Potential Economic Value of Growth of U.S. Aquaculture to U.S. Soybean Farmers

Carole R. Engle, Engle-Stone Aquatic$ LLC
Ganesh Kumar, Mississippi State University
Jonathan van Senten, VA SEafood AREC, Virginia Tech University

Soy Aquaculture Alliance

Study funded by Soy Aquaculture Alliance with soybean checkoff dollars.

Acknowledgement

We thank the many nutrition experts (federal and university researchers and nutritionists at various feed mills), extension aquaculture specialists, and industry representatives who provided their insights into this study.

Executive Summary

The U.S. is one of the largest seafood markets in the world. While U.S. aquaculture farming businesses have been successful for more than a century, studies have shown that growth of U.S. aquaculture has been constrained by a variety of overlapping and inefficient regulatory systems that have resulted in severe permitting delays and increased costs. As a result, U.S. aquaculture has not grown at the same rate as that of the rest of the world. There is a growing recognition, however, that U.S. aquaculture farms are managed responsibly and represent an important local source of healthy and safe seafood that is produced in a way that minimizes negative environmental effects. New investments in major aquaculture businesses have been announced in the U.S., and there has been some degree of effort to streamline the regulatory system to reduce the on-farm cost burden without sacrifice of adequate oversight.

Expansion and growth of U.S. aquaculture will be of clear benefit to the U.S. soybean industry, to both farmers and soybean crushing mills. The majority of feedstuffs used in U.S. aquaculture (with the exception of some fishmeal) are sourced within the U.S. and from local areas. While export markets have been important to many grain producers, such markets are volatile and subject to fluctuations not just due to weather but also due to complex international trade relationships. An increased domestic market for soybeans would add stability that would reduce market and price risk. Increased demand for soybeans from aquaculture would further serve to strengthen rural farming communities. While the same benefits would occur with expansion of poultry, swine, and dairy industries, the inclusion rates of soybean meal in the diets of aquaculture species such as catfish and tilapia are much greater than those for terrestrial animals. Moreover, the volume of imports of seafood imported into the U.S. (more than 90% of the seafood consumed in the U.S. is imported) offers tremendous potential for U.S. farms to capture increasing portions of market share in the large U.S. seafood market. The recent announcements and plans for major investments in aquaculture production in the U.S. (primarily of salmon, yellowtail amberjack, shrimp, and tilapia) recognize this opportunity.

The analysis that is presented in this report has resulted in the identification of those segments of U.S. aquaculture with the greatest potential to increase demand for soybeans. Overall, the single greatest potential to increase demand for soybeans is that of the U.S. catfish sector. U.S. catfish already consumes by far the greatest amount of soybean meal of any U.S. aquaculture sector due to its overall volume of production, combined with high inclusion rates of soybean meal in catfish diets. Low-priced pangasius catfish imports, primarily from Vietnam, captured approximately half of the market that had been developed by the U.S. catfish industry. However, that market share could be re-captured through policy changes that create a more level playing field in terms of food safety and environmental standards. Holding imported pangasius products to the same food safety and environmental standards as those of the U.S. would result in a more competitive U.S. industry. U.S. catfish farmers incur the costs associated with high food safety and environmental management regulations while countries that export pangasius to the U.S. do not, accounting for the major portion of the discrepancy in price. If the U.S. catfish industry recovery that has been underway for the past 4 years would continue and reach the production levels at its peak in 2003, demand for soybeans for catfish feeds would increase by 74%.

The next greatest potential to increase demand for soybeans would be that of salmon, followed by tilapia, trout, marine foodfish (other than salmon) production in the U.S., and shrimp. While salmon farms currently do not use feeds with high inclusion rates of soybean products, the dramatic volumes of production announced for the new, indoor salmon farms rank it as the second-greatest demand for soybeans. Tilapia production ranked third due to new investments and proposed expansion, combined with the high inclusion rates of soybean meal in tilapia diets. Trout ranked fifth, based primarily on existing markets that could be captured from imports with policy changes to remove constraints to expansion of trout production in the U.S., even with the relatively lower inclusion levels of soybean products in trout diets. New investments and proposals for projected expansion of marine finfish production from existing farms that produce yellowtail (Hawaii), sablefish (on the West Coast; sablefish is a native fish that is more socially acceptable than Atlantic salmon), branzino (northeast U.S.), and pompano production (Florida) as well as a newly announced indoor facility for yellowtail amberjack (Maine) ranked as the fifth-greatest demand for soybean products, followed by proposals for large-scale shrimp facilities in the U.S.

Longer-term, additional increases in demand for soybeans are likely to come from research that spares fishmeal from aquaculture diets and would result in increased inclusion rates of soybean products in diets for salmon, trout, and marine fish (especially yellowtail, branzino, sablefish, and pompano), for which existing businesses have been developed in the U.S.

Recommendations from this study include the following:

Support needed policy changes that would increase sales of soybeans to U.S. aquaculture. Examples include the following:

- Streamline the regulatory system in the U.S. This recommendation does not refer to reducing environmental protection, but rather to eliminate redundancy and duplication in monitoring and reporting along with reducing the frequency of testing required for farms with a history of no prior violations.

- Reduce permitting delays for U.S. aquaculture businesses.

- Encourage federal and state agencies to support the development of responsible aquaculture, abiding by the 1980 National Aquaculture Act rather than adopt an adversarial approach to regulating aquaculture.

- Work in partnership with the National Aquaculture Association, the Catfish Farmers of America, and the U.S. Trout Farmers Association on needed regulatory reforms.

More specific examples of the types of policy support for the U.S. catfish industry include the following:

- Encourage states to adopt labeling laws that require restaurants to label catfish and catfish-like products sold by the country of origin where raised or processed. Support efforts to include aquaculture products in federal programs for agriculture (i.e. disaster relief and risk management programs for which catfish and other aquaculture products currently fall through the cracks).

- Support efforts by the U.S. catfish industry that require USDA-FSIS to conduct annual in-country equivalency audits, including establishments that export Siluriformes catfish to the U.S.

- Enhance surveillance and testing of Siluriformes products imported into the U.S.

- Support efforts to urge USDA-APHIS to take steps to minimize risks associated with the introduction of aquatic animal pathogens by imported live and processed aquaculture products into the U.S.

- Support federal food purchasing programs for U.S. farm-raised fish such as school lunch, WIC, TANF and other surplus purchasing programs. Farm-raised fish is in high demand but is under-represented in their purchases of fish products.

For the U.S. trout industry, examples of the types of policy support needed would include:

- Reduction of frequency of testing of effluent water quality on farms with a history of compliance with established standards.

- Adoption of uniform fish health testing and certification requirements across states.

- Encourage federal aquaculture research dollars to support U.S. aquaculture industry priorities, ensuring that USDA-NIFA competitive funding, funding for USDA-SBIR grants, funding to USDA-land grant universities, and NOAA Sea Grant funding priorities are aligned and driven by aquaculture industry priorities. It should be noted that, while the term 'industry' is commonly used, the vast majority of aquaculture producers are family farmers. While some proportion of research funding is needed for long-term advancements on "novel" research topics, there is a need for a greater proportion of aquaculture research funds to address stated and more immediate needs of U.S. aquaculture businesses. Overall aquaculture production, and subsequent demand for soy products, will be advanced most quickly by developing effective solutions to key stated problems of aquaculture farmers.

- Invest in research leading to increased inclusion rates of soybean meal and other soybean products in trout and salmon. Promising lines of research include:

  - Low-oligosaccharide soybean meal for salmon diets.

  - Other "designer" varieties of soybeans that reduce anti-nutritional factors for trout and salmon.

  - Epigenetic effects that reduce effects of anti-nutritional factors for trout and salmon.

  - Nutritional research for marine species with especial opportunities for U.S. farms, such as yellowtail, branzino, sablefish, and European sea bass for which aquaculture businesses in the U.S. have been developed.

Table of Contents

List of Tables

List of Figures

Introduction

The U.S. is one of the largest seafood markets in the world, in spite of not having high per capita consumption rates of seafood. Demand in the U.S. is driven by the large population size and income levels in the U.S. However, while the U.S. is self-sufficient in terms of animal protein and livestock feed supplies (Hansen and Gale 2014), it imports more than 90% of its seafood.

The U.S. produces a wide variety of species on aquaculture farms. Some segments of U.S. aquaculture, such as catfish, trout, and oysters, are substantial business segments that make important contributions to local, state, and regional economies. Finfish, such as catfish, depend heavily on soybean meal as a key ingredient in its feed; in other major segments, such as trout, researchers are devoting substantial resources to developing all-plant diets to spare expensive fishmeal. Given the many positive attributes of soybeans such as its high protein content and favorable amino acid profile, most efforts to develop all-plant diets rely heavily on soybean products. Soybeans have been referred to as the "king of beans" (Saghaian 2017) with good reason. Thus, the demand for soybeans from U.S. aquaculture is likely to continue to grow.

In the U.S. aquafeed industry, all feed ingredients are sourced as locally as possible. Given the volume of grains produced in the U.S., this means that all feed ingredients are produced in the U.S., with many produced in relatively close proximity to major aquaculture-producing areas. Thus, increased aquaculture production in the U.S. would clearly increase domestic demand for soybeans produced. Increased domestic demand for soybeans is advantageous for U.S. soybean producers. This project aims to explore the likely effects of increased growth of U.S. aquaculture in terms of increased demand for soybeans through a comprehensive and detailed examination of soybean inclusion rates in feeds for the various types of aquatic animals raised in aquaculture, for both the near future (next 5 years) as well as longer-term potential development. Specific objectives were:

1 ▸ To estimate current soybean usage in U.S. aquaculture;
2 ▸ To estimate increased quantity demanded of soybeans for varying percentages of growth of U.S. aquaculture;
3 ▸ To develop case studies of U.S. aquaculture with greatest potential for growth;
4 ▸ To estimate potential benefits to U.S. soybean producers from increased domestic demand for soybeans from U.S. aquaculture; and
5 ▸ To finalize estimates based on the 2019 USDA Census of Aquaculture.

This report will first present a brief background of trends in U.S. soybean prices, supply, usage and trade, followed by a brief overview of U.S. aquaculture, and a discussion of the types of soybean products currently used in U.S. aquaculture and potential future uses. A discussion of factors that affect soybean prices and demand can be found in the Appendix of this report. The Methods and Results sections for each objective follow. The final section of the report presents Conclusions and Recommendations.

Background

An initial literature review was completed that examined recent economic literature related to the factors that affect demand for U.S. soybeans. A summary of these factors can be found in the Appendix to this report. Recent trade flows and price trends for U.S. soybeans were reviewed and general charts of trends were prepared. Price forecasts for U.S. soybeans were consulted as general background and for comparison with recent trends.

Trends in Soybean Prices, Supply, Usage, and Trade

The total supply of U.S. soybeans reached a record high in 2018 (Figure 1). The increase in total U.S. supply of soybeans has been particularly rapid since about 2013. For example, the average annual rate of growth in soybean production from 2012 to 2018 was 6.1% as compared to 1.8% average annual growth rate from 2003 to 2011. The total usage of U.S. soybeans over the same period of time mirrors that of the growth of supply with an all-time record set in 2017 followed by a slight decrease in 2018 (Figure 2).

The demand for U.S. soybeans is, of course, affected both by domestic U.S. demand for soy products and export demand. Figure 3 shows the change in volumes demanded in domestic markets as compared to volumes demanded in export markets from 1973 to 2018. Throughout the 1970s, export markets composed a somewhat relatively greater percentage of overall demand for soybeans than in the 1980s during which domestic market demand was approximately equivalent to that of export demand. From about 2007 on, however, export markets began to grow more rapidly than did domestic markets, exceeding demand for U.S. soybeans in 2016 (Figure 4). While domestic demand increased somewhat from 2017 to 2019, export demand decreased by nearly 12% from 2017 to 2018, primarily due to international trade conflicts.

Figure 1. Total supply of U.S. soybeans, 1973 to 2018
(Year is the marketing year from September 1 to August 31)

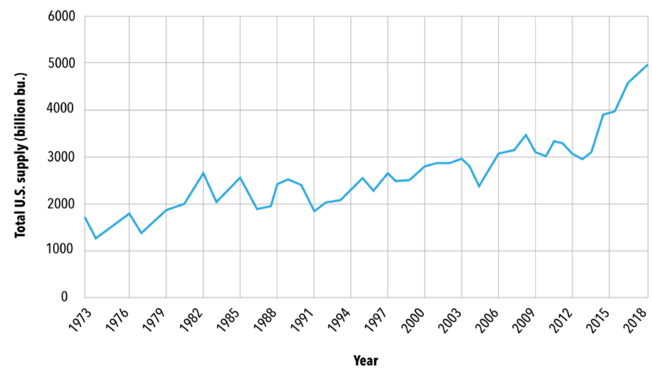


Figure 2. Total usage of U.S. soybeans, 1973 to 2018
(Year is the marketing year from September 1 to August 31)

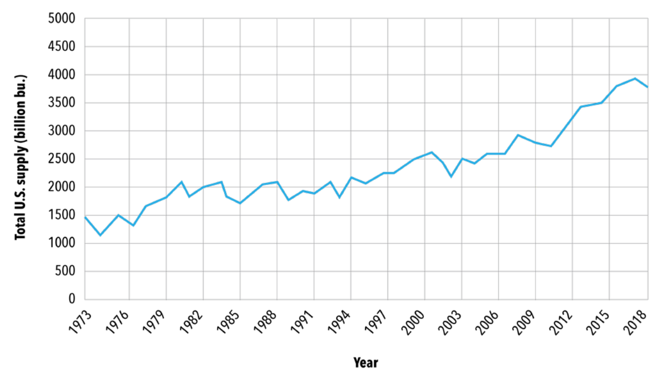


Figure 3. Volume of soybeans sold domestically and exported, 1973 to 2018
(in billion bushels)

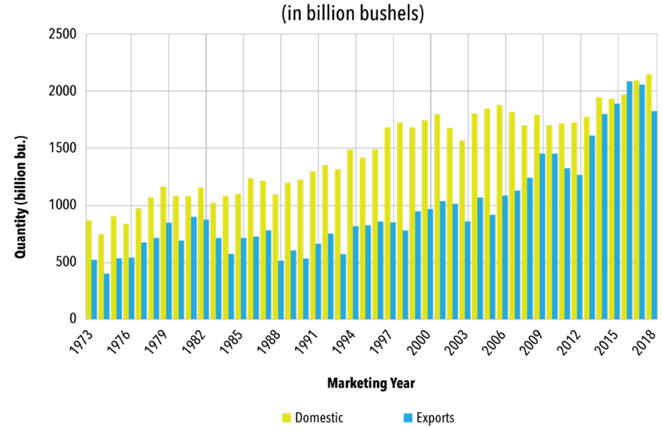


Figure 4. Volume of soybeans sold domestically and exported, 2000 to 2018
(in billion bushels)

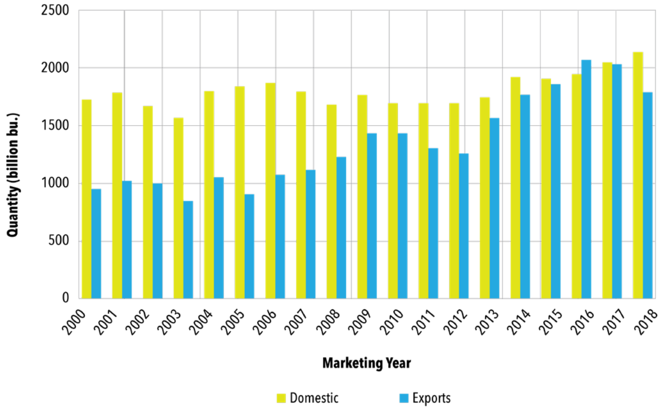
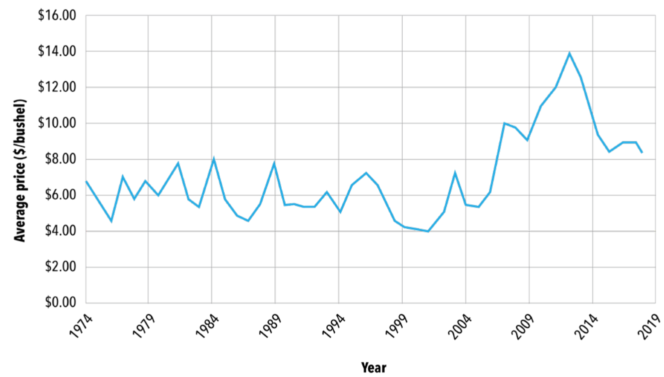


Figure 5. U.S. average soybean producer price received, 1974 to 2018
(Year is the marketing year from September 1 to August 31)



The combination of increased supply and the downturn in overall demand (driven largely by decreased export demand) resulted in decreased U.S. average soybean producer prices in 2017 and 2018 (Figure 5). Closer examination of price trends shows a generally declining trend in soybean prices from the record high prices in 2012. The 2018 average price of U.S. soybeans was the lowest price received since 2007.

The majority of soybeans exported are bulk beans, with much smaller quantities of soybean meal and oil exported. Most of the soybean meal exported is lower-protein soybean meal, with the higher-protein soybean meal consumed primarily in the U.S. (Larson and Rask 1992).

U.S. Aquaculture

Aquaculture is a diverse sector of the U.S. economy, with several hundred different species of aquatic animals raised. Of these, catfish farms produce the greatest value by far of U.S. aquaculture, with 2018 sales that were more than three times greater than the next greatest finfish sector, trout (Figure 6). Oysters contributed the second-greatest amount of total U.S. aquaculture sales, but since oysters are filter-feeding animals that are not fed, are not further considered in this report. The category of “other” (that includes hybrid striped bass, tilapia, sturgeon, and others) contributed the third-greatest volume of sales, followed by trout, crustaceans (i.e., crawfish and shrimp), ornamental/tropical fish, sportfish, and baitfish.

