Low-Phosphorus Feeds Development

Impact Statement

Western Regional Aquaculture Center

USDA NIFA
United States Department of Agriculture
National Institute of Food and Agriculture

IMPACTS HIGHLIGHTS

- Prevented a 20% loss in trout production.
- Allowed higher production levels worth more than $6 million/year in Idaho alone.
- Permitted efficient low environmental-impact trout production by reducing phosphorus levels in feed by nearly 40% without affecting growth of fish or product quality.

ISSUE

In the early 1990s, nutrients in aquaculture effluent waters came under increasing regulatory scrutiny because of their role in stimulating unwanted algal and aquatic plant growth in public waterways. As a result, a number of states developed regulations that restrict the amount of phosphorus, nitrogen, and fecal solids that are allowed in the discharge water of freshwater fish culture facilities. At the time, these new regulations threatened to dramatically reduce production by the trout industry.

WHAT HAS BEEN DONE

Because phosphorus is the nutrient with the greatest impact on algae and plant growth in freshwater, WRAC funded two research efforts that focused on determining ways to reduce phosphorus levels in hatchery discharge water.

1. Pollutant Reduction in Salmonid Aquaculture by Diet Modification (1993-1996)

Principal Investigators: R. Barrows, F. Dong, G. Fornshell, N. Haard, R. Hardy, W. Lellis

In 1993, the Western Regional Aquaculture Center funded an initial three-year research and outreach project to develop and evaluate feeds for juvenile, grower, and broodstock salmonids. The project's goal was to reduce levels of enriching nutrients, mainly phosphorus, in the effluent water of fish production facilities. Because feeds are the source of phosphorus in fish production systems, emphasis was placed on reducing total phosphorus levels in feeds, determining dietary phosphorus requirements of salmonids at various life stages, and ensuring that levels of available phosphorus in feeds were sufficient to meet the nutritional needs of the fish.

In the first phase of the project, strategies for reducing the level and/or increasing the bioavailability of phosphorus in key feed ingredients were developed and tested. Apparent digestibility coefficients for

phosphorus (ADCphos) were measured in feed ingredients. Low-phosphorus feeds were produced and ADCphos values were measured. Total ADCphos values were lower in some feeds than the predicted values calculated from ADCphos values of the ingredients in the feeds. Further research showed that ADCphos was lowered in a linear fashion as the concentration of calcium in the feed increased, suggesting that bone in fishmeal or animal protein meals lowered ADCphos to fish. Feed supplements that prevented antagonistic interactions between calcium and phosphorus in the intestine of fish were tested. Citric acid supplemen-tation increased phosphorus bioavailability and reduced phosphorus loss in feces, thereby improving the quality of hatchery effluent water.

In the second phase of the project, the dietary requirement for phosphorus at various life history stages was examined. Very low-phosphorus diets (0.4%P) resulted in smaller rainbow trout with higher body fat content, but did not affect egg quality or quantity, or fry survival and growth. Furthermore, a low-phosphorus diet (0.8%P) provided a 33% reduction in the amount of phosphorus discharged compared to a standard diet, with no effects on fish quality or growth. Varying phosphorus feed levels at different stages in production produced even better results. By feeding a standard diet (1.2%P) from hatch to 300 grams fish weight, then reducing feed phosphorus levels to just 0.3% until market size (500g), a reduction of 38% in phosphorus levels in hatchery effluent water could be achieved without affecting fish production.

2. Development of Economical, High-Performance, Low-Polluting Feeds and Feeding Strategies (1997-2001)

Principal Investigators: F. Dong, R. Hardy, R. Barrows, S. Chen, D. Brock, G. Fornshell, N. Haar

Starting in 1997, a second WRAC research and outreach project focused on further development of economical, high-performance, low-polluting feeds and feeding strategies. The study included additional efforts to reduce phosphorus discharge levels in aquaculture facility effluents.

In vitro methods to estimate phosphorus bioavailability and protein digestibility in feed ingredients for a number of common feed ingredients were developed and values were measured. These values were compared to apparent digestibility coefficients (ADC) values obtained using *in vivo* methods. After a number of method adjustments, high correlations were obtained for ingredients of both animal and plant origin. The *in vitro* methods were developed because they are faster and less expensive than *in vivo* methods, which require fish feeding trials and laborious chemical analyses.

The effects of particle size on nutrient digestibility were investigated because ingredient particle size is an important factor in fish feed manufacture: the smaller the particle size, the higher the energy consumption for grinding and sieving the feed material. For growers, the higher the feed digestibility, the better the feed utilization efficiency and the lower the cost of production. From an environmental perspective, higher feed utilization efficiency results in less waste excretion and lower pollution potential. Thus, finding the optimum balance between ingredient particle size and feed digestibility and utilization is an important aspect of producing economical and environmentally friendly fish feeds.

