Characteristics of the Recirculation Sector of Finfish Aquaculture in the United States and Canada

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ABSTRACT

In the autumn of 2001, a survey was conducted to examine basic farm production and human resource characteristics of recirculation facilities in the United States and Canada currently growing finfish. An 86% response rate was achieved. The survey data indicate that this sector of aquaculture is quite heterogeneous. The number and pounds of fish produced is quite variable, with presence of small-, medium- and large-sized farms in this sector. Recirculation technologies are employed to culture a wide variety of both warmwater and coldwater fishes in both saltwater and freshwater situations. The four fishes most commonly grown in recirculation units in the United States and Canada are Atlantic salmon smolts, tilapia, hybrid striped bass and ornamental fishes. A high proportion of facilities using recirculation technologies use pumped groundwater as a primary water source. Over 40% of facilities represented in the survey rely on a single water source to sustain their operation and have no secondary water source as backup. Management personnel of recirculation facilities are highly educated; more than 74% of respondents reported holding at least an undergraduate degree. The majority of personnel managing recirculation facilities are middle-aged individuals who have over 10 years of related work experience. The

findings of this study represent the first empirical description of the recirculation sector of finfish aquaculture in the United States and Canada.

INTRODUCTION

Over the past 25 years, aquaculture has been one of the fastest-growing sectors of US agriculture. In 1974, the farm gate value of all US aquaculture products was $45 million; by 1998, it had increased to almost $1 billion (USDA 2000). The 1998 Federal Census on Aquaculture (USDA 2000) indicated that there were over 4,000 aquaculture operations in the United States. These operations represent all sectors of aquaculture production (mollusks, finfish, crustaceans and plants). Many of these operations are quite small. Almost 50% of the aquaculture operations in the United States have an annual income of $25,000 or less (USDA 2000). These census data show that only a small percentage of the total US aquaculture industry currently uses recirculation technology. Of the 4,000 operations in existence, only 328 US fish farms identify themselves as "recirculation" facilities. However, due to the use of unclear terminology in the census, this number may be inflated and therefore misleading. The definition identifying recirculation operations was "reuse of water in an aquaculture facility (closed system) rather than releasing into nature and continually being replaced by new water (open system)". The use of this definition allowed a variety of activities that are pseudo-aquaculture in nature to be included under the recirculation category. For example, among the 328 recirculation facilities identified were operations run by fishermen to hold captured wild crustaceans during market lulls and when the animals are pre- and post-molt (and therefore less marketable).

The Canadian aquaculture industry also has grown substantially over the past two decades. Between 1984 and 1995, Canadian aquaculture production increased at an annual rate of 21.6% (FAO 1997). The Canadian Aquaculture Industry Alliance (CAIA) predicted that finfish producers will double 2001 production by the year 2006 (OCAD 2001). Similar to the US industry, the recirculation sector of the Canadian aquaculture industry lacks quantitative and qualitative description.

METHODS

A survey instrument was developed and administered to gather baseline information about facilities using recirculation technology in the United States and Canada. For this study, the defining element for a recirculation facility was that the operation "had to use a biofilter in its fish culture system". Information on currently operating recirculation facilities was obtained from three different and independent sources:

(1) government aquaculture representatives for each state and province,

(2) representatives from national associations representing particular sectors of aquaculture, and

(3) feed company representatives and research groups who have professional interaction with the recirculation sector of aquaculture.

Information from the three sources was cross-referenced to develop a final mailing list representing the current status of this sector. The initial sampling frame consisted of 162 facilities.

In spring 2001, the survey questionnaire and mailing protocol were developed using a modified version of Dillman's Total Design Method (TDM) (Dillman 1978). The questionnaire was pre-tested with six different managers of finfish rearing units in the United States and Canada. These managers represented different components of the finfish sector (business, research and demonstration facilities) and were asked to complete the questionnaire, give detailed comments on areas for improvement, and identify areas of ambiguity. Following the pre-test, the questionnaire was revised, printed, and mailed to 162 facilities in the United States and Canada. The questionnaire was composed of 43 questions. Three consecutive mailings were made during the fall of 2001. Each mailing included a cover letter, the complete questionnaire, and a stamped, return envelope. An incentive (a cookbook of farmed trout recipes) was offered to those respondents who returned the questionnaire promptly. Respondents were identified by a randomly-assigned number only.

