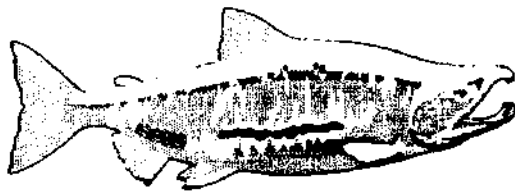


Part III:
Discussion Group
Summaries



Discussion Group Summaries

Introduction

Six informal round-table discussion groups were conducted during the selective breeding conference. These sessions provided an opportunity for participants to discuss and share information on the critical issues of selective breeding for aquaculture and stock enhancement. Conference participants served as moderators and developed the framework for their discussion group session.

Three of the discussion groups examined selective breeding from the aquaculture pro-

duction perspective and two groups considered the stock enhancement perspective. The interaction between selection and conservation of genetic resources was considered throughout the discussions.

The last discussion session was devoted to developing two sets of guidelines for selective breeding; one for aquaculture and the other for stock enhancement. Following the conference, these guidelines were further refined and developed by Graham Gall, Trygve Gjedrem, Kenneth Leber and William Smoker.

Aquaculture Production and Conservation

Priorities for Genetic Improvement of Cultured Fish Stocks

This discussion group focused on the initiation of genetic stock improvement programs for cultured fish stocks. Genetic improvement programs have been developed in some countries but in others, industry resistance persists. Several institutional breeding programs released selected fish for trials on private farms under conditions familiar to the farmers. Following the trials, farmers in many countries were willing to purchase the selected fish and support the selective breeding program. Successful genetic improvement programs for fish, as well as models from other animal industries, were discussed. The moderators for this session were Trygve Gjedrem and James Parsons.

• United States

In the United States, there are no industry-based genetic improvement programs for fish, as in other animal industries. Although research programs have shown that selective breeding can improve fish stocks' performance, it has been difficult to implement programs in the aquaculture industry.

From 1940-1960, university and the U.S. Department of Agriculture (USDA) research station programs were involved in selective breeding for chickens. However, in the 1960s, the chicken breeding program was taken over by private industry and the majority of government-supported selection research efforts ended. Since the 1950s, the USDA and university research stations have been involved in dairy cattle breeding. These programs are paid for largely by private industry and jointly managed. Genetic improvement programs for pigs, sheep and beef

cattle have received government and university attention since the 1930s, but are not integrated with private industry programs. Finally, research units or breeding stations have well defined processes of developing improved plant strains before they are distributed to the commercial producers.

Private research efforts have demonstrated improvements in rainbow trout stocks. However, with few exceptions, current industry trout stock improvement programs do not use up-to-date technology and are thus inefficient.

Genetic improvement programs for channel catfish have not made a strong impact on the industry because program applications have not been transferred throughout industry. Many farmers still use fish strains they developed themselves.

Why is aquaculture lagging behind other animal breeding programs? Possible reasons include: (1) resistance to community improvement programs for fish stocks by independent farmers, (2) the mechanisms for developing and distributing improved genetic material throughout the industry are not in place, (3) lack of funding continuity in research programs, and (4) absence of industry-based genetic improvement programs.

• Norway

In Norway, genetic improvement programs for fish have been cooperative efforts between industry and government research institutes. When programs for Atlantic salmon and rainbow trout were initiated, initial results convinced the farmers that genetic improvement was important. Since the 1980s, the fish farmers' association has been operating such a program, however, it is a cooperative effort, and research institutes are still involved in certain aspects of the program.

In Norway, as well as the rest of Europe, farmers' cooperatives and private companies have been very important in the development of selective breeding programs for other farm animals. The resistance to starting breeding programs for fish in other countries is difficult to explain, especially since research has shown there is a much greater potential for significant improvements in fish performance as compared to other farm animals.

