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SUBSTITUTABILITY OF FISHMEAL IN DIETS FOR SALMON AND TROUT: A META-ANALYSIS

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Abstract

Intensive aquaculture, especially the production of carnivorous species, requires artificial feeding. Fishmeal and oil are preferred to vegetable proteins, since marine proteins provide the essential nutrients required by farmed fish. Therefore, given the stagnant production of reduction species and the rapid increase in aquaculture production, fishmeal availability would pose a biological constraint on aquaculture contribution to world fish supplies in the future, unless alternative feed sources can be incorporated in diets. In this paper, the technical substitutability between fish and vegetable based feeds are assessed through the estimation of Morishima[2] elasticities of substitution. These are derived from a meta-analysis production function.

Keywords: Fishmeal, meta-analysis, salmon, trout, elasticity.
JEL: Q2

Introduction

Historically, the world's oceans were considered limitless, and thought to harbour enough fish to feed an ever-increasing population. Today, however, production from wild fisheries is in a state of crisis, given the decline in world fish stocks is an international problem. The FAO (2002) estimated that 69% of wild fisheries are fished to capacity, overfished, or recovering. On the other hand, production from aquaculture has increased rapidly (over 10% per annum) over the last two decades, as a result of new and intensive[3] farming techniques (Asche and Tveteras, 2004). These developments have led to the cultivation of highly valuable species, for example salmon and trout. In some producing countries, farmed fish contribute more to overall production than capture fisheries (for instance, salmon farming in Norway). Technological advances have facilitated the expansion of aquaculture, and further advances are expected in the future. This has led to an increase in aquaculture's

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[2] Several variants of the elasticity of substitution exist, including the Morishima, Hicks and Allen elasticities of substitution. Of these, the Morishima elasticity of substitution (MES) has been considered to be most theoretically sound.

[3] Extensive aquaculture differs from intensive aquaculture in both scale and production technology. Under extensive conditions the most significant difference in production is that fish are not fed, but consume whatever naturally occurs.

contribution to global supplies, which in 2001 accounted for 29% of total production compared with only 3.9% in 1970. However, growth in aquaculture (specifically carnivorous aquaculture in Europe) has caused increasing pressure on markets for marine raw materials. In particular, the limited availability of fishmeal for aquafeeds, coined the 'fishmeal trap', represents a concern (Tveteras, 2003). Indeed, the interaction between aquaculture and wild fisheries remains a constant cause of concern – will aquaculture increase global production of food fish, or is it further contributing to the overexploitation of the world's fisheries?

This paper presents the preliminary findings of a study looking at the impact of increased aquaculture production on the supply and demand of fishmeal and how this will affect future aquaculture production. The main aim of this study is to explore the potential for, and implications of, increased substitution of alternative feeds for fishmeal in diets for salmon and trout. Many papers have tried to evaluate the efficiency of various potential substitutes for fishmeal in diets for salmon and trout (see Hemre, 2000; Rodhutscord, 1994; Kaushik et al, 1995; Gomes *et al*., 1995). However, if new generation diets are to be accepted, they must be both technically and economically feasible. For example, increasing oil content of diets to maintain fatty acid composition (compensating for poorer oil source) is likely to increase overall production costs. Given the high control supermarkets have regarding price determination[4], this is of particular importance as it is unlikely that farmers will be able to demand that supermarkets pay a higher price for their product. Generally, an increase in price (at farm-gate level) is unlikely unless farmers are targeting niche markets (for example, organic produce), although this is not (currently) feasible for many fish farming operations as a result of the high capital costs involved in setting up such farming operations. Therefore, any attempt to replace fishmeal in diets for farmed fish must, as a first step, review technical feasibility, because if a diet is not technically feasible, it is unlikely that it will be economically feasible.