Data Analysis

Response data were analyzed using Statistical Package for Social Sciences (SPSS, version 11.0, SPSS Inc., Chicago, IL, USA) software. Most of the data collected through the survey were nominal in nature;

frequency distributions were constructed for responses to all questions within nominal response categories. There were four continuous variables in the results; frequency distributions and other summary statistics were produced for these variables.

RESULTS

Overall, there was an 86% response rate to the survey. Correctly identifying the target people (names and addresses) before the first mailing of the questionnaire was key to achieving the high response rate of this study. One hundred and forty-one completed questionnaires were returned, but 10 of the respondents did not use a biofilter in their operation, and therefore did not fit the study's defining frame of a "recirculation" facility. The following results, therefore, incorporate data obtained from 131 facilities in the United States and Canada. Seventy-one percent of the respondents were from the United States (n=93) and 29% were from the Canada (n=38). The data represent information obtained from facilities in 32 states and 8 provinces.

Production Characteristics of Recirculation Units

The recirculation sector of aquaculture is composed of small-, medium- and large-sized farms (Figure 1). A breakdown of the sector by size of production (annual volume of fish) shows that the majority of recirculation operations (58%) produce 22,679.6 kg (50,000 lbs) or less of fish per year. Medium-sized farms (producing >22,680.1 kg [50,000 lbs] to 113,398.1 kg [250,000 lbs] of fish per year) comprise 25% of the sector. The remaining 17% of the farms are large farms that individually produce over 113,398 kg (250,000 lbs) of fish per year. Five very large farms (annual production greater than 453,592.4 kg [1 million pounds]) responded to the survey. Two of these farms produce tilapia (*Oreochromis spp.*), and one each grow Atlantic salmon (*Salmo salar*), chinook salmon (*Oncoryhynchus tchawytscha*), and hybrid striped bass (*Morone sp.*). Annual production expressed as number of fish produced was similar to production by weight (Table 1). Small-sized farms, producing fewer than 50,000 fish annually, comprised 41% of the respondents, medium-sized farms, those producing 50,000 to 500,000 fish per year comprised 26% of the respondents, and large-sized farms, those growing more than 500,000 fish per year represented 28%.

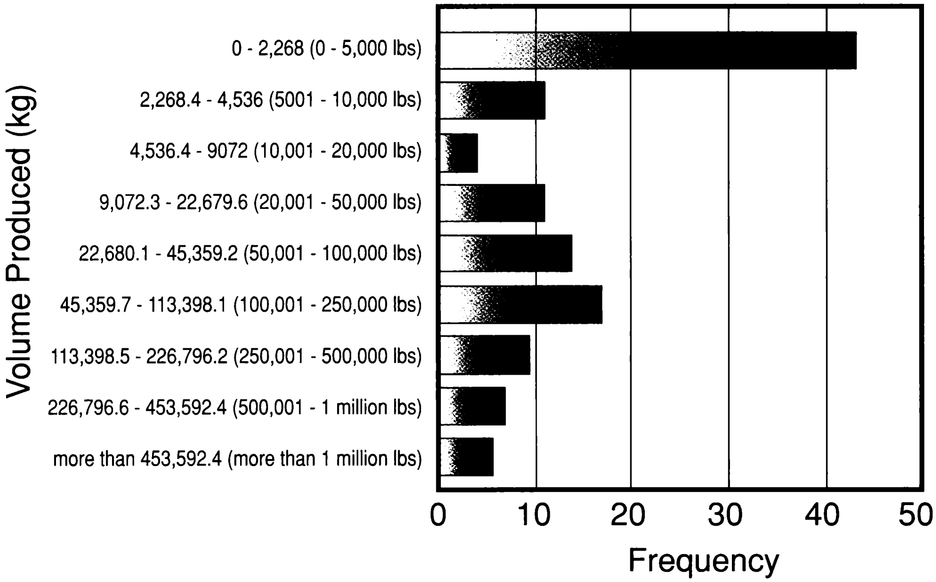

Figure 1: Annual production (kg) for recirculation facilities in the United States and Canada.