AKVAFORSK, a nonprofit research institute in Norway, exemplifies successful initiation of a selective breeding program for fish. Because of Norway's successful experience with breeding farm animals, breeders recognized a similar potential in salmon and trout. AKVAFORSK began operation in the 1970s when the government research institute initiated a breeding program. Base fish populations were established and the institute began a selection program. At first the farmers were not convinced by the research results. But when the selectively-bred fish were placed on their farms and they saw improved performance, farmers began to support the program. In the 1980s, a national breeding program was started and utilized AKVAFORSK improved stocks. Improvements have focused on growth rate, age at maturation and disease resistance. Now the breeding program is entirely supported by the private sector and the program's costs are built into the salmonid egg price.

• Thailand

In Thailand, selective breeding research on fish has been primarily conducted with tilapia. As in Norway, the research institute found the farmers were disinterested in obtaining genetically-improved tilapia until

they observed improvements in growth and performance on their own farms. There is very little interaction between government and industry in this program. At this time, tilapia breeding programs are supported by the Thai government, with assistance from donor countries.

• **Israel**

The breeding research model in Israel is different from those in Norway and Thailand. The best tilapia breeding research is conducted by communal farms or kibbutzim. The kibbutz develops improved strains and sells them to the farmers. Competition is keen, and the farmers are very interested in obtaining the best-performing tilapia. Carp cross-breeding programs have been conducted for many years in Israel. Hybrids are being produced by crossing different carp strains.

• **Indonesia**

Breeding research in Indonesia has been conducted with carp. Base populations have been collected and selective breeding programs have been initiated at research institutes. However, once the selected fish are transferred to private farms, breeding protocols are ignored and farmers often cross the improved strains with their own fish. It is, therefore, difficult to obtain reliable results about performance of the improved stocks.

• **China**

Selective breeding in China is conducted at research institutes and financed by the government. Though cross-breeding is common in the country, it wasn't until 1978 that private industry was allowed to develop and today, every time an improved fish strain is developed, the farmers want to obtain the fish. Thousands of private aquaculture

farms are in operation, but few make enough money to support genetics research. Therefore, the research is supported by the government. The Ministry of Agriculture receives funding from several government agencies to support selective breeding research. Scientific awards are given out to the best researchers, consequently providing the primary incentive for researchers to develop improved strains of fish. The availability of financial support for breeding research varies among research institutes; some are well funded while others struggle for livelihood.

• **Taiwan**

In Taiwan, selective breeding research at the universities and research institutes is focused on disease-resistance and improving cold-tolerance of species. Very few private farmers practice selective breeding, but those who do focus on improving growth rates. Some tilapia hatcheries have been successful in improving growth rates, but only the hatcheries that produce the fastest growing tilapia are able to compete and stay in business. Because there is competition between hatcheries to produce quality fry, genetic improvement will be important to fish farmers in the future.

• **Vietnam**

The biggest problem in Vietnam is the declining performance in cultured fish. Reasons for this decrease may include inbreeding depression, uncontrolled crossing between species and selection of smaller-sized fish as broodstock. In the 1970s, the Vietnamese government funded a selective breeding program, but because the farmers would not purchase the improved larvae, the program distributed them free of charge. About ten years later the selective breeding

program began to show some positive results and farmers personally observed improved fish performance. The demand for selectively bred fish increased and now the stocks are sold for higher prices than other fry and fingerlings.

- **Philippines**

A collaborative effort, The Genetic Improvement of Farmed Tilapias (GIFT project), has recently been initiated in the Philippines. Because the country lacks a national breeding program and a fish farmers' association, a government agency disseminates breeding information throughout the country via satellite research stations. The GIFT strategy is to (1) show the farmers that the "improved fish" are better than fish they are currently raising, (2) initiate a national tilapia breeding program, and (3) make the genetic resources available to the private farms because small farms lack the resources to start or operate a breeding program. The national breeding project is designed to be managed by national institutions and to generate research funds through the sale of fingerlings. The goal is that one day farmers will be able to run the program themselves. The GIFT project is modeled after the Norwegian selective breeding program (see discussion of AKVA-FORSK) and has as its mission, the development of breeding programs in Asian countries.

