INTRODUCTION

The accurate counting and measurement of fish ***in situ,*** without having to individually handle and stress the fish, has become a critical need in fish farming. Data on numbers and sizes are essential input information for financing, insurance, stock-management and feeding activities. Since 40-60% of total production costs in a variety of commercial aquiculture ventures often involve feeding, these data are essential to minimize feed wastage and **increase** the efficiency and economics of feed management. In salmon cage culture as an example, feed wastage has been measured to be in the order of 1/3 the total feed provided (Juell, 1991) . More recent unpublished data indicates that feed wastage in Scandinavian commercial cage systems has been considerably reduced.

Inefficient feed management, where there are large biomasses, is not only a major economic loss but can also lead to serious environmental problems. While the economic importance of uncertainty about size and numbers of fish under management has increased with the emergence of aquacultural industries, it is not a new problem. Such data on sizes and numbers are also of value in wildlife and fisheries management. There is a considerable history of attempted technical solutions, including acoustical, electrical and optical methods, involving a number of application areas. These application areas include stream monitoring, fish stock -assessments, hatcheries, and aquiculture grow-out.

The relevant technical data have been widely scattered. There has been a need to collect and evaluate all the relevant pieces of scattered information. This includes past and ongoing research, existing commercial equipment and the evaluation of the most promising approaches for both the short and long term. The importance of the subject area was recognized during an **Aquaculture Systems Technology Workshop** sponsored by the Northeastern Regional Aquacultural Center (NRAC) in Baltimore, Maryland, during February 1990. Participants at this meeting, including both Academic and aquacultural industry representatives, chose Inventory and Biomass Assesment for Finfish Culture as one of two priority areas for system's technology funding.

The basic objective of this the present review is to determine the current technology and status in regards to counting and measuring fish *in situ.* This is an essential first step in meeting an important and pressing need of the aquiculture industry. As the scale, value and importance of aquacultural industries increase, needs for vital management information will become even more critical. While the review is intended to be of broad interest and value, its emphasis is on applications centered on marine fish cage culturing. This is due to regional needs and the interests of the sponsors.

The approach to this study includes several different elements. The first is in acquiring and evaluating data on past and present research, through literature search and establishing contact with researchers and research organizations in North America and world-wide. Since much of the data are- scattered in a number of research areas, this is not straightforward. A large amount of data are in technical reports that have never been openly published or widely circulated.

Another element of this study is to determine what kind of commercial equipment is currently available for measuring and counting fish. This requires collecting information from equipment suppliers on a world-wide basis. Data sources include advertisements and listings in aquiculture magazines, newsletters and yearly equipment buyers' guides. Equipment suppliers often purchase from foreign sources with the intent of reselling and, thus do not fully understand the technical aspects of the equipment they sell. Particular attention is required to be directed toward Northern Europe and Japan due to the high level of aquacultural development activity in these areas. The available equipment should be evaluated in regards to usefulness in a commercial context. Some of what is available is only tangentially related to the main purposes of this study.

The last important element is evaluations and recommendations based on the state-of-the-art and user requirements. Recommendations will be separated into promising short-term options and actions with substantial but longer term potential.

While the intent of this study is on methods to count and measure fish, it is important to realize that this' information is only a means of providing data needed for proper systems management, particularly feed management. There may be alternate approaches to solving some of the management requirements that are outside the scope of this study. Direct feed monitoring may be such an approach and an annotated bibliography of available relevant scientific literature is presented in Appendix A.

PRECEDENTS AND REQUIREMENTS

The need to count and sometimes measure fish without undo stress is an old problem. It has existed in a number of application areas, which have already been mentioned. These are summarized in Table 1. While having a common problem, the situations are different. They differ in their monitoring conditions, measurement requirements, and in their technical challenges.

In all cases, the user requirements for accuracy and precision for either counting or measurement have never been defined and have only rarely been discussed in the scientific literature. While high values for both accuracy and precision are clearly desirable, indications are that relatively modest values would, in most situations, be very useful and a great improvement. Establishing specific numerical requirements is difficult, as operations vary considerably and in the end the numbers are at least partially subjective. A rough order of magnitude for a general requirement for counting might be 95% accuracy with a plus or minus of 5%. This is, in most cases, not a difficult goal, especially if the predictable error sources are factored out. Many of the available sensors will perform very well under optimum conditions but degrade very rapidly when conditions deviate from optimum. Errors from known sources can be eliminated by controlling the conditions leading to the errors, collecting more information through additional sensors, using more sophisticated sensors or increasing the complexity of the data reduction. In some cases much lower performance would be acceptable.

