

# **A Science-Based Analysis of Growth, Nutrition and Feeding of Coho Salmon (*Oncorhynchus kisutch*)**

## Background Information:

Brown, P.B., Wilson, K.A., Hodgins, Y., Stanley, J.D., 1997. Use of soy protein concentrates and lecithin products in diets fed to coho and atlantic salmon. *J. Am. Oil Chem. Soc.* 74, 187. <https://doi.org/10.1007/s11746-997-0122-0>

# Use of Soy Protein Concentrates and Lecithin Products in Diets Fed to Coho and Atlantic Salmon<sup>1</sup>

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**ABSTRACT:** Aquacultural production is increasing in most parts of the world, establishing new and rapidly growing markets for various oil products. One of the more interesting nutritional requirements for aquatic animals is lecithin or phosphatidylcholine. In this paper, lecithin in aquaculture is reviewed with emphasis on freshwater fish and crayfish. Further, new data on use of lecithin and two soy protein concentrates in diets fed to coho and Atlantic salmon are presented. Juvenile coho and Atlantic salmon were fed either solvent-extracted soybean meal (SBM) or Promocalf<sup>®</sup> at 30% of the diet, Promoveal<sup>®</sup> at 10, 20 or 30% of the diet, or one of three new lecithin products at a constant level of 3% of the diet. Juvenile coho salmon fed SBM, Promocalf<sup>®</sup>, or Promoveal<sup>®</sup> at 30% of the diet exhibited depressed weight gain and an elevated feed conversion ratio (FCR) compared to fish fed a positive control diet. Fish fed 10 or 20% Promoveal<sup>®</sup> had similar weight gain and FCR compared to fish fed the control diet. Coho salmon fed either of the three lecithin products (Aqualipid<sup>®</sup>, Blendmax<sup>®</sup>, or Centrol<sup>®</sup>) had similar weight gains and FCR values compared to fish fed the control diet. Whole-body proximate components were not as responsive to dietary treatments as weight gain and FCR data. Juvenile Atlantic salmon exhibited depressed weight gain only when fed 30% Promocalf<sup>®</sup> and all three lecithin products. Further, whole-body crude protein concentrations in fish fed the three lecithin products were depressed. *JAACS* 74, 187–193 (1997).

**KEY WORDS:** Crayfish, fish, phosphatidylcholine, salmon, soy protein concentrates.

Aquacultural production is increasing at rapid rates throughout the world (1). This increase is in response to loss of traditional supplies of fish from the oceans that occurred in the latter half of this century. Even if wild populations of fish returned to pre-1950 levels, harvest would be unlikely to keep pace with increasing population and demand for fish. The increase in fish production places demands on the available feed stocks around the world

and has resulted in a new active area of research. The initial focus of that research has been on sources of protein in diets fed to fish. The use of readily available commodities, particularly soy products, is a logical initial step (2–11).

Soybean production and processing are two of the largest agricultural pursuits in the world, and products from those industries serve as potential feedstuffs for the rapidly developing aquacultural industries. Fish require relatively high levels of crude protein in their diets as well as several atypical nutrients. Processed soy products and products from processing offer the potential of supplying both crude protein and several of the atypical nutrients.

Soy protein concentrates (SPC) are some of the new products from soy processing that could find an immediate use in diets fed to fish. A generalized proximate composition of SPC is >65% crude protein, <0.5% fat, <5% fiber, 23–25% nitrogen-free extract (NFE), and 7–8% ash. Fish grow maximally when fed diets that contain 25–45% crude protein, 6–25% fat, less than 7% crude fiber, and 20–30% NFE (12). Thus, SPC have potential as ingredients in diets fed to fish. The essential amino acid composition is also favorable for most species of fish. However, soy products contain antinutritional factors known to limit use of certain types of soy products in diets. Further processing of raw soybeans and soybean meal to SPC may remove some of these compounds and facilitate use of soy products.

Fish and aquatic crustaceans require several nutrients in their diets that are not typically thought of as essential nutrients in terrestrial animals. One of these is lecithin, or phosphatidylcholine (PC) (13–18). Lecithin is the primary phospholipid in most cell membranes and facilitates entry of compounds into cells. Phospholipids are both hydrophilic and lipophilic and are considered the primary compounds that impart viscosity to cell membranes. Fish and crustaceans are apparently the only animal groups that require PC in the diet; terrestrial vertebrates can synthesize sufficient quantities of PC, given sources of choline, methyl donors, and lipid substrates to form phosphatidylethanolamine.