- **Japan**

The situation in Japan is somewhat different than in other countries. There are two types of government-operated institutions that produce fish in each prefecture; one produces stocks for release or stock enhancement and the other produces fish for aquaculture operations. Non-selective breeding is practiced in the government stock enhancement

hatcheries where they produce large numbers of offspring, using as many parents as possible. For example, the Japanese government presently releases 16-20 million red sea bream offspring and 10 million chum salmon per year.

There are also many private hatcheries that produce fish for aquaculture. The type(s) of selective breeding for aquaculture used in those hatcheries is not well known. When operators are asked about their techniques, they say it is a trade secret, but researchers suggest it may be just poor record keeping.

To date, very little selective breeding research has been done in Japan. However, the government fisheries department recently took an interest in selective breeding research and is preparing to launch a large-scale research project. In 1992, a ten-year breeding research plan was initiated with an annual budget of \$2 million. The program will focus on breeding sea bream, abalone, flounder, salmon and most other species that are cultured in Japan. The problem is that the plan is very grand, and Japanese researchers and technicians are not well trained in genetics. Therefore, prior to initiating the research program, a large-scale educational effort must be implemented.

- **Singapore**

In Singapore, ornamental fish farms are small family-run businesses, which are unable to contribute to selective breeding research and development efforts. Extensive research has been conducted on selective breeding of ornamentals, but it all has been funded by the government.

Guppies exemplify the potential of selective breeding for improving fish performance. Selective breeding has been conducted for approximately 40 years with guppies, and

because they are able to produce about three generations per year, breeders have produced about 120 generations of selected guppies. This has resulted in a ten-fold increase in the size and weight of male guppies, as compared with the wild-type guppies. These results demonstrate selective breeding potential and its impact on fish production.

• Conclusions

To create a successful selective breeding program, there must be an on-site demonstration (data or photos are insufficient) that allows farmers to directly observe and compare improved fish in comparison to their own stock. This has been done successfully in Vietnam, Thailand, the Philippines, China and Norway.

Although conference participants thought the first-hand-observation approach might convince U.S. fish farmers, specifically salmonid farmers, of the merits of selective breeding, some participants suggested the difficulty might be in the length of time needed to observe economic results. The farmers' limited technical understanding of selective breeding also presents an obstacle. When comparing time elements of selective breeding improvements to those of improved feed, the feed industry can demonstrate an immediate improvement. The same rapid results are observed with the introduction of a new vaccine. But the general perception, even among many of the workshop participants, is that the results of genetic improvement may not be seen for many years.

A U.S. farmer/workshop participant believed the problem with initiating a genetic improvement program in the United States is that U.S. farmers are faced with many barriers to success (regulations, limited capital, etc.). These barriers consume all of the

farmers' energy and resources, leaving little time to consider genetic improvement. The same barriers limit the availability of U.S. funding for selective breeding research because research monies are committed to other areas such as nutrition.

Both Dr. Gjedrem and Dr. Gall noted that it does not take ten to fifteen years to see selective breeding results. Dr. Hershberger's research has shown that selective breeding of coho salmon can result in an average gain of 10% per generation. Because selection works in a step-wise fashion, improvements are seen in every generation. This is not the case with cross-breeding or hybridization. Cross-breeding takes approximately five generations to achieve a positive result, and the resulting crossbred stock is not itself amenable to further improvement. Many farmers have made the mistake of investing in hybridization or cross-breeding research, instead of selective breeding, and they have been dissatisfied with the results.

Genetic Conservation Issues Related to Aquaculture

The purpose of this discussion group was to consider conservation of genetic variability for aquaculture production. Many approaches are possible, therefore, conservation and preservation decisions must be handled on a country by country basis. Examples were cited from Indonesia, Vietnam, China and Taiwan of programs that have been established to conserve the genetic diversity of aquatic and terrestrial species. Some countries have determined which species to focus on and how to maintain the genetic material or germplasm, while others are still developing their criteria. Modera-

tors for this session were William Wolters and Sifa Li.

