

THE RELATIONSHIP BETWEEN FISHERIES AND FARMING^a

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ABSTRACT

Fishmeal is a critically important feed ingredient for use in animal (e.g., poultry and pork) and aquaculture production (e.g., salmon, trout, and shrimp). There is concern that demand for fishmeal may place additional stress on the world's pelagic fisheries and may undermine the sustainability of some aquaculture systems that rely on fishmeal. Our research suggests that since 1998 market for fishmeal has changed. An important explanation is likely to be the increasing use of specialized feed formulations in the pork, poultry and aquaculture sectors. It is clear that growth in aquaculture production alone is insufficient to explain the structural change since growth in the use of fishmeal in aquaculture has slowed considerably despite the continued rapid growth in global aquaculture sector. The increasing relative price of fishmeal is likely to increase costs for animal producers, act as a stimulus for innovation and have considerable implications for the management of pelagic fisheries.

Keywords: Interrelations between aquaculture/animal production and fisheries; Structural change

INTRODUCTION

Fishmeal is a critically important feed ingredient for use in animal (e.g., poultry and pork) and aquaculture production (e.g., salmon, trout, and shrimp). Across all animal protein sectors, fishmeal use has led to increases in growth rates, improvements in feed conversion ratios, lower allergic reactions, and improvements in disease resistance [2]. A major concern is that aquaculture has limited opportunities to substitute fishmeal with vegetable protein sources and that the limited supply of fishmeal may restrict the future expansion of the aquaculture industry and result in overfishing of the small pelagics used in fishmeal. While concerns regarding substitutability exist for the aquaculture sector, the agriculture sector is similarly affected by the issue of substitutability across protein sources. In fact, fishmeal cannot easily be substituted in the diets of fish [3-7], pork [8-10] and poultry [11, 12].

Trends in Global Animal Protein Production

This issue is especially concerning given the increasing trend in global animal production. Total global fisheries production has expanded substantially over the past 30 years, and the driving component of that growth has been the emergence of the global aquaculture sector. Total global aquaculture production has increased from 11.3 million metric tonnes (MMT) in 1985 to 59 MMT in 2004 (Fig. 1). However, when discussing the use of fishmeal in aquaculture, it is more appropriate to focus attention specifically on the production of finfish and crustaceans. Since finfish and crustaceans account for 54% of total aquaculture production, it is misleading to include the remaining 46% of production, which includes shellfish and marine plants (algae and seaweeds) that do not rely on fishmeal in their production cycles. The sub-

category of finfish and crustacean production has increased from 5.5 MMT in 1985 to 31.8 MMT in 2004.

