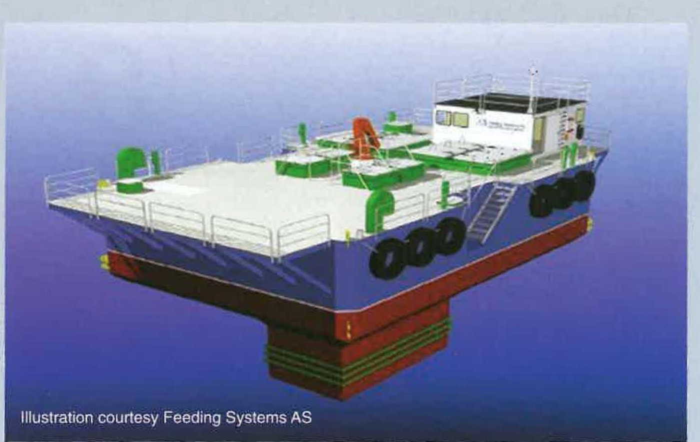
The evolution of aquaculture feed supply systems

As any fish farmer knows, feed is usually the most important variable production cost. A simple objective is therefore to minimize waste from uneaten food, which has the added benefit of reducing the risk of environmental degradation. However, decreasing feed level risks reducing growth rate, leading to a rise in other costs per unit of production. The optimum biological feeding rate is thus rarely the same as the optimum economic rate. In practice, these calculations are complicated as feed requirement and efficiency of conversion varies with changing environmental conditions including water temperature, oxygen concentration, water quality, current speed, light intensity and day length. Feed utilisation also varies with diet quality and physiological factors such as age/size, life-stage, stress level and endogenous rhythms. It is therefore not surprising that these factors contribute towards an element of uncertainty regarding the amount of feed required, often leading to under or over feeding of stock and resultant under performance of the system.

Traditional automatic feeders deliver fixed amounts of food at pre-programmed intervals and although they reduce the labour involved in such activities, cannot react to any unexpected changes in fish feeding behaviour. Demand feeders were developed as a possible solution, but found to be subject to problems with dominant fish preventing access for others to the feed, and were limited to those species that could be trained to use them.

The challenge has therefore been to develop feeding systems that take better account of the changing needs of the fish whilst remaining practical and robust. The emerging systems, known as "adaptive', "smart" or "intelligent" feeding systems, utilise an increased understanding of fish physiology, nutrition and behaviour and take advantage of improved sensor and computing technology.

As with earlier systems, the main variables that can be controlled are the timing of feed events, and the quantity of feed delivered. The rate of delivery and the degree of spread achieved tend to be a characteristic of the feeding system, although these may also be influenced by operators. The main advance from earlier systems is the inclusion of additional sensors, most commonly to detect feeding activity, either directly or indirectly through monitoring for waste pellets beneath the feeding zone. The systems described below are predominantly designed for grow-out cages.



Platform-based systems with large floating silos are increasingly available for cage sites that are not close to shore

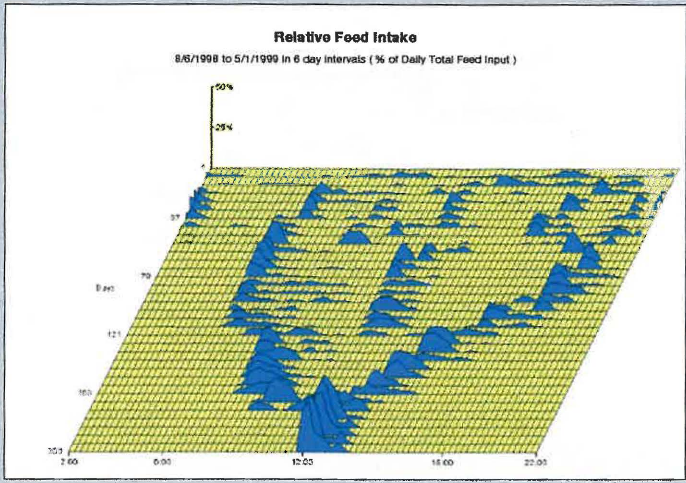
Feedback systems

Traditional hand-feeding uses feed tables and the experienced eye of the feeder to adjust the feed quantity to suit the needs of the stock. As holding units, and especially cages, have become larger and deeper accurate visual observations of the stock have become more difficult. Two relatively simple methods of improving information feedback of feed consumption are the airlift pump and the underwater video camera. Feed may be delivered via a feed cannon or other type of feeder, until a significant number of pellets are observed being drawn up through the airlift pump by the operators. The feeder is then turned off, and the operators can move onto the next unit. More advanced systems may have a pellet counter to provide an automatic feeder cut off, and a facility for recycling the uneaten pellets. Alternatively, some farms now make regular use of submersible video cameras to observe the stock during feeding. Again, this is usually to aid the judgement of the person controlling the feeder (usually a feed canon), although further developments in image analysis software might lead to video being incorporated into automated systems.

Adaptive automated systems

For feedback systems to be used in automatic feeders, it is necessary for more quantitative information to be produced, which can be analysed and used as a controlling variable within a feed control program. The most common approach has been the use of an in-situ pellet sensor to detect uneaten pellets falling out of the feeding zone. With this information, combined with data on both the quantity and timing of the food fed, the software can continuously optimise the quantity and timing of feed delivered. An example of this approach is the AKVASmart AQ1 Adaptive feeding system (Figure 1) that uses infrared sensors to measuring the rain of pellets passing through the confines of a collection funnel below the feeding zone. When pellet frequency reaches a critical point, indicating satiated fish, feed supply can be terminated. As the amount of feed introduced is sufficient to satiate the fish whilst limiting wastage, research in Norway has shown the system can achieve a 17% improvement in FCR over the industry average. As the software logs all events, analysis of the food fed data gives a detailed picture of the feeding behaviour of the fish, allowing the management to be further tuned, for instance to ensure sufficient feed is available in the feeders to meet peak demand.