In this study, particle size in the range tested had no significant effect on the apparent digestibility of dry matter, phosphorus, and crude protein. These results make it possible to identify optimal ingredient particle size. When coarse particle diets are fed, solid particles in the water are coarser than when either fine or medium particle diets are used. Because the coarse particles can be easily collected by sedimentation and/or screen filtration, this reduces nutrient discharge levels, including phosphorus levels. Determining the optimal grinding size contributes to reducing the effluent load, reducing feed production costs, and maintaining better feed conversion.

RESULTS

These two WRAC research and outreach projects have had a major impact on the aquaculture industry:

- Phosphorus levels in feeds can be reduced for grow-out rainbow trout without affecting weight gain or product quality.
  Feeding slightly phosphorus deficient diets during the final few months of production resulted in a significant (38%) reduction in phosphorus input into the system over the production cycle of the fish without affecting the health of the fish or product quality. Growers using new feed formulations were able to maintain production levels and meet stringent regulations limiting phosphorus levels in farm effluent water.
- Supplementing feeds with citric acid to reduce phosphorus pollution is effective provided that total dietary phosphorus is lowered at the same time.
  Pollution reduction must involve efforts to increase nutrient digestibility, and match total available dietary nutrient levels actually required by the fish.
- Determining the bioavailability of phosphorus in key feed ingredients allows feed manufacturers to modify standard diets to achieve lower phosphorus discharge rates and lower feed costs.
- Higher feed utilization efficiency results in lower costs for producers, and decreased waste excretion and pollution potential.
  Results of this study made it possible to identify optimal ingredient particle size for fish feeds, reducing the effluent load and feed production costs, and maintaining better feed conversion.
- Farm-scale testing validates the effects of dietary changes on production efficiency and the economics of production.
- Sensitive and rapid indicators for dietary deficiency of phosphorus are necessary to determine the minimum dietary requirement level of phosphorus for large, commercial-size fish.
  Study results suggest that fish require less dietary phosphorus for maintenance than during life stages where fish grow rapidly, such as fry and fingerling stages. Providing higher dietary phosphorus levels than fish require results in excess phosphorus being excreted by fish in urine. Thus, urinary phosphorus concentration is by far the most sensitive and rapid response criteria to use in studies of large, commercial-scale fish.
- These studies developed standards for feed ingredient grinding to optimize feed utilization and nutrient digestibility while maintaining sufficient particle size to allow indigestible material to be recovered and removed from fish farm effluent water.
- Information on the calcium and ash concentrations of feed ingredients and apparent digestibility of phosphorus provides a relatively easy way for the feed industry to avoid using feed ingredients that increase phosphorus pollution by choosing ingredients that do not contain high levels of calcium or ash, and those with high ADCphos values.
- Information from the studies on apparent dry matter, protein, and mineral digestibility coefficients in common aquatic feed ingredients (including the relationship between bone calcium and apparent phosphorus digestibility) is widely used by feed manufacturers.
- A new method of assessing the dietary phosphorus requirement of rainbow trout that shortens the time required to evaluate the phosphorus availability of feeds and feed ingredients by 75% was developed and validated.
  In fingerling trout, the concentrations of phosphorus, calcium, and magnesium in skin and vertebrae are responsive indices of phosphorus status of the fish. Vertebral height, area, and volume were highly correlated with total dietary phosphorus concentration in grow-out sized fish.

INDUSTRY PERSPECTIVE

Chris Nelson, *Silvercup Feeds*
Because of this research in the mid 1990s we were able to start producing low-phosphorus feeds (less than 0.8% phosphorus) with no fish health concerns for commercial, state, and federal fish hatcheries in Arizona, Idaho, Michigan, and Vermont, where EPA or other agencies had put stringent requirements on phosphorus discharge. This research also led to further research with extruded nutrient dense diets that dramatically improved feed conversion rate (FCR) and thereby reduced phosphorus effluent even further.

Randy MacMillan, *Clear Springs Foods*
These projects provided fundamental insight into how we might reduce our total phosphorus environmental footprint. The impact of calcium and citric acid in this regard were very helpful. I agree with Chris Nelson that the studies helped lead to the development of high energy, nutrient dense feeds which are now the standard in the industry. The economic impact of high-energy nutrient dense feeds is significant both in terms of improved feed conversion and reduced phosphorous discharge. It is however difficult to parse out that impact from other advances in the culture of our fish. For example, we have a selective breeding program that we believe has had a significant impact on feed conversion and disease resistance. The end result is greater production capacity with less environmental impact. We also have greater certainty and hence predictability of harvest weight and timing of harvest. Since that research was completed, fish meal costs have increased tremendously so much so that now the search is on for lower cost yet environmentally beneficial plant-based proteins. My expectation is that the research of the past will apply to the plant-based proteins as well. Hope this helps and sorry I cannot offer any quantitative value measurements that the research has brought to Clear Springs Foods or the industry.

