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Genetically Modified Salmon for Dinner? Transgenic Salmon Marketing Scenarios

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Increasing demand for fish must be satisfied sustainably, and genetically modified (GM) fish will probably be part of the solution. This article aims to describe the future trends in the salmon-farming sector and the potential effects of GM salmon introduction on the salmon industry. We have developed a qualitative scenario analysis based on a literature review and expert consultation (n=14). The majority of experts consulted do not believe that GM salmon introduction will be an important technical innovation. Nevertheless, three experts did agree that GM salmon would enter the market in the near future. This would cause new regulations to be introduced, reduce market price, make farmers more dependent on input suppliers, and pose risks to the environment. We used a cross-impact method to create three scenarios: 1) no market for GM fish, 2) GM salmon for dinner, and 3) GM salmon doesn't take off. The article describes the effects on the salmon industry under each scenario.

Key words: genetically modified (GM) salmon, salmon farming, qualitative scenario analysis, expert consultation, growth-enhanced transgenic salmon, cross-impact method, consumer acceptance.

Introduction

Worldwide fish demand is expected to increase dramatically in the coming years due to population growth and increasing disposable income. Fish farming is becoming an increasingly important player in satisfying demand, especially for high-value species. Accordingly, a rapid increase in aquaculture production has been observed (Food and Agriculture Organization of the United Nations [FAO], 2010). Aquaculture is the fastest-growing food industry in the world, and salmon farming is the fastest-growing sector in global aquaculture (McLeod, Grice, Campbell, & Herleth, 2006). This article describes the future trends in the salmon farming sector and the potential effects of genetically modified (GM) salmon introduction on the salmon industry. We have developed a qualitative scenario analysis based on a literature review and expert consultation to conduct this analysis.

Approximately 50 species of fish have been subject to genetic modification, resulting in more than 400 fish/trait combinations (Cowx et al., 2010). Most of the modifications have been carried out on food species, such as Atlantic salmon, tilapia, and common carp. Transgenic fish may offer many advantages for aquaculture, including growth enhancement, improved disease resistance, improved cold tolerance or resistance to freezing, sterility, and altered metabolism to reduce the requirement for fish-based diets in the case of carnivorous fish species (Beardmore & Porter, 2003; Cowx et al., 2010; Maclean, 2003). The biotech company Aqua Bounty Technologies, headquartered in Waltham, Massachusetts (United States), has produced a transgenic Atlantic salmon breed known as AquAdvantage®. The AquAdvantage® salmon is modified using a Chinook salmon growth hormone (GH) gene. In non-GM salmon, GH production decreases during the cold winter months. Using a promoter from an antifreeze gene derived from the ocean pout, the inserted gene is expressed in the cold season. The new promoter thus disrupts the salmon's normal growth cycle. Essentially, the modification works by making the salmon growth cycle continuous rather than seasonal, as is the case in unaltered varieties. As a result, the fish grows to a marketable size within 18 months instead of 3 years. The process does not produce a bigger fish overall.

The feed conversion ratio (FCR)[1] is expected to be more efficient (Clifford, 2009; Entis, 1998). Feed consumption is a critical environmental issue for salmon aquaculture: this issue increases pressure on wild fish stocks and results in the allocation of edible fish to feed

1. *FCR is the amount of body weight gained for every kilogram of feed consumed. Average FCR for salmon farming is about 1.2, meaning that 1.2 kg of feed are needed to produce 1 kg of salmon (Marine Harvest, 2010). This is more efficient than chicken (2.0), pork (3.0), and wild salmon (10.0).*

salmon. Feed consumption is also an economic concern: feed costs are approximately 50-60% of production costs for salmon farmers (Asche, 2008). Thus, GM salmon is expected to provide a sustainable solution both to environmental and economic constraints. Indeed, if each GM salmon substitutes one-for-one for a non-GM farmed salmon, then waste effluent and pressure on wild sources of fish meal and oil would decline because the GM salmon grows faster and requires less feed. However, if GM salmon introduction expands the overall market enough to offset the fish meal and oil input reduction, then the environmental pressure related to wastes and wild stock depletion will intensify because of higher production levels and feed usage (Smith, Asche, Guttormsen, & Wiener, 2010). Improving the salmon FCR is also a critical ethical question because sources of fish meal could be used to improve food security rather than feeding fish (Le Curieux-Belfond, Vandelac, Caron, & Seralini, 2009; Olesen, Myhr, & Rosendal, 2011).

The formal application for AquAdvantage® GM salmon approval, first presented by Aqua Bounty in September 1995, successfully passed the 7-additive step of the Food and Drug Administration (FDA) process (Van Eenennaam & Muir, 2011). To address environmental concerns regarding the risk of escape of transgenic salmon, AquaBounty has incorporated multilevel biological and physical containment measures. The company ensures that all AquAdvantage® salmon will be sterile (triploid) and single sex (female). These measures will guarantee that, in the event of escape into the environment, the AquAdvantage® salmon will be unable to reproduce and establish breeding populations and will be incapable of breeding with native fish populations. Moreover, AquaBounty will grow salmon eggs in Canada and juvenile salmon in Panama in a land-based facility with physical confinement barriers (Van Eenennaam & Muir, 2011; Vazquez Salat & Salter, 2011). The FDA also identified two food safety concerns: the effects of the ingestion of GH fish and allergenicity. The FDA dismissed the former concern but found several limitations with the study design presented by the company to address the latter. Thus, the FDA recommended further allergenicity experiments on AquAdvantage® salmon (Van Eenennaam & Muir, 2011; Vazquez Salat & Salter, 2011).

Despite these concerns, the growth-enhanced GM salmon could become the first genetically engineered food animal approved for human consumption. However, the FDA failed to account for several market issues. The effects of GM salmon introduction on salmon market price, consumption, production costs, public health, etc., are beyond the scope of the FDA assessment. This article aims to bridge these gaps by providing a discussion of these potential market-related issues. The next section provides a description of the method we have applied. Then, we analyze the salmon industry and the main driving forces of GM salmon introduction. We report the results of the expert consultation and provide a narrative description and validation of the three scenarios. Finally, we discuss the results and present some conclusions.