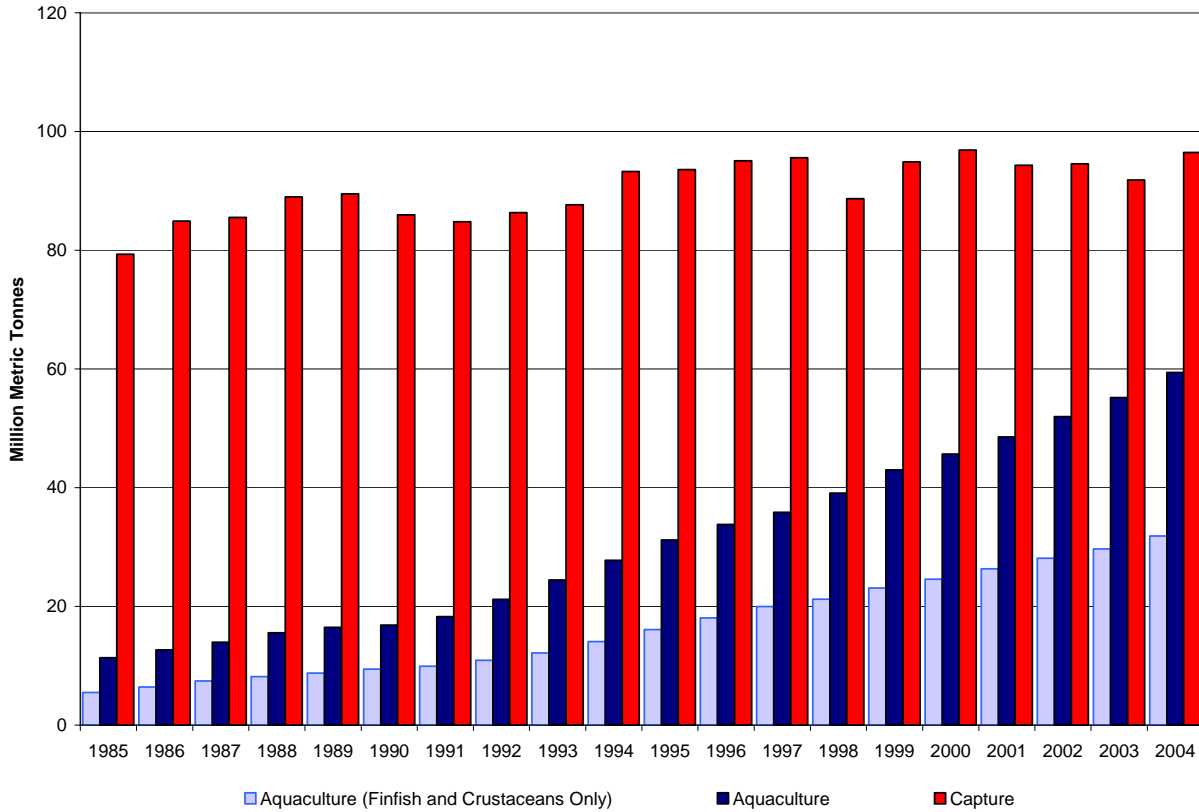


Figure 1. Global fisheries production: capture fisheries and aquaculture 1985-2004 [13]

In addition to the growth in the aquaculture sector, there has been considerable growth in the pork and poultry industries (Fig 2). The scale of finfish and crustacean aquaculture production (30 MMT in 2003) is quite different from that of pork and poultry production. In 2003 world pork meat production was 98 MMT, the poultry meat production was 76 MMT and egg production was 61 MMT. The increase in world production from 1990 to 2003 is 63.8% for eggs (24 MMT), 41.1% for pork (29 MMT), 86.7% for poultry (35 MMT), and 214.9% for aquaculture (20 MMT). The demand for fishmeal will only increase as production across these animal protein sectors increases.

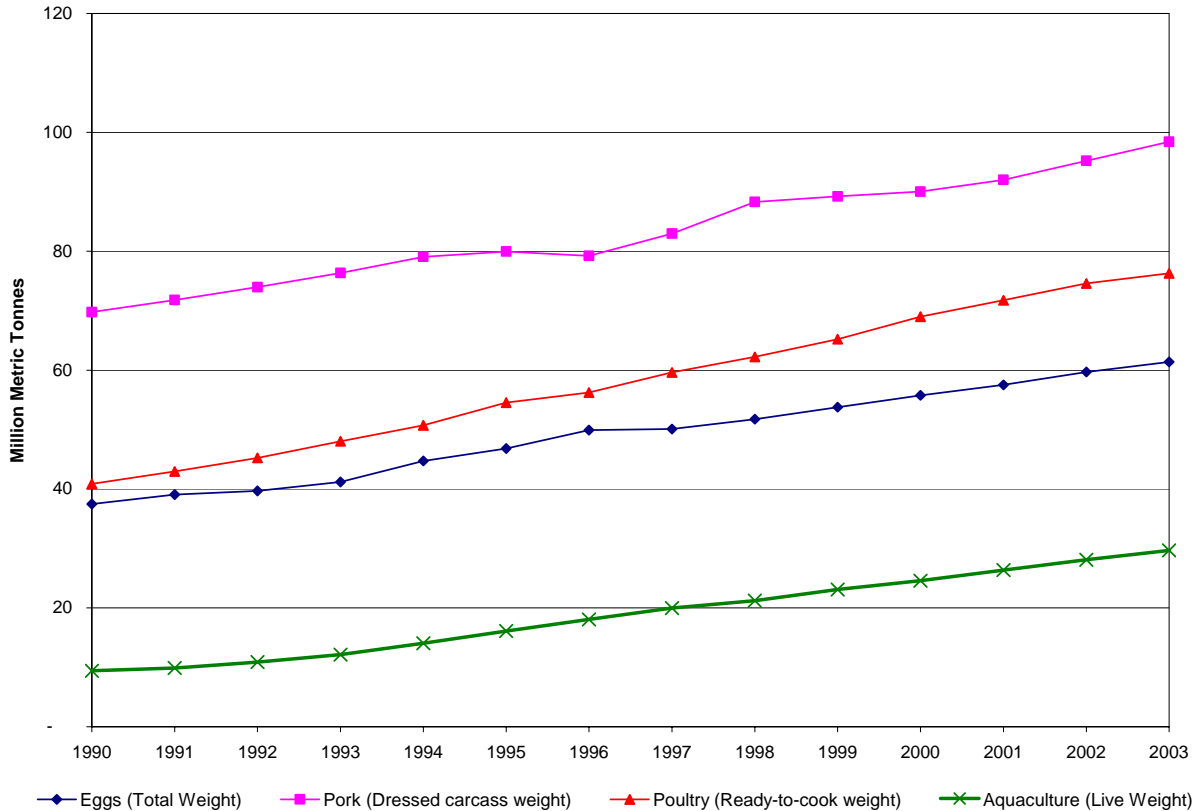


Figure 2. World production of poultry meat, pork, eggs, and aquaculture, 1990-2003. [13, 14]