While aquaculture is a major industry in several states in the U.S., overall U.S. aquaculture has not grown as fast as that of the rest of the world (Figure 7). The rate of

Figure 6. U.S. aquaculture, seven major species categories, by volume of sales, 2005, 2012, and 2018
SOURCE: Census of Aquaculture, USDA-NASS

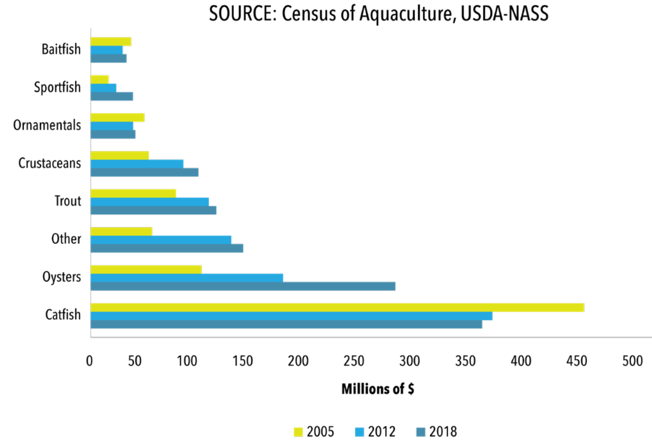
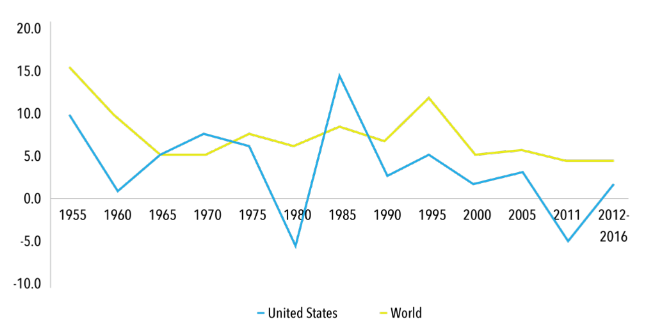
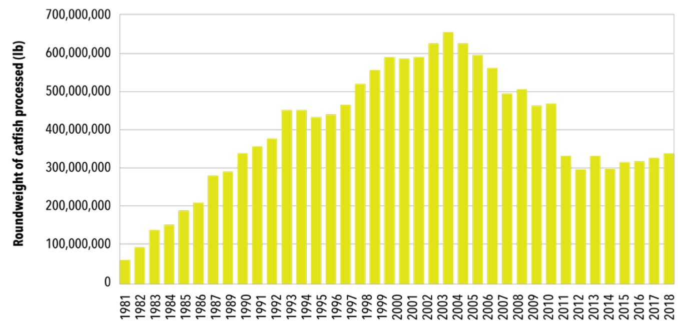


Figure 7. Rate of growth (5-year) of aquaculture globally and in the U.S.
SOURCE: FAO (2016)



growth became negative for several years during a period of contraction of its major segment (catfish), indicating a decline in the overall volume of production. The U.S. catfish industry, however, has begun to recover over the past 4 years (Figure 8). The recent positive growth in the U.S. catfish industry has generated a similarly positive rate of growth for U.S. aquaculture generally in the last several years.

Figure 8. Volume of production of U.S. catfish (in lb), 1981 to 2018
SOURCE: Catfish Reports, The Catfish Institute



Use of Soy Products in U.S. Aquaculture

Soybeans typically are transported to processing plants where they are crushed into two principal co-products: soybean meal and soy oil. The use of the oil extracted from soybeans is more limited in U.S. aquaculture due primarily to its greater cost as compared to other types of oils. Nevertheless, there is some limited use of soy oil in U.S. aquaculture, for example, as a top coating in some tilapia diets, because soy oil does not have to be heated prior to its use as a top coating.

Traditionally, the most commonly used soy product for terrestrial and aquatic animal feeds has been that of soybean meal (Saghaian 2017). Approximately 98% of U.S. soybean meal is used for livestock feeds (Saghaian 2017). The most common form used of soybean meal is dehulled, solvent-extracted toasted soybean meal that results from grinding soy flakes after the oil has been removed from the dehulled beans (Li and Robinson 2013).

Soybean meal can be further processed into soy protein concentrate and soy protein isolates. These more refined soy products have higher percentages of protein (65% to 67% for soy protein concentrate and 90% to 95% for soy protein isolates). Moreover, the refinement process removes carbohydrates, some of which result in problems of digestibility and palatability, particularly, for more carnivorous and marine fish species.

The amount of soybean meal used in diets for aquaculture animals differs by species and by life stage. The digestibility of soybeans and the extent to which anti-nutritional factors (ANF) in soybeans affect growth and performance varies across the many different species raised in aquaculture. Thus, different feed formulations and differing quantities of soybeans are used among different aquaculture species. Overall, of global production of aquafeeds, approximately 24% of that volume currently is from terrestrial sources, such as soybean meal (Tacon and Metian 2015).

Soybean Meal

Soybean meal is the principle soy product used in aquaculture due to its relatively high protein content. Moreover, soybean meal is highly digestible by many aquatic animals, particularly freshwater fish that have omnivorous feeding habits (United Soybean Export Council 2008). The amino acid content of soybean meal is favorable for many aquatic animal species, and soybean meal prices are much lower than those of fishmeal that had previously been the major source of protein for many aquatic animals (Masagounder et al. 2016).

While there are many advantages to its use, soybean meal also contains anti-nutritional factors that constrain its digestibility in a number of aquatic animals (Francis et al. 2001). Omnivorous freshwater fish tend to be less affected by anti-nutritional factors than some other species of aquatic animals, and, hence, soybean meal frequently constitutes a major proportion of diets for freshwater, omnivorous fish such as U.S. catfish and tilapia. Anti-nutritional factors that have been identified in soybean meal include: protease inhibitors, lectins, phytic acid, saponins, phytoestrogens, anti-vitamins, and allergens (Francis et al. 2001; Hardy 2010; Gu et al. 2016). Anti-nutritional factors can negatively affect the gut microflora and decrease digestibility of soybean meal. A number of carnivorous fish species have not performed well on soybean meal-based diets, partly due to its relatively lower protein content as compared to fishmeal and because soybean meal has lower concentrations of two essential amino acids, methionine and lysine than does fish meal (NRC 2011; Nunes et al. 2014; Li and Robinson 2015). The palatability of soybean meal has been problematic for its use in marine fish and shrimp diets, particularly if used as the sole source of protein (Lim and Dominy 1990). Thus, while soybean meal is used commonly as a major ingredient in diets of omnivorous species, its use in diets of carnivorous species is often restricted to less than 20% of the diet (Hardy et al. 2015).

On-going research has identified some combinations of ingredients that can be used to replace fishmeal in shrimp (Amaya et al. 2007) and marine fish diets. Most of these combinations include soybean meal. For example, Boonyaratpalin et al. (1998) replaced 37.5% of the fishmeal in diets of Asian seabass with soybean meal with no reduction in growth as compared to the traditional fishmeal diet. Some marine fish species appear to have a high tolerance for soybean meal. These include Japanese sea bass, red drum, cobia, cod, yellow croaker, pompano and gilthead sea bream (United Soybeans Export Council 2008). Forster (no date) reported results of studies showing that 45% of the fishmeal in Japanese flounder diets (Kikuchi 1999) could be replaced with soybean meal; 20% of the fishmeal with soybean meal in yellowtail (Shimeno et al. 1992a, 1992b, 1993), and 30% with full-fat soybean meal. Maximum levels of soybean meal used in marine fish, even those with a high tolerance for soybean meal typically do not exceed 35% because it is difficult to meet all nutritional requirements at greater levels of soybean meal, particularly for marine species (United Soybeans Export Council 2008).

Soy Oil

Soy oil is not commonly used in aquaculture diets. Forster (no date) indicated that its fatty acid profile limits its use for marine fish. There may be, however, scope for expansion, as in its use as a top coating for tilapia feeds. The price of soy oil is also a limiting factor as other oils are available at lower cost.

Soy Protein Concentrate

Soybean meal is also further processed into a form with a higher concentration of protein (65% to 67%), known as soy protein concentrate (NRC 2011). Further processing of soybean meal has been shown to improve digestibility of energy and organic matter of soybean meal (Glencross et al. 2004) by decreasing the quantities of anti-nutritional factors (Peisker 2001; Deng et al. 2006). For example, Day and Gonzalez (2000) showed that 25% of the fishmeal used in diets for turbot could be replaced by soy protein concentrate, while Berge et al. (1999) found that 28% of the total diet of halibut could be composed of soy protein concentrate (fishmeal use was reduced from 61% to 37% of the total diet).

Further processing of soybean meal into soy protein concentrates may reduce palatability problems for some species by removing carbohydrates, but feed attractants may still be needed for other species (Forster no date). Use of soy protein concentrates may also require dietary supplementation of some essential amino acids. In terms of energy efficiency, the process of producing soy protein concentrate has been considered to be a more energy-intensive process than that required to produce other soy products (Pelletier et al. 2018).

A low-antigen form of soy protein concentrate may be necessary for use in diets of marine fish species that have a low tolerance for soybean meal. These include: salmon, yellowtail and amberjack, many sea bass species, and groupers, among others. A low-antigen soy protein concentrate may negate the effects of the anti-nutritional factors (ANF's) found in soybean meal (United Soybeans Export Council 2008). Moreover, low-antigen soy protein concentrates can complement soybean meal in diets of species with greater tolerances for soybean meal as a substitute for fish meal (United Soybeans Export Council 2008).

Soy protein concentrate is a more expensive ingredient that is also used in human foods, pet foods, and feed for other animals. The greater cost of soy protein concentrate limits its use in aquaculture even though it is considered to be of higher quality than soybean meal.

Soy Protein Isolates

The protein in soybeans has been further developed into a powdered product referred to as soy protein isolate that further concentrates protein levels to 90% to 95% of the powder by removing most carbohydrates and fats. Soy protein isolates are used in human food products such as infant formulas, soymilk, power bars, and meat analogs. Often sold as a natural health product, soy protein isolates are expensive. Thus, while it can be used in feeds for aquaculture, its use often is cost prohibitive.

Future Potential Uses of Soy Products in U.S. Aquaculture

Concern over the risk of overfishing marine forage species to meet increasing demand for fishmeal in aquaculture and other livestock feeds has resulted in intensive efforts by aquaculture nutrition researchers to find alternative sources of protein for aquaculture feeds. The result has been an explosion of research studies designed to substitute a variety of plant-based ingredients for the fish meal that has historically been used in many fish diets. Soy products continue to be high-priority ingredients in many of these studies due to their high protein content (Barrows et al. 2008).

Brown and Smith (no date) listed 54 aquaculture species that have been fed soybeans. Those that are raised in the U.S. include: Atlantic salmon, rainbow trout, coho salmon, chinook salmon, tilapia, largemouth bass, hybrid striped bass, striped bass, channel catfish, blue catfish, grass carp, common carp, Pacific white shrimp, red swamp crayfish, American lobster, red drum, sea bass, Florida pompano, yellowtail, and seabream.

Brown and Smith (2000) summarized the available data on use of soy products in fish and argued that all fish could handle a minimum of 10% to 15% soybean meal in diets, but that several carnivorous species could not handle more than 20%. Salmonids were identified as most sensitive to soy products, with maximum inclusion rates of no more than 25% to 30% and some salmonid species restricted to only 15% inclusion in the diet. On the other hand, hybrid striped bass were found to be able to use soybean meal up to 45% to 50% of the diet, as long as critical essential amino acids and minerals were supplemented. Even alligators that typically have been fed diets that are nearly all animal meat have been shown to grow as well on plant-based diets with up to 33.7% inclusion of soybean meal (Reigh and Williams 2013; 2018).

Methods

Objective 1: To estimate current soybean usage in U.S. aquaculture
Objective 1 of the project was to conduct an analysis of current soybean usage in U.S. aquaculture. The analysis focused on the most important segments of U.S. aquaculture (i.e., catfish, trout, salmon, baitfish, sportfish (crappie, muskellunge, sunfish, walleye, smallmouth bass), hybrid striped bass, and ornamental/tropical fish production), but also included minor species such as largemouth bass, sturgeon, yellow perch, marine shrimp production, alligators, carp, red drum, salmon, sturgeon, and tilapia. Every effort was made to encompass as many segments as could be done in a meaningful manner.

A spreadsheet was developed that lists each species, the percent of diet formulations typically composed of soy products, as well as common ranges of inclusion of various soy products (i.e., soybean meal, soy oil), and representative averages and ranges of feed conversion ratios. To the extent possible, farm-level values were used rather than those from research studies, to more accurately estimate the total on-farm usage of soybean products. Given that the major soy product used in U.S. aquaculture feeds is soybean meal, most of this discussion refers to the use of soybean meal. Calculations were developed for each species, and life stage (i.e., broodstock, fry, fingerlings, and growout). Once the percent of the diets that were composed of the various soy products was known, then that percentage was multiplied by the feed conversion ratio (FCR) to obtain the weight in pounds of that soy product ingredient in a single pound of aquatic animal and then multiplied by the total weight of aquatic animal produced in the U.S. in 2018 to obtain the total volume of soybean meal used for each aquaculture segment. Those values were then converted to bushels of soybeans (using the conversion factor of: 1 bushel of soybeans = 47.5 lb of soybean meal and 10.7 lb of soy oil; USSEC 2019) and summed across aquaculture segments to estimate the current total usage of soybeans in U.S. aquaculture.

The initial estimates of the total pounds of current production of each segment of U.S. aquaculture were based on the best available data. For the preliminary report, the most recent available dataset on total production of other species was that of the 2014 Census of Aquaculture. To enhance the quality of the data, every effort was made to improve estimates by consulting with industry representatives and experts, including nutritionists, who work closely with those industry segments. For catfish production, for example, the monthly reports by the industry were used. USDA-NASS reports on trout production (USDA-NASS 2019) and data from a recent survey of U.S. trout and salmon farms were used (Engle et al. 2019). Throughout the project, experts were consulted for the various types of aquatic animals farmed. Experts consulted included nutritionists (federal and university researchers as well as nutritionists with various feed mills), extension aquaculture specialists, and industry representatives. When the 2018 Census of Aquaculture data became available in December, 2019, values were updated accordingly (Objective 5). The values included in this final report are those based on the updated 2018 census results.

Objective 2: To estimate increased quantity demanded of soybeans for varying percentages of growth of U.S. aquaculture

Objective 2 of this project was to estimate the increased quantity demanded of soybeans under various scenarios of increased percentages of growth of U.S. aquaculture. This was accomplished by increasing the total pounds of U.S. aquaculture production in increments of 10% up to 100%, to estimate the total increased quantity demanded of U.S. soybeans. There is evidence to support the possibility of an increase of as much as 100% of total U.S. aquaculture production (Engle et al. 2019; van Senten et al. in review).

Recent research advances have shown that soybean meal could be used at greater inclusion rates than used at present. Additional scenarios were run of maximum potential inclusion rates of soybean meal for all species currently raised in the U.S. with and without anticipated growth rates of U.S aquaculture.

Objective 3: To develop case studies of U.S. aquaculture with greatest potential for growth

In Objective 3, six case studies were developed of segments of U.S. aquaculture with the greatest potential for growth. Case studies developed included: U.S. catfish, trout, salmon, marine shrimp, tilapia, and expanded offshore production of marine finfish. Current demand for soybeans from each sector was compared with projections of growth for each case study. The first case study was that of U.S. catfish production. The U.S. catfish industry experienced a serious phase of contraction from 2003 to about 2012. During this period of time, the total volume of catfish production from U.S. catfish farms fell by 55%. However, from 2014 to 2018, the total volume of catfish processed has increased by 12%. There are a variety of reasons for the contraction that occurred, including the combined effects of: 1) bottom of the 10-year price cycle; 2) the September 11 terrorist attack on the World Trade Center that depressed seafood sales as fewer people ate out in restaurants; 3) a stagnant national economy; and 4) low-priced imports of Pangasius that were promoted as "catfish" using similar advertising that in some cases used the same photographs. The new markets that the U.S. catfish industry had developed on the west coast, the mid-Atlantic states, and other areas have been largely captured by imported products. Those markets still exist and could potentially be recaptured as evidenced by the growth in total volume processed over the past four years. In this case study, the current (2018) demand for soybeans from the U.S. catfish industry was compared with that of the U.S. catfish industry at its peak in 2003 to show what the demand for soybeans would be if the U.S. catfish industry would recapture the sales lost after 2003.

The second case study developed was that of trout farming in the U.S., the second largest finfish segment of U.S. aquaculture. Expansion of trout farming in the U.S. has been constrained by a complex set of regulatory requirements. A recent national survey of the U.S. trout industry has shown that market demand for U.S. trout is strong (Engle et al. 2019). Without regulatory restrictions on expansion of trout farming businesses or on market development, recent estimates show that the trout industry could be 24% larger than it currently is if the regulatory burden were to be streamlined. These values were used to demonstrate what the demand for U.S. soybeans could be if the trout industry were able to grow to meet the growing demand for their products.

The third case study developed was of salmon production in the U.S. Currently there is only one large salmon company operating in the U.S., with a few very small farms attempting to raise some salmon. However, there have been recent announcements of high-dollar, large-scale investments in indoor salmon production in the U.S. These include: Atlantic Sapphire in Florida (that received its first set of smolts in 2018 and has initiated production), Nordic AquaFarms (in the permitting process at the time this report was written) and Whole Oceans in Maine (permit approved), Pure Salmon in Virginia (announced in 2019), along with the announcement (2019) of a second Nordic AquaFarms indoor facility to raise Atlantic salmon or steelhead trout in Eureka, California. A large-scale aquaponics operation in Wisconsin (Superior Fresh) has been raising and selling Atlantic salmon for several years in addition to vegetable produce. These indoor salmon farm companies have announced targeted production levels that sum to 817.35 million pounds of new production of Atlantic salmon. The total volume of announced targeted production levels for indoor, tank production of salmon exceeds that of the U.S. catfish industry at its peak, of 630.45 million pounds. In this case study, the current demand for soybeans from current U.S. salmon production was projected to include the scale-up production volumes announced for the next five years.

Atlantic salmon pose an interesting case study in that, in spite of a current low average inclusion rate of 8% of soybean meal in the diet, some researchers have indicated that there is evidence that Atlantic salmon have a similar capacity to utilize higher-protein plant products as rainbow trout (Glencross et al. 2004). Thus, both current levels and greater levels of inclusion reported in the research literature have been used in this case study.

The fourth case study developed was that of marine shrimp production in the U.S., both in outdoor ponds and indoor tanks. There has been a great deal of excitement about indoor production of marine shrimp; yet, the only substantial commercial farms in the U.S. are those based on outdoor ponds (both low salinity water and saltwater). Nevertheless, one firm in Minnesota is selling shrimp from a pilot indoor system that is planned as the prototype for a large-scale indoor shrimp facility. There are plans underway by another company for a second large-scale indoor shrimp facility. This case study will compare the current demand for soybeans from U.S. shrimp production with that of estimates of potential growth of marine shrimp in the U.S. through expansion of indoor shrimp production.

The fifth case study was that of tilapia production in the U.S. While there has been less press coverage of tilapia in the U.S. in very recent years, there was continued growth in the number of tilapia farms, total production, and total sales in the U.S. through 2012. Moreover, there are a few new investments and proposed new investments in tilapia farms in the U.S., whose production was modeled to estimate the increased demand for soybeans from such expansion.

The sixth case study was that of growth of marine finfish production in the U.S. Average soybean meal inclusion rates were used with growth of marine finfish production from new investments currently underway.

Objective 4: To estimate potential benefits to U.S. soybean producers from increased domestic demand for soybeans from U.S. aquaculture

Objective 4 addresses the potential benefits to U.S. soybean producers from increased domestic demand for soybeans. This section was developed from a review of a number of research studies. The following principle benefits were discussed under the Results section below: 1) several segments of U.S aquaculture use greater inclusion rates of soybean meal than does terrestrial animal agriculture; 2) all feed ingredients used in U.S. aquafeeds are sourced domestically; 3) rural farming communities are supported and strengthened with greater domestic demand for their products; 4) the soybean crushing industry is supported by increased domestic demand for soybeans; and 5) increased domestic demand for soy products diversifies markets and reduces market and price risk.

Objective 5: To finalize estimates based on the 2019 USDA Census of Aquaculture

The 2018 aquaculture data were released December 19, 2019. The production values of the various segments of U.S. aquaculture included in this report were updated with the new census data.

Results

Objective 1: To estimate current soybean usage in U.S. aquaculture

A wide variety of information and data sources were used to compile the information needed to estimate current soybean usage in U.S. aquaculture. Data sources used include the Census of Aquaculture, catfish feed delivery reports produced for The Catfish Institute, and the USDA-NASS Trout Reports. In addition, contacts were made with Extension aquaculture specialists in major aquaculture-producing states, fish nutrition experts (government, university, and feed mills), and others knowledgeable of U.S. aquaculture. Information was obtained on the percent inclusion of soybean meal and other soy products in formulated feeds for various aquaculture species, on total feed fed, and typical feed conversion ratios from which to calculate soybean usage in U.S. aquaculture.