Methodology: Scenario Analysis

Scenarios are internally coherent depictions of possible futures (Mietzner & Reger, 2005). These are based on different assumptions about driving forces and their interactions. A scenario analysis should include both descriptions of different futures and plausible pathways to these futures (Meyer, 2007). Many predictions have been made using this technique in a variety of fields, including food systems (Reilly & Willenbockel, 2010). The distinction between qualitative and quantitative scenario analysis is generally accepted. A qualitative or descriptive scenario is generally used when the time horizon of the analysis is long and few data are available. Usually, it is based on a narrative description of the possible future evolution of the context without quantifying outputs; instead, the description focuses on describing the factors that would influence the outputs (Swart, Raskin, & Robinson, 2004). Quantitative scenarios usually apply a mathematical or statistical model. The simultaneous use of quantitative and qualitative approaches is sometimes the best way to provide a complete analysis while benefiting from the advantages of both approaches. In this study, we applied a qualitative approach using an iterative process of qualitative storyline development. Scenarios can be classified according to their projective, exploratory, and normative aims (Reilly & Willenbockel, 2010). Scenario analysis, as it is applied in this article, differs from scenarios based on statistical simulations of uncertainties; the focus of this study is to gain a better understanding of future uncertainties and trends, not to provide a precise prediction or single-line forecast. The more complex and uncertain is the system analyzed, the more useful is this method in building knowledge about likely future outcomes. This method may help to identify particular issues that deserve attention in policy development (Ingenbleek, Blokhuis, Butterworth, & Keeling, 2011; Shoemaker, 1993).

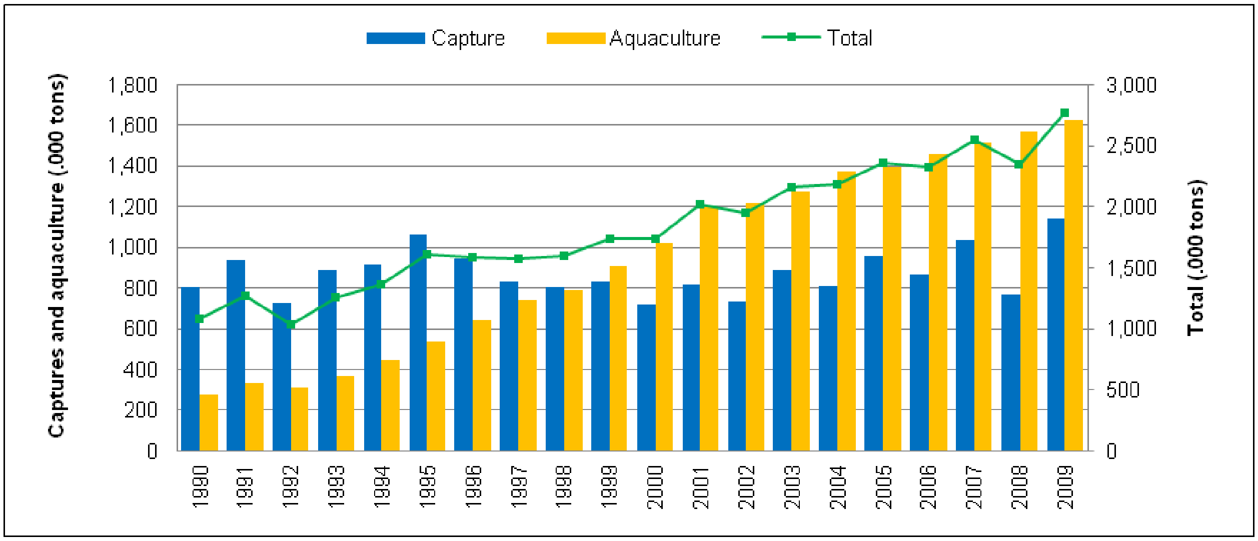

Figure 1. Captures and aquaculture of salmon species.
Source: FAO Fishstat (n.d.)

We used a cross-impact method complemented by an intuitive logic technique to create scenarios (Mietzner & Reger, 2005). This is a method in which the researcher must assess—often with help from experts—the main variables and uncertainties surrounding the sector of interest. The method we have applied includes different steps: after having defined the issue that we aimed to understand, the first step was to provide a detailed description of the current situation (the baseline scenario). The information on the production chain and market were collected through a literature review and web search (including official statistics, such as FAOStat and Eurostat), giving a complete picture of the salmon market. As the second step, potential trends and driving forces (e.g., productivity increases, consumer acceptance, and regulatory framework) which were considered likely to affect or be affected by the introduction of GM salmon were identified. Additionally, we identified the related uncertainties which could potentially have an effect on the marketing of GM salmon.

Next, we conducted personal interview with 14 experts in varying roles related to salmon farming. We used a questionnaire to identify the key variables and trends in the sector for the next 10 years. More specifically, the experts were asked to evaluate each driving force's influence on the future of the farmed-salmon industry. We asked their opinion on statements regarding GM salmon introduction in terms of public, producer, and retailer acceptance; uncertainty; marketing; and external effects (human and animal health, environmental impacts, etc.). For instance, we asked the experts to provide an opinion of the likelihood of GM salmon commercialization in the near future and an evaluation on its effects on producers' costs. The answers were cross-referenced to identify the links between the driving forces and effects—e.g., a high likelihood of commercialization in the near future and a significant reduction in production costs—in order to develop a description of the scenarios considering a time horizon of 10 years. In other words, we have derived consistent clusters of events that were interpreted, described, and validated by the same experts. These clusters resulted in three plausible scenarios. Finally, after we checked the consistency of statements and conditions themselves, the internal plausibility of these scenarios was evaluated by the same experts during a final round of consultation.

The Salmon Farming Industry and the Driving Forces

The Salmon Farming Industry and Markets

Global supply of salmonids increased by approximately 36% between 2002 and 2009, rising from 2.2 million tonnes to approximately 3 million tonnes. The majority of the growth has come from increased farming of Atlantic salmon (Figure 1). Global farmed-salmon production first exceeded the world's total wild salmon catches in 1998. Farmed Atlantic salmon constitutes more than 90% of the farmed-salmon market and more than 50% of the global salmon market (Le Curieux-Belfond et al., 2009). The development of salmon farming depends on many factors, such as market demand and

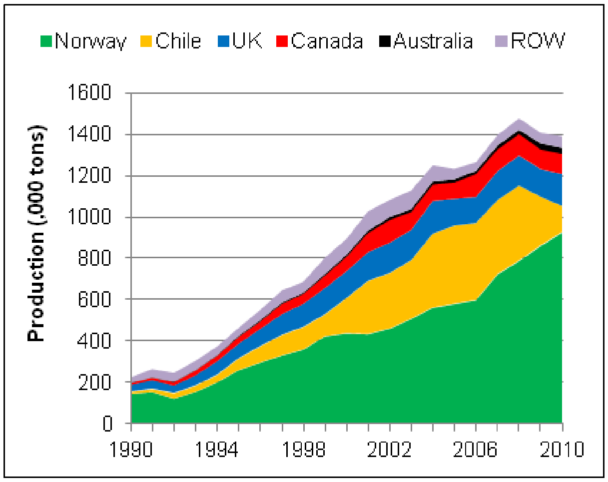

Figure 2. Production of Atlantic salmon in Norway, Chile, UK, Canada, Australia, and rest of the world (thousand tons).
Source: FAO Fishstat (n.d.)

competition, the availability of environmental resources, the development and transfer of appropriate technology, and a favorable business environment that allows entrepreneurs to profit from their investments in the sector (Bostock et al., 2010). The rapid increase in salmon aquaculture was made possible by declining production costs; this was driven by better FCR, development of new fish vaccines, and new farming technologies. Proponents of salmon aquaculture also argue that fish farming is a more reliable and predictable business than exploiting wild salmon capture fisheries. As a larger quantity of salmon has been farmed, there has been a corresponding drop in the price of even high-value products (Asche, 2008; McLeod et al., 2006). Nevertheless, many concerns have been raised about salmon aquaculture, such as environmental pollution, fish welfare, and the use of limited marine resources for producing fish meal and fish oil (Olesen et al., 2011).