Trends in Global Fishmeal Production

In contrast to the increasing demand for fishmeal, the global production of fishmeal has been relatively stable over the past 20 years. The supply of fishmeal has averaged 6.5 MMT over the past two decades, fluctuating between 5.4 MMT and 7.5 MMT. The major producers of fishmeal are: Peru, Chile, China, Thailand, USA, Japan, and Scandinavia, which is an aggregation of Iceland, Norway, and Denmark (Fig. 3). Fishmeal is derived from small pelagic species that are not generally used for human consumption, including herring, menhaden, capelin, anchovy, pilchard, sardines, and mackerel. These species are characterized by early maturation and high fecundity. In addition, these species are known to be sensitive to changes in environmental conditions, which leads to uncertainty in their stock forecasts. These species are especially sensitive to *El Niño* events, the most recent of which occurred in 1998. From Figures 3 and 4, one can see the impact of this event on the harvest and price of fishmeal in 1998.

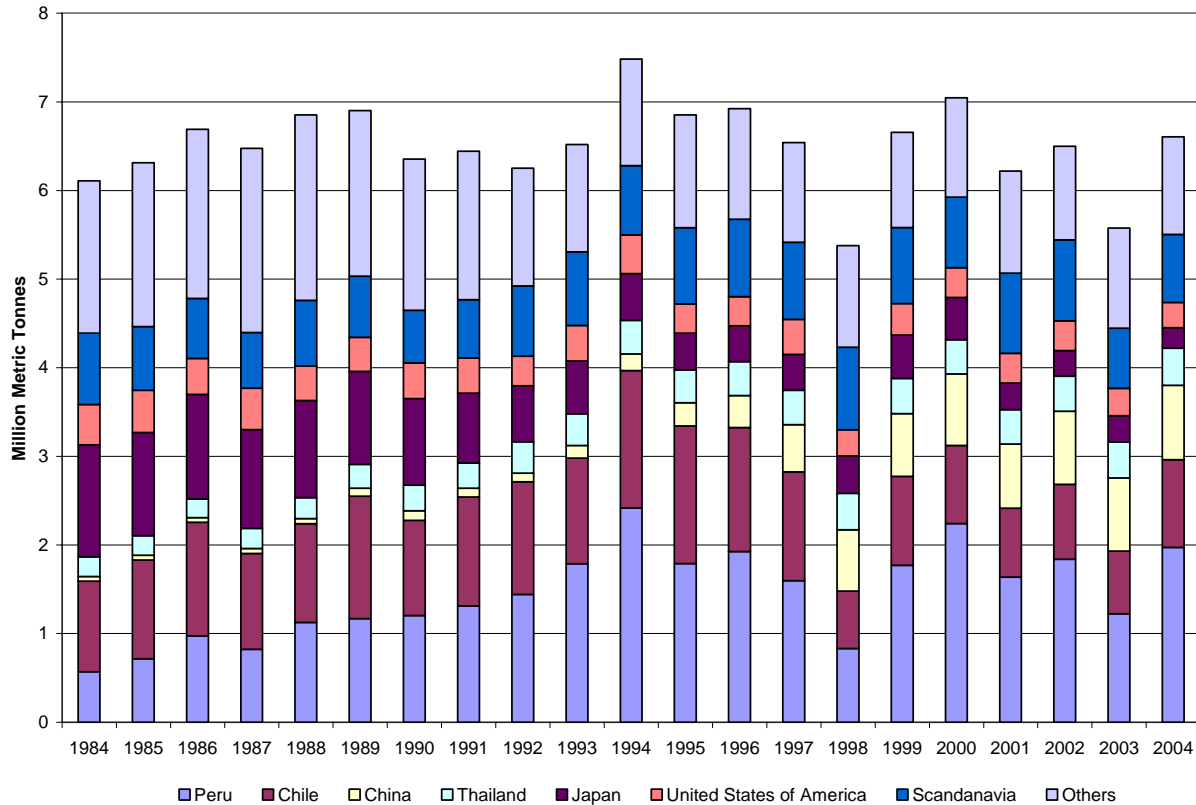


Figure 3. Global fishmeal production by country, 1984-2004.[13]