2018 Soybean Usage in U.S. Aquaculture (average inclusion rates)

Soybean meal was by far the principal soy product used in U.S. aquaculture, constituting 99.7% of the usage of all soy products, with very minor amounts of soy oil and soy lecithin used (Table 1). Thus, the discussion on inclusion rates below will focus on soybean meal inclusion in commercial formulated diets for the various species raised in U.S. aquaculture.

Table 1. Various Types of Soy Products Used in U.S. Aquaculture

Type of soy product	% used in U.S. aquaculture
Soybean meal	99.7%
Soy oil	0.1%
Soy lecithin	0.2%

The greatest inclusion rates were those for catfish feeds (Table 2). Commercial catfish feed mills produce a variety of products with differing overall levels of crude protein. Clearly, higher protein catfish diets have higher percentages of soybean meal included in the diets. For catfish, a weighted average of use of various crude protein levels (most catfish farmers use either a 28% or 32% crude protein diet) was used that included an overall inclusion rate of 35% of soybean meal in the diets. Soybean meal was assumed to contain 48% protein. In fish diets, soybean meal also contributes energy to feeds. Baitfish farmers tend to purchase catfish feeds similar to those used widely for catfish production, while sunfish/bream farmers also use catfish feeds, but typically use a 35% catfish feed resulting in a greater percent inclusion rate of soybean meal (40%). Tilapia also can digest soybean meal well, and commercial diets for tilapia typically include 35% soybean meal. The next greatest inclusion rates were for hybrid striped bass (31%), followed by sportfish species such as largemouth bass (25%), crappie (25%), and smallmouth bass (25%). Diets for coolwater species such as trout, walleye, yellow perch, and muskellunge were found to typically include 15% soybean meal. For the estimates to be conservative, 15% inclusion rates of soybean meal were also used for the categories of "other sportfish" and "other foodfish". Shrimp and prawn diets were reported to include 13% soybean meal, with salmon, red drum, alligator, ornamental/tropical fish, sturgeon, and carp diets including less than 10% soybean meal in typical diets.

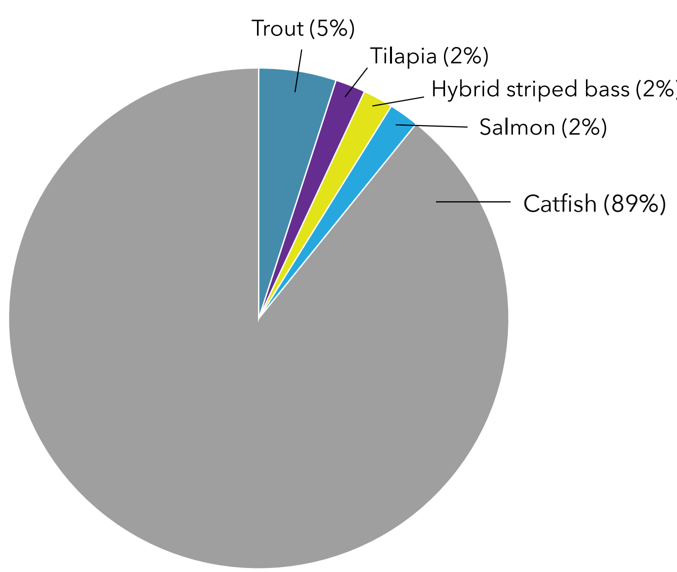
Total usage of soybean meal is related not just to the percent inclusion rate of soybean meal in the diet but also to the total volume of feed fed to that type of aquatic animal. Figure 9 shows the relative proportions of

Table 2. Inclusion Rates of Soybean Meal in Commercial Diet Formulations by Various Types of U.S. Aquaculture Products

	Percent of diet from soybeans		
Type of aquatic animal	**Mean**	**Minimum**	**Maximum**
Alligators	5%	1%	7%
Baitfish	35%	22%	51%
Carp	0%	0%	0%
Catfish	35%	22%	51%
Crappie	25%	20%	48%
Hybrid striped bass	31%	20%	40%
Largemouth bass	25%	20%	48%
Muskellunge	15%	10%	23%
Ornamental fish	3%	2%	5%
Prawns	13%	10%	28%
Red drum	8%	0%	8%
Salmon	8%	4%	15%
Shrimp, marine	13%	10%	28%
Smallmouth bass	25%	20%	48%
Sturgeon	3%	2%	5%
Sunfish	40%	25%	48%
Tilapia	35%	22%	51%
Trout	15%	10%	20%
Walleye	15%	10%	23%
Yellow perch	15%	10%	20%
Other foodfish	15%	10%	20%
Other sportfish	15%	10%	23%

NOTE: Commercial feed mills typically use least-cost feed formulations periodically; thus, inclusion rates vary as prices of various feed ingredients vary. Values in this table represent typical ranges used by commercial feed mills at the time this study was done. These may differ from potential inclusion rates identified in recent research.

Figure 9. Percent of total feed fed by U.S. aquaculture segment



total feed fed to U.S. aquatic animals in 2018. Catfish, as the leading segment of U.S. aquaculture, consumes 82% of the total feed fed to aquatic animals raised in the U.S., and is followed by trout (5%), tilapia (2%), hybrid striped bass (2%), and salmon (2%).

Total soybeans demanded in U.S. aquaculture in 2018 were estimated to be (at average inclusion rates) 8.6 million bushels, with a range of from 5.5 (minimum inclusion rates) to 12.6 million bushels (maximum inclusion rates). The range in values is due to the least-cost feed formulations used in the aquaculture industry in which feed formulations vary within a certain range of inclusion of various ingredients based on ingredient prices. Data were collected on the average, minimum and maximum inclusion levels in diets for each aquaculture species. It should be noted that soybean protein and fat content vary with geographic location and the quality of meal varies with the country and processing conditions; these are more standardized in the U.S., but varying geographic production locations can introduce some variability. Anti-nutritional factor levels and digestibility also vary as well. Thus, the actual inclusion rate of soybean meal in diets might vary among feed manufacturers, as some may be more quality-oriented. Thus, it is important to keep in mind that the above values are estimated soybean product use and potential use, but are not precise numbers.

Of these, the greatest demand for U.S. soybeans is that of the U.S. catfish industry (Figure 10). The U.S. catfish industry utilization of soybeans was 89% of the total demand for U.S. soybeans from U.S. aquaculture. This is due to two primary reasons: 1) catfish continues to be the largest segment of U.S. aquaculture; and 2) catfish tolerate soybean meal well and, hence, inclusion levels in diets are greater than in diets of many other aquaculture species.

Figure 10. Percent of soybean demand by U.S. aquaculture segment

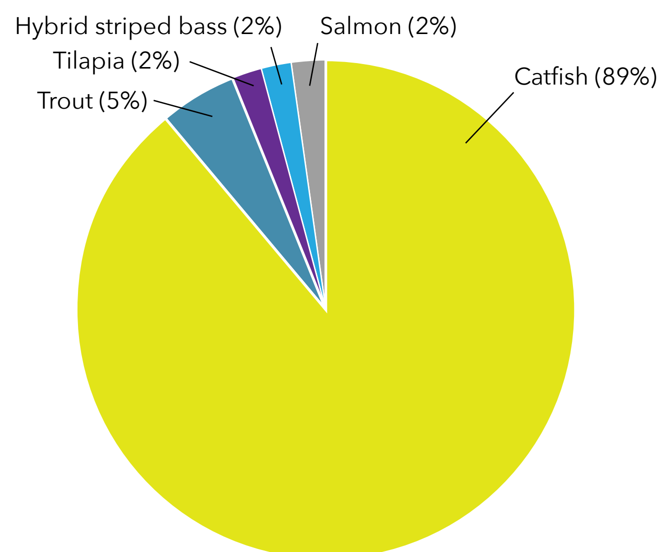
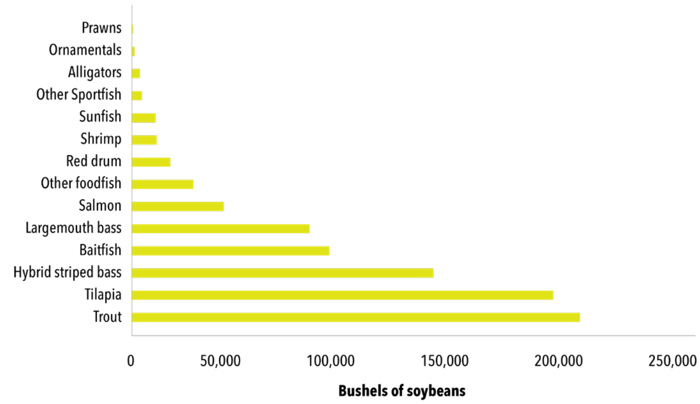


Figure 11 shows the average bushels demanded of soybeans by U.S. aquaculture segments other than catfish. After catfish, trout used the next greatest volume of soybeans, followed by tilapia, hybrid striped bass, baitfish, largemouth bass, salmon, other foodfish, red drum, shrimp, sunfish, and other minor species. Trout uses the second-greatest volume of soybeans primarily because it is the second most important finfish species raised in the U.S., and feeding rates are high in trout production. However, trout do not tolerate soybean meal as well as catfish and inclusion rates have been lower for trout than for more omnivorous species such as catfish. Tilapia, while a smaller segment of U.S. aquaculture,

Figure 11. Soybean demand by U.S. aquaculture segment other than catfish



tolerate soybean meal well and use a greater percentage of soybean meal in their diets than do most species other than catfish. Hybrid striped bass, similarly, tolerate soybean meal fairly well. Baitfish farmers feed only at relatively low levels per acre of pond due to the low fish biomass in ponds and because baitfish utilize natural zooplankton in ponds as a food source. Baitfish farmers rely on catfish feeds (that have a fairly high percentage of soybean meal) that result in good growth by the baitfish species raised in the U.S. Usage of soybeans tends to drop off more rapidly for other species due to the combination of lower volumes of total production in the U.S. and lower inclusion rates of soybean products in those feeds.

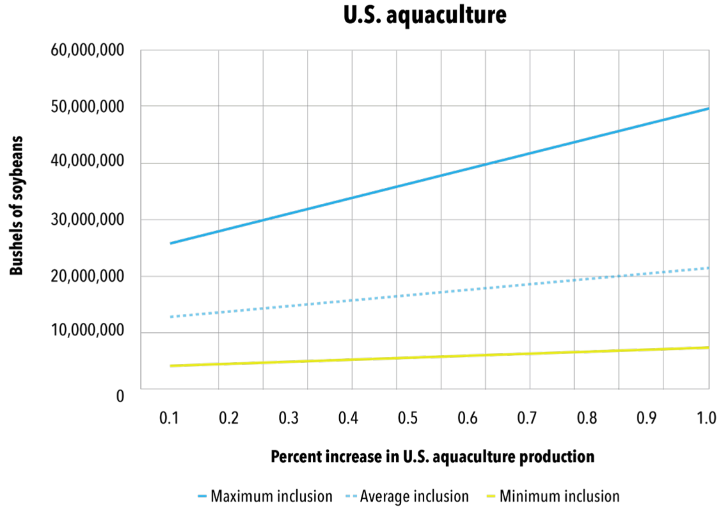
Maximum Inclusion Rates
Commercial feed mills use least-cost feed formulation algorithms that result in varying ingredient usage based on prices of feed ingredients. Table 2 includes the minimum and maximum rates reported to be used by commercial feed mills for the various types of aquaculture products. The overall ranking of soybean meal inclusion rates remains the same with catfish and tilapia feed formulations containing the greatest inclusion rates across U.S. aquaculture. If feed mills use minimum inclusion rates, soybean demand would be 36% less, but with maximum recommended levels of soybean meal inclusion, demand for U.S. soybeans would be 46% greater.

Objective 2: To estimate increased quantity demanded of soybeans for varying percentages of growth of U.S. aquaculture

Demand for U.S. Soybeans from Growth of U.S Aquaculture
Figure 12 shows the increase in demand for U.S. aquaculture with incremental growth (increments of 10%) in U.S. aquaculture production up to a doubling of the total volume of U.S. aquaculture production, assuming average current inclusion rates. Overall, for each 10% increase in growth, demand for soybeans increases by nearly 900,000 bushels a year.

Aquaculture feeds are generally formulated using a least-cost feed formulation that varies the inclusion rates of various ingredients within ranges known to be acceptable for each species, based on fluctuating prices of feed ingredients. Thus, the estimates of soybean usage in U.S. aquaculture were also calculated for the maximum inclusion rates for each species, at current levels of production of each species. Demand for soybeans increases at a much faster rate of 1.3 million bushels a year when soybeans are used at maximum current recommended inclusion levels (Figure 12).

Figure 12. Increase in U.S. soybean demand with growth of U.S. aquaculture



Research advances have demonstrated the nutritional feasibility of increasing soybean usage in diets for several species. Such findings are based on trials that address species-specific constraints to soybean meal usage that include: 1) improving the palatability of soybean meal with the addition of feed attractants; 2) amino acid supplementation; and 3) low-antigen forms of soy products, among others. Species for which research has shown potential to increase soybean usage include: alligators, ornamental/tropical fish, shrimp and prawns, red drum, salmon, sturgeon, and trout (Table 3). At these maximum inclusion rates from recent research (that have not yet been adopted as formal recommendations by feed mills), the total demand for soybeans from U.S. aquaculture would increase by 5% over the recommended maximum inclusion levels to 13.1 million bushels, at current production levels of U.S. aquaculture. The greatest increase in soybean demand would be from trout, with a 50% increase in the demand for soybeans for trout feeds.

Future Technological Changes that Might Affect Inclusion Rates and Demand for Soybean Products from U.S. Aquaculture

Concern over the future availability of fishmeal has generated intensive research efforts to identify alternatives to its use. Fishmeal is derived primarily from marine forage fish species such as menhaden. As forage fish constitute an important part of the marine food web and especially because it serves as a critical food source for carnivorous marine species, overfishing of marine forage fish could have negative effects on the sustainability of those wild species that depend upon forage fish as a food.

The research literature of studies that seek ways to reduce or eliminate fishmeal in diets for fish has grown dramatically in recent years. Much of the search has focused on plant-based alternatives, of which soybean meal is a major component of the alternative diets tested. Its high protein content and high digestibility for a number of species have made it a central ingredient in diets being tested to reduce or eliminate fishmeal use. The major constraint to

Table 3. Species for Which Research has Shown Potentially Greater Maximum Inclusion Levels Than What are Currently Recommended

Species	Current maximum	Maximum identified through research
Alligators	7%	34%
Ornamental/tropical fish	5%	34%
Prawns	28%	58%
Red drum	8%	74%
Salmon	8%	30%
Marine shrimp	28%	58%
Sturgeon	5%	34%
Trout	20%	30%

its use involves primarily the anti-nutritional factors in soybean meal, poor digestibility by some species, palatability problems for some species, and negative gastro-intestinal reactions in some species. A great deal of research has addressed these issues, particularly for marine fish for which these types of problems are more common. Palatability issues are addressed by adding feed attractants to diets; anti-nutritional factors have been addressed in some cases by the addition of specific enzymes or heat processing of soybeans, and negative gastro-intestinal effects by removing carbohydrates during the soybean crushing and further refinement during processing. Thus, these nutritional advancements will, over time, allow for greater use of soybean products in U.S. aquaculture diets.

Support for offshore mariculture in the U.S. is growing with increased legislative efforts making some headway in terms of creating opportunities for marine fish production. Additional scenarios were developed under the assumption that permitting processes will allow for development of mariculture in the U.S.

The field of genetics has similarly advanced and has created opportunities that have important implications for future diets for aquaculture species. Epigenetics is a field that has emerged that concentrates on factors during early development that affect gene expression that result in lifetime changes. For example, preliminary trials have suggested that feeding trout fry diets with greater levels of soybean meal resulted in trout that could better utilize soybean meal during the growout stages. Other advancements, such as in gene-editing techniques may have future applications in terms of overcoming some of the limitations of soybean meal use (such as the anti-nutritional factors and digestibility) (Stein et al. 2008; Cleveland 2019). One main genetics approach is to genetically modify the fish to enhance the ability to utilize plant proteins. Examples of farmed fish that have been genetically modified include the AquAdvantage salmon which was modified for faster growth and an ornamental fish, Glofish, modified to give it a unique appearance. The second major genetics approach is to modify feed ingredients. For soybeans, for example, genetic modifications might be sought that reduce anti-nutritional factors. This second approach, to modify soybeans, is likelier to be accepted more readily by consumers than approaches that modify the fish themselves. Low-oligosaccharide soybean meal, for example, may have value for use in trout and salmon feeds (Li et al. 2013).

Objective 3: To develop case studies of U.S. aquaculture with greatest potential for growth

Soybean meal use in fish feeds for aquaculture has increased over the years due to important advantages of soybean meal (such as its high protein content, relatively high digestibility compared to other plant-based proteins, availability, and price). Research studies over several decades have contributed to increased use of soybean meal in diets for a variety of fish species, including studies funded by soybean checkoff programs.

U.S. Catfish Case Study

As the largest segment of U.S. aquaculture, trends in the U.S. catfish industry tend to have relatively greater effects on the overall U.S. aquaculture industry than do trends in other industry segments. At its peak in 2003, 661.5 million pounds of catfish were sold nationally. The subsequent contraction of the U.S. catfish industry from 2004 through 2012 resulted in a negative growth rate generally for U.S. aquaculture. Since 2012, however, the U.S. industry has begun to recover with an overall 12% increase in the volume produced from 2013 through 2018.

The channel catfish (Ictalurus punctatus) and its hybrid with the blue catfish (Ictalurus furcatus), are the major species raised in the U.S. catfish industry. Catfish in the wild are opportunistic feeders that eat a variety of food items, a characteristic that is advantageous for it to be farmed. Catfish readily accept a wide variety of feeds in aquaculture. Research on feeds and nutrition of channel catfish date back to the 1950s when the first formulated feeds were developed and tested.

Soybean meal has been a major component of catfish diets from the very first complete diet formulated to meet the nutritional needs of catfish, Auburn No. 1 (Prather 1957). This first diet was a 42% protein diet that contained 35% soybean meal, 35% peanut meal, 15% fish meal, and 15% distillers' dry solubles (Robinson and Li 2020). Since that first formulated diet, soybean meal has continued to compose a major proportion of catfish diets for the past 60 years. The position of soybean meal as the major feedstuff for catfish feeds is due to several positive attributes of soybean meal: high protein content (48%), best amino acid profile of plant feedstuffs (including lysine, for example), high palatability for catfish, and its good digestibility in catfish (Lovell 1988; Robinson and Li 2014). Thus, the inclusion rate in catfish feeds for soybean meal has historically been 40% to 50% of the diet. Lovell (1988) reported that channel catfish readily consumed feeds with as much as 60% to 70% soybean meal, clearly demonstrating that catfish found soybean meal to be quite palatable.