Leo Ray, *Fish Processors of Idaho*
The phosphorus input reductions made possible by new low phosphorus feeds from the WRAC projects enabled us to continue to maintain annual production of 1,500,000 pounds, rather than having to reduce that production by 20 % to about 1,200,000 pounds to meet the EPA requirements.

Background: I do not believe we have been able to increase production because of the low phosphorus research. I do think we have been able to maintain our highest level of production. Without the research I would estimate we would have had to reduce production by 20%. This is just an estimate. Maximum production was about 25,000 lbs per cfs. and we were not meeting the EPA phosphorus limits then. We are now growing up to 25,000 lbs per cfs. and we are meeting the limits. In order to lower phosphorus more we would have to lower production. The research has probably allowed us to raise 20% more than we could have and still met the permit requirements.

David Brock, *Rangen Feeds*
The projects provided some much needed baseline information on the nutritional physiology of phosphorous in salmonids. The quality of the research was exceptional and it provided the field nutritionist with some solid data in which to base our formulation decisions. It influenced some of our purchasing decisions as well.

As pointed out by Chris and Randy, this project provided a springboard for research into nutrient dense feeds. Had we not had the good phosphorous data resulting from this project, nutrient dense feeds had the potential to ruin a lot of fish.

As good quality water becomes scarce, this project will continue to pay dividends for the industry.

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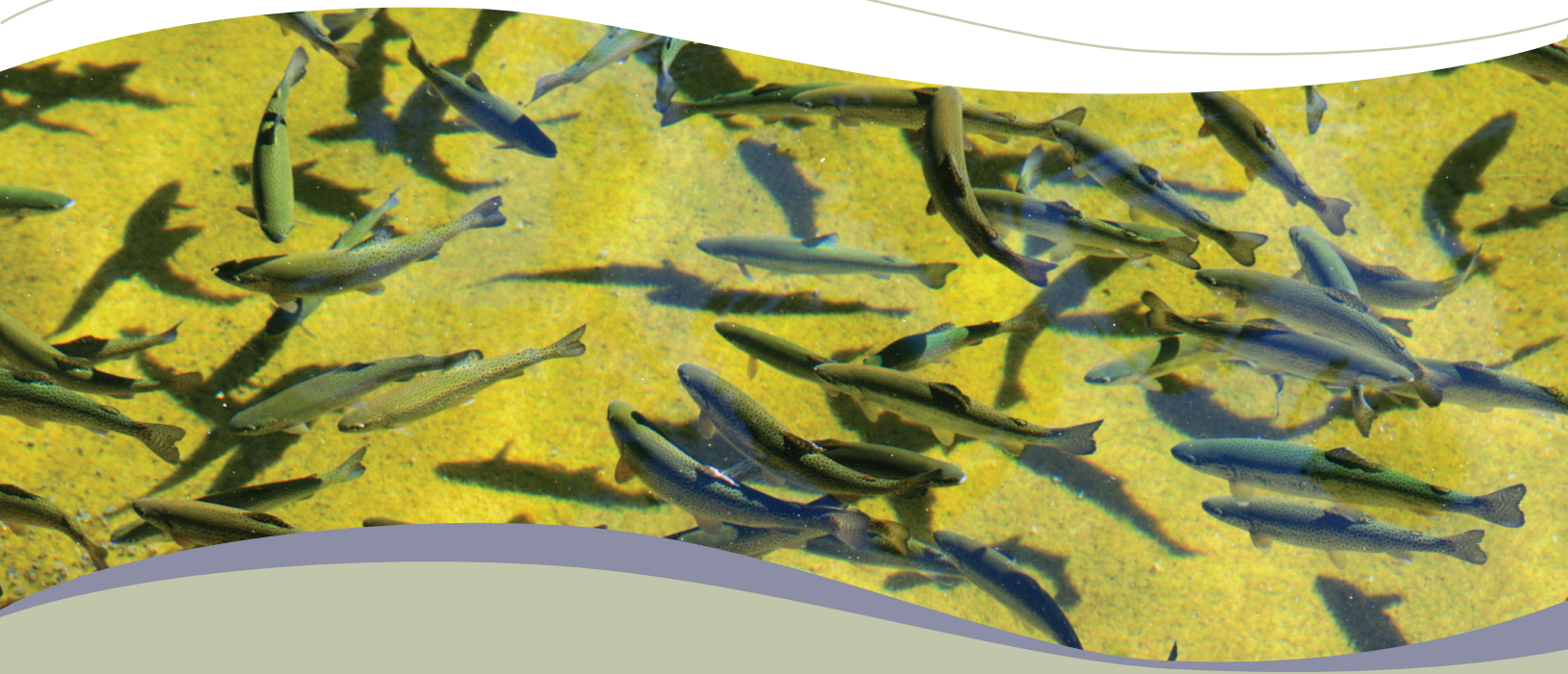

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