Lecithin is a phospholipid with a three-carbon back-

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Coho salmon: This species may be the best choice to meet growing demand for wild salmon, 2003. , in: Seafood Business. Seafood Business, p. 20+.



## Coho salmon

This species may be the best choice to meet growing demand for wild salmon

**W**ith consumers suddenly clamoring for fresh wild salmon, many buyers who have relied solely on farmed fish are in a conundrum. But coho salmon may just be the answer to their problem. Offering quality, quantity and value, coho presents an appealing combination of attributes other wild species can't match.

Their flesh is almost as red as a sockeye, and they're pretty big fish, averaging almost 8 pounds in Alaska, where almost 40 million pounds of cohos are caught in a good year.

The oil content is good, too. Although not as high as king or sockeyes, cohos have twice as much fat as pinks and 50 percent more than most chums.

But the best thing about cohos may be their price, making them the best wild-salmon value around. Last year, Alaska fishermen averaged just 36 cents a pound for their fish, while fishermen in the Pacific Northwest, which typically produces a catch of about 5 million pounds a year, were paid an average of just 33 cents. At those prices, buyers in Seattle could offer fresh H&G coho to wholesalers at about \$1 a pound.

Cohos are also farmed, especially in Chile, which produces more than 220 million pounds a year (compared to the annual U.S. coho catch of about 50 million pounds). However, most of the Chilean product goes to Japan. Last year, for example, U.S. imports of farmed cohos from Chile were only about 150,000 pounds.

Canada produced a lot of farmed cohos in the late 1980s, but salmon farmers there have all but abandoned cohos in favor of Atlantics and chinooks. A few small farms still produce cohos, but exports to the U.S. have declined to less than 500,000 pounds a year from more than 5 mil-

lion pounds in the 1990s.

In the wild, cohos are caught from the Kuskokwim River in western Alaska to the Columbia River. In Alaska about 60 percent of the catch comes from Southeast, where cohos are caught by both trollers and net fishermen.

Most of the troll catch comes in early August, when the fish are actively feeding before heading upriver to spawn.

Prince William Sound, including the Copper River along the central Gulf of Alaska coast, is also a large producer of cohos, yielding harvests of about 6 million pounds in a typical year. Famed for its high-quality sockeyes and kings, the Copper River is helping cohos capture some of the same marketing cachet, although the cohos are considered average quality by knowledgeable salmon buyers.

Other areas of Alaska that produce significant volumes of cohos are Cook Inlet and Kodiak, which normally yield a combined catch of about 6 million pounds a year.

In the Lower 48, coho catches have rebounded a bit from their lows of the late 1990s. From a typical average of about 10 million pounds in the early 1990s, coho catches from Oregon and Washington collapsed to under 1 million pounds before rebounding to 6 million pounds in recent years.

In British Columbia, meanwhile, commercial coho fishing is all but over, as the fishery has been largely shut down for more than five years.

### Supply outlook

The word from Alaska is that 2003 was not a big year for cohos. By mid September, with most salmon fishermen heading home, catches were just 25 million pounds, well below the 39



Cohos were on special in early October at Seattle's Wild Salmon Seafood Market, where H&G fish sold for \$3.99 a pound.

million pounds of cohos landed in 2002.

Things were looking better in Oregon and Washington, however, where ideal ocean conditions were expected to yield a bumper harvest that could exceed last year's catch of more than 5 million pounds.

### Price trends

Although lower catches this summer led to higher prices, cohos were still a pretty good value, as ex-vessel prices remained low.

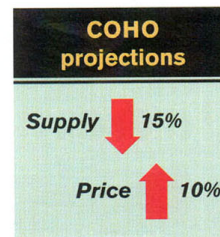
Fresh, gillnetted H&G cohos sold for between \$1.50 and \$1.75 a pound most of the summer, with troll fish at the high end of the range. After Labor Day, when demand typically falls off at the same time coho fisheries in Washington and Oregon hit their stride, prices fell to an average of \$1.30 to \$1.60 a pound for bright-skinned net fish.