However, the very high soybean prices from 2010 to 2013 resulted in a search for less-expensive feed ingredients to use as substitutes for soybean meal (Robinson and Li 2014). These have included cottonseed meal, corn gluten feed, corn germ meal, or distillers dried grains with solubles and supplemental lysine used in various combinations to replace soybean meal during times of high soybean prices. Nevertheless, research has led to the conclusion that no more than 50% of soybean meal in catfish diets can be replaced by other feed ingredients. Replacing more than 50% of the soybean meal in catfish diets has been found to result in lower processed yield that creates economic losses for catfish processing plants. The difficulty in replacing soybean meal with other types of plant-based meals is primarily due to their lower digestibility, high fiber, and an unbalanced composition of amino acids. Thus, soybean meal has and will continue to play a critical role in catfish feeds even when soybean prices are high. According to Robinson and Li (2014), the minimum inclusion rate of soybean meal in catfish diets is 20%, but later research (Li 2015) showed that the optimal inclusion rate of soybean meal in a 28% protein diet is about 25%, to ensure that growth, feed conversion ratio, and processing yield are not adversely affected.

While soybean meal does contain anti-nutritional factors such as a trypsin inhibitor, most are inactivated by high heat used during solvent extraction of soybeans and the process of extrusion and drying of floating feeds (Li and Robinson 2013; Lovell 1988). While phytate (another anti-nutritional factor in soybean meal) is not affected by the heat used to extrude pellets, the enzyme phytase can be supplemented in the diet to break down phytate.

Current Demand for U.S. Soybeans from U.S. Catfish

The U.S. catfish industry constitutes by far the greatest portion of demand for soybeans from U.S. aquaculture, 89% of total U.S. demand for soybeans. Recommended inclusion rates of soybean meal vary depending on the targeted overall percent of protein in the diets. Fingerling catfish, for example, require higher protein levels. Table 4 shows that recommended soybean meal inclusion rates vary from 22% to 35% in 28% protein foodfish diets for catfish. For 32% protein foodfish catfish diets, soybean inclusion rates vary from 31% to 48% and 51% inclusion rates for fingerling catfish feeds (35% protein) (Robinson and Li 1996; Li and Robinson 2013).

Table 4. Percent of Feed from Soybeans for Typical Catfish Fingerling and Foodfish Diets

Type of feed	Robinson et al. (2001)[a]	Robinson and Li (2007)[b]	Li and Robinson (2013)[c]
Fingerling feed	38.8%	44.2%%	51.05%
Foodfish feeds			
32%	34.6% to 48.4%	41.6% to 47.0%	30.6% to 44.1%
28%	24.4% to 32.9%	28.3% to 35.4%	22.3% to 32.9%

[a]Robinson, E.H., M. H. Li, and B.B. Manning. 2001. A Practical Guide to Nutrition, Feeds, and Feeding of Catfish. Mississippi Agricultural & Forestry Experiment Station Bulletin 1113, Mississippi State University, Mississippi.
[b]Robinson, E.H., M.H. Li. 2007. Catfish Feeds and Feeding. Mississippi Agricultural & Forestry Experiment Station Bulletin 1163, Mississippi State University, Mississippi.
[c]Li, M.H. and E.H. Robinson. 2013. Feed ingredients and feeds for channel catfish. Southern Regional Aquaculture Center Publication No. 1806, Southern Regional Aquaculture Center, Mississippi State University, Mississippi.

Current inclusion rates of soybean meal in catfish diets are approximately 30% inclusion of soybean meal in 28% catfish growout diets and 40% inclusion of soybean meal in 32% catfish growout diets. Across the U.S. catfish industry, approximately 70% of growout feeds used contain 28% protein and 30% of growout diets contain 32% protein.

Potential Future Demand for U.S. Soybeans if U.S. Catfish Regained Former Market Share

The market for U.S. farm-raised catfish, at its peak in 2003 was 661,504,000 lb sold, 94% greater than the 2018 volume of catfish sold. A more level playing field as related to food safety and environmental standards of imported pangasius, could allow the U.S. catfish industry to continue to grow and to re-capture markets in which pangasius has replaced U.S. catfish. A simulation model was run with the total production value of U.S. catfish of 661,504,000 lb. The result was that soybean demand from U.S. catfish production would be 74% greater, at 13.40 million bushels at average inclusion rates (range of 8.54 million bushels with minimum recommended inclusion rates to 19.53 million bushels at maximum inclusion rates) (Table 5).

Table 5. Increase in Demand for U.S. Soybeans if the U.S. Catfish Industry Recovered Back to 2003 Levels.

Soybean use in U.S. catfish industry	2018	2019
Pounds		
Mean	462,439,629	804,249,600
Minimum	294,640,107	512,421,888
Maximum	673,840,603	1,171,906,560
Bushels		
Mean	7,707,327	13,404,160
Minimum	4,910,668	8,540,365
Maximum	11,230,677	19,531,776

Figure 13. Top trout-producing countries globally, by volume of production (in metric tons)
SOURCE: FAO FishStatJ

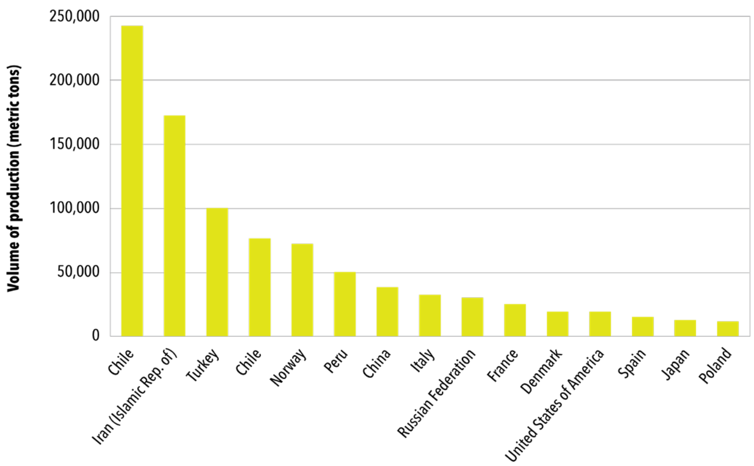
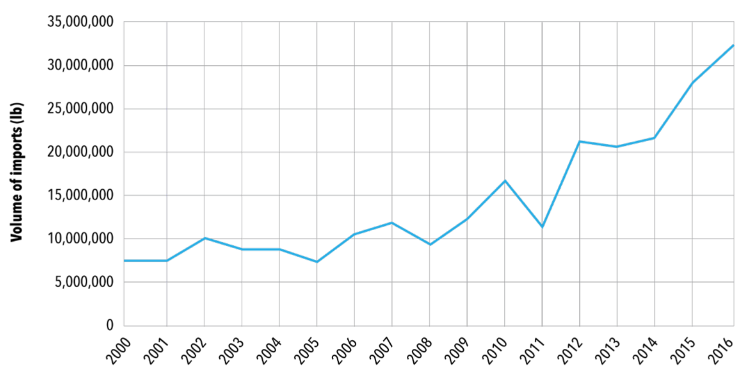


Figure 14. Volume of imported trout products, 2000 to 2016 (in lb)
SOURCE: NMFS



Differences between the minimum and maximum levels of soybean meal used in catfish are driven by varying prices of feed ingredients such as corn and soybeans. Catfish feed price has been shown to be affected by the prices of principal ingredients, particularly soybean meal and corn (Hasan et al. 2019). Moreover, cottonseed meal has also been used as a substitute for soybean meal in catfish feeds. The degree of competition for soybean meal is affected by the relative prices of cottonseed meal and soybean meal.

U.S. Trout Case Study

Trout are raised around the world, by volume constituting the 31st most important aquaculture crop overall, and the 18th most important aquaculture crop that is fed a formulated feed (excludes seaweed and filter-feeding shellfish such as oysters and clams) (FAO FishStatJ database, accessed Nov. 17, 2019). In terms of value, trout rank 18th overall globally (including trout raised in both freshwater and marine waters), and 14th of fed aquaculture crops. The U.S. is the 12th-greatest trout-producing country in the world (Figure 13).

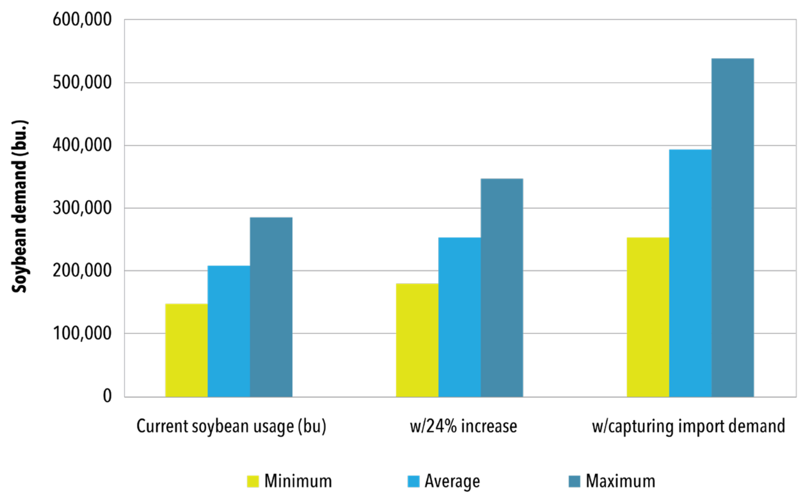
Unfortunately, increasing volumes of imported trout (Figure 14) from Chile and other countries have begun to replace U.S.-produced trout in U.S. markets. Imports of trout have tripled in volume over the decade from 2006 to 2016. Engle et al. (2019) present evidence that the regulatory environment has prevented U.S. trout producers from capturing increased demand for trout products in the U.S., directly documenting that U.S. trout sales could be 24% greater than at present.

Current Demand for U.S. Soybeans from U.S. Trout Production
Current demand for soybeans from U.S. trout production was estimated to be 212,419 bushels with average inclusion rates of soybean meal, with a range of from 141,612 bushels (minimum inclusion rate) to 283,225 bushels (at maximum inclusion levels).

Potential Future Demand for U.S. Soybeans, from Trout Production if Streamlined Permitting Would Allow Industry to Grow to Take Advantage of Opportunities
In this case study, increased demand for soy products was modeled based on the 24% greater volume of trout production documented by Engle et al. (2019) as well as the total demand represented by the volume of imported trout products. Figure 15 shows that streamlining the permitting process for expansion of trout production in the U.S. could increase soybean demand by 24%.

Potential Future Demand for U.S. Soybeans from Increased Trout Production if Domestic Trout would Regain Markets being Taken by Imports
Moreover, reducing un-necessary regulatory costs of production would allow U.S. trout producers to more effectively compete with imported product. A more competitive cost position of U.S. trout production if the regulatory cost burden would be reduced (i.e., due to reduced frequency of effluent testing for farms with no history of prior violations) has the potential to increase soybean demand from trout producers by as much as 92% with existing soybean meal inclusion levels (Figure 15).

Figure 15. Increased soybean demand from expansion of U.S. trout production



Future Potential Inclusion Rates of Soy Product Demand for U.S. Trout
Research has shown (Lovell 1988) that there is potential to increase the inclusion rates of soy products in trout diets, as long as palatability and anti-nutritional effects are managed. With increased inclusion rates of soybean meal that have been reported to be nutritionally feasible for trout production, soybean demand from U.S. trout production would increase by 50%, or 141,612 bushels above current maximum recommended inclusion levels.

U.S. Salmon Case Study
Atlantic salmon are the second-leading farmed aquatic product worldwide, in terms of value, second only to the Pacific white shrimp (Figure 16). Global sales of Atlantic salmon in 2017 were $16.6 billion. Norway and Chile dominate the production of Atlantic salmon worldwide, producing 45% and 34% of global Atlantic salmon by value, respectively (Figure 17). While the United States ranks 8th in global production of Atlantic salmon, the total value of its

Figure 16. Top 10 aquatic animals farmed worldwide, by value
SOURCE: FAO FishStatJ

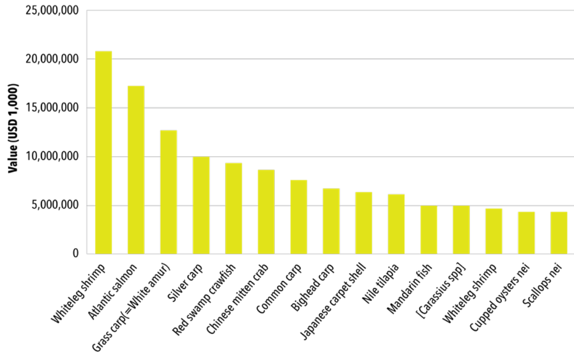
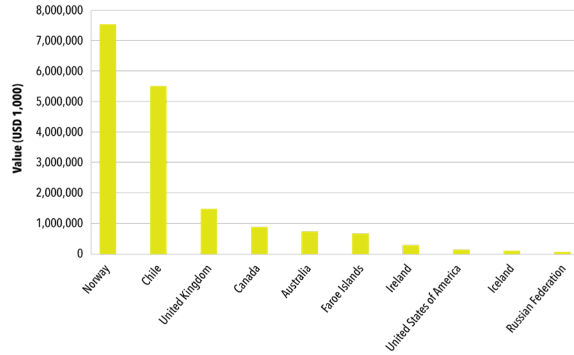


Figure 17. Top 10 salmon-farming countries worldwide (in USD 1,000)
SOURCE: FAO FishStatJ



production in 2017 was only 0.4% of the global value of Atlantic salmon. Moreover, the 2017 values pre-dated the court order that prohibited net pen production of Atlantic salmon in the state of Washington and resulted in the only company in that state shutting down its salmon farm.

The U.S. is one of the largest seafood markets in the world and is a major consumer of farm-raised salmon. Per capita consumption of salmon in the U.S. is second only to shrimp, with 2.41 lb/capita in 2017 (Shamshak et al. 2019). Approximately two-thirds of the U.S. salmon market was estimated to be farmed. While Alaskan wild-caught salmon are sold into U.S. markets, the majority of Atlantic salmon sold in U.S markets are farmed salmon that are imported from Norway, Chile, and other major suppliers (Knapp 2014). Some percentage of Alaskan salmon is also processed in China and then imported as a processed product. While demand for salmon continues to grow, it has become increasingly difficult to expand net- pen production of salmon. In Norway, restrictions on licenses for net farming sites have driven the cost of obtaining a license very high, from zero prior to 2002 to NOK 10 million in 2013-2014, with licenses trading at NOK 55 million to NOK 66 million in 2017, making it one of the greatest costs in Norwegian salmon farming (Bjorndal and Tusvik 2019).

As a result of the scarcity of new sites for net-pen farming of Atlantic salmon, there have been a series of announced investments in indoor recirculating aquaculture systems (RAS) for Atlantic salmon production around the world, predominantly in the U.S. Table 6 lists the companies that have announced investments in RAS production of Atlantic salmon in the U.S. and projected volumes over the coming years.

Until recent years, the only sales of Atlantic salmon were those of the net pen farms in Maine and those in the state of Washington that have been closed. There has been some very limited production and sales of Atlantic salmon produced in RAS (of fish that have been raised experimentally by The Freshwater Institute in West Virginia, now sold under the brand name of Spring Hill Salmon) with a sales volume of approximately 30,000 lb annually. In 2018, Superior Fresh initiated aquaponics production that included indoor production of Atlantic salmon in tanks in Wisconsin.

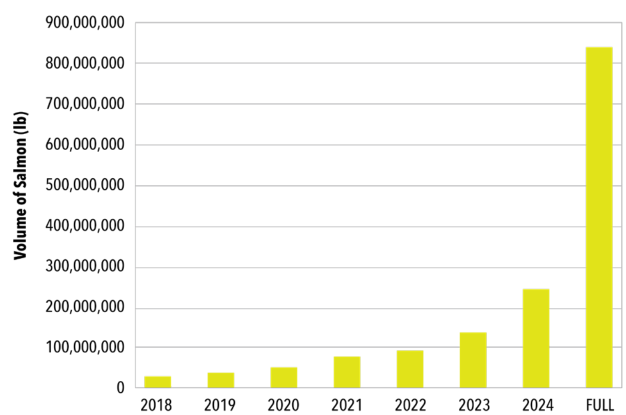
The first exclusively commercial indoor production facility for Atlantic salmon, Atlantic Sapphire in Florida, announced its plans to construct and develop an indoor tank-based facility in 2018. By 2019, smolts were under production with announced sales of market-sized

Table 6. Projected Volumes (lb) of Indoor, Tank-based Production of Atlantic Salmon in the U.S.

Year	Spring Hill Salmon	Superior Fresh - WI	Atlantic Sapphire - FL	Nordic AquaFarms - ME	Whole Oceans - ME	Nordic AquaFarms - CA	Pure Salmon - VA
2018	30,000	160,000	-	-	-	-	-
2019	30,000	860,000	-	-	-	-	-
2020	30,000	1,500,000	22,050,000	-	-	-	-
2021	30,000	1,500,000	44,100,000	-	-	-	-
2022	30,000	1,500,000	66,150,000	-	-	-	-
2023	30,000	1,500,000	88,200,000	22,050,000	-	22,050,000	-
2024	30,000	1,500,000	110,250,000	44,100,000	22,050,000	44,100,000	22,050,000
Full	30,000	1,500,000	485,100,000	66,150,000	110,250,000	110,250,000	44,100,000

fish to begin in 2020. In 2019, Atlantic Sapphire announced plans for further expansion to a full capacity scale of 485.1 million pounds (Table 6).

Figure 18. Projected growth of U.S. salmon production



Other announcements followed quickly and included the following: 1) Nordic Aquafarms in Belfast, Maine, with an announced full capacity production of 66.15 million pounds; 2) Whole Oceans in Bucksport, Maine, with an announced full capacity production of 110.25 million pounds; 3) Nordic Aquafarms in Samoa Bay, Eureka, California announced a full production capacity level of 110.25 million pounds; and 4) Pure Salmon in Tazewell County, Virginia, announced a facility with a full production capacity of 44.1 million pounds (Table 6). Assuming that all the companies that have announced these new investments to date reach full capacity without business failures, these announcements total 817.35 million pounds of Atlantic salmon, an increase of 3,446% over 2018 levels of Atlantic salmon production (Figure 18).

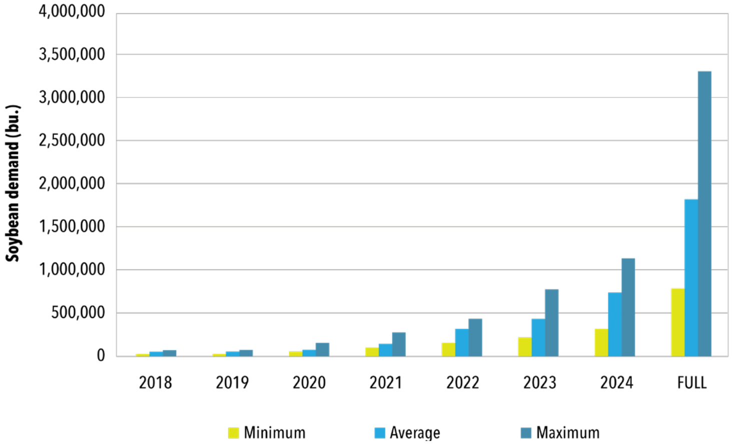
Current Demand for U.S. Soybeans from U.S. Salmon Production

Current demand for soybeans from U.S. salmon production was estimated to be 50,754 bushels at average soybean inclusion rates, with a range of 25,377 bushels (minimum inclusion rates) to 95,163 bushels (maximum rates).

Potential Future Demand for U.S. Soybeans with Increased U.S. Salmon Production

The projected increase in production of Atlantic salmon from RAS in the U.S. would result in increased demand of 1.75 million bushels of soybeans (increase in soybean demand from increased salmon production that would be greater than 3,446%) from this projected

Figure 19. Growth in demand for soybeans from the projected growth of salmon in RAS



expansion of RAS salmon, even at the relatively low current inclusion rates of soybean meal in salmon diets (Figure 19).