The most important salmon producers are Norway (928,000 tonnes produced in 2010), Chile (246,000 tonnes),[2] the United Kingdom (155,000 tonnes), and Canada (101,000 tonnes). These four countries supply more than 90% of world production of farmed salmon (FAO, 2010). Most of this supply is Atlantic salmon, accounting for 1.4 million tonnes per year (Figure 2). The market is becoming more and more globalized. Recently, Norwegian fresh salmon has faced more competition from Chilean frozen salmon on the European market.[3] Additionally, the Japanese market has seen strong competition, largely between Norwegian and Chilean salmon. The increase in exports from Scotland and Norway to the United States due to reduced supply from Chile is another indication of the increasingly global nature of the market (Marine Harvest, 2010). Nonetheless, there will still be home markets for the different production regions because only the frozen salmon can be delivered in large volumes to distant markets; there is no reason to believe that frozen products will outperform fresh products (Bostock et al., 2010).

The increase in world salmon aquaculture and the relative decline in wild-caught fish contributed to the reduced seasonality of fish processing and consumption. These factors also dampened variability in the quality and quantities processed. Technological change in salmon farming, processing. and food retailing has replaced labor with capital equipment as the largest input. This substitution across inputs has increased economies of scale and, in some stages, economies of scope. Retailers, which now sell 60-90% of salmon in many EU countries, have more stringent requirements in terms of timing, regularity, quantity, and quality of deliveries. Finally, while consumers are increasingly demanding fresh fish, they are also seeking out more varieties and processed products. This has led to increased concentration in several stages of production and more vertical integration (Tveteras & Kvaloy, 2004). This concentration process has accelerated quickly in North America and in the United Kingdom; in Norway and Chile, there are more companies with a significant production volume (Marine Harvest, 2010).

World salmon consumption can be divided into five major markets: the EU fresh and frozen market, the Japanese fresh and frozen market, the US fresh and frozen market, canned salmon markets, and other markets. There are significant differences between these markets in terms of their sources of supply, species, and products consumed and short-run market conditions (Knapp, Roheim, & Anderson, 2007). The Japanese fresh and frozen salmon market was once the world's largest market; however, it has declined in relative importance due to falling North American production and exports of

2. *The reduction in Chilean production in 2009 and 2010 (as compared to 2008) was caused by infectious salmon anemia (ISA) disease.*

3. *Chile's production drop in 2009 and 2010 reduced global supply and therefore pushed prices higher. Norway, the largest producer and exporter of salmon, has been the main beneficiary of Chile's production problems, although many Norwegian producers operating in Chile have also been hurt by the ISA outbreak.*

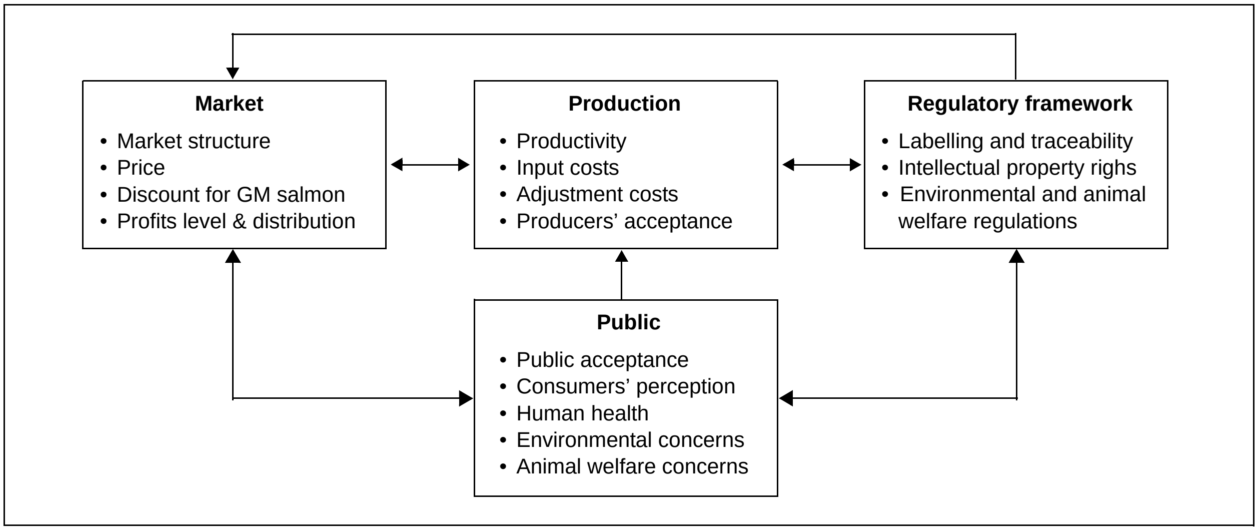

Figure 3. Driving forces framework.

frozen sockeye salmon. The rapidly growing European Union now consumes a slightly larger volume than does Japan. The European market is dominated by the Norwegian and UK salmon industries. Norway accounts for approximately half of all European consumption, while the United Kingdom accounts for approximately one-quarter. American wild salmon accounts for only approximately 4% of total EU consumption. In the EU, more than half of Atlantic salmon was marketed by large-scale retailers in 2010 and 45% by Ho.Re.Ca. (hotels, restaurants, and catering). Almost two-thirds of whole salmon and fillets were sold fresh; the remainder were sold frozen. In the EU, salmon fillets and smoked salmon have equal market shares of 32%, while whole fish has a market share of approximately 19% (Marine Harvest, 2010). The European market for smoked salmon was 125,000 tonnes in 2009; France and Germany were the largest constituent markets with a total market size of 45,000 tonnes between them.