In culturing applications it is common, by virtue of the stocking and harvesting processes, to have very accurate data on size and numbers at both ends of the culturing

TABLE 1 FISH COUNTING AND MEASUREMENT PRIOR EXPERIENCES AND DATA SOURCES

OBJECTIVE	PURPOSE	NEEDS	CONDIT ONS	COMMENTS
Open water fish stock assessments	Fisheries management data	Numbers and sizes	Primarily marine, 3-D situations, mostly schooling fish	*Past effort mostly acoustic *Results have not been completely satisfactory
Anadromous fish stream monitoring	Fisheries management data	Primarily numbers	Freshwater, unidirectional geometry at counting point often controllable, fish often large	*Very important data economically & politically *Relatively well funded *Often expensive but relatively successful
Fish hatcheries	Accurate counts required for accounting & marketing	Primarily numbers	Mostly freshwater, usually at end of process, geometry controllable, fish usually small	*Freshwater counters for small fish well established & relatively satisfactory
Aquaculture (growout)	Required for feeding & marketing	Numbers, sizes & size variations	Marine & freshwater, wide range of sizes & enclosure types, several distinctly different situations	*Counts & measurements in & out usually good-not problem *Data during process important *Variations in conditions make generic solutions difficult *Current capabilities poor & not satisfactory

process. As the culturing process continues after stocking, the uncertainties about numbers grow with time. With mortalities, escapes, and predation all difficult to quantify with any certainty, it may take only a few weeks to a few months before the estimated biomass can be a very crude guess. Accurate counts every few days should be adequate for most culturing applications.

Size measurement requirements for most applications appear to be even looser. Size information is not always of major importance. Occasionally netting a few fish and measuring them is often sufficient. Many instrumented *in situ* measurements to date have separated fish into only a very few size ranges, generally 2 to 4 categories. These have mostly been in stream monitoring, where major size differences have been used to identify year classes or separate out extraneous species from the counts. Size data have been most easily acquired in terms of total fish length. Correlations exist between length and other parameters, such as weight, for most species of interest. A correction factor for condition (fat or lean with respect to length) of the fish can be acquired by measuring and weighing a few animals. Aquacultural grow-out operations may require relatively precise size data. This may be needed to monitor the variations in growth of what is hoped to be a homogeneous population. A 5% variation in length could mean a substantially greater difference in weight. These size data are needed for determining if grading is needed and is particularly important in salmon grow-out. If the large fish are not removed by grading, the size variations will increase resulting in a few big fish and a lot of little ones. This size (length) measurement requirement in culturing applications is probably to recognize length differences of as little as a few percent and is a relatively severe requirement.

When grading is required (not all species require grading during grow-out, especially if tightly graded at stocking), *in situ* grading is preferred because it is usually much less stressful on the fish and results in reduced mortalities. However, many culturing applications use above water grading and subsequent counting before returning the fish to the water. This is done because reasonably good equipment is commercially available for grading and counting above water (see section on commercial equipment) . A good count at grading also reduces the criticality of *in situ* counting during subsequent grow-out. Since the time interval between gradings may be many months, there is ample time for the accuracy of the estimated fish numbers and biomass, on which most management decisions are based, to greatly degenerate. There are a number of ways to do less stressful *in situ* grading, but no equipment is commercially available. In addition, none of the operations that have used *in situ* grading have ever incorporated a counting capability into the equipment. *In situ* grading usually involves driving fish through adjustable slits or bars, i.e. a much simpler unidirectional situation. If counting could be combined with *in situ* grading, it might be the perfect solution. A number of the technical options discussed in this report might be adaptable to this requirement.

The needs and requirements for counting and measuring fish *in situ* even in aquiculture are not limited to salmonid cage culture. The needs are much more widely felt. A special session of the World Aquiculture Society in 1989 addressed the requirements for “Instrumentation in Aquiculture”. The editor of the Preceedings specifically-addressed needs of commercial aquiculture in a paper of his own (Wyban, 1989) . This paper talks about a survey on instrumentation needs by 265 respondents, of which 65% were commercial aquaculturists. From the geographic distribution, most were probably catfish farmers. Their highest automation priority was for monitoring of dissolved oxygen (54%) but it was followed by counting (41%) and weight measurement (28%) . These were clearly ahead of both feeding and control of water exchange. The single most important characteristic of instrumentation for commercial aquiculture use was determined in this survey to be durability.

TECHNICAL PROBLEMS

SYSTEM GEOMETRY

A number of technical problems have been encountered in past attempts to count and measure fish *in situ.* These can be categorized by the geometry of the situation (see Table 2). Unidirectional means that due to the physical layout inherent in the situation, fish swim by the sensors in only one direction. Either water current coupled with migration or physical "crowding from behind, force the fish through the sensor. This situation is very common in stream monitoring of anadromous fish and in counting of hatchery produced juvenile fish.