In this study, meta-analysis has been used to synthesise the results of previous experiments in a rigorous manner. A fixed-effect model has been employed to capture the effects of different experimental design (e.g. stocking density, temperature, starting weight and trial duration) on the growth of fish. The elasticity of substitution was estimated to determine the ease to which different feeds could be substituted, whilst maintaining current levels of productivity. The analysis is undertaken for both salmon and trout, which are considered for a number of important reasons. Firstly, salmon aquaculture has grown rapidly over the past two decades or so, and although growth in trout farming has been considerably more stable, salmon and trout demand a greater market share of fishmeal than any other farmed species in the UK. In addition, salmon farming has contributed significantly to economic development in parts of Europe where economic activity is restricted (i.e. seasonal), for example the Highlands and Islands of Scotland.

[4] In the early days of production salmon farmers received upwards of £10 per kilo, this figure plummeted to below £3 per kilo in the early 1990's and as low as £1.50 per kilo in 2003. However, prices in supermarkets have remained relatively stable, suggesting the existence of market power (see also Guillotreau, 2004).

Aquaculture and Fisheries

Salmon and trout farmers (and indeed farmers of other carnivorous species) prefer fishmeal to vegetable protein sources, since marine proteins satisfy essential nutritional requirements of farmed fish (Tveteras, 2003). Aquaculture's share of the fishmeal market has risen sharply over the past decade or so. Projections for future use suggest that this share will continue to increase, as there are strong signs that output from aquaculture will continue to rise. However, it is thought that increased demand from aquaculture can in part be met through diversion of inputs. While part of the increased demand form aquaculture is likely to be met through reduced use in agriculture[5], aquaculture's demand is likely in the short term to significantly increase the price of industrial species, with the potential to contribute to overexploitation. Nevertheless, a significant expansion of the global fishmeal production, beyond the 6-7mmt (million metric tonnes) that is normally produced, is unlikely unless prices for fishmeal increase substantially. However, in the long run this would not be sustainable and lead to lower long-run sustainable yields.

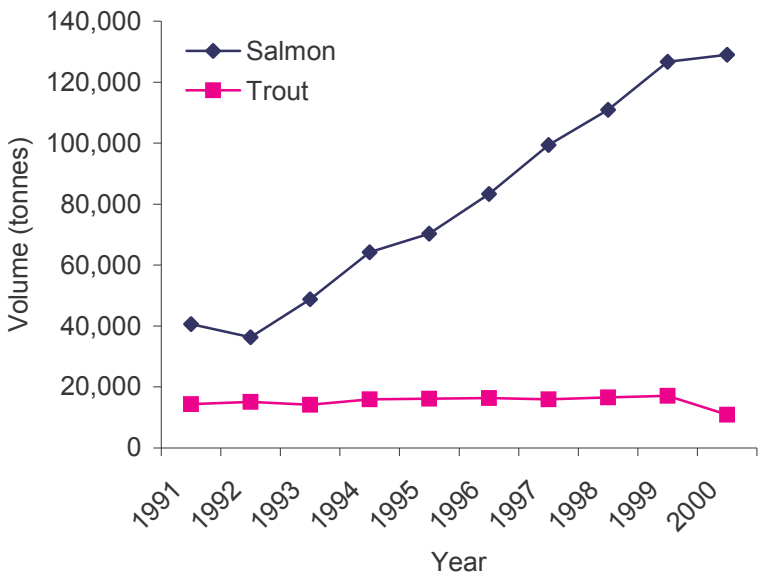
The rapid growth in aquaculture has led to a number of environmental concerns; these can be divided into two main groups. The first group is pollution to the environment as a result of discharge from farming sites (i.e. salmon farming) and destruction of habitat (i.e. shrimp farming and loss of mangroves), although regulations and legislation in part can control this problem. The second group is increased pressure on wild stocks as a result of increased demand for fishmeal. The latter observation is interesting, given that it suggests that aquaculture creates environmental problems via its input market, thus incurring a biological constraint on production (Guttormsen, 2002). The 'fishmeal trap' is an important problem given that the market for fishmeal is a global one. According to Asche and Tveteras (2004), the market for fishmeal is an important factor when considering the potential problems which aquaculture demand for fishmeal will pose for wild fisheries as aquaculture demand grows. It is, therefore, important to determine why fishmeal is used in diets for farmed fish (especially carnivores). If fishmeal is a unique product, it suggests that it is not part of the larger market for protein meals, including that for soya meal (the most abundant and researched replacement protein to fishmeal in diets of salmon and trout). There are certain indicators suggesting that fishmeal is a unique product, for example a characteristic of pelagic fisheries is that, while the quantity of pelagic fish going directly to human consumption stays relatively stable, the 'surplus' that goes to reduction can vary substantially (Asche and Tveteras, 2004). This does, therefore, mean that prices will fluctuate, most significantly during *El Niño* periods, suggesting feed producers are willing to pay increased price for fishmeal given its importance in diets (rather than substituting with alternative protein sources). Ultimately, if fishmeal