The Driving Forces of GM Salmon Introduction

The data obtained through our extensive literature review allowed us to develop a theoretical framework regarding the driving forces likely to affect or be affected by the development and marketing of GM salmon. We identified four different categories of driving forces connected to transgenic growth-enhanced salmon introduction: production, market, public acceptance, and regulatory framework (Figure 3).

Production of GM salmon is likely to be affected by increased productivity, costs, profits, and producers' acceptance. GM salmons are expected to grow faster than their non-GM counterparts; they reach marketable size in half as much time. The GM salmon exhibit an FCR that is 25% better than to a non-GM salmon (Aerni, 2004; Entis, 1998). These productivity-increasing technical features can have both positive and negative effects on other important market factors. For instance, the introduction of GM salmon results in a very large reduction in average costs for inputs such as feed, medical expenditures, and labor. On the other hand, production of GM salmon may increase other costs related to animal welfare, farm structures, and adjustment to new environmental, traceability, and labeling regulations. The level of profits and the way they are distributed throughout the production chain are variables that will influence producers' acceptance.

The global salmon market will be affected by GM salmon introduction in many different ways. Several argue that the introduction of GM salmon will likely be financially accessible only to medium- or large-scale farmers because of larger building and operating capital requirements. So far, the trend is a progression toward vertical integration of companies along the supply chain (Tveteras & Kvaloy, 2004); the introduction of GM salmon and related regulations might increase the dependence of producers on input suppliers (Beardmore & Porter, 2003) and hasten the process of integration. Changes in market structure may also influence market prices and the distribution of profits along the production chain. From the mid-1980s through the present, growth in production and cost reductions due to gains in productivity were transferred to consumers via lower prices (Asche, 2008). Sharp decreases in salmon prices given an increase in world supply could put some farmers out of business while inducing others to accept the new technology—willingly or unwillingly—for fear of losing out economically (Le Curieux-Belfond et al., 2009). On the other hand, the price discount is the most-cited personal benefit for accepting GM salmon (Bennett, D'Souza, Borisova, & Amarasinghe, 2005; Grunert et al., 2001). The discount required to purchase GM salmon varies between and within countries; for instance, EU consumers generally require higher discount than US counterparts (Chern, Rickertsen, Tsuboi, & Fu, 2002), and older, higher income, non-African American males are more likely to consume GM salmon in the United States (Bennett et al., 2005).

Public acceptance is influenced by environmental and health concerns related to GM salmon, as well as animal welfare issues. However, GM salmon may also help to reduce depletion pressure on wild fish populations; marketing that highlights this benefit may improve public acceptance (Van Eenennaam & Muir, 2011). Several studies have analyzed consumers' perception and acceptance of GM salmon (Chern & Rickertsen, 2004). Acceptance of GM salmon might increase if consumers identify more personal benefits than benefits to the business sector (Qin & Brown, 2006). Human health benefits from improved nutrition (higher n-3 fatty acid intake) may result from higher consumption of fish driven by a lower market price (Lutter & Tucker, 2002). In particular, the price reduction could stimulate fresh (GM) salmon consumption in low-income households susceptible to conditions linked to poor nutrition (Smith et al., 2010), thus, GM salmon consumption may have high marginal benefits to public health.

Should GM salmon have a specific labeling requirement? Although the EU already has specific rules for genetically modified organisms, the US salmon industry requires the FDA to adhere to current rules that prevent specific labeling for GM food. However, as the US consumer has shown higher resistance to the marketing of GM animals than GM plants, the FDA may respond with a set of more restrictive regulations (Vazquez Salat & Salter, 2011). The introduction of labeling and traceability schemes would likely result in higher costs such as personnel, software, and hardware costs (Mora & Menozzi, 2003). Consumers associate with traceability several benefits like health, quality, safety, and control, of which the latter is associated with trust and confidence (Mora & Menozzi, 2008; van Rijswijk, Frewer, Menozzi, & Faioli, 2008). Thus, traceability and labeling schemes would improve market information and public trust. Intellectual property rights legislation regarding licences, trademarks, and copyrights will also affect the costs of entering this market as a producer (Caswell, Fuglie, & Klotz, 2003). This regulatory framework may also influence the distribution of profits throughout the supply chain. The effects of GM salmon escapes on wild stocks have dominated the debate on environmental risk thus far (Cowx et al., 2010; Le Curieux-Belfond et al., 2009). This particular risk can be prevented by biological containment and the development of land-based water recirculating systems. However, these measures will increase building and operating costs; GM salmon's higher productivity level could make these expensive new systems more profitable (Aerni, 2004). There is also an extensive literature base describing the welfare of GM fish, especially fish engineered for accelerated growth (Cowx et al., 2010; Vazquez Salat & Salter, 2011). Animal welfare regulations introduced to address these problems may affect production costs and public acceptance.

Results: The Experts' Interviews

Using the theoretical framework described in Figure 3, we began the second phase of the data collection process, in which we identified a list of key stakeholders to interview. We developed a questionnaire sent to production chain participants and other stakeholders involved in the salmon industry. Their answers, together with information and data recorded through the literature review, were used to define the future trends of the salmon market and the possible effects of GM salmon introduction. The expert consultation was necessary to obtain relevant and more detailed information for the scenario-building process. The list of experts included representatives from large- and small-scale salmon farms, integrated and non-integrated operations, food and other input suppliers, processors, traders, and consulting and research institutes involved in the salmon market.

We contacted 89 experts from companies all over the world. The focus was on heterogeneity rather than homogeneity. The list was derived from web searches, a literature review, and from personal contacts of researchers involved in the project. These experts were contacted via email in July 2010 and received a copy of the questionnaire and a letter providing an explanation of the survey aim (i.e., describing the future scenario of the salmon market). We received 14 answers (response rate of 16%) by email, fax, and telephone interviews. These experts represent vertically integrated transnational companies (3); vertically integrated companies producing organic salmon (2); a farmer producing

Table 1. Main trends of farmed salmon industry.

	Mean	Std. dev.
Increasing demand for fish	4.23***	0.60
Market/sector concentration	3.50	1.09
Food safety regulations	3.50	1.24
Increasing farming yield	3.46	0.88
Increasing pressure on water resources	3.46	1.56
Limit to catch fish, licenses	3.46	1.05
Decreasing production costs	3.42	1.00
Food labeling regulations	3.31	1.03
Increasing sea temperature	2.67	1.07

*Note: All items have been measured on scales from 1 (not important at all) to 5 (very important). One-sample t-test on value 3 ("indifferent"): *** p < 0.001.*

Table 2. Research and development in aquaculture.