At those price levels, retailers in the Pacific Northwest were able to put fresh coho fillets on ad at \$3.99 a pound and still make a decent gross margin.

A soft market for sockeyes and farmed cohos in Japan has put a lid on frozen H&G wild cohos. Alaska processors were having trouble moving net fish at \$1.50 a pound and troll fish for \$1.75.

As the demand for wild salmon has grown, processors are putting up

more single-frozen, boneless coho fillets and portions, both skin-on and skin-off. Prices for single-frozen fillets this fall were averaging about \$2.30 a pound, while center-cut portions were bringing about 30 cents more.



### Buying tips

Wild salmon is tricky to buy, and cohos are no exception. With prices so low, beleaguered salmon fishermen see little reason to handle their fish with extra care. Still, savvy salmon buyers know how and where good cohos can be found.

If you're planning on promoting fresh wild cohos, be conservative. As shown this summer, fish supplies vary considerably from week to week. One West Coast distributor who found himself on the short side of a coho ad in mid August had to fork over \$2 a pound for fish that he

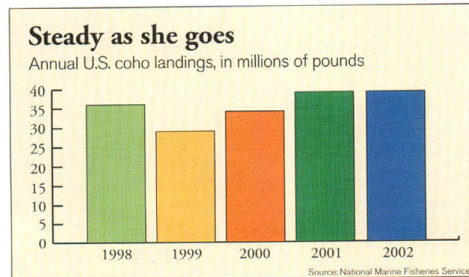


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had committed to sell at \$1.60 a pound.

For that reason, large retailers (and companies that sell to them) should limit their coho ads to either specific divisions or in-store specials.

Smaller chains, on the other hand, which need only 5,000 pounds or so of cohos for a fresh ad, can relax for the most part, as long as they make certain to get firm commitments from their suppliers.

From a supply standpoint, the best time for fresh cohos is in mid to late September, after demand tends to drop off. Gillnet fisheries in Copper River and Southeast Alaska are still going, at the same time Columbia River and tribal fisheries in Washington state are producing full throttle.

If you're looking for bright cohos, Alaska is generally your best bet, especially troll-caught cohos, which are landed well offshore. (The downside to troll fish is that they can be soft-meat if not handled well, as they are still actively feeding.)

Fisheries in the Lower 48 produce a higher percentage of "blush" and "redskin" coho. These are fish whose skin color has started to change, especially later in the run.

Because fishermen normally receive only about half the price they would for a bright coho, blush coho can be a very good value. The meat color is usually just as red, and if you're selling skinless fillets, your customers will be none the wiser.

The meat from redskin cohos, on the other hand, can be pale, so if you plan to cut fillets from redskins, make sure you have a market for pale fish.

Some suppliers will try to sell chums with good meat color as cohos. With a price difference of as much as 50 cents a pound, there's ample incentive.

If you're buying H&G fish, it's easy to spot the difference. Chums have a much thinner caudal peduncle (the part of the fish just in front of the tail) than a coho. If you're buying fillets it can be trickier, since some cohos from runs like the Columbia River can have a slightly less red color, which isn't that different from the best chums. As always, the best protection is education.

To get the most value from a coho, put some effort into merchandising it. Some restaurants and retailers have started selling cohos by the run to give the fish more cachet. More and more regional names already have positive appeal from sockeye fisheries, making it easier to convince consumers they're getting a special salmon.

Make sure you know where your coho is coming from, as it will help you determine shelf life. Fresh troll cohos from Alaska can have six to eight days on them when they hit

## COHO AT A GLANCE



**SCIENTIFIC NAME**  
*Oncorhynchus kisutch*

**MARKET NAMES**  
*Coho salmon, silver salmon; sometimes identified by river of origin (Copper River coho, Columbia coho)*

**Size range**  
To 18 pounds, but most fish are 6 to 9 pounds

**Yield**  
Whole to boneless fillet: 50 to 55%, depending on trim

**Primary product forms**  
Fresh: H&G; skin-on and skinless, boneless fillets  
Frozen: H&G; skin-on and skinless, boneless fillets and portions, steaks  
Smoked

**Packaging notes**  
Frozen portions and fillets should be vacuum-packed for maximum shelf life.

**Primary sources**  
Alaska, Washington, Oregon, Chile (farmed)

**Distribution**  
Alaska to Oregon

**Primary production methods**  
Farmed and wild

**Storage tips**  
Frozen fish should have a 3% glaze

**Defects**  
Pale meat color; soft, gaping flesh; poor trim

Seattle, so plan on selling them fast.