Potential Future Demand for US. Soybeans from Salmon with Research Advances that Increase Inclusion Rates of Soybean Meal in Salmon Diets

While some fish find soybean meal unpalatable, Lovell (1988) reported that older salmon accept soybean meal more readily than do younger fish. Glencross et al. (2004) reported that Atlantic salmon were able to use similar levels of soybean meal to those of rainbow trout. If a maximum level of 30% of Atlantic salmon diets can consist of soybean meal, then the future demand from salmon, assuming that the projected increases in production in RAS are met, would be an increased demand of 6.5 million bushels.

Figure 16. Top 10 aquatic animals farmed worldwide, by value
SOURCE: FAO FishStatJ

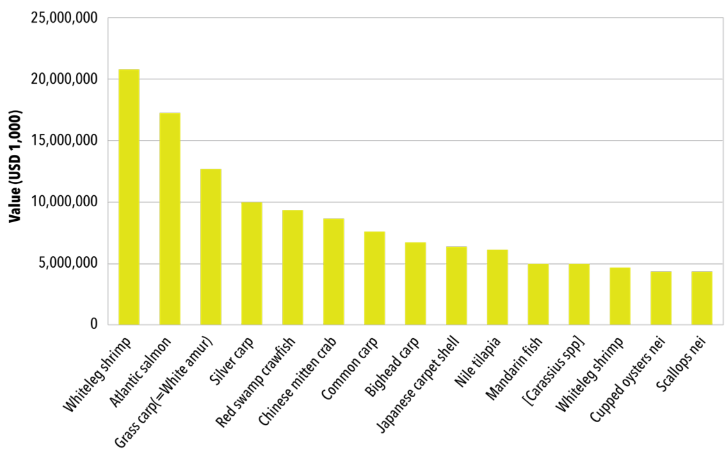
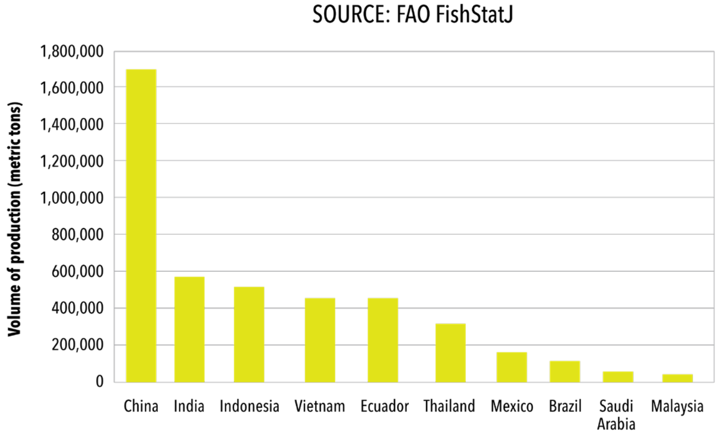


Figure 20. Top shrimp-producing countries worldwide
SOURCE: FAO FishStatJ



U.S. Shrimp Case Study

Background on Shrimp

Shrimp is the top-valued aquaculture species produced and sold in the world (Figure 16).The major species produced and sold worldwide is Litopenaeus vannamei, commonly referred to as the white-legged shrimp. Global sales of white-legged shrimp in 2017 were $20.3 billion. The five top-producing countries worldwide in 2017 were: China (with 37.5% of total global production), India (13%), Indonesia (11%), Vietnam (10%), and Ecuador (10%) (Figure 20). While the United States ranks 24th in global production of shrimp, its share of the world market in terms of value was only 0.04% of global production.

Current Demand for U.S. Soybeans from U.S. Shrimp Production

Current demand for soybeans from U.S. shrimp production was estimated to be 16,575 bushels, with a range from 12,277 bushels to 34,377 bushels. This level of demand represents less than 1% of the total demand for soybeans from U.S. aquaculture. This low level of demand for soybean meal from shrimp production in the U.S. is related to the overall low volume of shrimp production in the U.S. as well as the low inclusion rate of soybean meal in shrimp feeds (13%).

Table 7. Projected Volumes (lb) of Indoor, Tank-based Production of Marine Shrimp in the U.S.

Year	trū Shrimp	2nd not announced publicly
2018		
2019	500	
2020	1,000	20,000
2021	100,000	100,000
2022	2,075,000	1,500,000
2023	4,150,000	3,000,000
2024	6,225,000	4,410,000
Full	8,300,000	4,410,000

Future Potential Demand for Soy Products from Increased U.S. Shrimp Production

Interest in indoor, tank production of marine shrimp, Litopenaeus vannamei, has grown over the last decade. A number of small-scale shrimp farms have gone into production that target very local markets with fresh shrimp sold at a premium price ($12 to $20/lb). The total volume of production of these new indoor farms is not high, and there has been a great deal of turnover with a relatively high percentage exiting the business.

There has also been one high-profile announcement of investment in a large-scale indoor shrimp farm, trū Shrimp. Their pilot shrimp farm in Minnesota has begun to test market shrimp, and announcements have been made of acquisition of capital for a major production facility now planned to be constructed in South Dakota. Overall, trū Shrimp has a target production level, when in full production, of 8.3 million lb of shrimp (Table 7). A second potential investment is under consideration that has not been announced publicly that would be an indoor shrimp farm with a targeted production level of 4 million pounds annually. Figure 21 shows the increase in marine shrimp supply that would result from these two new facilities coming online. Such an expansion would nearly quadruple the 2012 volume of shrimp production in the U.S.

Quadrupling of U.S. production of shrimp would also result in a four-fold increase in the demand for soybeans from shrimp

Figure 21. Projected growth of U.S. shrimp production, with addition of new investments in U.S. shrimp production

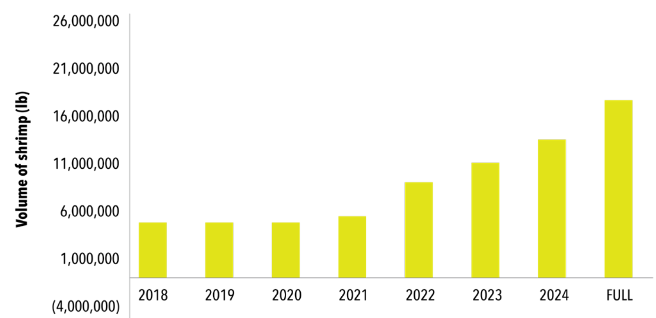
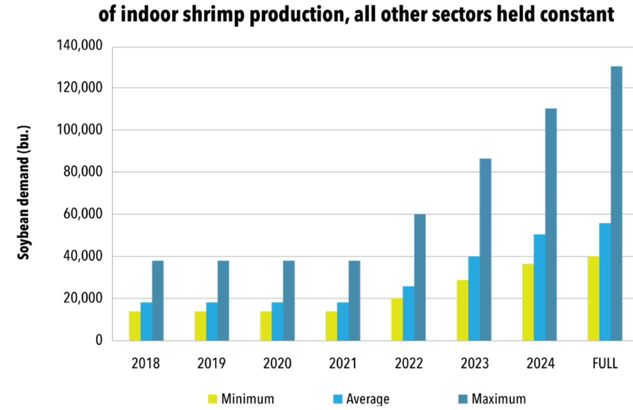


Figure 22. Projected growth in demand for soybeans from growth of indoor shrimp production, all other sectors held constant



production (Figure 22). However, it must be noted that the overall volume of U.S. shrimp production is very low; thus quadrupling U.S. production of shrimp is not a substantial increase. When combined with the low percentage of soybean meal used in shrimp diets (13%), the overall increase in demand for soybeans from these estimates of growth in shrimp production is minimal, an increase of less than 1%, even if the two new facilities reach full production capacities.

The major suppliers of shrimp to the world market are mostly located in S.E. Asia, where there have been serious issues of shrimp mortality due to various diseases. If the current disease problems are not resolved, the supply of shrimp may decrease, putting upward pressure on shrimp prices in the U.S. and elsewhere. Such increased prices of shrimp may result in additional investments in shrimp production in the U.S., especially if these first major investments prove to be feasible. In addition, the maximum inclusion rates of soybean meal in shrimp diets are more than double the average inclusion rates. Thus, with maximum inclusion rates and the projected expansion of U.S. shrimp production, total demand for soybeans from shrimp production could reach 131,776 bushels (Figure 22).

Figure 16. Top 10 aquatic animals farmed worldwide, by value
SOURCE: FAO FishStatJ

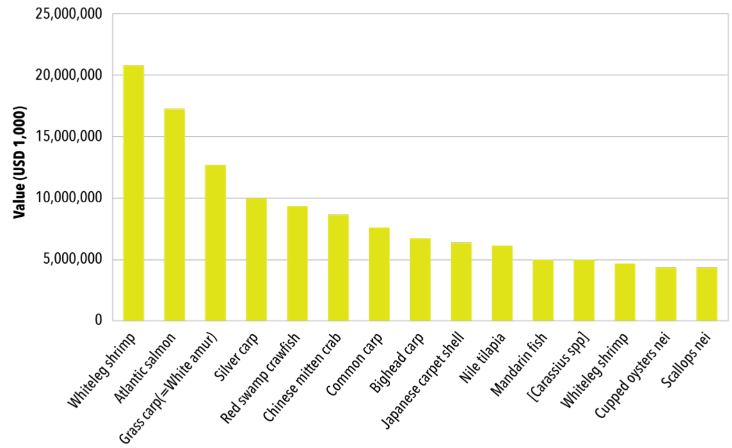
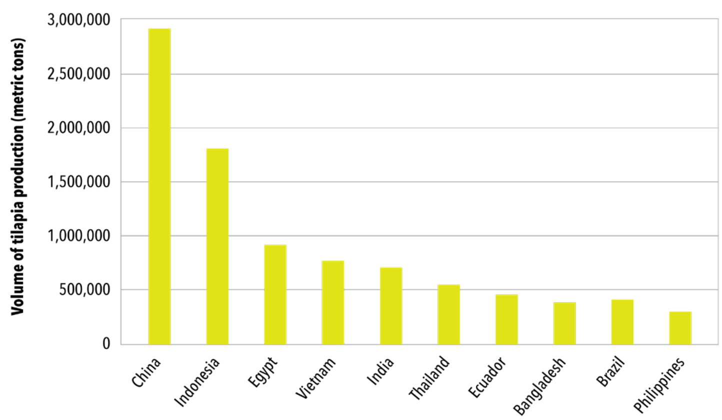


Figure 23. Top 10 tilapia-producing countries, 2017
SOURCE: FAO FishStatJ



U.S. Tilapia Case Study

Background on Tilapia

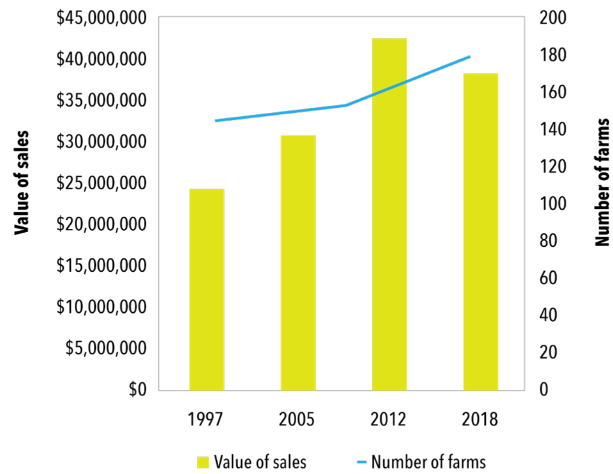
Worldwide, tilapia is the 10th-greatest aquaculture product produced (Figure 16). The major tilapia species raised globally is the Nile tilapia (Oreochromis niloticus). The five top-producing countries worldwide in 2017 were: China (with 29% of total global production), Indonesia (18%), Egypt (10%), Vietnam (7%), and India (6%) (Figure 23). The U.S. ranks 33rd in terms of volume of tilapia production, but this constituted less than 0.1% of the total global production in 2017. In the U.S., commercial tilapia growers tend to use various hybrids of tilapia species, some of which are proprietary.

Current Demand for U.S. Soybeans from U.S. Tilapia Production

Current demand for soybeans from U.S. tilapia production was estimated to be 194,968 bushels, with a range from 124,223 bushels to 284,097 bushels. This level of demand represents 2.2% of total demand for soybeans from U.S. aquaculture, the third-most important in terms of soybean demand from U.S. aquaculture. While this level of demand for soybeans from U.S. tilapia production is low, it is important to note that tilapia utilize soy products well and have one of the greatest soybean meal inclusion rates of all sectors of U.S. aquaculture, equivalent to that used in the U.S. catfish industry (35%).

Future Potential Demand for Soy Products from Increased U.S. Tilapia Production
Figure 24 presents data from the 1997, 2005, 2012, and 2018 Censuses of Aquaculture (USDA-NASS 1998, 2006, 2013, 2019) on tilapia production in the U.S. Tilapia production has not received much attention in the press in recent years, while imported tilapia have succeeded in creating a widely recognized aquaculture product in U.S. markets. Nevertheless, the U.S. tilapia industry grew from 2005 to 2012. The number of tilapia farms in the U.S. grew by 16%, the volume of production by 7%, and sales by 36%. The majority of tilapia raised and sold in the U.S. are sold as a live product, mostly to Asian supermarkets and to some upscale restaurants. In 2018, however, both sales volume and the number of farms declined from 2012 levels.

Figure 24. U.S. tilapia production, 1997 to 2018
SOURCE: USDA-NASS



While growth of tilapia production in the U.S. has been modest on an annual basis and has shown a decline in more recent years, there are two large projected ventures currently under discussion or implementation that are expected to increase the total volume of tilapia produced in the U.S. by approximately 18 million pounds. Such an expansion would more than double demand for soybeans from tilapia production to 433,705 bushels, with a range of 347,077 bushels (minimum inclusion rates) to 542,842 bushels (maximum inclusion levels).

Expansion of Marine Fish Production Offshore in the U.S.

Background on Marine Finfish Production in the U.S.
Much has been written in recent years related to the potential for responsibly managed marine aquaculture to expand to meet future food demands of the growing human population. One such estimate, based on a global modeling analysis that used very broad simplifying assumptions, reported that in the U.S. alone, there was potential to increase production of marine finfish in the U.S. EEZ by 4.4 to 8.8 billion pounds (Gentry et al. 2017). Such high-level generalizations point to substantial potential, but the specific values are unlikely to be realistic due to varying and un-accounted for conditions on the local level. Thus, while there does appear to be substantial potential in the U.S for expansion in marine areas, such estimates are not likely to occur in the near future and have not been included in this analysis.

The only marine finfish species separated out and identified by species in the 2012 Census of Aquaculture (USDA-NASS 2013) were: flounder, Atlantic salmon, and Pacific salmon. Any others were included in the category of “Other foodfish”. Yet the volume of production of the "other foodfish" category tripled from 2005 to 2018. This category includes several marine finfish species.

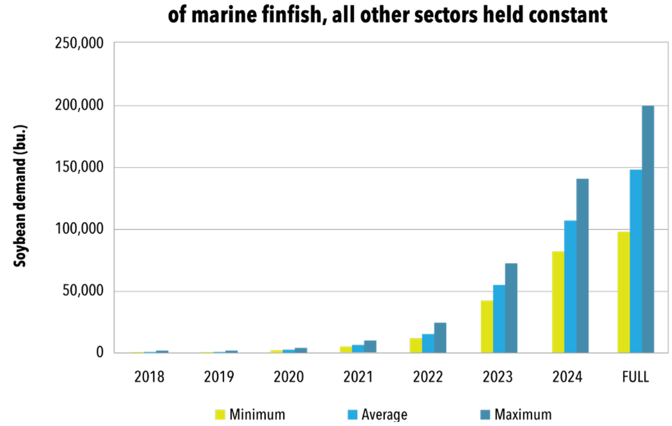
Current Demand for U.S. Soybeans from U.S. Marine Finfish Production
Given that the "Other foodfish" category was not sub-divided into species, it is not possible to calculate a specific percentage that this category composed of total aquaculture production.

Future Potential Demand for U.S. Soy Products from Increased U.S. Marine Finfish Production
There has been a great deal of discussion and debate in recent years related to the need for a regulatory framework that would allow for development of marine finfish aquaculture. In spite of what has been described as something of a policy stalemate and barrier to marine finfish production, there are investments and farms that are gearing up for greater production of several marine finfish species. Given that a scenario was presented above for Atlantic salmon production, this section will focus on some new recent developments and planned expansion of marine finfish commercial production, but does not include salmon production levels.

In the state of Washington, a number of studies underway have demonstrated that sablefish can be cultured successfully in net pens. A native species, sablefish net-pen farms have been permitted for at least one tribe and at least one commercial company. Projected future volumes have not been announced, but conservative volumes of increased production of sablefish over the next five years have been estimated. In addition, investments have been made in indoor production of several other species. Those announced that are actively growing fish and beginning to sell fish include production of branzino (European sea bass), Florida pompano, and yellowtail amberjack. In addition, Kampachi Kona raises Almaco jack yellowtail in open ocean cages with plans for expansion.

Figure 25 shows the projected growth in marine finfish production of investments and projects that are currently underway. By 2024, an additional 152,995 bushels of soybeans are expected to be demanded, based on an assumed average inclusion rate of soy products of 15%, with a range of from 101,996 bushels at minimum inclusion rates to 203,993 bushels at maximum inclusion rates. However, given that sablefish have been found to be able to use greater inclusion rates of soy protein concentrate, it is likely that the inclusion rate of 15% is highly conservative.

Figure 25. Growth in demand for soybeans with the growth of marine finfish, all other sectors held constant



More importantly, the estimated increase in inclusion rates of soy products in marine finfish diets shows an annual average increase in demand for U.S. soy products of 135%, albeit a percentage increase over a small initial base of marine finfish production. If new federal legislation provides the framework necessary for development of marine finfish production, much greater growth would likely occur in this sector.

Combined Effects of the Scenarios Analyzed

Table 8 combines the effects of the likeliest growth areas of U.S. aquaculture, based on current announcements and potential market demand. Overall, the greatest potential increases are in the U.S. catfish industry, given its current volume of production plus the high percent inclusion of soybean meal, followed by salmon, tilapia, trout, marine finfish, and shrimp. (Figure 26). On a percentage basis, however, marine finfish demonstrated the greatest percentage growth followed by salmon (Figure 27). These percentage increases show the potential growth over the longer-term if other, currently small segments of U.S. aquaculture experience rapid growth, with the announced substantial investments in new, relatively large-scale farms. Table 8 shows that the combined potential demand from the growth projections in this analysis for U.S. aquaculture were 16.7 million bushels at average inclusion rates, with a range of 10.2 million bushels (at minimum inclusion rates) to 25.1 million bushels (at maximum inclusion rates) over the next 5 years.