	Mean	Std. dev.
Environmental friendly brands	4.43***	0.65
Fish health management techniques	4.43***	0.51
Waste treatment innovations	4.07***	0.83
Breeding programs improvement	4.07***	0.62
Net-pens/cages technical improvement	3.93**	0.92
Marketing channels development	3.79**	0.89
Real time benthic impact monitoring systems	3.64*	1.15
New inventory control technology	3.50	1.02
In-land self-contained rearing systems	3.21	1.31
Fish nutrition improvement	3.14	1.35
GM salmon commercialization	2.15**	1.07

*Note: All items have been measured on scales from 1 (not important at all) to 5 (very important). One-sample t-test on value 3 ("indifferent"): * p < 0.05, ** p < 0.01, *** p < 0.001.*

salmon in land-based facilities (1); a pharmaceutical company specialized in products such as vaccines for aquaculture (1); a center of marine science and research on aquaculture (1); a company providing engineering consultancy services (1); companies delivering technical equipment for hatcheries and grow-out salmon farms (2); companies processing, smoking, and distributing imported salmon in non-producing countries (2); and a company trading processed and fresh salmon in non-producing countries (1). The companies and institutes are located in Norway (5), Chile (2), Scotland (2), Ireland (1), Canada (1), Italy (2), and France (1). In many cases, we contacted the general manager (5) or sales director (3), but we also had responses from chief operating officers (2), technical managers (2), a production manager (1), and a marine scientist (1). The group of experts, although not fully representative, covers a heterogeneous and satisfactory range of stakeholders from different countries. It covers the production and importation of salmon. The experts represent highly skilled and competent participants in the production, marketing, and trading of salmon.

The questionnaire was divided into four parts. We first asked about the most important trends affecting the farmed-salmon industry in the next 10 years. The respondents were required to assess the importance of these items on a Likert scale from 1 to 5 ('not important at all' and 'very important,' respectively), including the option 'don't know/don't wish to disclose.' We asked about the increase in demand for fish, market concentration, production cost trends, and the introduction of new regulations such as licenses, labeling, and food safety. Table 1 shows the results. The answers are quite homogeneous except for the most important factor, i.e., the increasing demand for fish. The only aspect considered unimportant is the increasing sea temperature.

Next, we asked about the importance of the introduction of some technical innovations, including genetic modification (Table 2). Interestingly, the non-GM techniques were the most important according to the expert replies. The most important innovations according to the experts were fish health-management techniques (e.g., new vaccines), branding of environmentally friendly salmon farming, innovative techniques for waste capture, removal and treatment (e.g., ozone treatment), breeding program, and technical improvements. GM salmon marketing was considered the least important. Each technical variable was also interacted with all the trends identified at the beginning of our analysis. This process helps us understand how every single technical innovation influences a specific trend within the sector. Not surprisingly, the experts believed that the introduction of GM salmon in the market would have effects on yields, production costs, and new regulations. They did not think that the other trends would be affected by GM salmon.

The experts, with some exceptions, believed that GM salmon is still a long way from the market (Table 3), although, at the beginning of this round of questions, they were informed about the recent developments of the AquAdvantage® salmon application with the FDA. The experts were doubtful of the acceptance by consumers, producers, and retailers. Consumers' and producers' acceptance is likely to be higher in emerging and developing economies (such as Chile and Eastern Asia), Oce-

Table 3. Agreement on the introduction and public acceptance of GM salmon.

	Mean	Std. dev.
GM salmon will reach the market within 5-10 years	2.07**	1.21
GM salmon will reach the market later than 10 years	2.31*	1.18
GM salmon will never reach the market	3.00	1.28
Consumers will accept worldwide	2.43*	1.09
Consumers will accept in some countries	3.00	1.15
Producers will accept worldwide	2.29*	1.07
Producers will accept in some countries	3.21	0.97
Retailers will accept worldwide	2.29*	0.99
Retailers will accept in some countries	3.43	0.85

*Note: All items have been measured on scales from 1 (completely disagree) to 5 (completely agree). One-sample t-test on value 3 ("indifferent"): * $p < 0.05$, ** $p < 0.01$.*

ania, and the United States. Public acceptance is considered a key driving force in other scenario analyses of biotechnology introduction (Sager, 2001). Three experts out of 14 did agree that GM salmon would enter the market in the near future; these experts were from a company producing organic salmon, a pharmaceutical company producing vaccines, and a company trading salmon in non-producing countries.

Finally, we asked what effects GM salmon could have on key variables (Table 4). There were conflicting answers from the experts; these uncertain results were used for building scenarios. The experts generally agreed that GM salmon introduction would cause new regulations to be introduced within the production chain (e.g., labeling and chain traceability), reduce market price because of decreased farmer costs, and pose risks to the environment. Moreover, the production chain context would likely change. They believed that additional profits would not be equally distributed along the supply chain. They also thought that this innovation would make farmers more dependent on input suppliers, thus increasing the power of upstream stages. Given the power of retailers in the food supply chain, salmon farmers could be constrained by two sides. The experts also speculated that consumer health is more likely to be harmed than improved by GM salmon. Some experts were critical of the effectiveness of GM salmon to alleviate hunger and increase consumer welfare; other species such as tilapia or carp may have more potential to increase the world's animal protein production (Vazquez Salat & Salter, 2011).

Table 4. Possible effects of GM salmon introduction.

If GM salmon will reach the market, ...	Mean	Std. dev.
new regulations will be introduced.	4.31***	0.62
salmon market price will likely decrease.	3.90**	0.88
salmon farmers will be more dependent on input suppliers.	3.64*	0.92
salmon farmers' production costs will likely decrease.	3.30	1.25
the environment will be damaged.	3.45	1.13
consumers' health will be harmed	2.77	1.09
salmon farmers' production costs will likely increase.	2.80	1.23
salmon farmers' profits will likely increase.	2.91	1.14
fish health will improve.	2.73	1.27
fish quality will improve.	2.55	1.29
fish safety will improve.	2.50	1.35
the environment will benefit.	2.46	1.39
consumers' health will improve.	2.45	1.13
profits from GM salmon introduction will be equally distributed.	2.00**	0.78

*Note: All items have been measured on scales from 1 (completely disagree) to 5 (completely agree). One-sample t-test on value 3 ("indifferent"): * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.*

Future Scenarios for GM Salmon and Validation

We applied the cross-impact method complemented by an intuitive logic technique to the information provided by experts to build three different scenarios. For instance, three experts agreed that GM salmon would enter the market in the near future; these answers were combined with other factors (e.g., the evaluations of the effect of GM salmon introduction on producers' costs, new regulations, and consumer health) to derive a description of the scenario forecasting a likely introduction of GM salmon on the market. In general, scenarios must be realistic, internally consistent, and defined in such a way to cover the widest possible range of uncertainty (Lindgren & Bandhold, 2009). The three scenarios were named as 1) 'no market for GM fish,' 2) 'GM salmon for dinner,' and 3) 'GM salmon doesn't take off.' Table 5 provides a summary of the main outcomes for each scenario.