Cohos caught in Oregon and Washington, on the other hand, can often be ready to be flown or trucked out of Seattle less than 12 hours after being landed, in some cases.

**Culinary notes**  
Cohos are a very versatile fish that are suitable for simple or complex preparations. They have enough oil to lend themselves to grilling or broiling, yet they also perform well in the pan and oven.

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## ORIGINAL ARTICLE

# Long-term changes in the fine-scale population structure of coho salmon populations (*Oncorhynchus kisutch*) subject to extensive supportive breeding

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The long-term viability of a metapopulation depends partly on the gene flow among sub-populations. Management approaches such as translocations and supportive breeding between closely related populations may affect gene flow and overall structure, and therefore viability. Here, we examined temporal changes in the fine-scale population structure of coho salmon (*Oncorhynchus kisutch*) by comparing archived (1938) and modern (2001–2005) populations in six rivers within a single conservation unit (Puget Sound, Washington) sampled before and after an extended period of between-river transfers and releases of millions of cultured salmon. Genotype frequencies at eight microsatellite loci showed that current populations descended from historical Puget Sound populations, but populations in different rivers that exchanged fish for hatchery propagation share more of their ancestry recently than they did historically. Historically, populations in different

rivers were isolated by geographic distance, but that relationship is no longer significant. Allelic richness among all populations declined significantly, suggesting that genetic drift has increased because of a population bottleneck. Populations in different rivers and within the same river have become more diverged, providing further evidence for a widespread bottleneck. Previously, we observed that genetic distance significantly decreased with the number of fish exchanged; however, some populations apparently resisted introgression. Altered gene flow and lost diversity may affect the complexity, and therefore resiliency of sub-populations within a conservation unit. Plans for artificial culture need to maintain existing genetic diversity and avoid disrupting the fine-scale structure by using local populations for parents whenever possible.

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**Keywords:** hatchery; pacific salmon; microsatellite loci; genetic diversity; metapopulation; temporal

## Introduction

Population structure has important consequences for the evolution of a species and for implications for conservation, because drift, selection, migration and mutation act to differentiate allelic diversity among semi-isolated populations (Whitlock, 2004). Phenotypic diversity can evolve over short genetic and geographic distances (McKay and Latta, 2002), and semi-isolated populations can diversify and become locally adapted (Taylor, 1991). Furthermore, the accumulation of deleterious mutations is dependent on the global effective population size, as well as on the levels of gene flow between populations (Waples, 2002; Whitlock, 2004). Semi-isolated populations represent the range of diversity within a species or conservation unit over a variety of environmental conditions, and afford resilience to perturbations (Allendorf and Luikart, 2007). To be most effective, conservation actions should consider the existing population structure

and the processes that lead to structuring among populations.

The recovery of a species may require human intervention, but care is needed to maintain population structure. Activities such as supportive breeding and translocations are often used to increase population abundance, provide surplus fish for harvest and expand a species' range. However, these activities present risks after the escape or release of domesticated or nonindigenous fish (Ellstrand *et al.*, 1999; Barilani *et al.*, 2005; Halbert *et al.*, 2005; Naish *et al.*, 2007) that may culminate in introgression or a partial or complete displacement of native populations (Hansen, 2002; Haygood *et al.*, 2003; Vasemagi *et al.*, 2005). Ongoing supportive breeding could result in a loss of genetic diversity and reductions in effective population size (Ryman and Laikre, 1991; Gaffney *et al.*, 1996) and could alter the sub-population structure (Utter, 2001; Birnbaum *et al.*, 2003). Despite these risks, supportive breeding and translocations may provide an effective avenue for the recovery of a population's fitness or for the prevention of a loss of genetic diversity (Tallmon *et al.*, 2004; Edmands, 2007). It thus becomes important to establish the relationship between evolutionary divergences and impacts on population structure that might be expected after human-mediated hybridization (McClelland and Naish, 2007).