The first step in genetic conservation is to determine which species, and varieties within a species, will be conserved. If only the species important to aquaculture production are considered, they need to be identified and ranked in order of importance. Another approach is to preserve a few individuals from a variety of species. Genetic conservation of all species and their varieties may be unrealistic, but such an approach would provide greater conservation of genetic variability.

Identification of genetic resources for selected species is the second step in genetic conservation. An inventory of the populations or species must be conducted and a determination of the population size and numbers of varieties must be established.

Some researchers have expressed concern about selective breeding and its potential to decrease the genetic variability in cultured species. However, in some agricultural crops that have a long history of culture, this has not been the case. For example, the poultry industry was concerned about losing genetic variability in chickens and turkeys. Yet, despite many years of selection, significant loss in genetic variability has not been documented. Variability has been further

maintained by commercial producers and hobbyists.

Individual countries must also determine how to use the safest or most secure approaches to maintain the genetic variability of conserved species (Fig. 1). The maintenance of live fish, for example, may not be feasible.

There is a high degree of risk in maintaining species in stock-centers. Care must be taken to prevent gene loss and contamination from other varieties or species, to maintain genetic differences and to minimize domestication. The funding required to maintain genetic material can change as priorities within a country or government change.

The potential of breeding programs to revitalize endangered species was also discussed. This has been done with terrestrial and aquatic species, such as the American bison and American alligator.

Conservation Issues Related to Biotechnology/Genetic Engineering

The purpose of this discussion group was to consider the conservation issues related to biotechnology and genetic engineering of fish. The first half of the discussion considered the benefits and risks associated with biotechnology. The second half focused on steps to consider in the decision-making process regarding the field testing and use of genetically-modified organisms (GMOs). The moderators for this discussion group were Eric Hallerman and Chingjiang Wu.

• Benefits and Risks

One of the benefits posed by biotechnology is aimed at gene pool conservation. Three techniques that may prove useful in gene pool conservation are cryopreservation, an-

Figure 1. Current Conservation Methods

- ▣ DNA or cell banks
- ▣ cryopreservation of gametes (especially sperm)
- ▣ establishing stock centers or "fish parks"
- ▣ hatchery maintenance of broodstock
- ▣ maintaining stocks in nature

drogenesis and chimera production. Cryopreservation of sperm can effectively create a stored gene pool, androgenesis will allow subsequent regeneration of those sperm into complete living animals and chimera production is used to generate complete animals from cryopreserved embryonic cells. Although fish embryos cannot yet be cryopreserved, fish cells can. Cells from the early embryonic cleavage stages can be injected into the blastocysts of developing eggs and become incorporated into a newly forming embryo. In the future, cryopreservation of raw DNA may be a mechanism to conserve gene pools; however, at this time we are unable to regenerate animals from raw DNA. The San Diego Zoo in California has set up a storage facility and is presently cryopreserving the DNA of many different types of organisms. This material will be held at the zoo until the technology is developed.

Another potential benefit of biotechnology is to relieve the commercial fishing pressure on wild stocks. Through biotechnology sterile fish can be produced, which can then be harvested by commercial fishermen. With few exceptions, these fish are unable to reproduce and, therefore, pose little threat to the wild stocks, although behavioral and ecological impacts of the released fish have not been examined.

There are some risks posed by biotechnology. Both ecological and genetic interactions could occur between wild and genetically modified fishes. The ecological interactions could occur through competition, predation and habitat alteration due to the presence of genetically modified fish. Crosses between wild and genetically modified fish could effect the fitness of the wild fish. The result could span between two

extremes, where at one end of the spectrum there is a genetic improvement in the stock and at the other end the genetic stock could become less viable. There is also the concern that these genetically modified fish could potentially affect the evolution of wild stocks.

Another risk from biotechnology is that it is often seen as a technical fix and may not address the real problem affecting the fishery. For example, biotechnology does not address the problem of decreased habitat quality or over-exploitation. It is possible, though, to rephrase this risk as a benefit, rather than a deficit. Biotechnology may enable compensation for decreases in habitat quality or over-exploitation through increased fisheries production. An appropriate balance between conservation and utilization of resources needs to be achieved.