Fish Produced	Count	Percent	Cumulative Percent
0 - 10,000 fish	31	24.4	24.4
10,001 - 20,000 fish	7	5.5	29.9
20,001 - 50,000 fish	14	11.0	40.9
50,001 - 100,000 fish	7	5.5	46.5
100,001 - 250,000 fish	12	9.4	60.6
250,001 - 500,000 fish	14	11.0	71.7
500,001 - million fish	12	9.4	81.1
1 million - 1.5 million fish	12	9.4	90.6
more than 1.5 million fish	12	9.4	100.0
Total	127	100.0	

Table 1: Annual numbers of fish produced in recirculation facilities in the United States and Canada

Eighty-five percent of recirculation facilities were freshwater operations (Figure 2). The primary water source for 48% of the respondents was well water. Chlorinated municipal water was the second most common primary water supply (24%) for recirculation facilities. The respondents were also queried regarding secondary water sources used during a production cycle. Well water (28%) and chlorinated municipal water (18%) were the most commonly used secondary water sources for recirculation facilities (Table 2). Surface water was used by 14% of the respondents as a secondary water source. However, over 40% of the facilities used only a single water source and did not have a secondary water source for use in times of emergency.

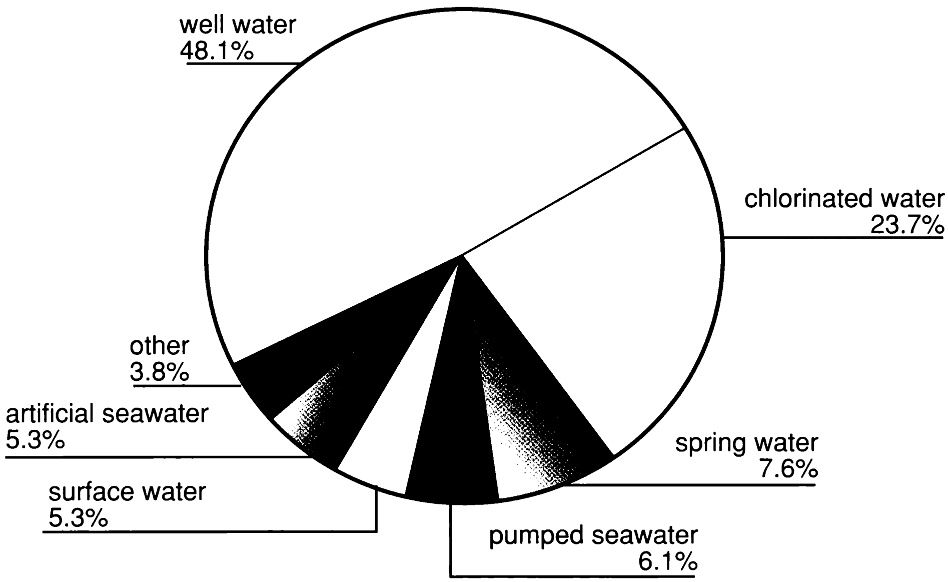

Figure 2: Main source of water for recirculation units in the United States and Canada.

Sixty-two percent (62%) of respondents used recirculation technology for business purposes, i.e., for profit-oriented production (Table 3). At present, recirculation technology is not frequently used for education (8% of respondents) or for demonstration (3%) purposes. However, the survey population included only college and university aquaculture programs and did not include secondary schools. We recognize that many secondary schools use small-scale recirculation systems in their natural science and agriculture curricula (there are over 20 of these units in secondary schools

Source of Water	Count	Percent Responses	Percent[1] Cases
well water - fresh	34	23.3	27.6
chlorinated water	22	15.1	17.9
surface water	17	11.6	13.8
artificial saltwater	6	4.1	4.9
pumped saltwater	5	3.4	4.1
spring water	5	3.4	4.1
reverse osmosis	4	2.7	3.3
saltwater well	3	2.1	2.4
only one water source	50	34.2	40.7
Total responses	146	100.0	118.7

[1] *Respondents were allowed to report more than one answer. Indicated percent represents the proportion of respondents reporting each particular answer.*

Table 2: Secondary source of water supply for recirculation facilities in the United States and Canada.