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## Coho salmon productivity in relation to salmon lice from infected prey and salmon farms

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### Summary

1. Pathogen transmission from open net-pen aquaculture facilities can depress sympatric wild fish populations. However, little is known about the effects of pathogen transmission from farmed fish on species interactions or other ecosystem components. Coho salmon *Oncorhynchus kisutch* smolts are susceptible hosts to the parasitic salmon louse *Lepeophtheirus salmonis* as well as a primary predator of juvenile pink *Oncorhynchus gorbuscha* salmon, a major host species for lice.

2. We used a hierarchical model of stock-recruit dynamics to compare coho salmon population dynamics across a region that varies in salmon louse infestation of juvenile coho and their pink salmon prey.

3. During a period of recurring salmon louse infestations in a region of open net-pen salmon farms, coho salmon productivity (recruits per spawner at low spawner abundance) was depressed approximately sevenfold relative to unexposed populations. Alternate hypotheses for the observed difference in productivity, such as declines in coho prey, perturbations to freshwater habitat or stochasticity, are unlikely to explain this pattern.

4. Lice parasitizing juvenile coho salmon were likely to be trophically transmitted during predation on parasitized juvenile pink salmon as well as directly transmitted from salmon farms.

5. *Synthesis and applications.* The finding that species interactions may cause the effects of pathogen transmission from farmed to wild fish to propagate up a marine food web has important conservation implications: (i) the management of salmon aquaculture should consider and account for species interactions and the potential for these interactions to intensify pathogen transmission from farmed to wild fish, (ii) the ecosystem impact of louse transmission from farmed to wild salmon has likely to have been previously underestimated and (iii) comprehensive monitoring of wild salmon and their population dynamics in areas of intensive salmon aquaculture should be a priority to determine if open net-pen salmon aquaculture is ecologically sustainable.

**Key-words:** aquaculture, Pacific salmon, parasite, predator–prey, trophic transmission

### Introduction

As a result of the extensive marine migrations of anadromous salmonids, juveniles are spatially and temporally separated from adults during early marine life. This serves as an allopatric barrier to pathogen transmission between age classes until they occur in sympatry either in the outer coastal environment

or in the open ocean (Krkosek *et al.* 2007b; Gottesfeld *et al.* 2009). A consequence of migratory allopatry is that during the first few months of marine life, when they are most vulnerable, juvenile salmonids are not subject to some pathogens common to older and larger salmonids. Intensive open net-pen salmon aquaculture can undermine this natural barrier to transmission by providing a year-round host population in the nearshore marine environment whose pathogens can spill over to sympatric wild juvenile salmonids (Costello 2009). As global

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**Aquaculture**

## Apparent protein digestibility and mineral availabilities in various feed ingredients for salmonid feeds

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### Abstract

Apparent digestibility of protein and availability of minerals (Ca, K, P, Mg, Na, Cu, Fe, Mn, Sr, Zn) in various feed ingredients were determined for coho salmon and rainbow trout using yttrium oxide ( $Y_2O_3$ ) as the inert marker and passive feces collection tanks. The feed ingredients were herring meal, menhaden meal, anchovy meal, deboned whitefish meal, poultry by-product meal, feather meal, soybean meal, corn gluten meal, wheat gluten meal, wheat middling and wheat flour. Apparent digestibility (%) of protein and availability (%) of minerals were determined as a fractional net absorption of nutrients from diets. Apparent digestibility of protein and availability of K was high (> 80%) in all feed ingredients, whereas digestibility of dry matter and availability of Ca, Cu, Fe, Mg, Mn, Na, P, Sr and Zn were variable among ingredients. Apparent availability (%) of mineral elements was not significantly correlated to the amount of nutrient intake ( $\mu\text{g nutrient g}^{-1} \text{ BW day}^{-1}$ ) in any test diet. Net nutrient absorption ( $\mu\text{g g}^{-1} \text{ BW day}^{-1}$ ) was positively correlated ( $P < 0.05$ ) to the nutrient intake except for Mn, Fe and Ca. Fecal nutrient losses ( $\mu\text{g g}^{-1} \text{ BW day}^{-1}$ ) were positively correlated ( $P < 0.05$ ) to nutrient intake except for protein, Na, K and Zn. © 1998 Elsevier Science B.V.