Market forces and the search for substitutes

Given the relatively fixed supply of fishmeal and the growing demand for fishmeal, the price of fishmeal is expected to rise as demand increases. As the price of fishmeal and fish oil rises relative to other protein sources, such as soybean meal, both agriculture and aquaculture users will attempt to substitute across protein sources to reduce production costs while maintaining nutritional and quality standards for their products. Following the *El Niño* event in 1998, this sort of price driven substitution was observed in the poultry and pork sectors as the price of both fishmeal and fish oil rose. The poultry sector halved its annual demand for fishmeal from 2.4 MMT to 1.2 MMT, while the pork sector reduced its demand by 20% [15]. Still, there is a point where both the agriculture and aquaculture sectors will face limitations regarding their ability to substitute fishmeal and fish oil within their production cycles.

Soybean meal as a possible substitute

Soybean meal is a vegetable based protein source that provides amino acids and essential nutrients, although not of the same caliber as fishmeal. Historically, fishmeal has commanded a higher price than soybean meal (Fig. 4). The price differential between the two protein sources is related to differences in quality [5]. The critical question to ask is, does fishmeal have unique nutritional properties that distinguish it from the general oilseed market? If fishmeal is a substitute for other protein sources on the market, then substitution across protein sources should occur. The ability to make substitutions will reduce the possibility of large increases in the price of fishmeal as the demand for fishmeal increases. However, if it is the case that fishmeal is a unique protein with limited substitution possibilities across other proteins sources, then this has implications for the future price of fishmeal. Asche and Tveteras [5] examined the relationship between aquaculture and reduction fisheries by analyzing monthly prices for soybean meal and fishmeal from the United States and Europe from January 1981 to April 1999. Using

cointegration analysis, they found evidence that fishmeal and soybean meal are strong substitutes and that fishmeal is part of the larger oilmeal market.

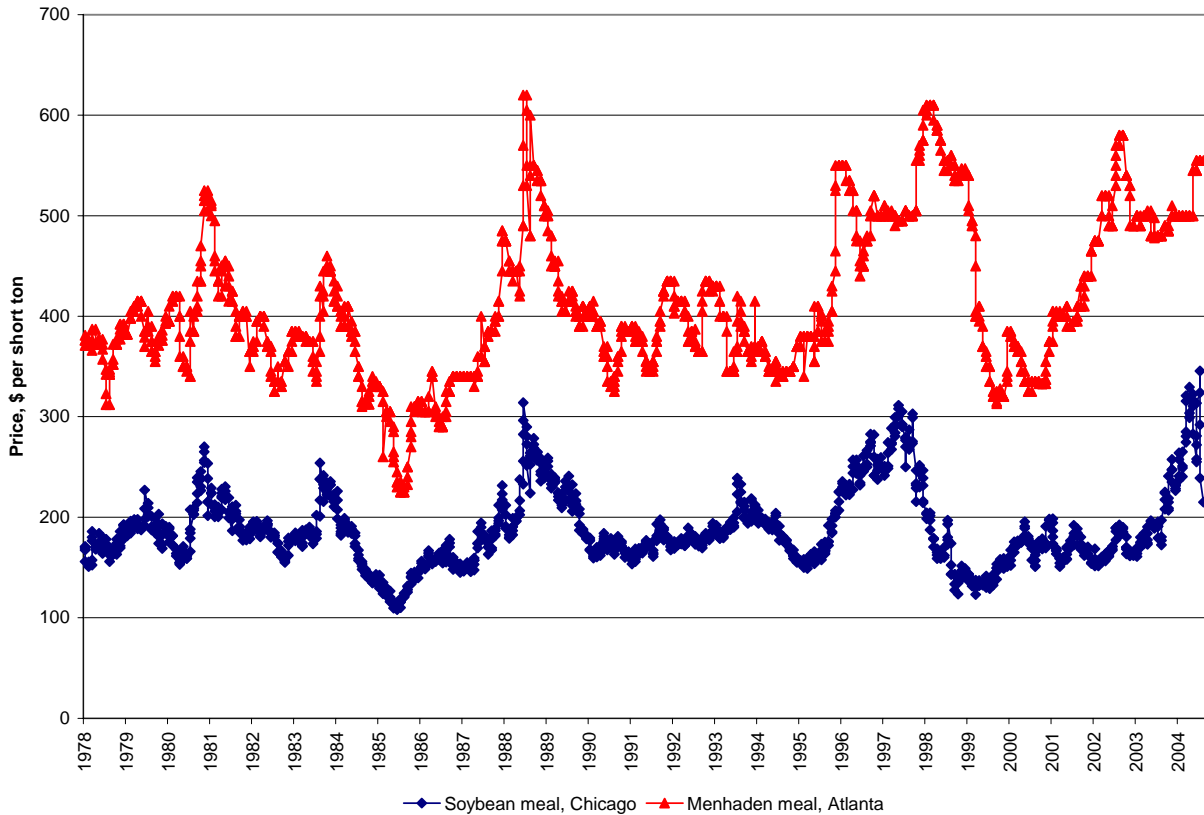


Figure 4. Price of fishmeal and soybean meal. [16, 17]