In the first scenario ('no market for GM fish'), transgenic salmon will not be commercialized because of the high environmental risks posed by its production and

Table 5. Main results of GM salmon qualitative scenarios analysis.

	Results	Economic advantages	Economic disadvantages
No market for GM fish	• No market for GM salmon • Other innovations (environmentally friendly) • Premium price for environmentally friendly methods	• Premium price for environmentally friendly farming—profit margins even for small firms • Market segmentation • Lower environmental / economic impact	• Higher private costs for environmentally friendly salmon farming • Slower price decline—lower consumers' benefit • Slower increase omega-3 intake
GM salmon for dinner	• GM salmon produced in Central and South America, Oceania, and Canada; consumed in Asia and United States (10% in 2015, up to 20% of world production in 2020) • Lower market price (-20%) • More profitable for large companies • New regulations	• Lower prices—consumers better off • Increase in omega-3 intake • Increase profits for larger firms (cost reduction) • Fewer escapes (land-based systems)—economic savings • Development of new markets	• Adjustment costs for new regulations • Economic losses for small-scale companies (concentration) • Environmental/economic impact of land-based systems (more energy required) • Environmental/economic impact of trade flows increase
GM salmon doesn't take off	• GM salmon produced in Central and South America and Oceania (5-10% in 2020) consumed in Asia and in the United States • Lower market price (-10%) • Other innovations • Profitable only for large integrated companies • New regulations	• Lower prices—consumers better-off • Increase in omega-3 intake • Profits for larger firms (cost reduction) • Less escapes (land-based systems)—economic savings	• Adjustment costs for new regulations • Market concentration (but less accelerated) • Environmental/economic impact of land-based systems (more energy required)

because of the strong parallel resistance of consumers, retailers, and producers. For this reason, companies will focus their research on other areas (fish health management techniques, reduction of environmental impacts, breeding program improvements, etc.), leading to higher production efficiency and lower costs. Large-scale and highly integrated producers will increase production, causing a further reduction of market prices; thus, the market concentration trend will continue. Price reductions, resulting from increases in productivity, will benefit low-income consumers in both developed and developing countries. There will be a development of marketing programs to brand environmentally friendly farming techniques and other specific salmon quality attributes; this will leave some profitable market niches for small-scale farmers in less-competitive countries, such as the United Kingdom.

In the second scenario ('GM salmon for dinner'), the GM salmon reaches the market in the near future and is produced, accepted, and consumed, especially in certain countries and by certain types of consumers. Specifically, production for US and Asian markets will be primarily Central-Southern American and Canadian, while the Eastern Asian market will be served by Australian production. This will lead to market segmentation both at the international level, between countries, and within countries between different types of consumers. Growing environmental concerns will also stimulate the introduction of other sustainable methods of production, such as offshore farming systems. Market price will decrease because of higher production and cost reductions (improved FCR). At the same time, profits will not be equally distributed along the supply chain; for instance, some farmers (e.g., small-scale non-integrated farmers) may experience economic losses, and producers' dependence on input (eggs/smolts) suppliers will likely increase. Large-scale farmers will be more likely to introduce this technique because of the large associated capital requirements, and the market will become more concentrated. There will be great attention paid to the regulatory framework with the introduction of new regulations (such as traceability and labeling of GM salmon), as well as physical and biological containment of GM fish that will prevent GM salmon escapes.

In the third scenario ('GM salmon doesn't take off'), growth-enhanced transgenic salmon will be produced and commercialized in some countries (Central-Southern American production for the US market and Australia production for the Asian market), but it will encounter strong resistance from consumers and, consequently, of most producers; at the same time, only a few retailers will stock GM salmon on their shelves. However, there will be niches for GM salmon in the US and Asian markets because of the lower price of GM salmon. Other innovations will be preferred and introduced by the salmon-farming industry, such as improved breeding programs, technical improvements in net-pens/cages, and new waste treatment techniques. These innovations will improve farmers' yields and reduce production costs, resulting in a market price decline. There will also be great attention paid to the regulatory framework, especially in some countries (e.g., Australia). The uneven application of this framework will result in the concentration of GM salmon production in those countries where regulations are loosely applied (e.g., Chile).

To evaluate the internal consistency and plausibility of these scenarios, we sent a second questionnaire to the same experts. In this case, the questionnaire was divided into two parts: a short narrative description of the three scenarios and a table indicating the consistency and plausibility of each scenario. All of the experts agreed with the internal consistency of the three scenarios and stated their perceptions of the likelihood of each, as summarized in Figure 4. The graph shows that the "votes" are distributed fairly homogeneously across the three options, and there is no clearly preferred scenario. This final round validates our qualitative analysis; the scenarios we have identified are all feasible, realistic, and consistent with the stakeholders' point of view. Overall, the third scenario ('GM salmon doesn't take off') is considered slightly more likely by the experts. This confirms the sceptical attitude of the experts toward the success of the introduction and marketing of GM salmon.

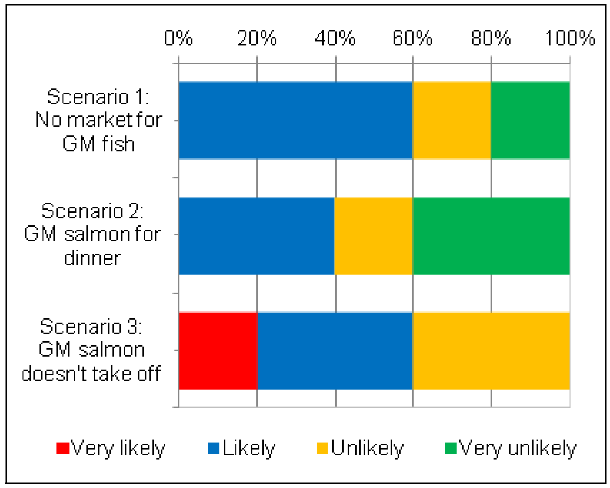

Figure 4. Likelihood of each scenario (% of responses; n=5).

Discussion and Conclusions

The emphasis on exploring several possible future outcomes implies that scenario analysis does not focus on prediction; instead, it presents a range of plausible futures in a coherent narrative fashion for consideration (Reilly & Willenbockel, 2010). In this article, we have presented a qualitative exploratory scenario analysis on trends and drivers of the salmon-farming sector; in particular, we have focused our analysis on the possible marketing of GM salmon.