Purpose	Count	Percent
Business	81	61.8
Research	37	28.6
Education	10	7.6
Demonstration	3	2.3
Total	131	100.0

Table 3: Main purpose of recirculation operations in United States and Canada.

in the State of West Virginia alone; (Don Michael, WV Dept. of Education, personal communication). However, these secondary school units have little or no production output, and many are not functional year-round; thus, they were excluded from the survey population.

For respondents who indicated that business was the main purpose for using recirculation technology (Table 4), the most common business activities were: 1) growing fish for the food market (59%), 2) growing fish for sale to other farmers for grow-out (46%) and 3) supplying fish eggs to others (21%). Under the heading "other business activities", public aquaria, education outreach, and supplying fry to others for grow-out to smolt stage were each identified more than once.

Business activity	Count	Percent[1]
Grow food fish to market size	51	58.6
Supply fish for others to grow-out	40	45.5
Supply fish eggs to others	18	20.7
Grow fish for the ornamental market	14	16.1
Grow fish for stocking in natural waters	11	12.6
Grow fish for the bait market	2	2.3
Other	10	11.5

[1] *Respondents were allowed to mention more than one answer. Indicated percent represents the proportion of respondents mentioning each particular answer.*

Table 4: Types of business activities using recirculation technology in the United States and Canada.

The four fish types most frequently grown in recirculation facilities in the United States and Canada are tilapia (15%), Atlantic salmon (13%), ornamental fishes (9%) and hybrid striped bass (8%) (Table 5). Collectively, these four fish types constitute 45% of the sector. Fishes belonging to the family Salmonidae represented almost 28% of the fish taxa grown as the primary crop in recirculation facilities. Seventeen different categories of fish were identified in the questionnaire, plus a write-in area to report on other fish types not mentioned in the questionnaire. In the "other" category (n=48), a wide variety of different species were reported, including some saltwater species (Table 6).

When operators were asked to identify which taxa of fishes they had grown in the past, more facilities had grown rainbow trout (*Oncorhynchus mykiss*) than any other fish type (46% of cases) (Table 7). Tilapia was the second most common fish type grown in the past (39% of cases).

The three life stages most commonly reared in recirculation operations (Table 8) were fingerlings (96%), fry (77%), and eggs (73%). Smolts constituted the smallest percentage of life stages grown (27%), but this is not surprising since this life stage is specific only to the group of facilities that grow salmonids.

Many facilities did not know the survival rates of the earliest life stages, but they did have this information for later life stages (Table 9). Overall, the highest rates of survival were found in the later life stages. From fry to

Name	Count	Percent Responses
Tilapia spp.	26	14.8
Atlantic salmon	23	13.1
Ornamental fishes	15	8.5
Hybrid striped bass	14	8.0
Arctic charr	9	5.1
Flatfish	9	5.1
Rainbow trout	8	4.5
Yellow perch	8	4.5
Brook trout	5	2.8
Chinook salmon	3	1.7
Sturgeon	3	1.7
Brown trout	1	0.6
Catfish	1	0.6
Baitfishes	1	0.6
Bass - LM and SM	1	0.6
Sunfishes	1	0.6
Others	48	27.3

Table 5: Types or species of fish currently produced in recirculation facilities in the United States and Canada.

Freshwater species		
lake whitefish	white bass	carp
hybrid carp	cobia	grass carp
walleye	coho salmon	striped bass
tiger trout	white seabass	pacu
paddlefish	bonytail	Rio Grande silvery minnow
razorback sucker	mummichog	Japanese medaka
Marine species		
cod		
sea bream		
haddock		
Asian catfish		
muttonfish		
black sea bass		

Table 6: "Other" fishes grown as primary production (fish crop) in recirculation facilities in the United States and Canada.