Two dimensional (2-D) would be a shallow pond or broad shallow river with very large horizontal dimensions compared to the water depth. Commonly the water depth is only a few feet but through-water visibility is often very poor, limiting visual observations. Sensors can be aligned horizontally, viewing the fish from the sides, or vertically, viewing the fish from above. Either way the technical problems are formidable and have yet to be solved with any operationally available system.

Three dimensional (3-D) would be monitoring fish in open water, large tanks or cages. Again both horizontal and vertical orientations for sensors are possible. However, the vertical orientation has the option of viewing the fish from below, which is not really an option for 2-D.

The 2-D and 3-D situations with tanks and cages are the culturing situations of primary interest to this study.

TABLE 2 TECHNICAL PROBLEMS ENCOUNTERED IN COUNTING & MEASURING FISH

ORIENTATION	PROBLEMS	SOLUTIONS
UNIDIRECTIONAL, 1-D (stream monitoring, hatchery output)	WRONG WAY (fish 180^0 off)	*Same as multipass, below
	MULTIPASS (same fish back & forth across sensor)	*Subtract downstreams from upstreams or vice versa *Maintain high water velocity at counting point
	OVERLAP (more than 1 passing at one time)	*Keep cross-X at counting point small to reduce probability of occurrence
TWO-DIMENSIONAL, 2-D (large shallow ponds, broad shallow rivers)	OVERLAPPING & SHADOWING when viewed from side, particularly difficult at high fish densities	*View from top if possible *Not solved from side at high densities *Range-gating, signal integration & other signal processing may help
THREE-DIMENSIONAL, 3-D	All problems of 2-D but more difficult, can not assume single horizontal layer uniform in vertical direction, problems increased at high density	*Same as 2-D but seriously complicated by high fish densities *Multiple viewing angles might be helpful

While there is considerable research data, there is little verifiable successful field use of 2-D or 3-D counting systems. The most developed precedent involves open sea fish stock assessments. However, it is very important to remember that the fish do not have to be counted and/or measured in their culturing unit. They can be herded from one unit to another without leaving their water environment. This is already being done in commercial cage culturing. If they are crowded through an in *situ* grader or fish pump, the situation **becomes unidirectional** and they could be monitored at the same time that other activities are carried out. The very difficult 3-D cage problem might be more easily solved by temporarily altering the conditions to an easier unidirectional case. This would be akin to practices in feed lots where large numbers of animals in large pens are directed one at a time into narrow chutes and by way of gates directed to "stations" for specific treatment and then returned to the pens. Large numbers of animals can be processed quickly, efficiently and with minimum stress.

SYSTEM PROBLEMS

The unidirectional (l-D) counting has received the most attention and has the most operational experience. It has encountered several generic technical problems in actual field use (see Table 2) . In some stream monitoring situations, there may be other fish, which are not to be counted, going the other way. The solution to simultaneous counter migrations is the same as for the multi-pass problem. Multi-pass occurs when a fish goes through and is measured and allows itself to be carried by the current backwards through the measurement zone, and then coming through again in the correct direction. This can lead to multiple counts and measurements on the same fish.

There are several solutions to the multi-pass problem that work under the proper conditions. One is to install several sensors in-line. This allows direction of travel to be determined by time of signal arrival. Downstream passages can either not be counted or can be subtracted from the dominant upstream passages. Another approach is to select the dimensions of the measurement zone so that the water velocity is sufficiently high that fish do not linger in the test area. This will not work well where water flowrates, hence water velocity, are highly variable. Variable flowrates are often a problem in stream monitoring but are unlikely to be a problem in culturing applications.

Another unidirectional problem is that of several fish going through the measurement area and overlapping each other. This can lead to their counting and measurement as one large fish rather than several smaller ones. This is particularly troublesome when large numbers of fish are counted at the same time. Unfortunately, high fish passage rates are very characteristic of hatchery and culturing applications. A variation of this problem in 3-D situations at high fish densities is shadowing, where fish are “hidden” behind those in front.

The last problem that can occur, but is not likely to be a problem in culturing applications, is non-target fish going in the same direction. These may be a different year class or different species. Size has been used to segregate targets and only count within a specified size range. Very crude and imprecise size measurements in many cases have proven to be adequate, due to major size differences between target and non-target fish. If major size differences do not exist the technical problems become more difficult. There is no evidence in the literature that this is a serious problem in stream monitoring applications. If needed, differences in shape or coloration might have to be used to separate the undesirables from the count.