Their work is consistent with previous research by Vukina and Anderson [4] which examined weekly observations from the soybean meal/fishmeal market from June 5, 1986 to May 23, 1991 and found a high degree of substitutability between soybean meal and fishmeal such that cross-commodity futures hedging could successfully reduce price risk in the fishmeal market.

Has the price relationship changed?

With rapid growth in global aquaculture, pork and poultry production, it is hypothesized that there is likely to be a breakdown in the historic relationship between fishmeal and soybean meal prices as a greater share of the users need fishmeal for specialty diets. Kristofersson and Anderson [1] formally test if and when this relationship has changed. If there is a change in this relationship, then this lends support for the hypothesis of increasingly limited substitutability in the fishmeal/soybean meal complex, and therefore suggests that fishmeal may become an important constraint to growth in the aquaculture, pork and poultry sectors.

Figure 4 illustrates weekly cash prices for Menhaden fishmeal in Atlanta, as reported by *Feedstuffs* magazine, and soybean meal prices from the Chicago Board of Trade for the period January 2nd 1978 to August 8th 2004 [16, 17]. The two prices follow similar patterns and have been subject to similar shocks, which is consistent with the assumption that the two commodities are close substitutes. The largest price shocks, in 1988-1989 and 1998, coincide with temperature anomalies in the Pacific, the 1988 *La Niña* and the 1998 *El Niño*. These anomalies have been shown to affect rainfall in the US Midwest and pelagic fish stocks of the Pacific coast of South America.