[5] Several authors (e.g. Thiel et al 2004) suggest that this will not happen (to the extent some suggest), as fishmeal is generally not substitutable in diets for pigs and poultry to maintain high growth rates, particularly in starter and weaner diets. However, there is also some evidence that fishmeal in the diets of pigs can produce detrimental effects on the quality of meat produced (Coronado et al 2002)

is used heavily because it cannot be replaced, it raises the question – what role does aquaculture play in global food fish production? (Asche and Tveteras, 2004)[6].

Globally, the production of fishmeal and oil has remained stable over the past decade at 6.0 million tonnes and 1.2 million tonnes respectively. This suggests that fishmeal and oil has reached a production limit, with most industrial fisheries classified as fully or over exploited. The demand for fishmeal and oil, however, is expected to increase in some sectors, in particular aquaculture's rapid expansion is expected to continue (see Figure 1). There are no indications, other than the limited availability of fishmeal, that growth in salmon farming will not continue.

Figure 1: Comparison of salmon and trout production in the UK (1991-2000)



Salmon farming receives particular attention, as the industry is the leading consumer of marine raw materials[7] (especially Norwegian salmon farming). A number of studies project the scarcity of fishmeal and oil. Pike and Barlow (1999) suggest that aquaculture will consume over half the global fishmeal production and the entire global supplies of fish oil by 2010. New and Wijkstrom (2002) indicate a similar scenario, in that aquaculture will consume world supply of fish oil by 2010 and fishmeal by 2020[8]. Waagbo *et al.* (2001) suggest a shorter time span,i.e. entire use of

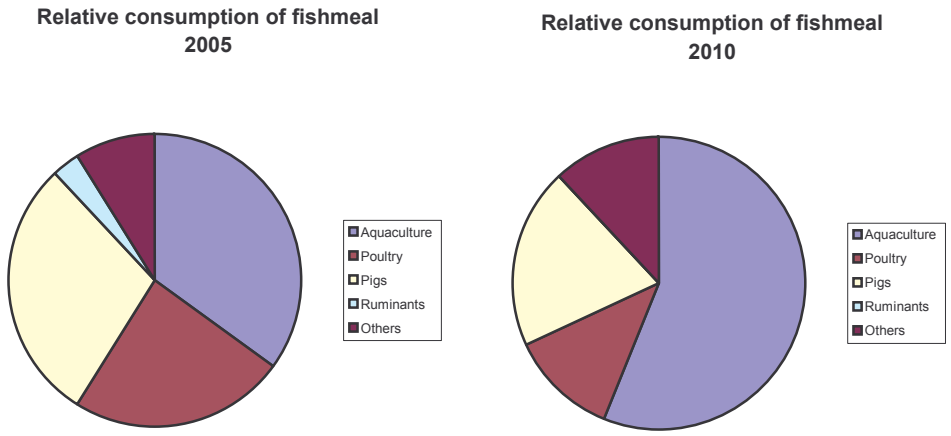
[6] A number of papers investigate the relationship between aquaculture and fisheries – see Asche and Tveteras, 2004; Tveteras, 2003; Hannesson, 2003; Anderson, 2002; Kristofersson and Anderson, 2005

[7] Although trout feeds utilise a similar amount of fishmeal, actual use of fishmeal in trout farming is substantially less than salmon farming given significantly less production.