The 2-D situation has many of the problems of the unidirectional case plus some of its own. The 2-D case has one major advantage over the more complex 3-D situation. For 2-D the fish can often be assumed to all be in one horizontal layer, one fish high and with the fish oriented in the horizontal direction. However, the distribution often can not be assumed to be uniform within this layer. This is especially true for large areas, such as large shallow ponds. In smaller units, or if fish behavior or distribution is known, a small area can be sampled and an estimated count for the whole area calculated. Having implicit assumptions about fish distribution buried within the data reduction software is a big potential problem with many 2-D and 3-D counting systems. If the conditions at a given time invalidate the assumptions inherent in the data processing equations, the resulting “fish count” might be both worthless and misleading. Inconsistencies between measurements might be indicative of this problem.

The 3-D case has the worst technical problems (see Table 2). The problems are considerably increased by the high stocking densities necessary in culturing applications. Solutions appear to be considerably more difficult than those encountered in other counting and measurement applications. A number of the technical approaches discussed in this report have shown some promise at low densities, specifically in open sea stock assessment. How they will perform at realistic culturing densities remains to be demonstrated. It is quite possible that the simplifying assumptions and data reduction “tricks” that are required for implementation may seriously compromise the credibility and value of the resulting measurements.

Data reduction models are likely to include assumptions about vertical and horizontal distribution of the fish, about “average” aspect angles of the fish relative to the sensor and about “signature” values of the fish in various acoustic and electromagnetic bands. These are likely to be highly variable and critical parameters. There is evidence that high fish densities can significantly alter both the physical properties of the water and the “signiture” values of the fish. The viewing angle of the sensor relative to the fish (aspect angle) has been shown, by itself, to be critical. The shape, color and acoustic target strength are all highly dependent on aspect angle. As an example, the top view may produce a much different “signature” value than the bottom view. In addition, dead or anesthetized fish may give different “signature” values than freely swimming fish.

TABLE 3 **FOREIGN ORGANIZATIONS INVOLVED WITH AQUACULTURAL EQUIPMENT DEVELOPMENT**

NORWAY	NHL - Norwegian Institute of Technology
	SINTEF - The Foundation for Scientific and Industrial Research, part of NHL, N-7034 Trondheim
	MARINTEK - Norwegian Marine Technology Research Institute, N-7002 Trondheim
	Norwegian Agricultural University, P.O. Box 65, N-1432 As-NLH
	NTNF - Royal Norwegian Council for Scientific and Industrial Research
JAPAN	MITI - Ministry of International Trade and Industry
	Marinal Forum 21 - Reported (unconfirmed) to be consortium of 135 companies sponsored by MITI at level of $100 m/year to do commercial aquacultural equipment development. (There is apparently also a similar fisheries consortium) .
CANADA	Department of Fisheries and Oceans Canada, 555 W Hastings St.,Vancouver, B.C. V6B 5G3 (Nanaimo)

regards to applications in commercial aquiculture. This also proved to be true. However, several sources were found that did assemble and evaluate the state-of-the-art with respect to counting and measurement *in situ,* but primarily for other applications. A **Symposium on the Methodology for The** Survey, Monitoring of Fishery Resources and Rivers was carried out under FAO sponsorship in 1975. The "Panel Reviews and Relevant Papers" were published (Welcomme, 1975) and contained 23 papers, most including review and evaluation of fish counters in specific applications and also in more general context. Most of the emphasis is on conductivity counters and acoustic systems.

Another excellent compilation of data is Mulligan, 1985. This is an evaluation of 10 different techniques for counting fish in streams with emphasis on acoustic and radar methods. While not directly applicable to aquiculture situations, these data are still valuable. The basic technologies that can be used to count and/or measure fish are listed on Table 4.

ACOUSTIC SYSTEMS

Acoustic systems are very diverse and varied. They can be categorized by orientation (looking up, looking down or looking horizontally) by frequency (low frequency- good range broad beam, high frequency- good resolution, small beam) and by signal processing (signal integration, discrete targets, doppler shift, etc.) . For the vast majority of the systems, transponders are used. This means that the acoustic transmitter and the receiver are the same unit. In a few cases additional receivers are placed at some angle to measure scattered acoustic energy. The output signals can be interpreted as a discrete count of fish, a measure of total biomass or size of individual fish through determination of

TABLE 4 FISH COUNTING & MEASUREMENT TECHNOLOGIES

ACOUSTIC	----	Signal Integration
	----	Discrete Targets
	----	Swim Bladder Resonance
	----	Doppler Shift
ELECTRICAL	----	Conductivity/Resistivity
	----	Electromagnetic Induction
	----	Time Domain Reflectrometry
ELECTROMAGNETIC OPTICAL FREQUENCIES	----	Visual/TV
	----	Collimated light Beams
	----	Infrared
	----	Laser Radar (LIDAR)
ELECTROMAGNETIC NON-OPTICAL FREQUENCIES	----	Myoelectric
	----	Radar -Wave Guide -Underwater - Aerial Down looking