Name	Count	Percent Responses	Percent [1] Cases
Rainbow trout	36	12.0	46.2
Tilapia spp.	30	10.0	38.5
Ornamental fishes	26	8.7	33.3
Hybrid striped bass	21	7.0	26.9
Catfish	19	6.3	24.4
Atlantic salmon	17	5.7	21.8
Sturgeon	16	5.3	20.5
Sunfish	16	5.3	20.5
Brook trout	15	5.0	19.2
Yellow perch	15	5.0	19.2
Baitfish	14	4.7	17.9
Bass- LM and SM	14	4.7	17.9
Arctic charr	14	4.7	17.9
Chinook salmon	8	2.7	10.3
Flatfishes	8	2.7	10.3
Brown trout	5	1.7	6.4
Chum salmon	2	0.7	2.6
Others	24	8.0	30.8
Total responses	300	100.0	384.6

[1] Respondents were allowed to mention more than one answer. Indicated percent represents the proportion of respondents mentioning each particular answer.

Table 7: Fishes that have been grown in the past in current recirculation units in the United States and Canada.

Life stage	Count	Percent of Responses	Percent [1] Cases
Egg	94	14.7	72.9
Fry	99	15.4	76.7
Fingerling	124	19.3	96.1
Smolt	34	5.3	26.4
Yearling	68	10.6	52.7
Adult fish	83	12.9	64.3
Food market-sized fish	69	10.8	53.5
Broodfish	70	10.9	54.3
Total responses	641	100.0	496.9

[1] Respondents were allowed to mention more than one answer. Indicated percent represents the proportion of respondents mentioning each particular answer.

Table 8: Life stages grown in recirculation facilities in the United States and Canada.

market-sized fish, over 50% of the respondents reported survival rates of 90% or greater. Survival rates of the different life stages is a point of sensitivity both from a business performance standpoint and in terms of the fish culture ability of personnel. Therefore, it was not surprising that 38% of the respondents chose not to answer this particular question.

Use of recirculating technologies to grow fish is not limited to “new” facilities. The mean number of years of operation for the different farms responding to the survey was 11. The most frequently reported age of a facility was 6 years. However, it is important to note that the question on the survey did not ask the length of time that the operation had been using recirculation technology, but rather asked the number of years the facility had been operating. This wording was purposeful; many facilities embrace recirculation technologies in a step-wise fashion over a fairly long time. Therefore, the data on years of operation is indicative of the longevity of operation of the facility rather than the history of its use of recirculation technology. It is interesting to note that both old and new operations are using the technology and that age of the facility was not necessarily a criterion or obstacle to employment of the technology. However, newer facilities more frequently are using recirculation technology.

Characteristics of personnel of recirculation units

One purpose of the survey was to describe key characteristics of personnel managing recirculation units in the United States and Canada. A number of survey questions were directed towards characterizing staffing and personnel attributes.

Seventy percent of recirculation operations had 1 to 8 full-time employees. The most common situation in recirculation units is to have one full-time employee, but there is a broad range of staff size for full-time employees among the different facilities (Table 10). Most operations had a low number of part-time staff (the modal number of part-time staff employed at recirculation facilities in the United States and Canada is 2). Sixty-six percent of operations had 1 to 5 part-time staff (Table 10).

Overall, the majority of managers operating recirculation facilities in the United States and Canada are middle-aged, highly educated and well-experienced in aquaculture. Manager’s ages ranged from 22 to 72 years (Figure 4) . The average age for a manager was 43 years (mode = 45

	Rate of Survival										
Life stage	**More than 90%**	**90%**	**80%**	**70%**	**60%**	**50%**	**40%**	**30%**	**20%**	**10%**	**Less than 10 %**	**Not known**
From fertilized eggs to eye-up	12.3	17.3	18.5	13.6	6.2	4.9	1.2	1.2	—	—	—	24.7
From eyed-egg to hatch	23.0	23.0	14.9	11.5	3.4	2.3	1.1	—	—	—	—	20.7
From hatch to first feeding	23.1	22.0	11.0	9.9	5.5	3.3	5.5	2.2	—	—	—	17.6
From first feeding to fry	24.1	20.7	17.2	8.0	5.7	4.6	1.1	1.1	2.3	1.1	—	13.8
From fry to fingerling	35.8	15.8	11.6	8.4	4.2	5.3	2.1	2.1	1.1	2.1	—	11.6
From fingerling to yearling (smolt)	40.4	23.1	15.4	6.7	1.0	1.9	1.0	2.9	—	—	1.0	6.7
From yearling to market	43.8	24.7	9.0	5.6	—	—	—		3.4	—	1.1	9.0
From market to broodfish	39.1	18.8	10.1	2.9	—	—		1.4		2.9	2.9	21.7

Table 9: Average rates of survival reported for life stages held in recirculation facilities in the United States and Canada.