*Keywords:* Minerals; Phosphorus; Protein; Digestibility; Availability; Absorption; Ingredients

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## Comparison of growth, feed intake, and nutrient efficiency in a selected strain of coho salmon (*Oncorhynchus kisutch*) and its source stock

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### ABSTRACT

We compared growth in a domesticated strain of coho salmon (*Oncorhynchus kisutch*), that had been selected for rapid growth over 16 generations, to that of its hatchery-origin unselected parental stock. Fish were spawned on the same date and incubated under similar conditions. First feeding fry were fed to satiation and then were fed a commercial salmon feed at two ration levels, either to satiation or on a fixed ration from the size at which the smallest fish could accept a 1-mm pellet (domesticated 0.65 g, hatchery 0.96 g). The domesticated fish outperformed unselected fish by growing faster and to a larger size, ingesting a greater amount of feed when fed to satiation, and exhibiting greater efficiency in feed conversion. When fed to satiation, domesticated fish ingested 53% more feed and gained 78% more weight compared to unselected fish. The selected fish also appeared to utilize dietary lipids for energy while sparing protein for growth, while unselected fish deposited dietary lipids as body fat. These results indicate that selection over 16 generations for growth also resulted in changes in feed efficiency and energy allocation. Understanding the mechanisms underlying improved growth will aid future selection studies by identifying multiple targets of selection that contribute most to growth.

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### 1. Introduction

The number of cultured fish undergoing selective breeding is increasing worldwide, but is still relatively small compared to farmed terrestrial animals. Gjedrem (2005) stated that breeding programs aim to improve three primary attributes of cultured animals: (1) animal welfare through domestication to reduce stress, (2) animal productivity, and (3) product quality. Rapid growth and high feed conversion efficiency of farmed animals, including salmonids, is a key determinant of commercial farming success (Sizemore and Siegel, 1993; Fjalestad et al., 2003). Variation in growth rate in salmonids can be attributed to many mechanisms. These include maternal effects (Heath et al., 1999), rate of embryonic development (Robison et al., 2001), stomach size (Rindorf, 2002; Grove et al., 1978), feed intake (Ogata et al., 2002; Mambrini et al., 2006), metabolic rate (Boily and Magnan, 2002), temperature and genotype (Wangila and Dick, 1988), domestication and behavior (White, 1985; Robinson and Doyle, 1990; Ruzzante, 1994), and digestion efficiency (Bendiksen et al., 2003; Menoyo et al., 2003). Understanding the mechanisms underlying changes in growth rate enable one to develop effective breeding programs and predict potential changes in performance.

One long running selection program with Atlantic salmon (*Salmo salar*) was initiated in 1971 by AKVAFORSK, and has been under selection for multiple generations (Gjedrem, 2000). Thodesen et al. (1999)

compared growth of the fifth generation of the AKVAFORSK fish with that of the source population and reported faster growth in the domesticated stock and attributed this to higher feed intake and feed efficiency. Gjedrem (2000) reported that an 11% genetic gain per generation, for growth rate, has been seen in highly selected stocks of Atlantic salmon. Because salmon have a high degree of phenotypic plasticity, environment can play a large role in genotype expression. Overall, both genetic and environmental factors are implicated in variation in many traits among conspecific strains of fish.

This study compared a domesticated strain of coho salmon (*Oncorhynchus kisutch*), selected for rapid growth, to its source population, a hatchery stock from a watershed with a robust naturally spawning population. Dømsea-Aquaseed,<sup>1</sup> in cooperation with scientists from the University of Washington (UW), developed the Dømsea coho salmon strain in 1977 in Washington State (USA), from a line of mass-selected fish developed by NOAA Fisheries in 1971 (Novotny, 1975). These fish have been subjected to intensive selection for over 16 generations. Northwest Fisheries Science Center (NWFS) and University of Washington scientists have used Dømsea stock coho salmon in numerous studies since 1977 (Tave, 1989). This strain has a recorded pedigree and considerable information on its genetics and performance has been compiled and analyzed (Myers et al., 1999, 2001).