[8] Such projections are often cited and criticised as they use current trends and extrapolate these trends to derive estimates for future use. This can be problematic given this takes little account of certain economic criteria.

fish oil by 2005 and fishmeal before 2010 (Tveteras, 2003). In economic terms, sharp increases in price of both fishmeal and fish oil, reflecting the scarcity of both raw materials, will occur within the next decade or so (Tveteras, 2003).

Figure 2: Relative consumption of fishmeal



Source: Pike and Barlow (1999).

The increased demand from aquaculture can only be met either through diversion of inputs from other sources or through substitution with a suitable replacement. Aquaculture is, however, not the only user of this scarce resource. In fact, agriculture (specifically, pigs and poultry) consumes over half of fishmeal produced globally, although its reliance is not as rigid as alternative feeds are more substitutable.

Methodology

Meta-analysis

First used by psychologists (Glass, 1976; Schmidt and Hunter, 1997), meta-analysis has become a widely used tool across many disciplines[9]. Meta-analysis refers to the statistical analysis of a large collection of results from individual studies, which typify our attempt to make sense of the rapidly expanding research literature. There are two types of meta-analysis: those that use the actual data from multiple studies, and those that use the results of multiple studies (Woodward and Wui, 2001). It is the latter method that has been applied in this study to interpret the results of studies concerning the substitution of fishmeal with vegetable proteins.

For example, substitution effects – if fishmeal is significantly replaced in diets for carnivorous species, projections will prove to be inaccurate (Tveteras, 2002).

[9] See Glass (1976) and Hunter and Schmidt (1997) for full description.

While several studies have been undertaken looking at the effects of different food combinations on fish growth, each study examined only a limited range of alternatives. However, across the studies, a wide range of combinations has been considered. Nevertheless, variation in research results can be explained by the systematic variation in dietary design as well as methodological (for instance, stocking density, water temperature etc.) or unexplained study-level factors, which are factored into the meta-analysis production function, since it is known that biological characteristics affect growth and performance of farmed fish. For example, there are known temperature ranges within which a species can grow, grow successfully, and grow optimally. The same is true for other factors affecting growth, i.e. stocking density (over-crowding fish will lead to poorer growth and possibly other problems, such as disease). The rationale for the meta-analysis presented here is: this research is the assessment of the influence of dietary characteristics on potential substitutability, compared to systematic influences of study methodology or experimental design. This may provide insight into the overall substitutability of fishmeal with vegetable proteins and provide a diet composition that achieves the highest growth, with minimal effects on economic performance.

An in-depth review of the literature concerning fishmeal replacement in diets for salmon and trout was conducted. This included searches of relevant journals, academic working papers, dissertations, books, and through relevant academic search engines. The criteria for selection were firstly, a requirement that the study estimates growth with respect to food conversion ratios, or provides sufficient information to allow such a value to be calculated. Second, a common set of feeds was required for comparison (fishmeal, fish oil, soy, wheat and vitamins and minerals. All other ingredients were combined into an "other" category). This led to the inclusion of 16 studies concerning the substitution/replacement of fishmeal in diets for trout and 12 studies for salmon (Table 1). Each study considered several alternative feed regimes, resulting in a total of 77 feed combinations for trout and 49 for salmon.

Production function estimation

A production function was estimated relating the average growth per day of the fish to feed level and composition. The production function describes the technical relationship between inputs and outputs of a production process, defining the maximum output(s) attainable from a given vector of inputs (Coelli and Battese, 1998). The production function assumes that the goal of a firm is to maximise profits.