Another approach developed by several manufacturers utilises hydroacoustic sensors. These are usually suspended below a fish cage, facing the surface, to provide a sonar image of the cage contents (fish and, depending on the transducer capabilities, also the feed). AKVA market a hydroacoustic sensor (the Doppler unit), which is claimed to distinguish pellets from other items in the cage, and hence determine when significant proportions are reaching the bottom of the cage. With the merger between AKVA, AquaSmart and Superior Systems, the AKVA and Aquasmart control systems are being merged. A similar system (The Peneye) is marketed by Feeding Systems A.S., in this case the hydroacoustic sensor is optimised to measure the fish position and density within the cage. If feed is supplied when the fish are



Output from AKVASmart computer system showing feed pattern varying with time

hungry, they will rise to the surface, descending when their appetite has diminished. The location of the fish therefore relates to changes in appetite, although it may also be indicative of other events such as predator attack, changes in water quality and disease. The appearance of fish below the bottom net of a cage indicates over-feeding, which is attracting wild fish. Once again, analysis of the signals by software can provide the basis for controlling feeders, and could potentially be linked to alarm systems or anti-predator devices.

An early implementation by Simrad estimated biomass and calculated the spread and distribution of fish size. Rapid changes in calculated biomass could be interpreted by software as indicative of a problem such as a hole in the net allowing fish to escape. The cost-benefit of these systems is strongly correlated to cage size, with the investment cost being easiest to justify on farms using larger cages.

Approaches to bulk feeding

As the average sizes of aquaculture units grow and the pressure for efficiency increases, feeding systems have developed greater capacity as well as greater control. Separate feeders for each tank or cage are often no longer cost-effective and new developments have focused on centralised systems for large tanks and cages and robot feeders for smaller tanks.

Robots

In land based systems, particularly those with a large number of tanks (> 30), Arvo-tec of Finland has developed a "robot system" This consists of 1-4 hopper/feeder units which move between tanks by means of an overhead track. A computer control system allows unattended operation, with the robot feeders guided by magnets in the track, backed up with optical sensors. Each tank is fed according to the individual directions of its programme. As the robot progresses, temperature and dissolved oxygen levels in the supply and discharge water can be measured and the values incorporated into the underlying feed model so that any required changes can be made to the feed supply. For instance, if the oxygen level of discharge water decreases to unsuitable levels, the system will begin to reduce or terminate feeding whilst raising the alarm. The robot hoppers are refilled automatically when they reach a refill station on the track. The system offers ►

a more cost-effective approach to placing sophisticated feeders on each tank, and can handle smaller feed amounts more accurately than most centralised pneumatic systems.

Centralised feeders

Centralised air-powered feed systems have been available for several years. Feed is stored in one or more central silos, from here the feed empties into a dosing unit from which it is transferred to an injector unit, main transport pipe and, via air from a blower, to its destination tank, pond or cage by a distribution valve and individual feed pipes. This approach massively reduces the amount of labour required for feeding (traditionally a labour intensive activity), but has a high capital cost, and may not be suitable for widely spread or offshore sites. Platform-based systems with large floating silos are increasingly available for cage sites that are not close to shore. These systems are all computer controlled and their potential is especially enhanced when used in combination with feedback controller systems. Manufactures include AKVAsmart, ETI (Environmental Technologies Inc), Feeding Systems AS, ARE, and Sinergia.

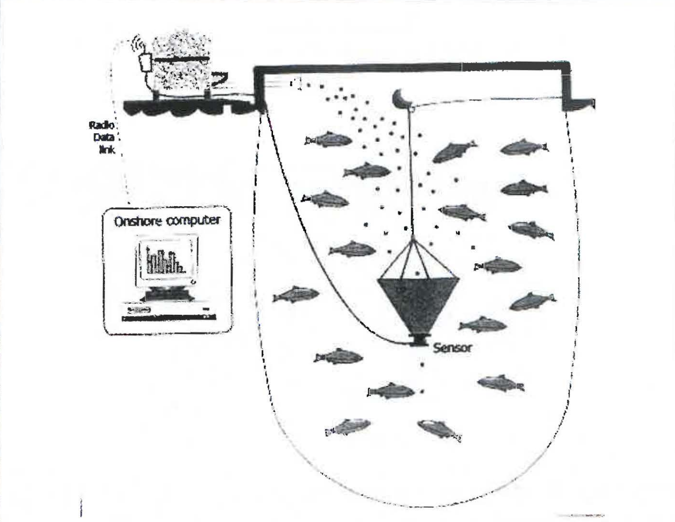


Figure 1: Illustration of the AKVASmart AQ1 Adaptive Feeding System

The Future

A 35% reduction in food conversion rate is theoretically possible, suggesting scope for further improvements to diets and feeding systems. Increased automation looks likely so long as farm units continue to increase in size under pressure to reduce production costs. Further research will help provide a better understanding of the environmental factors affecting feeding and food assimilation, which should lead to further refinement of the type of systems described above.

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