The Dømsea coho salmon strain was bred primarily for rapid growth. Selection program goals were to produce fish with a 2-year life cycle that would have a large body weight at the end of the freshwater phase of

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## Dietary arginine requirement of fingerling coho salmon (*Oncorhynchus kisutch*)

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### Abstract

An 8-week experiment was designed to re-evaluate the arginine requirement of fingerling coho salmon. Triplicate groups of fish were fed semipurified isonitrogenous (av. protein as g amino acids/100 g dry diet = 45.2) and isolipidic (av. crude lipid 11.9% dry weight) diets containing graded levels of arginine in a 6 × 2 factorial design with six arginine levels (expected values 3.5, 4.5, 5.5, 6.5, 7.5 and 8.5% of the dietary protein) and two feeding rates (satiation and restricted). The apparent digestibility of arginine in the experimental diets was also evaluated. The growth rates of the fish fed the experimental diets was comparable to that of fish fed a practical control diet, indicating a more than acceptable overall performance of the experimental diets. When broken-line analysis was performed on the weight gain data against the actual arginine content of the diets corrected by their apparent digestibility coefficients, a breakpoint was found at an arginine level of 4.9% of the dietary protein for the satiation-fed groups and of 5.5% for the restricted-fed groups. Results from the present study confirm that the arginine requirement of Pacific salmon is the highest among the values reported for other salmonid species studied to date. © 1998 Elsevier Science B.V. All rights reserved.

*Keywords:* *Oncorhynchus kisutch*; Arginine; Amino acid requirement; Amino acid apparent digestibility

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## Effects of fish meal- and fish oil-free diets on growth responses and fatty acid composition of juvenile coho salmon (*Oncorhynchus kisutch*)

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### ABSTRACT

Commercial diets fed to coho salmon (*Oncorhynchus kisutch*) contain high levels of fish meal and fish oil. Given concerns about future supplies and prices of these commodities, more nutritional research aimed at identifying alternative dietary ingredients for Pacific salmon is needed. Thus, utilizing a factorial design, terrestrial proteins and lipids were evaluated in practical diets fed to coho salmon. The two basal diets, containing mostly marine proteins or containing only terrestrial proteins, were extruded and top-coated with either marine fish oil or a 63:37 mixture of canola and flaxseed oils. Each of the four dietary treatments was fed to quadruplicate groups of juvenile coho salmon initially weighing 7.5 g/fish. At the end of the 15-wk feeding trial, weight gain (WG), feed efficiency (FE) and survival were significantly higher in fish fed diets containing marine protein compared with fish fed diets containing terrestrial proteins. Similarly, WG and FE were significantly higher in fish fed diets containing fish oil compared with fish fed diets containing plant oils. Survival was not significantly affected by dietary lipid source. Hemoglobin, hematocrit and total protein concentrations in whole blood were significantly higher in fish fed the marine protein diets compared with fish fed the terrestrial protein diets. Hematological responses were not significantly affected by dietary lipid source. Tissue (liver, muscle and carcass) lipids in fish fed the diets with added fish oil contained significantly higher proportions of 20:5n-3 and 22:6n-3 and significantly lower 18:1n-9, 18:2n-6 and 18:3n-3 percentages compared with fish fed the diets with added plant oils. Tissue fatty acid profiles also were significantly affected by dietary protein source, as liver, muscle and whole body lipids of fish fed the terrestrial protein diets contained significantly higher percentages of 18:2n-6 and total n-6 PUFA and a significantly lower total n-3:n-6 fatty acid ratio compared with fish fed the marine protein diets. Results of this study indicate complete replacement of dietary fish meal or fish oil individually have similar inhibitory growth effects in coho salmon, but have different effects on survival, hematological responses and tissue fatty acid percentages in this species.

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### 1. Introduction

The fish reduction industry utilizes one-quarter of the global capture fishery supply to produce fish meal and fish oil (De Silva et al., 2011). As aquaculture utilizes 68% and 89% of global fish meal and fish oil supplies, respectively (Tacon and Metian, 2008), there are concerns about the sustainable use of these commodities in aquaculture feeds (Naylor et al., 2009). Further, marine fish meal and fish oil are potential sources of contaminants such as dioxins, polychlorinated biphenyls (PCB), brominated flame retardants (BFR) and organochlorine pesticides in farmed fish fed these ingredients (Pickova et al., 2011). These and other concerns have prompted fish meal and fish oil replacement studies with numerous aquaculture species (Gatlin et al., 2007; Naylor et al., 2009; Turchini et al., 2009).