- **Decision making process for the use of genetically-modified organisms**

Before genetically-modified organisms find general use, the risks need to be assessed. It is possible to use a model system or an experimental mesocosm (a simulation of the natural environment) to assess the types and magnitudes of risk. The closer the simulation to natural conditions, the better the test. The mesocosm could even be a small, isolated, manageable natural system. It may be possible to include conspecifics and other elements of the relevant aquatic community, along with the genetically modified fish. By monitoring the results, looking for perturbations and determining if the aquatic system has the resiliency to deal with those perturbations, it may be possible to assess the risks associated with genetically-modified organisms. There are problems with scale, replication and cost.

The best way to look at the decision making process is to consider it as a step-wise process of risk assessment. It should start with a simple mesocosm and if the results show a negligible risk, then the assessment can move to a more complex or larger-scale test. There are time constraints on this process, though. The risk assessment must be done expeditiously so that it has academic and industry support. Also, the experiments to evaluate the risk need to be strong tests. In other words, the genetic manipulations have to be great enough to generate an impact; if no impact is observed as a result of the manipulation, then the evidence supporting no impact is stronger. Similarly, the test must be well designed so that presence or absence of impact is regarded as credible.

Once the risks have been identified, they need to be managed. A decision making process for management of risks is outlined in Gregory (1992). Gregory identified a six-step process in decision making (Fig. 2).

The key stakeholders in aquatic biotechnology include the developers of genetically-modified organisms, aquaculturists, environmentalists, regulators and society as a

Figure 2. Six-step Decision Making Process

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| <ul style="list-style-type: none"> ▣ Identify key stakeholders who will be impacted ▣ Determine possible technical and managerial alternatives ▣ Identify consequences of each alternative ▣ Estimate likelihood of these consequences ▣ Determine the stakeholders' values regarding consequences ▣ Link values to the consequences of the alternatives |
|--|

whole. The technical and managerial alternatives must be clearly identified in order to consider the options. The consequences of each alternative must be identified (i.e., enhanced aquaculture profitability, displacement of local genetic stock). The likelihood of both good and bad consequences should be outlined. Estimating likelihood of particular consequences is the most difficult step to accomplish. An approximation using a computer model might be the first step. The likelihood of increased aquaculture profitability due to use of genetically-modified organisms would be high, but the likelihood of ecological risk may be lower than with non-modified organisms, if the modified organisms are sterile. The reactions of the stakeholders to the various consequences of use of genetically-modified organisms need to be considered and weighed against one another. Finally, as the consequences are linked to one another, all stakeholders need to be included in the decision making process.

A better understanding of the usual complications in risk management will improve the decision-making process. Gregory (1992) identified the complications listed below:

- > Zero risk is an illusion.
- > Risk decisions involve conflicting objectives.
- > Risk decisions involve statistical rather than individual effects.
- > Risks to life must be traded off against other considerations.
- > The analysis of risk is never objective.

Risk management is a process and the outcome varies with the society. What works best in one location or country may not work in another.

Reference:

Gregory, R. 1992. A Decision Framework for Managing the Risks of Deliberate Releases of Genetic Materials. *In*: A. Rosenfield and R. Mann, Eds. *Dispersal of Living Organisms into Aquatic Ecosystems*. Maryland Sea Grant. pages 421-434.

Guidelines for a Selective Breeding Program to Improve Fish Performance

These guidelines outline a general approach to the development of selective breeding programs for improved fish performance. However, each selection program must be designed for specific species, production system, breeding goals and community of farmers involved in fish production.

It must be emphasized that an effective selection program requires a dedicated commitment to long-range permanent improvement of production efficiency. Because substantial physical and financial resources may be required, industry representatives must find the program acceptable and beneficial.

Experience has shown that during the early years of a breeding program, new and innovative selection programs require strong leadership and resource support from a governmental and/or institutional organization. One mechanism that insures a successful long-term selection program is the formation of a breeders' cooperative. Initially, it can provide orderly advice for the development of the selection program and later take over responsibility for the selection program.