The model was estimated as a fixed-effects translog production function of the form:

$$\ln y_{i,j} = \beta_0 + \sum_f \beta_i \ln x_{j,f} + \frac{1}{2}\sum_f \sum_k \beta_{i,k} \ln x_{j,f} \ln x_{j,k} + \sum_{i=1}^{N-1} D_i + v_{i,j} \qquad (1)$$

where $y_{i,j}$ is the observed average growth rate per day of treatment j in trial i, $x_{j,f}$ is the amount of feed type f used in treatment j, and D_i are a set of dummy variables representing the impact of the trial on growth (i.e. water temperature, starting size etc.). The translog is a flexible functional form that allows both the growth elasticity

and the elasticities of substitution to vary from one treatment to the next. The Cobb-Douglas production function is a special case of the translog production function, where all $\beta_{i,k} = 0$. However, the Cobb-Douglas production function imposes an implicit assumption that the elasticity of substitution is 1 for all inputs.

The data were normalised and logged such that the mean level was 1 (hence $\ln(\bar{x}) = 0$). Given the problems of multicollinearity inherent in translog production functions, the model was estimated using principal components regression.

Elasticity of substitution estimation

Several variants of the elasticity of substitution exist, including the Morishima, Hicks and Allen elasticities of substitution. Of these, the Morishima elasticity of substitution (MES) has been considered to be the most theoretically sound (Blackorby and Russell, 1981, 1989), and is asymmetric when more than two outputs are present. Following Blackorby and Russell (1981), the MES can also be directly derived from the production function, given by

$$MES_{x_m x_n}(x, y) = x_m \left[\frac{\partial^2 \ln y}{\partial \ln x_m \, \partial \ln x_n} \Big/ \frac{\partial \ln y}{\partial \ln x_n} \right] - x_m \left[\frac{\partial^2 \ln y}{\partial \ln x_m^2} \Big/ \frac{\partial \ln y}{\partial \ln x_m} \right] \qquad (2)$$

A negative value indicates the outputs are substitutes, while a positive value indicates complementarity. The size of the value is a measure of the strength of the substitute/complementarity relationship. For the purposes of this paper, the elasticities were evaluated at the mean input levels (i.e. x_m=1).

Results and discussion

For the trout model, 13 principal components were selected based on the amount of variation represented and also the level of collinearity between the principal components (detected from the condition index). This accounted for 96% of the variation in the original data. In addition, 15 dummy variables were generated to represent the 16 studies.

The estimated production function for trout (Table 2) produced an adjusted R-square value of 0.8071, indicating that the model is a good fit, has good predictive powers, and that 80% of the proportion of variation in the dependent variable is explained by the independent variables. The estimated fixed-effects coefficients indicate that in only one trial (represented by D3) did the effects of experimental design (stocking density, temperature etc.) affect growth of trout ($P<0.05$). In the other 16 trials, there was no significant effect on growth with differing experimental design ($P>0.05$). In addition, the estimated coefficients of the dietary components in many cases are significant.

As discussed earlier, the Morishima elasticities of substitution (MES) were derived from the production function for trout. Although there were a number of significant coefficients, the MES (see Table 3) indicated few substitution possibilities. The model did, however, indicate that the most substitutable ingredient was fish oil ($P<0.05$). To summarise, it was found that fish oil could be substituted for fishmeal maintaining current levels of productivity. Likewise, the model indicated that fish oil could be replaced with soybean meal and other ingredients (for example, the other ingredients that make up the protein and oil content of the diet) whilst maintaining productivity ($P<0.05$). However, many of the signs of the elasticity measures were as expected (showing some degree of substitutability between ingredients), although, as these values were not significant, we cannot refer to them with any degree of confidence.

It can be concluded from the results of the principal components model that experimental design had little effect on growth, the cross products of dietary ingredients in many cases were significant, and although the MES indicated ingredients were substitutable they were largely not significant.