— *Indicates no response in this category.*

Number of Staff	Full-time Count	Full-time Percent	Part-time Count	Part-time Percent
0	8	6	18	15
1 – 5	74	59	80	66
6 -10	25	20	15	12
11 -15	10	8	4	3
16 - 20	5	4	3	2
> 21	4	3	2	2
Totals	126	100	122	100

Table 10: Number of employees in recirculation facilities in the United States and Canada.

years). Greater than 74% of the respondents had an undergraduate degree or higher level of education (Table 11). Personnel managing recirculation units have a considerable amount of practical experience in aquaculture as well as a high level of formal education. The managers who responded to this survey had on average 15 years of experience working in aquaculture, with the majority of managers having between 15 to 25 years of work experience.

Level of Education	Count	Percent	Cumulative Percent
Less than high school	2	1.5	1.5
High school diploma	8	6.2	7.7
Some college	9	6.9	14.6
Community College graduate	15	11.5	26.2
Bachelor's Degree	34	26.2	52.3
Graduate Degree	62	47.7	100.0
Total	130	100.0	

Table 11: Level of education of personnel operating recirculation facilities in the United States and Canada.

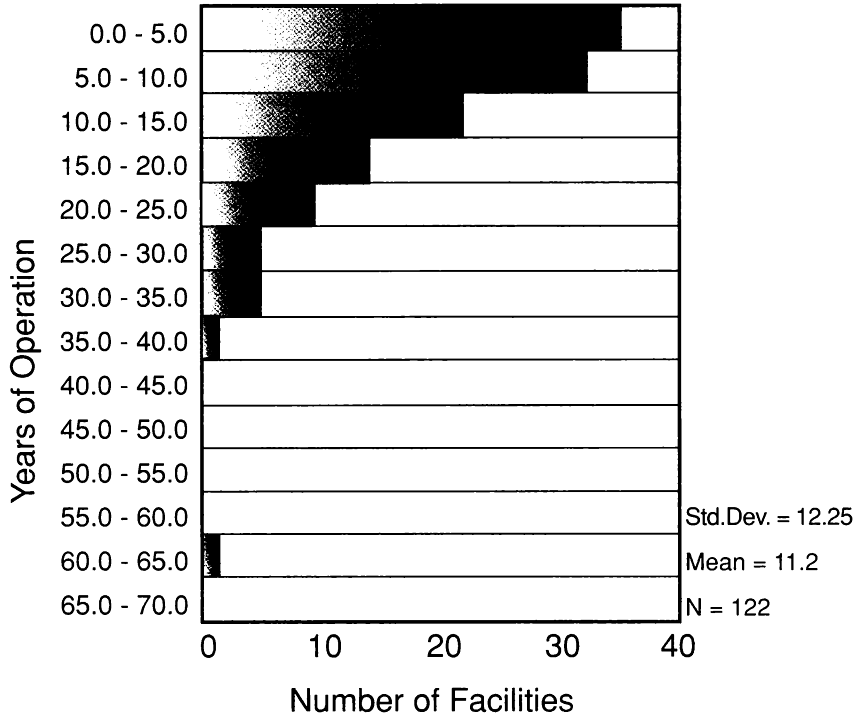

Figure 3: Age of facilities using recirculation technology to produce finfish in the United States and Canada.