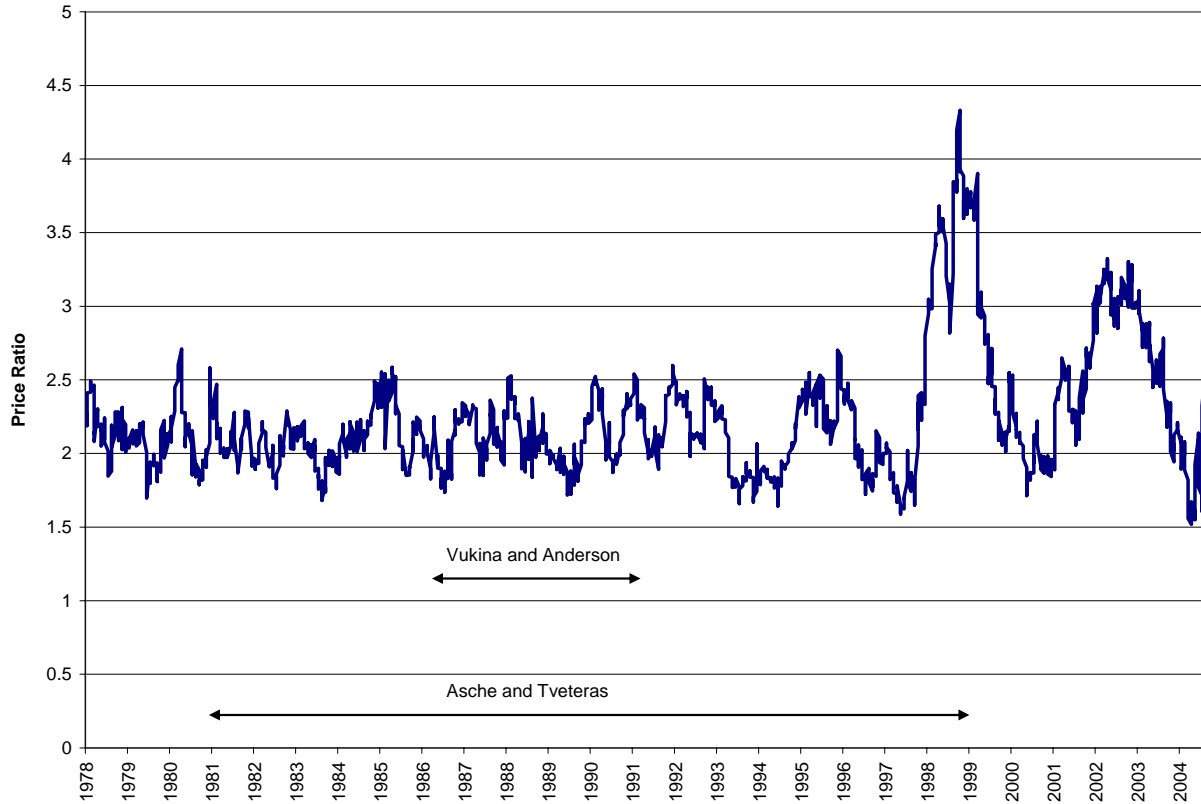


Figure 5. Fishmeal and soybean meal price ratio

Figure 5 shows that the fishmeal and soybean meal price ratio has been relatively stable in the past. However, there appears to be change in the relationship during the 1998 and thereafter. Since then fishmeal has since had periods of considerably higher relative price compared to soybean meal and increased variance. This observation is verified by applying the test procedure suggested by Bai and Perron [18, 19] to the data shown in Figure 4. This method is used to test for structural breaks at an unknown point in time as well as to identify the number of breaks and most probable time of the break. Since the data are found to be non-stationary [20] as well as highly seasonal [21] the Bai-Perron test was conducted on yearly differences in prices. As seen in Table I, the test of the hypothesis of no structural break was rejected at the 1% significance level and the hypothesis of one structural break was rejected at the 5%. However, the hypothesis of two structural breaks was not rejected.

	Null hypothesis ^a		
	H0:j=0	H0:j=1	H0:j=2
SupF	37.7**	11.3*	4.2

** significant at 1% level, * significant at 5% level

^a The letter *j* refers to the number of structural breaks.

^b Critical values for the test statistic are found in Bai and Perron [22]

Table I. The SupF statistics for the Bai-Perron sequential test of a structural change

The two breaks are identified below in Table II as beginning in late 1996 and late 1998. Both break dates roughly coincide with supply side events, the first with the reduced catch of US Menhaden in late 1995-1996 and the second with the supply shock caused by the 1998 *El Niño*.

	Period		95% CI for change	
	Start	End	Upper	Lower
First period	1/3/79	11/6/96	11/8/95	12/18/96
Second period	11/13/96	10/28/98	6/24/98	8/30/00
Third period	11/4/98	8/4/04		

Table II. The point estimate of structural change with 95% confidence interval identified by the Bai-Perron method

Kristofersson and Anderson [1] also conducted cointegration tests [23] which suggest that the high degree of integration which had existed in much of the 1980s and 1990s has been disrupted. The results do not indicate the market is returning to the historic price relationship. What are the likely causes of structural change? Did the growing aquaculture sector demand vast quantities of fishmeal as hypothesized by Naylor et al [24] and New and Wijkström [3]? Table III presents world aquaculture production of finfish and shrimp along with the share of carnivorous species, the world production of fishmeal, the quantity and share of fishmeal used in aquafeed.

Year	Aquaculture		Fishmeal			Reference ⁶
	World production ¹ MMT ²	Share of carnivorous Species ³	World production ⁴ MMT	Use in aquafeed use MMT	% of WP ⁵	
1986	6.41	20.5%	6.69	0.52	7.8%	[25]
1988	8.19	22.2%	6.85	0.69	10.1%	[26]
1992	10.89	23.3%	6.25	0.96	15.4%	[3]
1994	14.06	20.3%	7.48	1.27	17.0%	[6]
1995	16.10	19.6%	6.85	1.73	25.2%	[27]
1996	18.04	18.8%	6.92	2.00	28.9%	[28]
1997	19.97	18.8%	6.54	2.32	35.5%	[7]
1998	21.23	19.1%	5.33	2.13	39.9%	[29]
1999	23.09	19.3%	6.66	2.10	31.6%	[29]
2000	24.57	20.7%	7.04	2.46	34.9%	[30]
2001	26.35	21.9%	6.08	2.62	43.1%	[31]
2002	28.10	22.0%	6.20	2.90	46%	[32]
2003	29.67	24.8%	5.58	2.93	52.6%	[31]

¹ World production of finfish and crustaceans [13]

² Million metric tonnes

³ FAO FISHSAT Filter: ISSCAAP Division (Marine Fish, Diadromous Fish, and Crustaceans)

⁴ World production of fishmeal [13]

⁵ World production

⁶ Partly based on Table V in New and Wijkström [3].