Increasing demand for fish is considered by the experts to be the most important trend driving the salmon-farming industry in the future. Demand for fish has grown quickly in the past and is expected to continue growing (Bostock et al., 2010); population growth, higher global welfare, penetration of emerging markets and product development will support 6 to 7% annual growth in demand (Aarskog, 2010). Many have argued that this increased demand must be satisfied sustainably and that transgenic salmon will probably be part of the solution (Entis, 1998; Maclean, 2003). However, opinions differ even among the contacted experts (McLeod et al., 2006; Vazquez Salat & Salter, 2011). The majority of experts consulted do not believe that GM salmon introduction will be an important technical innovation; however, three experts out of 14 agreed that GM salmon would enter the market in the near future. This confirms the reluctance of producers to accept the innovation, unless wholesalers (e.g., salmon trading companies), retailers, and consumers signal their willingness to buy such fish (Aerni, 2004).

Other researchers have considered that the commercial availability of GM salmon could drive down the price of farmed salmon. In the past, productivity gains in the salmon industry and related cost reductions have largely been passed on to the consumer (Asche, 2008; Smith et al., 2010). It has also been observed that the ability of the world salmon market to absorb further supply increases without reduction in farm prices may be limited (Xie, Kinnucan, & Myrland, 2009). GM salmon production would likely be financially viable only to medium- or large-scale farmers; they are able to invest in more costly land-based systems and will gain more from the higher productivity associated with making two harvests instead of one. The expected price reduction, especially in the 'GM salmon for dinner' scenario, will solely harm small-scale non-adopters, who will lose out due to the lower prices; we expect them to focus on niche markets (e.g., organic salmon) or to earn lower profits. These developments will result in an increase in the optimal scale of production, thus accelerating the concentration process of the sector (Le Curieux-Belfond et al., 2009). Interestingly, according to the experts, producers' dependence on input (eggs/smolts) suppliers will also increase (as also argued by Beardmore and Porter [2003]), and profits will be distributed unevenly along the supply chain. This pessimistic "future" picture is a possible explanation of experts' actual reluctance to accept this innovation.

The experts also think that consumers are unlikely to accept this product worldwide, whereas consumer willingness to purchase may be higher in some countries (i.e., United States, Eastern Asia). This is consistent with studies showing that European consumers require a higher price discount as compared to US consumers; young consumers in the United States were willing to pay a 53% premium for non-GM salmon over GM salmon, whereas Norwegian students demanded a 67% discount to consume GM salmon (Chern et al., 2002). However, it has recently been shown that Swiss consumers would buy bread made of GM corn even if an analogous organic product is priced identically (Aerni, Scholderer, & Ermen, 2011). Although the price discount is the most-cited personal benefit from accepting GM salmon, other benefits have been reported in the consumer literature, such as environmental benefits (Bennett et al., 2005; Grunert et al., 2001) and health benefits resulting from higher omega-3 intake (Qin & Brown, 2006). Consumers are more likely to accept GM foods if the production process reduces the use of chemicals (Bennett et al., 2005) or uses less feed (Grunert et al., 2001). On the other hand, the risk that GM salmon may disturb wild salmon stocks seems to be of greater concern for Northern European consumers (Grunert et al., 2001).

It is widely recognized that GM salmon, being targeted for higher-value markets—where food security is not a priority—would hardly contribute to reducing world hunger (McLeod et al., 2006). However, by expanding the world market as in the second scenario, GM salmon would likely improve consumers' health (i.e., by reducing the risk of coronary diseases [Lutter & Tucker, 2002]). This improvement would likely reach lower-income households (Smith et al., 2010).

The experts believe that GM salmon is more likely to damage the environment than provide benefits. However, salmon farming is already a source of pollution from waste effluents, diseases, and pressure on wild fish stocks (Olesen et al., 2011; Smith et al., 2010). In this context, GM salmon is often presented as part of the solution for satisfying the increasing demand for fish in developed and developing countries because of its improved FCR and waste reduction. However, this would happen only if GM salmon takes the place of non-GM farmed salmon (Smith et al., 2010), as it is more likely in the 'GM salmon doesn't take off' scenario. If GM salmon contributes to an increase in overall global production that offsets the FCR gains (as in the 'GM salmon for dinner' scenario), then environmental pressure from wastes and wild stock depletion will increase. Other feeding techniques are under development—such as replacing fish oil with plant-based oils—in order to tackle increasing feed needs (Nasopoulou & Zabetakis, 2012).

We used the information gathered from the expert consultation and from the existing literature to build three narratives of exploratory scenarios to cover the widest range of possibilities regarding the introduction of GM salmon. According to the second scenario ('GM salmon for dinner'), GM salmon will soon reach the market, being produced in some specific regions for some specific markets. In all of the scenarios, the reluctance of European consumers to accept GM food—especially GM animal-derived food—will limit marketing in the EU and production development in Norway and the United Kingdom, at least within the time horizon analyzed (10 years). This is consistent with another scenario analysis of aquaculture, arguing that "the widespread adoption of transgenic fish for a single trait such as growth performance, even if it were licensed, would meet with consumer resistance" in the EU (Bostock et al., 2010, p. 2908). In the two other scenarios, 'No market for GM fish,' and 'GM salmon doesn't take off,' GM salmon introduction will be more complicated (or completely banned) because of consumers' and producers' reluctance to buy and produce this fish. In all scenarios, new innovations will be introduced to make salmon farming more sustainable.

The results of this case study provide support for policymakers aiming to regulate GM animals and related food introduction and marketing. They show that GM Atlantic salmon production is not a primary objective of European producers such as Norway, or EU members such as the United Kingdom, although the future production of GM fish is likely to affect the international market. EU consumers, given the salmon imports from third countries not interested in GM innovation (e.g., Norway), will have few opportunities to get GM salmon on their plates in the near future. On the other hand, the increase of the competitive power of Chilean producers (including GM salmon producers) may lead to an increase of Chile's market share within the European Union. Given some EU consumers' acceptance of GM fish at discounted prices, the EU may adopt "strong" legislation on the sale of GM animals, including fish traceability and labeling, to ensure food safety and transparent information on the market. On the other hand, US consumers also express moral and ethical concerns regarding the "unnaturalness" of farming and eating GM fish. This consumer sentiment, together with the reluctance of wild salmon producers and their Congressional delegation in the US House of Representatives to support GM salmon (Van Eenennaam & Muir, 2011), could induce the FDA to introduce a set of more restrictive regulations than those for GM crops, including (GM) fish traceability and labeling measures (Vazquez Salat & Salter, 2011).

The small number of experts interviewed and the qualitative nature of the analysis are two of the main limitations of the current research. Despite these shortcomings, this scenario analysis has provided a consistent and global picture of the likely effects of GM salmon marketing in the future development of the salmon industry. A next step could be the quantification of the results presented in this study using model simulation; for instance, partial equilibrium modelling could be utilized.