These guidelines were initially developed by the discussion group session moderators (Ta-

Table 1. Guidelines for a Selective Breeding Program to Improve Fish Performance

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| <ul style="list-style-type: none"> ▣ Establish a sound support base and a well developed mission ▣ Assess potential production system, set market objectives and evaluate available stocks ▣ Choose a selection method and mating system ▣ Define a rearing and testing system ▣ Develop protocols for data collection ▣ Establish data collection method |
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ble 1). The guidelines were expanded and revised during a subsequent discussion session and later significantly expanded by Graham Gall. The moderators for this discussion group were Graham Gall and Supattra Uraiwan.

• **Guidelines**

- ▣ Establish a sound support base and a well developed mission.

Fish farmers can provide valuable ideas and focus to a selection program. Therefore, its design and development should involve farmers at the earliest possible stage. However, based on genetic knowledge of the species and its performance characteristics, extensive scientific evaluation must be conducted to ensure that the program's goals are achievable. The evaluation requires a thorough study of the scientific literature and an interpretation of available data by qualified quantitative geneticists.

The scientific evaluation should review

- > the biology of the species,

- > the biological nature of characteristics potentially affecting the economics of production,
- > the degree of heredity (heritability estimates) for all potentially important characters,
- > possible correlations between performance characters,
- > the relative importance of all identified characters to the economics of production, and
- > the potentially limited genetic material required for the program.

Genetic material may be limited by importation regulations, current numbers of stocks used by farmers and the domestication level of available stocks.

The selective breeding program should include replicate selection lines (broodstocks). An unselected control line should be included if it involves a new species, a new approach or a demonstration and feasibility research effort. Replication is important for monitoring selection responses, providing genetic information to improve the selection program and for validating results. The unselected control line will identify changes in performance due to environmental fluctuations that might otherwise be interpreted as genetic changes.

- » Assess potential production system, set market objectives and evaluate available stocks.

It is extremely important that industry production systems and market objectives be carefully examined for both current operations and anticipated future changes. This information is essential for defining sound

breeding objectives. Program goals must be specifically designed to define the characteristics (performance traits) that will be the targets of selection and to improve performance and economic gain for the industry.

Improved growth rate is the fish breeder's most commonly pursued goal, and discussion of this performance trait exemplifies why breeding goals must be specifically defined. Growth rate can be described in a number of ways, but the only genetically and biologically meaningful definition is "the change in body size observed over a specified growing period." For example, the trait for carp growth rate could be defined as weight gain seen during the second summer of rearing. This would require that both the beginning and ending dates be specified, with growth calculated as the gain in weight of individual fish (or families of fish) over this specified time interval. Body weight at a specified time or size should not be used as a measure of growth rate. Rather, since larger body size can be achieved through changes in growth rate at various points during the life of the fish, body weight is simply the body size at the specified time. For example, larger tilapia could be produced by faster growth during the juvenile stage, with little change in growth rate during later stages – just prior to market size. Thus, selection for body weight will be effective in improving growth only for those cases in which selection will reduce the time required to grow fish to market size. In these cases, either the life-cycle stage at which changes in growth occur is not important in the production system, or available scientific information indicates that changes in growth with greatest economic impacts can be expected during the stage of production with greatest economic impact.

Once breeding goals have been defined for the production system and market objectives identified, all available genetic material in the form of stocks or strains, should be evaluated for its appropriateness to the breeding goals. It is important to begin the selection program with a stock that meets the industry's performance objectives as closely as possible. Following evaluation of performance, the most productive stock(s) are chosen to form the initial broodstock (referred to as the base populations).

It is possible to design a simple selection program using only a single base population or a more complex program using two or more populations. With the latter system, the objective is usually to improve parallel lines (broodstocks) for different performance characters with the intent of combining the lines for production through cross-breeding.

If a single stock is chosen, then a relatively large sample of individuals should be obtained to form the base population. The size of the initial sample should be sufficient to ensure a broad sampling of the genetic material possessed by the donor stock.