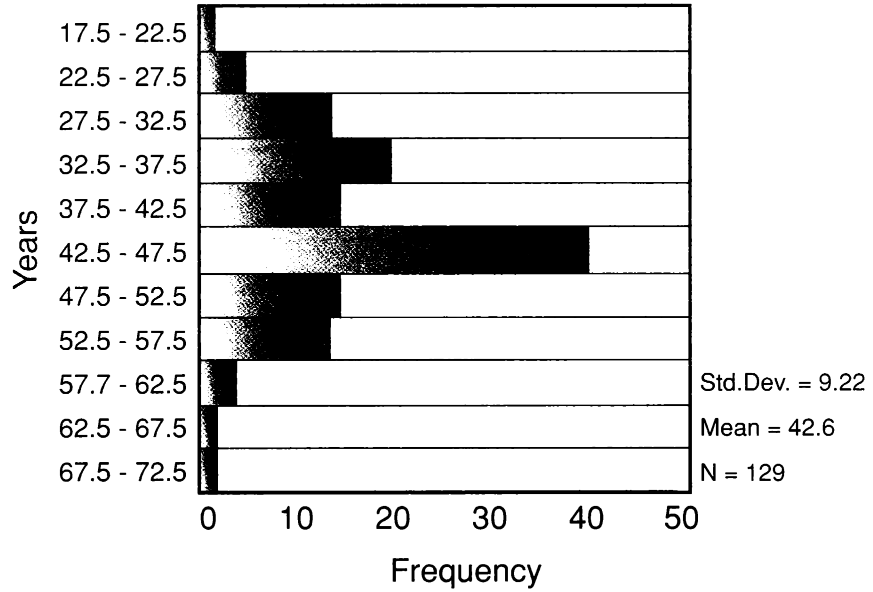

Figure 4: Age of personnel operating recirculation facilities in the United States and Canada.

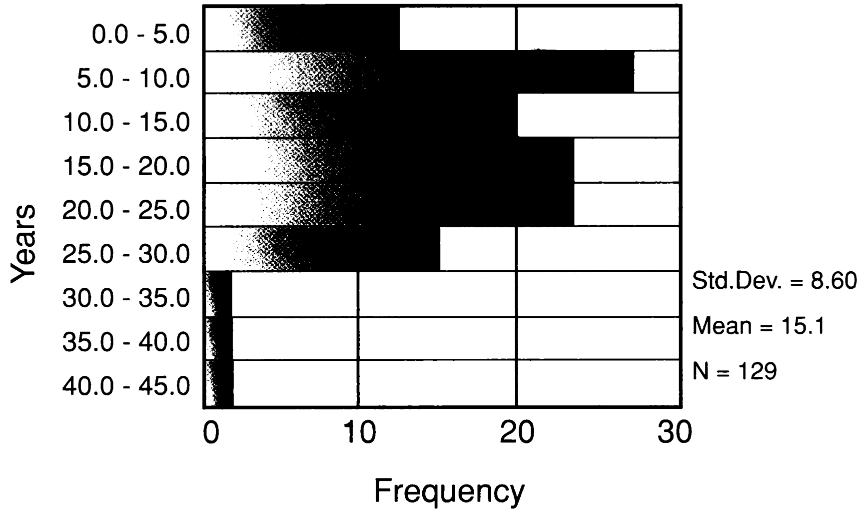

Figure 5: Years of work experience in aquaculture of personnel managing recirculation facilities in the United States and Canada.

DISCUSSION

Recirculating aquaculture systems have been under development in the United States and Canada for the past 30 years. As recently as 10 years ago, however, Masser et al. (1992) commented that "recirculating systems still have not proven to be an economical method of food fish culture". Data from this survey however, indicate that significant shifts have occurred in this sector of aquaculture during the past decade. Business enterprises, specifically facilities growing fish for the food fish market, are today the predominant users of recirculating technologies in the United States and Canada. Masser et al. (1992) also mentioned that "to date, most commercial systems have failed". Here, also, much has changed. Although business failure is common in aquaculture, the survey results show that the sector has expanded and diversified in size and purpose, and that many commercial operations have withstood the test of time. Our survey provides quantitative and qualitative information on many aspects of recirculation aquaculture including size of production, water sources used, and qualifications of personnel working in recirculation facilities. This background information is important for understanding the current status of this still-developing sector. Efforts continue in many areas around the United States and Canada to develop recirculating technologies as a means to grow fish efficiently. These technologies are expected to increase in importance in future aquaculture production, driven largely by the increasing shortage of large quantities of suitable water needed for more traditional methods of finfish culture. Therefore, it seems appropriate that the current status of recirculating technology in United States and Canada be considered to provide a context for how best to develop this sector through the future. A thorough understanding of the constituents in a sector is a key requirement for successful oversight. Previous to this study, however, no information was available on the characteristics of the recirculation sector of aquaculture in the United States and Canada. For government agencies and policymakers to promote growth and to respond effectively to issues related to the recirculation sector of aquaculture, they must have an accurate account of the status of the sector. Likewise, up to this point, researchers have had little empirical information on the biological, physical and managerial characteristics of the recirculation sector of aquaculture, and were to that degree limited in providing research efforts that are applicable to the current situation. Armed with information collected in this study, educators and extension specialists should be better able to assist personnel within the recirculation sector with learning instruments and informational resources that are relevant to the sector's needs.