Table III: World aquaculture production of finfish and shrimp and fishmeal use

Changes in fishmeal use over time

As seen in Table III, aquaculture production of finfish and crustaceans has increased over 397% since 1986. Over that same time period, the world production of fishmeal has remained essentially stable at 6.5 MMT. Table III presents the increasing percentage of fishmeal used in aquafeeds as estimated by various sources. Based on 2002 estimates, the aquaculture sector consumed the same percentage of fishmeal (46%) as the poultry (22%) and pork (24%) sectors combined [32]. By 2012 Pike [32] estimates that the aquaculture sector will consume 50% of total fishmeal production, while pork usage will remain essentially unchanged (25%) and poultry consumption will decline (15%).

An indication of the changes that are occurring with regard to the relationship between fishmeal and the aquaculture industry can be seen in Figure 6. This figure presents an index of predicted fishmeal use in aquaculture under the assumption of no substitutability with the input/output relationship reported by Naylor et al. [24]. If no substitution with other protein sources is possible, predicted fishmeal use should follow closely the estimate of actual fishmeal use.

While the trends of the actual and predicted fishmeal use were similar prior to 1997, it appears that post-1997, this relationship has started to change. Based on the input/output ratios found in Naylor et al. [24] predicted fishmeal use was forecast to increase approximately 7% from 1997-2003, while in fact the estimated actual use of fishmeal was around 4%. By 2012, the estimated use of fishmeal by the aquaculture sector is forecast to be in the vicinity of 3 MMT, essentially the same amount of fishmeal consumed in 2003.

The divergence between the fishmeal usage line derived from Naylor et al. [24] and estimated actual use is a result of one of three possible developments. First, a change in the species produced, from carnivores to herbivores for example, could explain the transition away from the predicted use line. A second explanation is that the aquaculture industry has been able to find substitutes for fishmeal, thereby lowering actual fishmeal use. And finally, a third explanation is that the aquaculture industry has improved farm management and/or the formulation of the diet as to improve the efficiency of the production process.

With regard to the composition of species produced, the share of carnivorous species has remained relatively stable, ranging from 18.8% to 24.8% over the past two decades (Table III). This suggests that the deviation in actual fishmeal use is not attributed to a change in species mix.

