and accuracy depends on size distribution of eggs. Intrinsic precision is believed to be about 0.2%. Counter counts only “live” eggs.
Lethlean, 1953	An electric device installed in two fish passes for counting salmon and kelts, operation was successful for periods of over twelve months	Some of original developments of such counters for practical use with large salmon. Conditions required for success are described,

Liscom, et al. , 1975	Electric counter used for large salmon based on the impedance bridge concept and measuring small differences in electrical resistance between fish & water.	Details of circuitry and accuracy as a function of conditions are given.
Smith Root Inc. 1982	Six page “Introduction to Electronic Fish Counting” available from company	Information on how to use counters & avoid problems along with information on various models that are available.
Weiss, 1972	Modification of salmon smelt counter with two electrodes in-line allows subtraction of fish going “wrong way” from count eliminating multipass errors & fish going other way.	Test results and circuitry details are presented

APPENDIX B: Fish Counting / Measurement Literature

Table B-3 Electromagnetic

References	Type/Characteristics	Comments
Barham, et al., 1969	.01 to 40 microvolt pulses are detected from fish most likely generated by white fiber muscle action potentials.	Equipment, signal characteristics and sources of electrical noise are discussed. Five species of freshwater fish were tested
Kronman, 1992	Airborne LIDAR (laser radar) used to identify and count fish at sea.	Difference in spectral properties allow species to be identified. Penetration of several hundred feet into water possible with high potential counting accuracy.
Camougis, 1960	Guidelines for equipment to measure muscle action potentials are provided.	Data on ranges of values and factors efecting these values are given.
George, 1970	A mathematical model for single muscle fiber action potential of fish swimming at uniform speed in axial direction is presented.	Based on dipole model. Physiological evidence to support the model is given and predictions are made.

APPENDIX B: Fish Counting / Measurement Literature

Table B-4 Optical

References	Type/Characteristics	Comments
Irvine, et al., 1991	A computerized video-camera system used to count and measure salmon smelts viewed from above swimming through acrylic tunnels	Single passage computer counts very accurate. Overlap resulted in under counts of about 29% compensated for by “expansion factor”. Computer length data complicated by overlap & crowding in tunnel.
Poxton, et al., 1986	An image analyzer was used to determine the projected area of flatfish as seen from above.	Data used to develop area-weight relationships for cultured turbot. Variations in relationships as function of size & fish condition are presented.
Ramcharan, et al., 1988	Motion analyzer using two views (top & one side) measures distance, duration, angle of movement and overall swimming speed of free-swimming zooplankton	System valuable in behavioral research.
Savage, et al., 1992	Underwater low light level video camera used to count & measure fish in cages. Image computer processing include contrast enhancement, edge detection, connectivity & edge thinning.	Considerable detail on equipment and computer processing provided.