For salmon, 9 principal components were selected, representing 98% of the variation in the data. The adjusted R-square of 0.9891 suggests that the model is a very good fit (98% of the variation in the dependent variable is caused by the independent variables). The dummy variables indicate that experimental design in a number of the studies significantly affected growth ($P<0.05$) (see Table 2). As shown in Table 2, many of the coefficients (individual ingredients, squared terms and cross products) are significant, indicating a good model.

For salmon, the MESs indicate (see Table 4), similarly to trout, that there are substitution possibilities between protein sources. However, as with trout, the elasticities generated (for the most part) are not statistically significant. Nevertheless, we can conclude that soybean meal can be substituted in diets for salmon with wheat whilst maintaining current levels of productivity ($P<0.05$). Likewise, wheat can be substituted for vitamins and minerals ($P<0.05$) and other ingredients (for example, the other ingredients that make up the protein and oil content of the diet) can be substituted for either wheat or soybean meal ($P<0.05$). However, a significant relationship was found between soybean meal and vitamins and minerals, which suggested that they are complements (rather than substitutes). Therefore, if productivity is to be maintained, soy cannot be used to replace wheat in diets for salmon unless the use of vitamins and minerals is also increased.

Conclusions

Aquaculture has grown rapidly over the past two decades or so, and as a result aquaculture's share of the fishmeal market has increased significantly over this period. Given that feed is the most expensive input factor of production (representing 60-70% of total costs), replacement of marine proteins may be essential for further growth.

However, this depends on why fishmeal is used – if it is because it achieves the best growth as demand increases from aquaculture, price is likely to become more inelastic, and thus increases in the price of fishmeal will be seen. This will, however, only be true for the short term because it is unlikely that aquaculture could use fishmeal in diets at highly inflated prices. Historically, profitability in salmon and trout farming would not allow for this to happen. However, if fishmeal can be substituted for alternative feed ingredients, economic factors (i.e. increased price) are likely to determine when farmers switch to vegetable-based diets. Nevertheless, pig- and poultry-producing sectors utilised fishmeal in diets long before aquaculture increased its fishmeal consumption. Fishmeal is used in pig and poultry production (similarly to aquaculture) as it achieves high levels of growth, and, given that only relatively small amounts are required[10], high increases in the price of fishmeal would not affect pig and poultry producers to the extent that it will for salmon producers. There are, therefore, no obvious reasons why the livestock sector should easily abandon fishmeal use (Tveteras and Tveteras, 2004).

Induced innovation in the aquaculture industry (as a result of rising prices) also indicates that the industry is not inclined to replace fishmeal with vegetable proteins (innovation has reduced fishmeal content of diets). It is, nevertheless, expected that global demand for fish and meat products will continue to increase in line with the world's population, so at some point in time neither salmon and trout aquaculture nor pig and poultry farming can be considered sustainable unless alternatives to fishmeal are found. Aquaculture is, nonetheless, by far the most efficient user of fishmeal. For example, 100kg of feed provides 65kg of salmon, 20kg of chicken and only 15kg of pork (Sabaut, 2002). Sabaut (2002) suggests that aquaculture's use of fishmeal (for this reason) does not constitute unsustainable development, as the same fish caught growing within a natural ecosystem will consume between 5-10kg of the same wild-caught fish. This figure could be inflated to 10-15kg, if one considers the inefficiency of fisheries, which at best only keeps 25% of the by-catch species caught.