Numerous terrestrial proteins and lipids have been evaluated as partial or total replacements for fish meal and fish oil in aquaculture feeds (Glencross et al., 2007; NRC, 2011). Results of alternative protein studies with salmonids have varied. In some studies with rainbow trout (*Oncorhynchus mykiss*), no significant differences in growth rates between control fish and those fed fish meal-free diets containing mixtures of animal and plant protein sources (Lee et al., 2002) or only plant protein sources (Barrows et al., 2007; Kaushik et al., 1995; Lee et al., 2010) were detected. In other studies, rainbow trout fed diets containing only plant protein sources had significantly lower growth rates compared with those fed a fish meal control diet (Adelizi et al., 1998; Alami-Durante et al., 2010; de Francesco et al., 2004; Gomes et al., 1995; Panserat et al., 2009). Similarly, growth rates of Atlantic salmon (*Salmo salar*) fed diets in which alternative proteins partially or completely replaced fish meal were significantly reduced in some studies (Mundheim et al., 2004; Opstvedt et al., 2003; Pratoomyot et al., 2010, 2011), but not in others (Carter and Hauler, 2000; Mente et al., 2003; Refstie et al., 2001). Variable results

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## Growth Potential and Characterization of the Growth Curve:

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### The Effect of Temperature and Ration Size on the Growth, Body Composition, and Energy Content of Juvenile Coho Salmon

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**ABSTRACT.** Juvenile (post-smolt) coho salmon (*Oncorhynchus kitsuch*) were held in fresh water in the laboratory at 5, 10, 15, and 18°C for 8 weeks and fed freshly thawed, juvenile alewives (*Alosa pseudoharengus*) at rates equal to 1 and 2 % of their wet body weight/day, and also at the ad libitum or unrestricted ration rate. Most rapid growth in weight (1.2% wet body weight/day) occurred among fish fed the ad libitum ration at 15°C; growth was most rapid at about 10°C for fish fed the 2% ration (0.7% /day), and the 1% ration (0.1% /day). Gross conversion efficiency was highest at 10°C for all three ration levels. Gross body constituents and energy content of the test fish changed with temperature and ration during the study. Growth rate was positively related to lipid, energy content, and ration; lipid and energy content were positively related to water temperature; lipid, energy content, growth rate, ration, and water temperature were negatively related to water content; and protein was not related to any of the test variables. At the end of the study, water (68.7 to 76.4%) and lipid (3.5 to 10.4%) content were more variable than ash (1.8 to 3.1%), carbohydrate (0.1 to 1.9%), and protein (16.9 to 19.4%) content. Energy content of the fish increased with ration and was highest for each ration level at 15°C.

**INDEX WORDS:** Coho salmon, growth, bioenergetics, proximate composition, Great Lakes.

#### INTRODUCTION

The coho salmon (*Oncorhynchus kitsuch*) is an anadromous species native to Pacific Rim drainages from Japan to California. It was successfully introduced into Lake Michigan in 1966 by the Michigan Department of Natural Resources to control the abundance of alewife (*Alosa pseudoharengus*), an invading species, and to enhance sportfishing (Tody and Tanner 1966). In the Great Lakes basin, the life cycle of the coho salmon is similar to that of populations in their native range except that it is typically shorter (about 3 years) and is spent entirely in fresh water. Stocking of coho salmon now occurs annually in selected tribu-

aries throughout the Great Lakes basin and spawning runs of mature adult fish occur regularly in a number of these tributaries. Significant natural reproduction occurs in some Great Lakes tributaries (Rybicki *et al.* 1990) and the species probably can be considered a naturalized component of the fish fauna of the basin.

This study was conducted to provide bioenergetic information on juvenile (post-smolt) coho salmon that were held in fresh water and maintained on a diet of alewives—conditions similar to those faced by coho salmon at this life stage in the lower four Great Lakes. Such information contributes to an overall understanding of trophic relations in the Great Lakes ecosystem and the accumulation of contaminants in coho salmon. It can also be used to help develop estimates of the forage requirements of Great Lakes coho salmon populations and to adjust stocking rates so that these hatchery-enhanced populations do not overwhelm the forage base available to support them.

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