Table 8. Increased Soybean Demand with Projected Increases from the Case Studies (percentage inclusion rates of soybeans are listed in Table 2)

U.S. aquaculture sector	Current soybean demand (bu)	Potential increase in soybean demand (bu)	Maximum
Catfish			
Minimum[a]	4,910,668	3,629,697	8,540,365
Average[b]	7,707,327	5,263,492	13,404,160
Maximum[c]	11,230,677	8,301,099	19,531,776
Trout			
Minimum	141,612	130,868	272,481
Average	212,419	196,302	408,721
Maximum	283,225	261,736	544,961
Salmon			
Minimum	25,377	874,134	899,511
Average	50,754	1,748,797	1,799,022
Maximum	95,163	3,278,004	3,373,167
Shrimp			
Minimum	12,277	34,785	47,063
Average	16,575	46,960	63,535
Maximum	34,377	97,399	131,776
Tilapia			
Minimum	124,223	152,109	347,077
Average	194,968	238,737	433,705
Maximum	284,097	347,874	542,842
Marine finfish			
Minimum	600	101,396	101,996
Average	900	152,095	152,995
Maximum	1,200	202,793	203,993
Total			
Minimum	5,493,602	4,922,989	10,208,553
Average	8,620,834	8,079,724	16,700,558
Maximum	12,568,208	12,488,905	25,057,133

[a]Minimum inclusion rate of soybean meal.
[b]Average inclusion rate of soybean meal.
[c]Maximum inclusion rate of soybean meal.

Figure 26. Greatest potential increases in soybean demand (bushels)

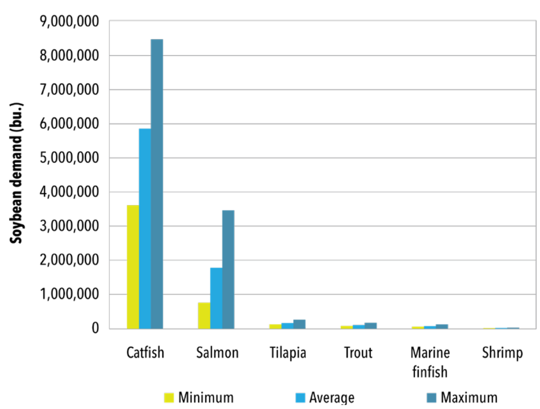
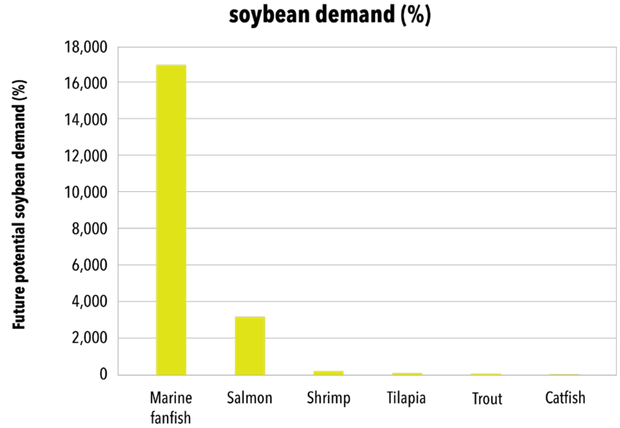


Figure 27. Greatest percentage growth in future (beyond 5 years) soybean demand (%)



Objective 4: To estimate potential benefits to U.S. soybean producers from increased domestic demand for soybeans from U.S. aquaculture

There are a number of clear benefits to U.S. soybean producers from expansion and growth of U.S. aquaculture. These include the following:

1 ▸ Feed ingredients in U.S. aquafeeds are sourced from the U.S.

2 ▸ Many U.S. aquafeeds use greater percentages of soybean meal than those used in terrestrial animal agriculture.
3 ▸ Rural farming communities would be supported and strengthened.
4 ▸ Soybean crushing mills would be supported.
5 ▸ Markets would be diversified and demand for U.S. soybeans would be more stabilized.
6 ▸ Effects on prices of U.S. soybeans from expansion of U.S. aquaculture
7 ▸ U.S. food security would be increased.

Each of these benefits will be discussed in the following section.

Feed Ingredients in U.S. Aquafeeds are Sourced from the U.S.
The U.S. is one of the leading food-producing countries in the world and is considered to be the top food exporter in the world (Maxwell 2019) as well as the most efficient food producer. The top commodities exported from the U.S. are: soybeans, corn, tree nuts, beef, and cotton. The size and scope of the agricultural sector in the U.S. results in ready availability of a wide variety of grains and other feed ingredients for animal feed manufacturing.

As a result of the ready availability of feed ingredients, especially in major aquaculture-producing regions, all feed ingredients (with the exception of some fishmeal) fed to fish in the U.S. are sourced from within the U.S., often from sources in close proximity to fish farms and feed mills. Thus, the demand for increased quantities of soy products that will accompany expansion of U.S. aquaculture will be to the exclusive benefit of U.S. producers and suppliers of feedstuffs, especially soybean farmers.

Table 9. Percentages of Various Livestock Diets That are Composed of Soybean Meal. SOURCE: Decision Innovation Solutions 2018

Type of animal livestock	Percent of soybean meal fed to animals in the U.S., 2016/2017	Percent of diet that is soybean meal	Major dietary ingredient
Poultry			
Broilers	48%	28%	Corn (48%)
Layers	9%	16%	Corn (47%)
Turkeys	7%	24%	Corn (43%)
Hogs	24%	18%	Corn (57%)
Dairy cows	9%	3%	Legume silage (43%)
Beef cattle	-	Negligible (small amounts in creep feed for calves)	Forage
Companion animals	-	Negligible	Human food for dogs & cats; forage for horses
Sheep	-	Negligible	Forage
Meat goats	-	Negligible	Hispanic markets, the largest segment, no SBM

Many U.S. Aquafeeds Use Greater Percentages of Soybean Meal Than Those Used in Terrestrial Animal Agriculture

Animal agriculture in the U.S. is the major consumer of soybean meal in the U.S. as soybean meal is a widely used ingredient in broiler, hog, layer, dairy cow, and turkey sectors (Decision Innovation Solutions 2018). Total U.S. animal agriculture consumption, including that of aquaculture, was estimated to be 31.2 million tons of soybean meal during the 2016/2017 marketing year. Broilers consumed 48% of soybean meal, hogs 24%, layers 9%, dairy cows 9%, and turkeys 7% (Table 9). Thus, the volume of animal livestock production is a strong driver of demand for soybean meal and other soy products (Houck 1964; Ash 1984; Saghaian 2017).

The total quantity demanded of soybean meal is related to: 1) the size of those sectors of animal agriculture that consume the most non-forage feeds; and 2) the percent of various livestock diets that is composed of soybean meal. From Table 9, it is clear that, of terrestrial animal livestock, broiler diets have the greatest percentage of soybean meal at 28%, followed by turkeys at 24%, hogs at 18%, layers at 16%, and dairy cows at 3%.

Catfish, the largest sector of U.S. aquaculture, uses proportionately greater percentages of soybean meal in the feed consumed than that of any type of terrestrial animal. The catfish farmed in the U.S. average approximately 35% of their diet of soybean meal, which is 25% greater than the inclusion rate of 28% in broiler diets. The minimum percentage of soybean meal used in catfish diets is 22% and the maximum is 51%. Thus, an equivalent tonnage increase in catfish production will require proportionately more soybean meal than the same tonnage produced of other types of animal livestock. Thus, growth of the U.S. catfish industry has potential to increase overall demand for U.S. soybeans at a more rapid rate than that of terrestrial animal production, all of which feed proportionately less soybean meal per pound of feed than U.S. catfish.

Other fish species for which the average percentage use of soybean meal in the diets is greater than that of broilers (the greatest consuming sector of terrestrial animal livestock) include: tilapia (35%), baitfish that use a catfish feed (35%), sunfish/bream (40%) that use a higher protein catfish feed, and hybrid striped bass (31%). Other fish species that use diets with soybean meal percentages greater than those of the second-greatest terrestrial animal livestock sector, hogs, include: sportfish such as crappie, largemouth bass, and smallmouth bass (25%). Those aquaculture sectors that feed percentages of soybean meal that are similar to those of layers, the third-greatest consumer of soybean meal among terrestrial animal livestock, include: trout, walleye, yellow perch, and muskellunge at 15%.

Rural Farming Communities Would be Supported and Strengthened

The demand for soy products from expansion of U.S. aquaculture will support and strengthen rural farming communities generally, but especially those of soybean farmers through the economic benefits and contributions of a strong soybean farming sector. These benefits and contributions will remain in the U.S. rather than flow to other countries because all feed ingredients (with the exception of some fishmeal) used in US. aquaculture are sourced from the U.S.

Stronger demand for products and prices will also contribute to profitability of U.S. soybean farms that further contributes to local and state economies. U.S. soybean farmers purchase a variety of inputs from equipment such as tractors, combines, and trucks, but also purchase seed, other input supplies, and hire employees. As these expenses are paid, the amount of money available from upstream sectors, such as equipment manufacturers and dealers, seed producers, farm supply companies, and farm employees is then further circulated in the economy as each upstream company pays bills and employees spend their wages and salaries on housing, food, health care, and other household and family expenses. Slaper et al. (2015) estimated that the overall multiplier from agricultural production in Indiana was 1.57, with soybean farming multipliers of 1.7 for both employment and value-added economic contributions.

Economic support for rural, local economies provides for quality of life enhancements that support the farm family way of life. Farming families are the backbone of rural communities. The soybean industry, as well as the aquaculture industry, are composed primarily of farm families, not corporations. Strong rural and local economies support the quality of life of farm families through tax revenues available for use in public schools, health care services, and greater household spending on various necessities such as food but also on other amenities such as entertainment and recreational activities.

As an example, a recent analysis of the economic impact of the soybean industry in Illinois found that the soybean industry contributed more than $7 billion to the economy of Illinois (www.ilsoyadvisor.com/ impact/soybean-facts (Illinois Soybean Association; accessed 11/10/2019). Approximately 40% of the soybeans grown in Illinois were crushed by mills in the state. The rest were exported, but could also be used to supply an expanded soybean crushing industry as an alternative to export. Soybean crushing mills add value and capture greater margins that result in greater economic contributions to local areas as compared to the margins that result from exporting raw products such as soybeans. Domestic livestock farms in the U.S. are a major customer for U.S. soybeans. The Illinois study showed that, of the total volume of soybeans sold, the hog industry consumed 74%.

In addition to the direct economic contributions and jobs created by the U.S. soybean economy, spending by the soybean industry further creates indirect and induced effects. Indirect effects occur, for example, as a result of expenditures on production inputs that include equipment, fertilizer, seed, and other supplies. Payments to utility companies for electrical service and natural gas provide indirect effects to those sectors that result in additional expenditures by employees for food, clothing, medical care, entertainment, and other expenses, often purchased locally. Such expenditures by employees of soybean farmers, crushing plants, and businesses that sell products to employees constitute the induced economic effects derived from the soybean industry.

In Arkansas, for example, the soybean industry contributed 20,477 total jobs (most of which were direct effects), $713.95 million in total economic activity, and $1.4 billion in economic value-added to the state (Kemper et al. 2014). Other sectors supported indirectly and from induced effects as a result of the contributions of soybean farming in Arkansas included: agriculture, forestry, fishing, and hunting, retail trade, manufacturing, construction, and real estate. In addition, there were 790 jobs supported in the health and social services, 756 jobs in retail trade, 589 jobs in other services, 513 jobs in real estate and rental, and 484 jobs in finance and insurance. The contributions to the above economic sectors from the economic value-added activity from soybean farming constituted more than 60% of the total value-added in the state for these sectors. It is important to note that the Kemper et al. (2014) study found that 94% of the jobs supported by the soybean industry in the state and 98% of the income and value-added from soybean farming occurred inside the region itself. Clearly, soybean farming has a substantial and primary effect on local rural economies.

Soybean Crushing Mills Would be Supported

Increased demand by U.S. aquaculture for soybean meal would also support soybean crushing mills that add value to raw soybeans and support further upstream and downstream economic activity and jobs in rural economies and communities in the U.S.

One of the foremost benefits of stimulating domestic demand in the U.S. for soy products is that such domestic demand supports the soybean crushing industry and the mills that extract soy oil and make soybean meal as well as further refined products. Other competing countries export greater volumes of soybean meal and soy oil whereas the U.S. exports primarily whole soybeans (Taheripour and Tyner, 2018). Thus, the domestic benefits of jobs, economic value-added, labor income, and total economic value from soybean crushing mills would be greater due to increased demand for the soybean processing industry.

Markets Would be Diversified and Contribute to Stabilization of U.S. Soybean Industry

Greater domestic demand for soy products from a different economic sector such as aquaculture diversifies overall market demand for soy products and offers the potential for reduction of risks associated with market prices and income.

Market diversification is a primary strategy to reduce market risks associated with low prices or access to markets. Access to a market in which prices and demand vary in patterns that are opposite from an existing market provides the opportunity to hedge potential losses in one of those markets. It is important to note that markets can be based on geographic locations, such as domestic and international markets. Geographic diversification of markets provides opportunities to manage risks of downturns in one or more markets, and introduces some degree of market and price stability.

Thus, increased production of aquaculture in the U.S. would increase the quantity demanded of U.S. soy products through increased demand for feed. Increased demand typically results in support for increased prices. Essentially, increasing the portion of demand for soybeans that is from domestic industries may reduce some of the market volatility and add some stability to the market for U.S. soybeans. Moreover, a domestic market would be more stable and less subject to the sudden shocks of international trade disputes, political disagreements than export markets are.

Price Effects of U.S. Soybeans from Expansion of U.S. Aquaculture

The price of U.S. soybeans is affected by a wide range of complex factors that interact in a variety of ways. Appendix A includes a summary of the economics literature related to the supply and demand of soybeans and the various factors that affect the price of soybeans.

These include prices and quantities of livestock produced and feed fed to livestock in both the U.S. and countries that import from the U.S., competing feed ingredients such as other types of meals and oils, the price, quantity, and demand for corn that has been shown to be a substitute for soybean acres, weather conditions and expected yields in major producing countries, and international conditions that affect exchange rates, and policies that affect international trade.

Soybean meal is likelier to remain an important ingredient in aquafeeds more so than for other livestock sectors that may have greater numbers of good substitutes. For example, while canola meal has been shown to be a good substitute for soybean meal in broiler diets, its use in fish diets is more restrictive than is that of soybean meal (USSEC 2008).

It is beyond the scope of this study to attempt to develop quantitative estimates of how soybean prices would be affected by expansion of U.S. aquaculture. Price forecasting models rarely are extended beyond the next several months because weather, trade, and the many factors affecting supply and demand of complex agricultural crops are uncertain and unknowable.

Nevertheless, increased domestic demand for soybeans would undoubtedly put upward pressure on prices of soybeans. The major sectors of U.S. aquaculture use more soybean meal, pound for pound of feed fed, than do most sectors of terrestrial animal agriculture. Moreover, there is growing recognition of the health benefits of consuming more seafood and also of the realization that greater availability of seafood globally will need to come from aquaculture. It is also becoming increasingly more evident that seafood raised within the stringent regulatory environment of the U.S. will be safer to eat and will be raised in a more environmentally and socially responsible fashion.

Increased U.S. production of aquaculture, moreover, will generate substantial impacts, not just in the aquaculture-producing regions of the U.S., but will support and contribute to the economies and communities in the major soybean-growing regions of the U.S. Since the demand from U.S. aquaculture will be for soybean meal, such an expansion will add further economic value by supporting the soybean crushing industry, its economic output, and the jobs created in that sector.

U.S. Food Security Would be Increased

Food security is a major issue on an international scale and often discussed primarily in the context of lower-income nations. Nevertheless, with the growing dependence in the U.S. on imported food supplies, there is increased concern over what that might mean in terms of food security in the U.S. As long as the U.S. maintains strong trade relationships with its major agriculture trading partners, the risk of food shortages in the U.S. may not be high. Nevertheless, there is a growing movement to increase local production of food in the U.S. While much of this interest in local food production stems from an interest in reducing food miles and more responsible environmental management, concerns over the safety of imported food as well as the security of the overall food supply have also increased. Clearly, increasing aquaculture production in the U.S. is a way to reduce the substantial trade deficit in seafood and enhance security of our seafood supply in addition to the other economic benefits to the soybean industry and rural economies and communities in the U.S.

Objective 5. To finalize estimates based on the 2019 USDA Census of Aquaculture
All analyses were re-done with the 2018 values reported in the 2019 USDA Census of Aquaculture. All tables and figures in this report reflect 2018 values as the base situation. Thus, the specific values reported in this final report differ somewhat from those reported in the December, 2019, preliminary report submitted to the Soy Aquaculture Alliance.

Conclusions and Recommendations

Supporting the development of U.S. aquaculture would provide benefits to U.S. soybean farmers in terms of sales and in supporting strong rural farming communities. Moreover, as export markets can be unreliable, increasing domestic markets would help to stabilize sales. This analysis has identified those segments of U.S. aquaculture with the greatest short-term and longer-term potential to increase demand for soybeans. The greatest short-term potential to increase demand for soybeans is that of the U.S. catfish sector. U.S. catfish already consumes by far the greatest amount of soybean meal of any sector of U.S. aquaculture due to the overall size of the sector, combined with its high inclusion rates of soybean meal. The market share of imported pangasius catfish could be re-captured through policy changes that create a more level playing field in terms of food safety and environmental standards. Holding imported pangasius products to the same food safety and environmental standards of the U.S. would result in a more competitive U.S. industry because the U.S. industry currently incurs the costs associated with high food safety and environmental management regulations unlike countries that export pangasius to the U.S. If the U.S. catfish industry recovery would continue and reach the production levels at its peak in 2003, its demand for soybeans would increase by 74%.

More specific examples of the types of policy support for the U.S. catfish industry include the following:

- Encourage states to adopt labeling laws that require restaurants to label catfish and catfish-like products sold by the country of origin where raised or processed.
- Support efforts to include aquaculture products in federal programs for agriculture (i.e. disaster relief and risk management programs for which catfish and other aquaculture products currently fall through the cracks).
- Support efforts by the U.S. catfish industry that require USDA-FSIS to conduct annual in-country equivalency audits, including establishments that export Siluriformes catfish to the U.S.
- Enhance surveillance and testing of Siluriformes products imported into the U.S.
- Support efforts to urge USDA-APHIS to take steps to minimize risks associated with the introduction of aquatic animal pathogens by imported live and processed aquaculture products into the U.S.
- Support federal food purchasing programs for U.S. farm-raised fish such as school lunch, WIC, TANF and other surplus purchasing programs. Farm-raised fish is in high demand but is under-represented in federal purchases of fish products.

For the U.S. trout industry, examples of the types of policy support needed would include:

- Reduction of frequency of testing of effluent water quality on farms with a history of compliance with established standards.
- Adoption of uniform fish health testing and certification requirements across states.

In the shorter term, the next greatest potential to increase demand for soybeans would be that of salmon, then tilapia, and trout production in the U.S. While salmon farms currently do not use feeds with high inclusion rates of soybean products, the dramatic volumes of production announced in the new, indoor salmon farms rank it as the second-greatest demand for soybeans. Tilapia ranked third due to new investments and proposed expansion, combined with the high inclusion rates of soybean meal in tilapia diets. Trout ranked fourth, based primarily on existing markets that could be captured from imports with policy changes to remove the constraints to expansion of trout production in the U.S., even with the somewhat lower inclusion levels of soybean products in trout diets.

Longer-term, additional increases in demand for soybeans are likely to come from research that would result in increased inclusion rates of soybean products in diets for salmon, and marine fish, especially yellowtail, branzino, sablefish, and pompano, for which existing businesses have been developed in the U.S.