In conclusion, the results of this study indicate that there are only limited substitution possibilities between ingredients in diets for salmon and trout. Although MES values indicated that there were substitutes for fishmeal, the results were mostly not statistically significant. This suggests that current productivity levels cannot be maintained on a diet based on vegetable proteins. However, as fishmeal becomes increasingly scarce, then alternative feeds may become economically more appealing. The loss in productivity through the use of alternative feeds will need to be assessed against the cost savings. Acceptable and economic alternative means of supplying protein in diets for farmed salmon and trout must be found, or the reliance on fishmeal to provide protein in diets will be a biological constraint on the further growth of the fastest-growing food sector in the world. Nevertheless, this is unlikely to happen until demand from aquaculture significantly increases the price of marine raw materials, as

[10] Pig and poultry culture requires significantly less fishmeal (<10%) compared with highly intensive salmon aquaculture (40-50% and as high as 75% in starter diets).

vegetable-based diets currently demand a higher price than traditional fishmeal diets due to processing costs (i.e. anti nutrients).

Endnotes:

[2] Extensive aquaculture differs from intensive aquaculture in both scale and production technology. Under extensive conditions, the most significant difference in production is that fish are not fed, but consume whatever naturally occurs.
[3] In the early days of production, salmon farmers received upwards of £10 per kilo, this figure plummeted to below £3 per kilo in the early 1990s and as low as £1.50 per kilo in 2003. However, prices in supermarkets have remained relatively stable, suggesting the existence of market power (see also Guillotreau, 2004).
[4] Several authors (e.g. Thiel *et al.,* 2004) suggest that this will not happen (to the extent that some suggest), as fishmeal is generally not substitutable in diets for pigs and poultry to maintain high growth rates, particularly in starter and weaner diets. However, there is also some evidence that fishmeal in the diets of pigs can produce detrimental effects on the quality of meat produced (Coronado *et al.,* 2002)
[5] A number of papers investigate the relationship between aquaculture and fisheries – see Asche and Tveteras, 2004; Tveteras, 2003; Hannesson, 2003; Anderson, 2002; Kristofersson and Anderson, 2005
[6] Although trout feeds utilise a similar amount of fishmeal, actual use of fishmeal in trout farming is substantially less than in salmon farming, given significantly less production.
[7] Such projections are often cited and criticised as they use current trends and extrapolate these trends to derive estimates for future use. This can be problematic given that this takes little account of certain economic criteria, for example, substitution effects – if fishmeal is significantly replaced in diets for carnivorous species, projections will prove to be inaccurate (Tveteras, 2002).
[8] See Glass (1976) and Hunter and Schmidt (1997) for full descriptions.
[9] Pig and poultry culture requires significantly less fishmeal (<10%) compared with highly intensive salmon aquaculture (40-50% and as high as 75% in starter diets).

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Table 1 – Fishmeal substitution studies included in the meta-analysis

Trout	Salmon
Adelizi *et al. et al.* (1998)	Azevedo *et al.* (2002)
Azevedo *et al.* (2004)	Azevedo *et al.* (2004)
Davies and Morris (1997)	Carter and Hauler (1999)
Glencross *et al.* (2004)	Hevroy *et al.* (2005)
Gomes, Rema and Kaushik	Julshamn *et al.* (2004)
Hernandez et al	Kaushik *et al.* (1995)
Mambrini *et al.* (1999)	Refstie *et al.* (2000)
Morris *et al.* (2005)	Refstie, Olli and Standal (2004)
Mwachireya *et al.* (1999)	Refstie, Storebakken and Roem (2000)
Refstie, Helland and Storebakken (1997)	Refstie *et al.* (2001)
Refstie *et al.* (2000)	Storebakken, Shearer and Roem (1998)
Rodhutscord (1994)	Storebakken *et al.* (1998)
Satoh *et al.* (2003)	
Thiessen, Campbell and Adelizi (2003)	
Thiessen *et al.* (2004)	
Xie and Jokumsen (1997)	