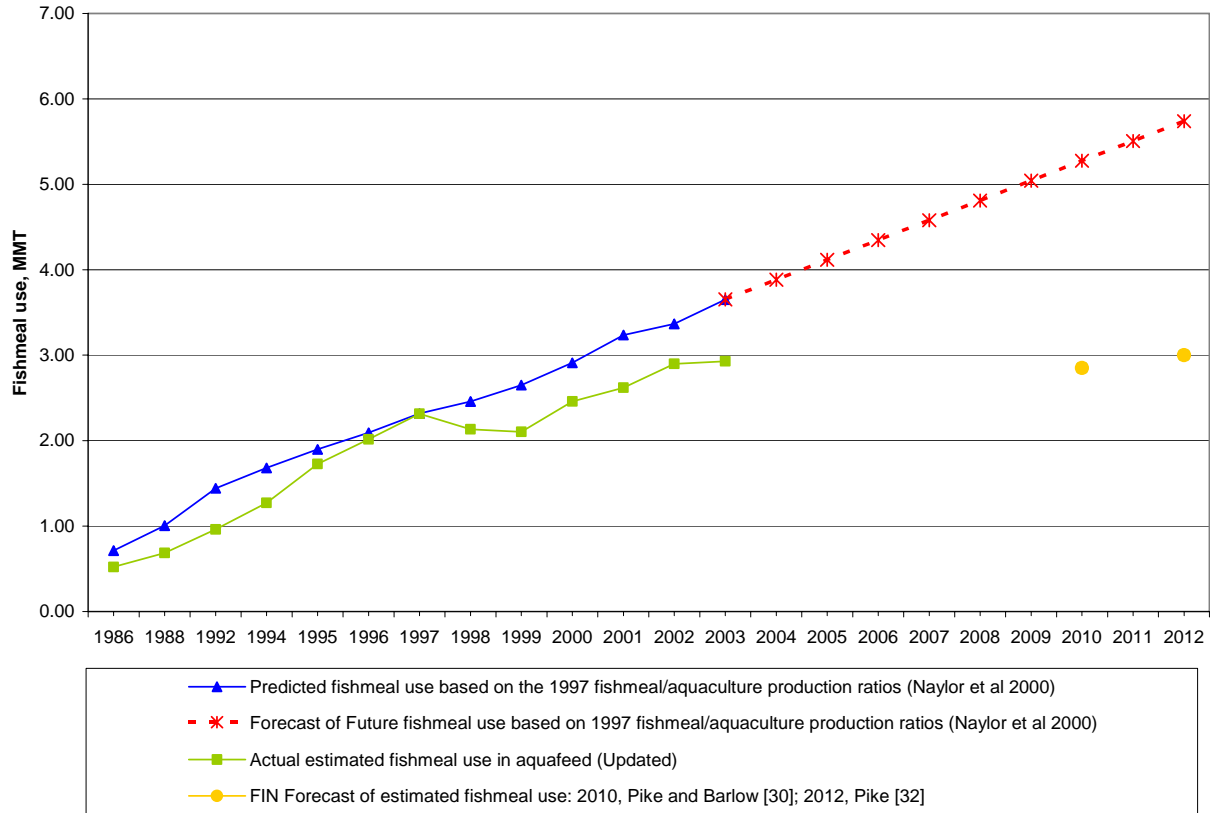


Figure 6. Estimated fishmeal use versus predicted use of fishmeal in aquaculture.
 (Source: Predicted [13, 24]; Actual: see Table III)

Looking at the farmed salmon industry, the percentage of dietary fishmeal and fish oil used within salmon feeds has changed dramatically over the past two decades (Table IV). There has been a decrease in dietary protein levels within salmon feeds, with an equivalent increase in dietary lipid and energy levels [33]. This shift has resulted in faster fish growth rates and improved feed efficiencies. Today, Chilean salmon production cycles are at least 20-25% shorter than they were 10 years ago due to the use of higher energy and lower protein feeds [34]. Canadian and Norwegian producers currently lead the way in terms of the current level of dietary marine protein (i.e. fishmeal) and marine lipid (i.e. fish oil) substitution rates at 55% and 50%, followed by Chile at 60% and 20% and the UK at 45% and 10%, with no apparent loss in fish growth or the nutritional quality of the fish carcass [33].

Year	Fishmeal Inclusion	Dietary Lipid Levels
1985	60%	10%
1990	50%	15%
1995	45%	25%
2000	40%	30%
2005	35%	35-40%

Table IV: Inclusion of Fishmeal within Salmon Feeds, 1985-2005 [33]

Finally, with regard to better farm management practices and improvements in the efficiency of production, it appears that the aquaculture industry has made great strides in improving its performance in

this area. Already within salmon production the feed conversion ratio has fallen significantly from over 2 to 1.3 over the past 20 years (Table V).

Year	FCR¹
1983-1985	> 2.0
1986-1990	1.7
1991-1995	1.6
1996-2000	1.5
2001-2003	1.4
Current 2003	1.3 (range 1-1.5)

¹ The feed conversion ratio is defined as (FCR = Total feed fed / total live fish produced) which takes into account all fish mortality over the production cycle.

Table V: FCR for Farmed Salmon, 1983-2003 [33]

It is interesting to note that the FCR for farmed salmon (including large rainbow trout) is the lowest of all the major cultured/fed aquaculture species, ranging from a high of 2.4 (freshwater crustaceans) 2.0 (feeding carp, tilapia, milkfish, marine finfish, eel), 1.9 (marine shrimp), 1.6 (catfish) to a low of 1.3 (trout and salmon) [7]. These gains in efficiency can be attributed to better feed manufacture and formulation and better farm management [33]. Such technological advancements will help check prices until a biological limit on vegetable protein inclusion is reached.

CONCLUSION

The empirical evidence supports the hypothesis that a structural change has occurred in the late nineties and that the strong historical price relationship between fishmeal and soybean meal has changed. The most likely cause for this change is increased demand for specialty uses of fishmeal, not only from aquaculture but also from the pork and poultry industries as well. Poultry and pork farmers also face limited possibilities for substitution, especially in specialty and starter diets. The concerns of Naylor et al [24] and New and Wijkström [3] regarding the long run economic sustainability of current practices in aquaculture apply to these industries as well. However, as the relative price of fishmeal increases there is considerable incentive for these industries to innovate. Innovation is likely to come in many forms, such as direct substitution of new soybean meal products, more efficient production systems, better diet formulations for animal and fish feed, changes in species grown and breeding and/or genetic engineering of new vegetable substitutes for fishmeal. The industry has already responded to this price driven stimulus by improving farm management practices and finding protein substitutes for fishmeal, all with the effect of reducing the actual use of fishmeal within the aquaculture sector. It remains to be seen if the industry can continue to innovate and improve management practices further. Without such innovations, both the animal production and the aquaculture industries may be faced with a long-run constraint to growth as feed costs increase.

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ENDNOTES

^a Parts of this paper are drawn from Kristofferson and Anderson 1. Kristofferson, D. and J.L. Anderson, *Is there a relationship between fisheries and farming? Interdependence of fisheries, animal production and aquaculture*. Marine Policy, 2006. **30(6)**: p. 721-725.