Our data show that the recirculating sector is diverse, both in terms of sizes of farms using recirculating technology and the types and life stages of fish grown. The current mix of small, medium and large farm enterprises suggests that this sector is quite early in its development. In most agri-businesses, because of the commercial realities of economy of scale, an industry eventually evolves to having few participants growing very large volumes of product. In the present group of respondents, there were five very large farms - possible indication that this sector is already evolving toward large volume production units. Government agencies, educators and extension specialists must plan their programming to account for the fact that annual production of only one of these large farms exceeds the total annual production of all of the farms grouped in the small-farm category (n=69).

One key finding of this study is that the recirculation sector of aquaculture is reliant on groundwater sources for its operation. Because of this, participants in this sector are vulnerable to changes in groundwater availability due either to changes in hydrological conditions or changes in policy or regulation regarding groundwater access and consumption. Any restriction that is applied to groundwater use for aquaculture will impact this sector more severely than other finfish growing sectors. In addition, the findings suggest that research in support of recirculation technologies would fruitfully be directed towards solving key problems associated with the use of groundwater for fish culture. These problems include hazards associated with lethal gas levels, certain fish disease conditions which are more pronounced with the use of groundwater (i.e. nephrocalcinosis) and operational difficulties associated with some types of groundwater (Muir 1994). Our results also show that fully 40% of operations have no secondary water supply. Extension agents might discuss the importance of backup water supplies and explore technical alternatives with clients in their region.

The results of this study may have uncovered a key reason why some recirculation operations that are viable on paper do not succeed in reality. Theoretically, one of the major advantages of recirculation over flow-through culture of finfish is the reduced amount of water required to grow an equal volume of fish. The "cost" of accessing water in recirculation systems is supposedly lower. However, the "cost" of using a water source is a variable factor in the economics of these operations, and our survey indicates that within the recirculation sector, a broad range of water sources are used to grow fish. Pre-treatment water "costs" prior to applying the water to fish or eggs can include costs associated with dechlorination, purchase and installation of equipment to reduce incoming pathogen load, and construction of mixing chambers to adjust water chemistry. Likewise, the necessary post-treatment of a facility's effluent is often influenced by the source of its incoming water. Many economic models of recirculation technologies fail to account for the variety of incoming water sources used and the differences in costs associated with this choice of water source.

The recirculation sector has changed over time with respect to fish species grown. Only a few fish species are currently grown in large quantities using recirculation technology. The diversity of species that farmers have attempted to raise indicates that aquaculture enterprises are seeking and continue to experiment with alternative applications of the technology. At the same time, use of recirculation technology is an initially expensive fish culture endeavor, and therefore it must be acknowledged that market forces, not biological success, may drive the application of recirculating technology to new species.

Management personnel in the recirculating sector of aquaculture are highly educated. Because management capability is usually a combination of formal education and experience, it is quite promising for the development of this sector that the personnel managing these units have on average 10 years of related work experience. Although this sector is considered one of the newcomers to aquaculture production, it has a fairly solid human resource base with respect to skilled management personnel. Indeed, there is no other sector of agricultural enterprise with such a high frequency of higher levels of education at the management level. Government regulators, policy makers and extension agents should be aware of this level of education in order to interact effectively with this group. Vehicles of communication (e.g., workshops, extension bulletins) should provide information at a sophisticated level in order to be viewed as relevant and useful by this group of aquaculturists.

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