Table 2 – Production function coefficients

	Trout			Salmon		
	Coeff	Stand. error		Coeff	Stand. error	
CONSTANT	-0.373	0.329		1.246	31.090	
FISHMEAL	0.164	0.055	***	-0.001	0.002	
FISHOIL	0.099	0.066		-0.001	0.002	
SOY	0.042	0.065		-0.017	0.017	
WHEAT	-0.008	0.068		0.006	0.004	*
VITMIN	-0.016	0.031		0.005	0.002	**
OTHER	-0.109	0.097		-0.020	0.009	**
$FISHM^2$	-0.077	0.044	*	-0.001	0.002	
$FISHO^2$	-0.154	0.121		0.004	0.002	*
SOY^2	0.119	0.062	*	-0.007	0.011	
$WHEAT^2$	0.053	0.084		-0.025	0.006	***
VIT^2	-0.007	0.011		0.015	0.011	
$OTHER^2$	0.017	0.054		0.033	0.010	***
MEAL*OIL	0.132	0.052	**	0.002	0.002	
MEAL*SOY	-0.010	0.047		-0.018	0.008	**
MEAL*WHT	0.188	0.066	***	0.019	0.007	**
MEAL*VIT	0.044	0.026		0.004	0.002	*
MEAL*OTH	0.176	0.040	***	0.017	0.007	**
OIL*SOY	0.063	0.043		-0.009	0.005	*
OIL*WHT	0.024	0.075		0.018	0.006	***
OIL*VIT	0.044	0.026		0.001	0.001	
OIL*OTH	-0.219	0.057	***	0.017	0.006	***
SOY*WHT	0.104	0.067		0.031	0.004	***
SOY*VIT	0.113	0.054	**	-0.030	0.011	***
SOY*OTH	0.098	0.040	**	-0.001	0.003	
WHT*VIT	-0.013	0.022		0.038	0.011	***
WHT*OTH	-0.084	0.047	*	0.011	0.008	
VIT*OTH	-0.121	0.049	**	-0.067	0.031	**
D1	0.037	1.083		-2.408	0.854	***
D2	0.474	1.179		-2.095	0.733	***
D3	-2.674	1.154	**	-0.724	0.504	
D4	0.793	2.042		-1.980	0.709	***
D5	-0.507	1.056		-3.000	0.609	***
D6	-1.679	1.227		-1.498	0.321	***
D7	0.908	1.378		-2.249	0.482	***
D8	0.447	0.933		-0.716	0.645	
D9	0.048	1.179		-0.829	0.478	*
D10	0.724	0.844		-0.704	0.494	
D11	-0.005	1.212		-3.477	0.233	***
D12	0.379	0.868				
D13	-1.233	1.006				
D14	0.841	0.976				
D15	0.671	0.911				
R^2	0.807			0.981		

* Significant at 10%, ** Significant at 5%, *** Significant at 1%

Table 3 – MES trout

	m					
n	fishmeal (g)	fishoil (g)	soy (g)	wheat (g)	Vit+min (g)	other (g)
fishmeal (g)		**-3.925**	5.734	-13.816	0.654	-1.385
fishoil (g)	-2.276		5.033	-12.917	0.476	1.915
soy (g)	-0.705	**-4.630**		-15.161	-1.766	-2.656
wheat (g)	21.361	-0.271	18.057		-0.568	-10.252
Vit+min (g)	1.888	-0.298	12.928	-13.481		-8.116
other (g)	-2.948	**-5.134**	6.577	-13.442	-0.191	

Note: Bold figures indicate significant at P<0.05

Table 4 – MES salmon

	m					
n	fishmeal (g)	fishoil (g)	soy (g)	wheat (g)	Vit+min (g)	other (g)
fishmeal (g)		-5.844	-33.879	27.789	13.115	28.090
fishoil (g)	4.778		-8.837	12.077	7.362	15.800
soy (g)	1.946	-9.370		-6.390	4.344	**-3.288**
wheat (g)	-0.076	-11.823	**-4.182**		-0.098	**-5.069**
Vit+min (g)	2.266	-9.095	**6.831**	**-15.754**		10.157
other (g)	3.843	-8.028	0.782	-7.619	2.788	

Note: Bold figures indicate significant at P<0.05