If more than one stock is chosen to form the base population, the stocks should be crossed in all combinations and then interbred as a closed population for one or two generations prior to initiating selection. This process ensures that genetic material contributed by each stock is mixed before the selection of desirable individuals.

» Choose a selection method and mating system.

The operation of a selection program involves two steps per generation: (1) selecting superior individuals to parent the next generation (referred to as the **selection method**);

and (2) mating the selected individuals to produce the next generation of individuals (referred to as the **mating system**). The first step defines the way the fish will be ranked in terms of performance. The second step determines the method used to produce eggs (seed). The mating system can (1) be part of the production system, in which case all production is from the eggs of selected parents; or (2) produce only eggs that will form the next generation of selected broodstock. In the second case, eggs for production must be obtained through a multiplication step, which can include the cross-breeding of selected broodstocks.

There are several different selection methods that can be used, and the decision between them is based on which approach is expected to provide the most efficient response. Briefly stated, the choices available to fish breeders include:

- > **Mass Selection** - selection of individuals based solely on the performance of the individual fish,
- > **Family Selection** - selection of families based on the average performance of all family members,
- > **Within-Family Selection** - selection of individuals within families based on the performance of individual fish relative to the average performance of their family members,
- > **Combined Selection** - a specific combination of family and within-family selection, and
- > **Breeding Value Selection** - selection based on estimated true breed-

ing value of individuals obtained from a linear models statistical procedure.

All selection methods (except mass selection) require that the breeding population be pedigreed (individual fish marked for identification). Although mass selection can be performed without pedigree data, the lack of information upon which to judge the ancestry of individual fish will result in a slower selection response and may produce a response rate that is not economically viable.

Superior (selected) individuals must be mated to produce the progeny for the next generation of improved broodstock. A number of mating systems might be used, including random mating, assortative mating and cross-breeding. Random mating is the most popular system. Selected males are mated randomly with selected females. This can be done by mating the fish in single pairs and producing full-sib families. Assortative mating involves mating the best selected males with the best selected females in rank order. This method is desirable when a large number of broodstock are used to provide both the future selected progeny and seed for future production. Selected future progeny are taken from matings among the best individuals. Production eggs are obtained from the lower ranking fish.

To enhance the effectiveness of the selection method, regardless of whether mating is random or assortative, it is generally desirable to establish families of both half- and full-sibs within the selected broodstock. In these cases, the families are produced by mating each male to more than one female, usually at random. If there is concern about the rate of inbreeding or the desire to prevent inbreeding in early generations of selected parents and their progeny, the random mat-

ing method can be modified to eliminate matings among half- and full-sibs.

The cross-breeding method of mating is used to produce eggs whenever it is desirable to combine genetic material from more than one selected broodstock source. Selection methods that produce special lines for specific performance traits in separate broodstocks must use cross-breeding for seed production. However, cross-breeding cannot be used to produce future generations of the selected broodstocks. For example, in one line a selection program could be set up to select for improved body size at a specific age, and in a parallel line selection could be for improved survival. Eggs for production are then obtained by crossing males from one selected line with females from the second selected line. However, the pure lines (selected broodstocks) must be maintained by mating selected males and females within each line.

» Define a rearing and testing system.

Rearing and testing systems will determine the kind of data used to rank fish performance. The rearing system should reflect industry use; however, it is often more desirable to rear fish at the research station and at test stations located on cooperating farms. Rearing at the research station will provide detailed information on broodstock performance for traits of direct interest for selection, as well as on other traits being monitored. The use of test stations ensures that broodstock are regularly tested for selected traits of interest under farm conditions. The information from the two sources can be used to rank the fish for selection.

Defining rearing and testing systems involves identifying the types of rearing containers (i.e., tanks, raceways, net pens),

rearing densities, seasons or stages of life-cycle for the test (i.e., complete life cycle, final stage growth, first and second maturation) and length of test periods (i.e., full summer growout, 120-day test period, through first maturation). The test also determines the number of fish tested, including total number of individuals and families. In addition, the test design must include the number of fish to be selected.