Recommendations:

1 ▶ Support needed policy changes that would increase sales of soybeans to U.S. aquaculture. Examples include the following:

- Streamline the regulatory system in the U.S. This recommendation does not refer to reducing environmental protection, but rather to eliminate redundancy and duplication in monitoring and reporting along with reducing the frequency of testing required for farms with a history of no prior violations.

- Reduce permitting delays for U.S. aquaculture businesses.

- Encourage federal and state agencies to support the development of responsible aquaculture, abiding by the 1980 National Aquaculture Act rather than adopt an adversarial approach to regulating aquaculture.

- Work in partnership with the National Aquaculture Association, the Catfish Farmers of America, and the U.S. Trout Farmers Association on needed regulatory reforms.

2 ▶ More specific examples of the types of policy support for the U.S. catfish industry include the following:

- Encourage states to adopt labeling laws that require restaurants to label catfish and catfish-like products sold by the country of origin where raised or processed.

- Support efforts to include aquaculture products in federal programs for agriculture (i.e. disaster relief and risk management programs for which catfish and other aquaculture products currently fall through the cracks).

- Support efforts by the U.S. catfish industry that require USDA-FSIS to conduct annual in-country equivalency audits of establishments that export Siluriformes catfish to the U.S.

- Enhance surveillance and testing of Siluriformes products imported into the U.S.

- Support efforts to urge USDA-APHIS to take steps to minimize risks associated with the introduction of aquatic animal pathogens by imported live and processed aquaculture products into the U.S.

- Support federal food purchasing programs for U.S. farm-raised fish such as school lunch, WIC, TANF and other surplus purchasing programs. Farm-raised fish is in high demand but is under-represented in their purchases of fish products.

3 ▸ For the U.S. trout industry, examples of the types of policy support needed would include:

- Reduction of frequency of testing of effluent water quality on farms with a history of compliance with established standards.

- Adoption of uniform fish health testing and certification requirements across states.

4 ▸ Encourage federal aquaculture research dollars to support U.S. aquaculture industry priorities, ensuring that USDA-NIFA competitive funding, funding for USDA-SBIR grants, funding to USDA-land grant universities, and NOAA Sea Grant funding priorities are aligned and driven by aquaculture industry priorities. It should be noted that, while the term 'industry' is commonly used, the vast majority of aquaculture producers are family farmers. While some proportion of research funding is needed for long-term advancements on "novel" research topics, there is a need for a greater proportion of aquaculture research funds to address stated and more immediate needs of U.S. aquaculture businesses. Overall aquaculture production, and subsequent demand for soy products, will be advanced most quickly by developing effective solutions to key stated problems of aquaculture farmers.

5 ▸ Invest in research leading to increased inclusion rates of soybean meal and other soybean products in trout and salmon. Promising lines of research include:

- Low-oligosaccharide soybean meal for salmon diets.

- Other "designer" varieties of soybeans that reduce anti-nutritional factors for trout and salmon.

- Epigenetic effects that reduce effects of anti-nutritional factors for trout and salmon.
- Nutritional research for marine species with especial opportunities for U.S. farms, such as yellowtail, branzino, sablefish, and European sea bass for which aquaculture businesses in the U.S. have been developed.

References

Adiemian, M.K. and A. Smith. 2012. Using USDA forecasts to estimate the price flexibility of demand for agricultural commodities. American Journal of Agricultural Economics 94 (4):978-995.

Amaya, E. A.; D. A. Davis, D. B. Rouse. 2007. Replacement of fish meal in practical diets for the Pacific white shrimp (Litopenaeus vannamei) reared under pond conditions. Aquaculture 262 (2−4):393−401.

Anderson, M. and P. Garcia. 1989. Exchange rate uncertainty and the demand for U.S. soybeans. American Journal of Agricultural Economics 71(3):721-729.

Ash, M.S. 1984. A supply response model for Iowa soybeans and net farm income implications. Retrospective Theses and Dissertations. 16529. Iowa State University. Available at: https://lib.dr.iastate.edu/rtd/16529.

Barrows, F.T., D. Bellis, Å. Krogdahl, J. T. Silverstein, E. M. Herman, W. M. Sealey, M. B. Rust, and D. M. Gatlin III. 2008. Report of the plant products in aquafeed strategic planning workshop: an integrated, interdisciplinary research roadmap for increasing utilization of plant feedstuffs in diets for carnivorous fish. Reviews in Fisheries Science, 16(4):449-455.

Beckman, J., A. Borchers, and C. A. Jones. 2013. Agriculture's supply and demand for energy and energy products, EIB-112, U.S. Department of Agriculture, Economic Research Service, Washington, D.C.

Berge, G.E., B. Grisdale-Helland, and S.J. Helland. 1999. Soy protein concentrate in diets for Atlantic halibut. (Hippoglossus hippoglossus). Aquaculture 178:139-148.

Bjorndal, T. and A. Tusvik. 2019. Economic analysis of land based farming of salmon. Aquaculture Econoics & Management 23(4):449-475.

Boonyaratpalin, M., Suraneiranat, P., Tunpibal, T. 1998. Replacement of fish meal with various types of soybean products in diets for the Asian seabass, Lates calcarifer. Aquaculture 161: 67 – 78.

Brown, P.B. and K. Smith. No date. Soybean use-aquaculture. Soybeanmeal INFO Center. United Soybean Board. Found on website www.soymeal.org. Accessed 8/1/2019.

Cleveland, B. 2019. A perspective of the future value and challenges of genetic engineering in aquaculture. Journal of the World Aquaculture Society 50(5):890-893.

Day, O.J., Plascencia Gonzalez, H.G. 2000. Soybean protein concentrate as a protein source for turbot Scophthalmus maximus L. Aquaculture Nutrition 6:221-228.

Decision Innovation Solutions. 2018. 2018 Soybean meal demand assessment: United States. Report prepared for the United Soybean Board. Available at: www.unitedsoybean.org/ wp-content/uploads/LOW-RES-FY2018-Soybean-Meal-Demand-Analysis-1.pdf. Accessed: November 13, 2019.

Deng, J., K. Mai, Q. Ai, W. Zhang, X. Wang, W. Xu, Z. Liufu, Z. 2006. Effects of replacing fish meal with soy protein concentrate on feed intake and growth of juvenile Japanese flounder, Aralichthys olivaceus. Aquaculture 258 (1−4), 503−513.

Engle, C.R., J. van Senten, and G. Fornshell. 2019. Regulatory costs on U.S. salmonid farms. Journal of the World Aquaculture Society 50(3):522-549.

Foreign Agricultural Service. 2019. China tariffs driving U.S. soybean exports
to the European Union to a 30-year high IN: Oilseeds: World Markets and Trade. Foreign Agricultural Service, Office of Global Analysis, United States Department of Agriculture, Washington, D.C.

Forster, I. No date. Use of soybean meal in the diets of non-salmonid marine fish. Soybean Meal InfoCenter. United Soybean Board. Available at: www.soymeal.org/wp-content/uploads/2018/04/use_of_soybean_meal_in_the_diets_of_non_salmonid_marine_fish.pdf. Accessed October 15, 2019.

Francis, G., H.P.S. Makkar, and K. Becker. 2001. Antinutritional factors present in plant-derived alternate fish feed ingredients and their effects in fish. Aquaculture 2001 (3-4):197−227.

Gentry, R.G., H.E. Froehlich, D. Grimm, P. Kareiva, M. Parke, M. Rust, S.D. Gaines, and B.S. Halpern. 2017. Mapping the global potential for marine aquaculture. Nature Ecology and Evolution 1:1317–1324.

Glencross, B., C. G. Carter, N. Duijster, D. R. Evans, K. Dods, P. McCafferty, W. E. Hawkins, R. Maas, and S. Sipsas. 2004. A comparison of the digestibility of a range of lupin and soybean protein products when fed to either Atlantic salmon (Salmo salar) or rainbow trout (Oncorhynchus mykiss). Aquaculture 237:333–346.

Gu, M., N. Bai, Y. Zhang, Y., and Å. Krogdahl. 2016. Soybean meal induces enteritis in turbot Scophthalmus maximus at high supplementation levels. Aquaculture 286−295.

Hansen, J. and F. Gale. 2014. China in the next decade: rising meat demand and growing imports of feed. Amber Waves. Available at https: //www.ers.usda.gov/amber-wavves/2015/ April/China-in-the-next-decade; accessed January 25, 2020.

Hardy, R. W. 2010. Utilization of plant proteins in fish diets: effects of global demand and supplies of fishmeal. Aquaculture Research 41(5):770−776.

Hardy, R. W., K. Overturf, A. Brezas. 2015. Breaking the 20% soy barrier in fish feed. Global Aquaculture Advocate 20−22.

Hasan, M.R., M.M. Dey, and C.R. Engle. 2019. Forecasting monthly catfish (Ictalurus punctatus) pond bank and feed prices. Aquaculture Economics & Management 23(1):86-110.

Heady, E., and V. Rao. 1965. Acreage response and production supply functions for soybeans. Iowa State University Research Bulletin #555, Iowa State University, Ames, Iowa.

Houck, J.P. 1964. A statistical model of the demand for soybeans. American Journal of Agricultural Economics 46(2):366–374.

Kemper, N.P., W.P. Miller, J.S. Popp, and R.L. Rainey. 2014. Economic contribution of the soybean industry to the Delta, Arkansas River Valley, and Red River Valley Regions of Arkansas in 2012. Division of Agriculture Research and Extension, University of Arkansas, Fayetteville, Arkansas.

Kikuchi, K. 1999. Use of defatted soybean meal as a substitute for fish meal in diets of Japanese flounder (Paralicthys oliveaceus). Aquaculture 179: 3-11.

Knapp, G. 2014. Estimating U.S. salmon consumption. Paper presented at IIFET 2014, July 8, Brisbane, Australia.

Larson and Rask. 1992. Changing competitiveness in world soybean markets. Agribusiness 8(1):79-91.

Li, M.H. 2015. Summary of studies on alternative feedstuffs in catfish feeds. Mississippi Agricultural & Forestry Experiment Station Research Report 24(17), Mississippi State University, Mississippi.

Li, M.H. and E.H. Robinson. 2013. Feed ingredients and feeds for channel catfish. Southern Regional Aquaculture Center Publication No. 1806, Southern Regional Aquaculture Center, Mississippi State University, Mississippi.

Li, M. H., E.H. Robinson. 2015. Complete feeds-intensive systems. Pages 111-126 in D.A. Davis (ed.). 2015. Feed and Feeding Practices in Aquaculture. Woodhead Publishing, Oxford, England.

Li, M., F. Barrows, J. Silverstein, and B. Peterson. 2013. Oligosaccharide levels in soy meals don't affect channel catfish performance. Global Aquaculture Advocate Sep./Oct. Issue:64−65.

Li, X. 2009. Estimating the non-commercial-commercial feed gap in China and its impact on future world demand for soybeans. Thesis. University of Illinois at Urbana-Champaign, Urbana, Illinois.

Lim, C. and W. Dominy. 1990. Evaluation of soybean meal as a replacement for marine animal protein in diets for shrimp (Penaeus vannamei). Aquaculture 87 (1): 53−63.

Longmire, J. and A. Morey. 1983. Strong dollar dampens demand for u.s. farm exports. Foreign Agricultural Economic Report FAER-193. Economics Research Service, United States Department of Agriculture, Washington, DC.

Lovell, R.T. 1988. Practical feeding-catfish. Pages 145 to 162 in R.T. Lovell (ed.). 1988. Nutrition and Feeding of Fish, Springer Publishing Company, Boston, Massachusetts.

Marchant, M.A., C. Fang. B. Song. 2002. Issues on adoption, import regulations, and policies for biotech commodities in China with a focus on soybeans. AgBioForum, 5(4):167-174.

Masagounder, K., S. Ramos, I. Reimann, and G. Channarayapatna. 2016. Optimizing nutritional quality of aquafeeds. Pages 239-264 in S.F. Nates (ed.). 2016. Aquafeed Formulation. Academic Press, San Diego, California.

Matthews, J., A. Womack, and R. Hoffman. 1971. Formulation of market forecasts for the U.S. soybean economy with an econometric model. Fats and Oils Situation 260:26-31.

Maxwell, M.J. 2019. U.S. farmers feed the world. Available at: https:///share.america.gov/u-s-famers-feed-world/. Accessed November 28, 2019.

NRC. 2011. Nutrient Requirements of Fish and Shrimp. National Research Council, The National Academies Press, Washington, DC.

Nunes, A. J. P., M.V.C. Sá, C.L. Browdy, and M. Vazquez-Anon. 2014. Practical supplementation of shrimp and fish feeds with crystalline amino acids. Aquaculture 20−27.

Pelletier, N., D. H. Klinger, N. A. Sims, J-R Yoshioka, and J. N. Kittinger. 2018. Nutritional attributes, substitutability, scalability, and environmental intensity of an illustrative subset of current and future protein sources for aquaculture feeds: joint consideration of potential synergies and trade-offs. Environmental Science Technology 52:5532−5544.

Peisker, M. 2001. Manufacturing of soy protein concentrate for animal nutrition. Cahiers Options Mediterraneennes 54:103−107.

Prather, E.E. 1957. Preliminary experiments on winter feeding small fathead minnows. Proceedings of the Southeastern Association of Game and Fish Commissioners 11:249–253.

Reigh, R.C. and M.B. Williams. 2013. Amino acid availability of selected plant products and fish meal for American alligator (Alligator mississippiensis). Aquaculture 412-413:81-87.

Reigh, R.C. and M.B. Williams. 2018. Plant products in compounded diets are effectively utilized by American alligator, Alligator mississippiensis. Journal of the World Aquaculture Society 49(6):1014-1018.

Robinson, E.H and M. H. Li. 1996. A Practical Guide to Nutrition, Feeds, & Feeding of Catfish. Mississippi Agricultural & Forestry Experiment Station Bulletin 1041, Mississippi State University, Mississippi.

Robinson, E.H. and M.H. Li. 2014. Plant-based catfish feeds. Mississippi Agricultural & Forestry Experiment Station Research Report 24(14), Mississippi State University, Mississippi.

Robinson, E.H. and M.H. Li. 2020. Channel catfish, Ictalurus punctatus, nutrition in the United States: A historical perspective. Journal of the World Aquaculture Society DOI: 10.1111/jwas.12657.

Saghaian, S.Y. 2017. Export demand estimation for U.S. corn and soybeans to major Destinations. Theses and Dissertations--Agricultural Economics. University of Kentucky, Lexington, Kentucky, USA. https://uknowledge.uky.edu/agecon_etds/53.

Shamshak, G.L., J. L. Anderson, F. Asche, T. Garlock, and D. C. Love. 2019. U.S. seafood consumption. Journal of the World Aquaculture Society 50(4):715–727.

Shimeno, S., Hosokawa, H., Kunon, M., Masumoto, T., Ukawa, M. 1992a. Inclusion of defatted soybean meal in diet of fingerling yellowtail. Nippon Suisan Gakkaishi 58:1319-1325.

Shimeno, S., Hosokawa, H., Yamane, R., Masumoto, T., Ueno, S-I. 1992b. Change in nutritive value of defatted soybean meal with duration of heating time for young yellowtail. Nippon Suisan Gakkaishi 58:1351-1359.

Shimeno, S., Kumon, M., Ando, H., Ukawa, M. 1993a. The growth performance and body composition of young yellowtail fed with diets containing defatted soybean meal for a long period. Nippon Suisan Gakkaishi 59:821-825, 1993.

Slaper, T.F., M. Kinghorn, and G. Ortuzar. 2015. Beyond the farm: a state and regional report on the economic contribution of farms,forests and related industries. Report prepared for the Indiana Soy Alliance. Indiana Business Research Center, Indiana University. Available at: https://ibrc.kelley.iu.edu/analysis/articles-topic/economic-impact.html. Accessed November 28, 2019.

Stein, H. H., L. L. Berger, J. K. Drackley, G. C. Fahey, Jr., D. C. Hernot, and C. M. Parsons. 2008. Nutritional properties and feeding values of soybeans and their co-products. Pages 613 - 660 in L. Johnson, P.J. White, and R. Galloway (ed.). 2008. Soybeans, Chemistry, Production, Processing, and Utilization. AOCS Press, Urbana Ilinois.

Tacon, A. and M. Metian. 2015. Feed matters: satisfying the feed demand of aquaculture.
Reviews in Fisheries Science & Aquaculture 23(1):1-10.

Taheripour, F. and W. E. Tyner. 2018. Impacts of possible Chinese protection on US soybeans. Global Trade Analysis Project Working Paper No. 83, Purdue University, Indiana.

Tuan, F., C. Fang, and Z. Cao. 2002. Increasing demand for soybeans and soybean products in China (e-Outlook). Washington AgBioForum 5(4):174.

United Soybean Export Council. 2008. Soy protein concentrate for aquaculture feeds. Technical Bulletin, U.S. Soybean Export Council. Available at: USSEC.org/wp-content/ upload/2012/09/Soy-Protein-Concentrate-Aquaculture.pdf. Accessed 5/23/2019.

USDA-NASS. 1998. Census of Aquaculture (1997). National Agricultural Statistics Service, USDA. Retrieved from www.agcensus.usda.gov.

USDA-NASS. 2006. Census of Aquaculture (2005). National Agricultural Statistics Service, USDA. Retrieved from www.agcensus.usda.gov.

USDA-NASS. 2013. Census of Aquaculture (2012). National Agricultural Statistics Service, USDA. Retrieved from www.agcensus.usda.gov.

USDA-NASS. 2019. Census of Aquaculture (2018). National Agricultural Statistics Service, USDA. Retrieved from www.agcensus.usda.gov.
USDA-NASS. 2019. Trout Reports. National Agricultural Statistics Service, USDA. Retrieved from https://downloads.usda.library.cornell.edu/usda-esmis August, 2019.

USSEC. 2019. United States Soybean Export Council. Conversion tables. Retrieved from https: ussec.org/resources/conversion-table June 2019.

van Senten, C. Engle, B. Hudson, and F. Conte. In review. Regulatory costs on Pacific Coast shellfish farms. Aquaculture Economics & Management.

Additional Resources

Alltech. 2014. Alltech global feed survey summary, 8p. Alltech, Nicholasville, Kentucky, USA (2014). Available from http://www.alltech.com/sites/default/files/ alltechglobalfeedsummary2014.pdf.

Amerio, M., D. Vignali, L. Castelli, L. Fiorentinin, and E. Tibaldi, E. 1991. Soybean products in feeds for sea bass. Pp. 1099-1010 in Proceedings of the IX National ASPA Congress, ASA.

Aoki, H., H. Shimazu, T. Fukushige, H. Akano, Y. Yamagata, and T. Watanabe. 1996. Quality in red sea bream fed with diet containing a combination of protein sources as total substitution for fish meal. Bulletin of the Mie Fisheries Research Institute 6:47-54.

Aoki, H., M. Furuichi, K. Watanabe, S. Satoh, Y. Yamagata, and T. Watanabe. 2000. Use of low or non-fish meal diets for red sea bream. Suisanzoshoku 48:65-72.

Blaufuss, P. and J. Trushenski. 2012. Exploring soy-derived alternatives to fish meal: using soy protein concentrate and soy protein isolate in hybrid striped bass feeds. North American Journal of Aquaculture:74(1):8-19.

Brown, P.B., S. Kaushik, and H. Peres. 2008. Protein feedstuffs originating from soybeans. Pages 205-223 in C. Lim, C.S. Lee and C.D. Webster (eds.). 2008. Alternative Protein Sources in Aquaculture Diets. The Haworth Press, Taylor and Francis, Philadelphia, Pennsylvania.