The intensity of selection will be determined by the total number of fish tested relative to the number selected. The total number of fish tested will be determined by the capacity of the rearing and testing system, while the number of fish selected will be determined primarily by the number of females required to provide the appropriate number of eggs. To ensure that selected individuals in seasonal spawning species (i.e., salmon, trout) of both sexes mature at the same time during the spawning season, it may be necessary to select a larger number of individuals than needed to meet egg requirements. However, this should be avoided if possible.

» Develop protocols for data collection.

Performance traits must be precisely described and defined, relative to when and how performance will be measured. The description defines the specific genes, or genotypes, that control performance traits. To evaluate the full effects of the selection program on overall net performance of broodstock, protocols should be developed for traits of interest in the selection program (traits used to rank fish for selection) and monitored traits.

To achieve a proper trait description, data collection protocols must properly reflect the performance traits as defined for production systems and market objectives. For exam-

ple, if the selection program goal was to increase body size of salmon at market time, setting up a protocol to measure body weight at the end of a two-year growout period would define a different performance trait than a protocol to measure body length at the end of a two-year growout period. Similarly, a protocol to measure body weight at the end of one year would define a third performance trait. The most appropriate measure of body size will depend on the objectives of the program. If the salmon are sold (marketed) and valued by weight, then measuring body weight would define a trait more reflective of the product to be marketed. Conversely, a protocol based on body length would be more appropriate for a market in which value is based on body length.

Deciding when measurements should be taken (e.g., at the end of one or two years) depends on the market and the genetic correlation among traits. If the stock requires two years to reach market size, then measuring body size at market time directly reflects the production objective. Improving market size at two years, based on measuring body weight at one year, would be successful if there was a high genetic correlation between body weight at the two ages. Shortening the data collection period may reduce the time required to complete the selection of superior individuals, thus reducing the cost of rearing.

The data collection system should not only identify and measure performance for the trait under selection, but also monitor economically significant performance traits not under selection. These non-selected traits should be carefully defined and data collected at the appropriate interval as an essential part of monitoring the overall effects of selection. One or more of these traits may

negatively change as a correlated response to selection. For example, selection for larger body weight at a specific age or time could result in correlated changes in age at first maturity. If these changes become economically significant, the selection program should be modified to prevent the continued accumulation of detrimental effects on net performance of the stock—possibly by including additional traits as selection criteria.

» Establish data collection method.

Establishment of an effective and efficient data recording method is one aspect of selection programs that is often neglected. Key design aspects of the data collection method include identification of fish, maintenance of pedigree information, ease of access to data used in making selection decisions, computer maintenance of data files and compatibility of data type and format with data analysis programs.

Fish identification is particularly important in evaluating results and identifying necessary modifications to the selection program, because it is possible for genetic correlations between traits to change as selection advances. For example, selection to improve two-year body weight based on performance at one year could initially be effective due to a high positive genetic correlation. However, because selection changes gene frequencies, it is possible that the correlation between the two traits could deteriorate to an unacceptable level after a few generations.

A large amount of data will be generated as a selection program progresses. This information should not be lost because of poor data recording and storage methodologies. Data can be used to estimate genetic parameters specific to the program's broodstock and potentially reveal facts not available in the scientific literature. In addition, parameter estimates for these data will be more applicable to the broodstock under selection than estimates contained in published literature. Finally, the genetic information will be valuable for monitoring selection progress and defining specific and essential modifications to the selection program.

» Design a regular evaluation procedure.

The program should be monitored frequently during the initial phases. In fact, following the order of activities given in these guidelines, it may be necessary to undertake one or more iterations of the program design even before selection is initiated. It is often difficult to anticipate each step in advance.

Once selection is initiated, changes should not be undertaken until at least two generations of selection have been completed, unless a major problem is identified. Short-term responses may reflect random chance events. When modification appears necessary, the program should be evaluated by reviewing each activity outlined in these guidelines. It is also important to identify how modification decisions will be made, particularly with regard to involving the fish farmers who are associated with the program.