Brown, P.B., B.J. Brown, S. Hart, J. Curry, and A. Hittle-Hutson. 2008. Comparison of soybean-based practical diets containing 32, 36, or 40% crude protein fed to hybrid striped bass in earthen culture ponds. North American Journal of Aquaculture 70:128–131.
Davis, D.A., D. Jirsa, and C.R. Arnold. 1995. Evaluation of soybean proteins as replacements for menhaden fish meal in practical diets for the red drum Sciaenops ocellatus. Journal of the World Aquaculture Society 26:48-58.

Day, O.J., and H.G. Plascencia Gonzalez. 2000. Soybean protein concentrate as a protein source for turbot Scophthalmus maximus L. Aquaculture Nutrition 6:221-228.

El-Sayed, A-FM. 1994. Evaluation of soybean meal, Spirulina meal and chicken offal meal as protein sources for silver seabream (Rhabdosargus sarba) fingerlings. Aquaculture 127:169-176.

Francis, G., H.P.S. Makkar, and K. Becker. 2001. Antinutritional factors present in plant derived alternate fish feed ingredients and their effects in fish. Aquaculture 199:197- 227.

Gentry, R.R., H.E. Froehlich, D. Grimm, P. Kareiva M Parke, M. Rust, S.D. Gaines, and B.S. Halpern. 2017. Mapping the global potential for marine aquaculture. Nature Ecology and Evolution. DOI: 10.1038/s41559-017-0257-9.

Gomes, E., J. Dias, and S.J. Kaushik, S.J. 1997. Improvement of feed intake through supplementation with an attractant mix in European seabass fed plant-protein rich diets. Aquatic Living Resources 10:385-389.
Hardy, R.W. 1995. Current issues in salmonid nutrition. Pages 26-35 in C. Lim and D.J. Sessa (eds.). 1995. Nutrition and Utilization Technology in Aquaculture. AOAC Press, Champaign, USA.

Hardy, R.W. 1999. Alternate protein sources. Feed Management 50:25-28.

Houck, J.P. and J.S. Mann. 1984. Domestic and foreign demand for U.S. soybeans and
soybean products. Technical Bulletin 256. Department of Agricultural Economics, University of Minnesota, Minneapolis, Minnesota.

Kikuchi, K., T. Furuta, and H. Honda. 1994. Utilization of soybean meal as a protein source in the diet of juvenile Japanese flounder (Paralicthys oliveaceus). Suisanzoshoku 42:601-604.

Kissil, G.W., I. Lupatsch, D.A. Higgs, and R.W. Hardy. 2000. Dietary substitution of soy and rapeseed protein concentrates for fish meal, and their effects on growth and nutrient utilization in gilthead seabream Sparus auata L. Aquaculture Research 31:595-601.

Lanari, D., M. Yones, R. Ballestrazzi, and E. D'Agro. 1998. Alternative dietary protein sources (soybean, rapeseed, and potato) in diets for seabream. 8th International Symposium on Nutrition and Feeding in Fish. Las Palmas De Gran Canaria, Spain. p. 145.
Li, M.H. and E.H. Robinson. 2013. Feed ingredients and feeds for channel catfish. Southern Regional Aquaculture Center Publication No. 1806, Mississippi State University, Mississippi.
Liener, I.E. 1994. Implications of anti-nutritional components in soybean foods. Critical Reviews of Food Science and Nutrition 34:31-67.

Lim, C., P.H. Klesius, and W. Dominy. 1998. Soyabean products. International Aqua Feeds 3:17-23.
Lovell, R.T. 1988. Feed formulation and processing. Pages 107-127 in R.T. Lovell (ed.). 1988. Nutrition and Feeding of Fish, Springer Publishing Company, Boston, Massachusetts.

Lovell, R.T. 1988. Fish feeding experiments. Pages 129 to 144 in R.T. Lovell (ed.). 1988. Nutrition and Feeding of Fish, Springer Publishing Company, Boston, Massachusetts.

Lupatsch, I, G.W. Kissil, D. Sklan, and E. Pfeffer, E. 1997. Apparent digestibility coefficients of feed ingredients and their predictability in compound diets for gilthead seabream, Sparus aurata. L. Aquaculture Nutrition 3:81-89.

Lusas, E.W. and K.C. Rhee. 1995. Soybean protein processing and utilization. Pages 117-160 in: D.R. Erickson, (ed.). 1995. Practical Handbook of Soybean Processing and Utilization. AOCS Press, Champaign, Illinois.

McGoogan, B.B., D.M. Gatlin III. 1997. Effects of replacing fish meal with soybean meal in diets for red drum Sciaenops ocellatus and potential for palatability enhancement. Journal of the World Aquaculture Society 28(4):374-385.

Masumoto, T., B. Tamura, and S. Shimeno. 2001. Effects of phytase on bioavailability of phosphorus in soybean meal based diets for Japanese flounder Paralichthys olivaceus. Fisheries Science 67:1075-1080.

Naylor, R.L., R.J. Goldburg, J.H. Primavera, N. Kautsky, M.C.M. Beveridge, J. Clay, C. Folke, J. Lubchenco, H. Mooney, and M. Troell, M. 2000. Effect of aquaculture on world fish supplies. Nature 405:1017-1024.

Nengas, I., M.N. Alexis, and S.J. Davies, S.J. 1996. Partial substitution of fish meal with soybean meal products and derivatives in diets for the gilthead seabream Sparus aurata (L.). Aquaculture Research 27:147-156.

NRC (National Research Council). 1983. Nutrient Requirements of Warmwater Fishes and Shellfishes, Revised Edition. National Academy Press, Washington, USA.

Reigh, R.C. and S. C. Ellis, S.C. 1992. Effects of dietary soybean and fish-protein ratios on growth and body composition of red drum (Sciaenops ocellatus) fed isonitrogenous diets. Aquaculture 104:279-292.

Robaina, L., M.S. Izquierdo, F.J. Moyano, J., Socorro, J.M. Vergara, D. Montero, and H. Fernandez-Palacios. 1995. Soybean and lupin seed meals as protein sources in diets for gilthead seabream (Sparus aurata): nutritional and histological implications. Aquaculture 130:219-233.

Robinson, E.H. and M.H. Li. 2007. Catfish Feeds and Feeding. Mississippi Agricultural & Forestry Experiment Station Bulletin 1163, Mississippi State University, Mississippi.

Robinson, E.H., M. H. Li, and B.B. Manning. 2001. A Practical Guide to Nutrition, Feeds, and Feeding of Catfish. Mississippi Agricultural & Forestry Experiment Station Bulletin 1113, Mississippi State University, Mississippi.

Shiau, S-Y., B.S. Pan, S. Chen, H-L Yu, and S-L Lin. 1988. Successful use of soybean meal with a methionine supplement in diets for milkfish Chanos chanos Forskal. Journal of the World Aquaculture Society 19:14-19.

Shimeno, S., M. Kumon, H. Ando, and M. Ukawa. 1993a. The growth performance and body composition of young yellowtail fed with diets containing defatted soybean meal for a long period. Nippon Suisan Gakkaishi 59:821-825, 1993.
Shimeno, S., T. Mima, T. Imanaga, and K. Tomaru, K. 1993b. Inclusion of combination of defatted soybean meal, meat meal, and corn gluten meal to yellowtail diets. Nippon Suisan Gakkaishi 59:1889-1895.

Shimeno, S., T. Mima, O. Yamamoto, and Y. Ando, Y. 1993c. Effects of fermented defatted soybean meal in diet on the growth, feed conversion, and body composition of juvenile yellowtail. Nippon Suisan Gakkaishi 59:1883-1888.

Shimeno, S., S-I Seki, T. Masumoto, and H. Hosokawa. 1994. Post-feeding changes in digestion and serum constituent in juvenile yellowtail force-fed with raw and heated defatted soybean meals. Nippon Suisan Gakkaishi 60:95-99.

Shimeno, S., H. Hosokawa, T. Masumoto, T. Ruchimat, and S. Kishi, S. 1996. Addition of combined defatted soybean meal, malt protein flour, and meat meal to yellowtail diet. Nippon Suisan Gakkaishi 62:243-247.

Shimeno, S., T. Ruchimat, M. Matsumoto, and M. Ukawa. 1997. Inclusion of full-fat soybean meal in diet for fingerling yellowtail. Nippon Suisan Gakkaishi 63:70-76.

Storebakken, T., S. Refstie, and B. Ruyter. 2000. Soy products as fat and protein sources in fish feeds for intensive aquaculture. Pages 127-170 in J.K. Drackley (ed.). 2000. Soy in Animal Nutrition. Federation of Animal Science Societies, Savoy, Illinois.

Swick, R.A. 2002. Soybean meal quality: assessing the characteristics of a major aquatic feed ingredient. Global Aquaculture Advocate 5:46-49.

Tacon, A.G.J. 1990. Standard methods for the nutrition and feeding of farmed fish and shrimp. Argent Laboratories Press, Redmond, Washington.

Tacon, A.G.J., W.G. Dominy, and G.D. Pruder, G.D. 1998. Global trends and challenges in aquafeeds for marine shrimp. AquaFeed International 4:28-35.

Takagi S., H. Hosokawa, S. Shimeno, M. Maita, M. Ukawa, and S. Ueno. 1999. Utilization of soy protein concentrate in a diet for red sea bream Pagrus major. Suisanzoshoku 47:77-87.

Takagi, S., S. Shimeno, H. Hosokawa, and M. Ukawa. 2001. Effect of lysine and methionine supplementation to a soy protein concentrate diet for red sea bream Pagrus major. Fisheries Science 67:1088-1096.

Tucker, Jr., J.W., W.A. Lellis, G.K. Vermeer, D.E. Roberts, Jr., and P.N. Woodward. 1997. The effects of experimental starter diets with different levels of soybean or menhaden oil on red drum (Sciaenops ocellatus). Aquaculture 149: 323 - 339.

Tulli, F, M. Ramelli, E. Tibaldi, F. Manetti, D. Volpatti, and M. Galeotti. 2000. Feeding seabass (Dicentrarchus labrax) juveniles with soybean products: effects on growth, feed utilization, serological response and non-specific defense. Bollettino Societa Italiana di Patologia Ittica12:3-9.

Tulli, F. and E. Tibaldi. 2001. Apparent nutrient digestibility of different protein sources for sea bass (D. labrax). Pages 697-699 in Recent Progress in Animal Production Science .2. Proceedings of the ASPA ZIV Congress, Florence, Italy, June 12-15, 2001. University of Florence, Italia.

Viyakarn, V., T. Watanabe, H. Aoki, H. Tsuda, H. Sakamoto, N. Okamoto, N. Iso, S. Satoh, and T. Takeuchi. 1992. Use of soybean meal as a substitute for fish meal in a newly developed soft-dry pellet for yellowtail. Nippon Suisan Gakkaishi 58:1991–2000.

Watanabe, T., H. Sakamoto, M. Abiru, and J. Yamashita. 1991. Development of a new type of dry pellet for yellowtail. Nippon Suisan Gakkaishi 57:891–897.

Watanabe, T., V. Viyakarn, H. Kimura, K. Ogawa, N. Okamoto, and N. Iso. 1992 Utilization of soybean meal as a protein source in a newly developed soft-dry pellet for yellowtail. Nippon Suisan Gakkaishi 58:1761–1773.

United Soybeans Export Council. 2008. Soy protein concentrate for aquaculture feeds. USSEC Technical Bulletin GL1008_R1_MSD, U.S. Soybean Export Council, St. Louis, Missouri.

Appendix

Factors That Affect Prices of Soybeans
Soybean prices are affected by a wide variety of factors. Given the importance of soybean production in the U.S., economists have studied the factors that affect soybean prices for many decades, with supply and demand models dating back to 1964 (Houck 1964). These various models developed over time have accounted for the critical drivers of the quantities demanded and supplied that jointly determine farm-level price of soybeans. Typical models account for factors that affect prices of both soybean meal and soy oil. Basic factors that affect soybean prices include: export volumes, quantities of livestock feed (especially hogs, poultry, and cattle) produced in the U.S. and importing countries, livestock prices in the U.S. and in importing countries, U.S. supplies of edible oils, and income in the U.S. and in importing countries (Houck 1964; Ash 1984). The volume of government-owned stocks of soybeans [and corn] also affect prices (Ash 1984). Other studies have shown that prices of soybeans were especially affected by the price of corn, more so than cotton, wheat, or oats (Heady and Rao 1965). Domestic and international prices of competing products, such as other sources of meals (i.e., rapeseed meal) and oils (i.e., sunflowerseed oil) have also been shown to affect soybean prices (Anderson and Garcia 1989). Saghaian (2017) showed that soybean prices were affected by corn prices, exchange rates, and the inventory, or quantity of hogs and poultry on farms, that are major users of feeds of which soybeans is a major ingredient.

Expected Yield of Soybeans
Commodities traders pay close attention to the acreage planted, weather conditions that affect crop yields, and forecasts of expected yields of soybean crops in the major soybean growing areas of the world. Adverse growing conditions in major soybean-growing areas will reduce the overall supply of soybeans in that area and increase prices of soybeans in other growing areas.

Price, Quantity, and Demand for Corn
The quantity of corn production and the price of corn have long been understood to affect the price of soybeans (Heady and Rao 1965; Ash 1984). Corn and soybeans are related in a variety of ways. Corn and soybeans are edible foods, although soybean consumption in the U.S. is very small. The U.S. leads the world in corn production and is followed by China, then Brazil, and the EU. Unlike corn, of which 80% of U.S. production is consumed in the U.S., soybean consumption by humans in the U.S. is low (Saghaian 2017). Both corn and soybeans are major ingredients in livestock feeds around the world. Corn-soybean rotations have been effective cropping systems, given the nitrogen-fixing characteristics of soybeans and that corn requires high levels of nitrogen. Otherwise, both crops use similar production inputs, and thus, are competing choices for use of agricultural crop land.

The growth in demand for biofuel has further increased demand for corn. The use of crops such as corn for production of ethanol as a biofuel and government policies to encourage its use has created additional U.S. demand for corn. The production of corn increased by 13% from 2001 to 2012, largely due to demand for corn-based ethanol, driving prices of other major field crops up (Beckman et al. 2013). Thus, the supply and demand for energy affects the demand for corn (Beckman et al. 2013). Since corn competes for use of row crop land, the effects on soybeans from changes in supply and demand of corn have an even greater effect on soybeans than before the advent of demand for biofuels.

The demand for corn is affected by the price of corn, quantities and prices of other commodities that are substitutes for the use of corn, income levels, and the volume of poultry production in the U.S. (Saghaian 2017). Moreover, Saghaian (2017) showed that corn and soybeans are substitutes for each other such that the price of soybeans is affected by changes in the quantity of corn produced and its price. Other factors that affect the price of corn include: 1) the small percentage of corn produced for export from the U.S.; 2) the variability in Chinese demand for corn (strong one year and weak the next); and 3) the demand for corn-produced ethanol for biofuel.

Quantities of Livestock Production in the U.S. and Internationally
Given that soybeans are a major ingredient in livestock feeds around the world, the demand for soybeans is affected by changes in the volume of livestock (Anderson and Garcia 1989). In other words, as more livestock are raised, the demand for soybeans increases, and as fewer livestock are raised, demand for soybeans decreases.

International Trade and Trade Policies
Soybeans are, of course, the top agricultural commodity exported in bulk from the United States. Thus, international trade clearly affects demand for and price of U.S. soybeans, as demonstrated in Figures 3 to 5. Much of the export demand has been fueled by demand for soybeans from China. However, beginning in April, 2018, sales to the EU have increased. Increased sales to the EU reflect the duties on U.S. soybeans sold to China as well as high prices for soybeans from Brazil, Argentina, and Uruguay. Moreover, anticipated increases in rapeseed production in the EU may reduce EU demand for US soybeans.

China is the world's leading importer of soybeans, and is the largest export market for U.S. soybeans. Much of the increased demand for soybean meal and soy oil in China has been attributed to increased income levels and urbanization (Marchant et al. 2002) as well as from adoption of modern feeding technologies for livestock (Li 2009). Higher incomes in China have resulted in increased demand for animal protein sources such as meat, eggs, and seafood.

The importance of China as a trade partner for U.S. soybeans also means that Chinese trade policies will affect import demand and prices for U.S. soybeans (Taheripour and Tyner. 2018). China began to invest in soybean crushing plants on sites near major port cities in the late 1990s and subsequently imposed a 13% value-added tax on imported soybean meal (Tuan et al. 2002). Thus, the majority of the exports to China are bulk soybeans that are crushed in China for use in animal feed industries (poultry in particular), with soy oil used as a cooking oil. Demand for soy cooking oil has grown as incomes in China have risen (Marchant et al. 2002).

Prior to 2018, there were relatively few Chinese tariffs or other trade restrictions for soybeans. The relative effect of various trade policies depends on the Armington elasticities.

For China, soybean import Armington elasticities tend to be relatively high and result in stronger reactions to price changes (Taheripour and Tyner. 2018). Thus, any tariffs imposed on soybean imports would effectively raise prices and would likely result in a proportionately greater decrease in the quantity of soybeans imported. Taheripour and Tyner (2018) showed that, under certain scenarios, reduced soybean imports by China results in reduced soybean prices everywhere else in the world other than China. Under the scenario of a 30% tariff on soybean exports to China, consumption in the U.S. increased by 7%.

In addition to China, the top importers of U.S. soybeans are, in declining order of importance, the EU, Mexico, Indonesia, and Japan ((Taheripour and Tyner. 2018). Mexico is the greatest importer of soybean meal, and is followed in declining order, by the Philippines, Canada, Colombia, and the Dominican Republic, with another 44% to other countries. In terms of soy oil, Mexico was the greatest, followed by China, the Dominican Republic, South Korea, and Colombia, but "all other" countries imported 34% of U.S.-produced soy oil. Nevertheless, the total volumes exported of soybean meal and soy oil from the U.S. are orders of magnitude less than exports of bulk soybeans.

Soybean production has increased worldwide. Competitor countries in soybean production, such as Brazil and Argentina developed polices to promote export of soybean meal and soy oil rather than bulk soybeans. These policies, in addition to the greater productivity of GMO soybeans, have been attributed to the increased world market share of these countries in terms of soybean supply (Saghaian 2017). U.S. soybean production increased by 56% from 2000 to 2016, while Brazil increased its soybean production by 189% over this same time period, aided by its adoption of GMO soybeans (Taheripour and Tyner 2018). The fastest growth of soybean production has been in Brazil, while it has decreased in China.

The 2018 tariffs imposed on U.S. soybean exports to China have likely triggered increased exports to the EU (Foreign Ag Service 2019). Higher prices for soybeans from Brazil, Argentina, and Uruguay due to drought conditions, have increased attention from EU buyers in the U.S.

Exchange Rates

Exchange rates have been shown to affect the price of soybeans. In the early 1980s, the value of the US dollar increased as compared to currencies of other countries (Longmire and Morey 1983). This resulted in decreased exports of U.S. grains. The opposite occurred in the 1970s when a weakening dollar sparked increased U.S. crop exports. Matthews et al. (1971) estimated that if the value of the dollar decreases by 10%, the price of soybeans would likely rise by $0.24/bushel. Not only do the exchange rates themselves affect the price of soybeans, but uncertainty about exchange rates has been shown to affect supply, demand, and price of soybeans (Anderson and Garcia 1989).