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Appendix: Questionnaire Sent to Experts

We would like to ask you to answer some questions about your business. We are a research group at the University of Parma, and we are working on the EU project called Pegasus.

PEGASUS is a support project financed by the 7th Framework Programme FP7, European Commission, DG Research. The general aim of PEGASUS is to provide policy suggestions regarding genetically modified (GM) animals, as well as derivative foods and pharmaceutical products. The results will improve existing social (including public perception), environmental, and economic knowledge regarding GM animals. PEGASUS focuses on existing data, collected through a literature review, desk research, expert interviews, and workshops.

In particular, we ask you either to answer the following questionnaire (which proposes future scenarios in the salmon market) or to inform us as to which representative within your company could best answer these questions.

The data obtained will not be used for commercial purposes and will be analyzed in an anonymous and aggregate way. Your answers will be considered confidential and will not bind your company in any way.

We know your time is valuable, but we need the collaboration of several companies in order to collect this information. The results of this project will be provided in the coming months. For further information and an explanation about the project, please contact us.

Farmed-salmon Production

Salmon farming is the fastest growing sector in world aquaculture; aquaculture, in turn, is the fastest growing food industry in the world. The world production of farmed salmon rose from 280,000 tons in 1990 to 1,500,000 tons in 2007; two-thirds of the world production of salmon comes from farmed species. In particular, farmed Atlantic salmon constitutes more than 90% of the farmed-salmon market and more than 50% of the total global salmon market. According to FAO, the value of global salmon farming was US$7.7 billion in 2008.

What do you think will be the most important factors affecting the farmed-salmon industry in the next 10 years?*

Factors	Not important at all	Not important	Indifferent	Important	Very important	Don't know / don't wish to disclose
Increasing demand for fish						
Increasing farming yield						
Market/sector concentration						
Decreasing production costs						
Increasing pressure on water resources by aquaculture						
Increasing sea temperature						
Limit to catch fish, licenses						
Food labeling regulations						
Food safety regulations						
Others factors						

** In making your ratings, please remember the following points:*

Mark with an X the column that best describes your opinion; for instance, if you think that "Increasing demand for fish" is not an important aspect, mark an X in the second column of that row.

Be sure to answer all items/rows—do not omit any.

Do not mark more than one cell in a single row.

Research and Development (R&D) Priorities

The purpose of these questions is to determine how R&D can improve competitiveness in the salmon-farming industry **in the next 10 years**.

Please indicate how important each R&D item is to your company and/or for the salmon farming industry.*

R&D items	Not important at all	Not important	Indifferent	Important	Very important	Don't know / don't wish to disclose
Breeding programs improvement						
GM salmon commercialization						
Fish nutrition improvement (e.g., alternative feeds introduction, feed with growth hormones)						
Marketing channels development						
Branding of environmentally friendly salmon farming						
Fish health management techniques (e.g., vaccines)						
Waste capture, removal, and treatment innovations (e.g., ozone treatment)						
Net-pens/cages technical improvement (anti-fouling, break resistant, hole alert systems, etc.)						
Real-time benthic impact monitoring systems (chemical indices)						
In-land self-contained rearing systems						
Developing new inventory-control technology (counting devices)						
Other items						

** In making your ratings, please remember the following points:*

Mark with an X the column that best describes your opinion; for instance, if you think that "Breeding programs improvement" is an important aspect, mark an X in the fourth column of that row. Be sure to answer all items/rows—do not omit any. Do not mark more than one cell on a single row.

Please indicate what would be the effect of the introduction of each R&D item for your company and/or for the salmon farming industry.*

R&D items	Yield increase	Production cost reduction	Increase market concentration	Environmental sustainability	New regulations introduction	Fish quality	Fish health	Fish safety	Don't know / don't wish to disclose
Breeding programs improvement									
GM salmon commercialization									
Fish nutrition improvement									
Marketing channels development									
Branding of environmentally friendly salmon farming									
Fish health-management techniques									
Waste capture, removal, & treatment innovations									
Net-pens/cages technical improvement									
Real-time benthic impact monitoring systems									
In-land self-contained rearing systems									
New & better inventory control technology									
Other items									

** In making your ratings, please remember the following points:*

Mark with an X the column that best describes your opinion; for instance, if you think that "Breeding programs improvement" have an effect on "Yield increase," mark an X in the first column of that row.

Multiple answers per row are allowed: for instance, if you think that "Breeding programs improvement" have an effect on both "Yield increase" and "Environmental sustainability," you should mark an X in the first AND fourth columns of that row.

Be sure to answer all items/rows—do not omit any.

Genetically Modified Salmon

The biotech company AquaBounty Technologies, headquartered in Waltham, Massachusetts (US) produced a transgenic Atlantic salmon breed, known as AquAdvantage®, modified using a Chinook salmon growth hormone (GH) gene. In non-modified salmon, growth hormone production is decreased during the cold winter months. Using a promoter from an antifreeze gene, the inserted gene is also expressed in the cold season, thus **causing the fish to grow to a marketable size within 18 months instead of 3 years** (the process does not actually produce a bigger fish). Also, feed conversion rates (FCR) become more efficient (+25% according to the company).

Some unintended side-effects of the modifications may become apparent if the GM salmon were to escape into the wild (e.g., increased ability to compete for food with wild salmon, etc.). For this reason, the company stated that they will only sell **sterile AquAdvantage® salmon** to growers who raise them in **secure confined systems** (e.g., land-based systems of breeding).

AquaBounty Technologies first applied to the US Food and Drug Administration (FDA) in 1999 to release a transgenic Atlantic salmon for commercial use. **Last month, AquaBounty received the approval of five of the seven steps foreseen by FDA**. To finish the FDA process, AquAdvantage® Salmon must pass two more steps **referred to the food/feed safety and environmental safety assessments**.

We would like to know your opinion about this issue; please answer the questions below by marking with an X the answer that best describe your opinion. Please be sure to answer all items in each row—do not omit any.

To what level do you agree/disagree with the following statements about GM salmon introduction?

Statement	Completely disagree	Disagree	Indifferent	Agree	Completely agree	Don't know / don't wish to disclose
GM salmon will be commercialized in the near future (within 5-10 yrs).						
GM salmon will be commercialized in the future (more than 10 years).						
GM salmon will never be commercialized.						

To what level do you agree/disagree with the following statements about the public acceptance of the GM salmon?

Statement	Completely disagree	Disagree	Indifferent	Agree	Completely agree	Don't know / don't wish to disclose
Consumers will accept this GM salmon worldwide.						
Consumers will accept this GM salmon only in some countries.						

Please indicate where you believe consumers' acceptance of GM salmon will be higher. [space for write-in answer]

To what level do you agree/disagree with the following statements about GM salmon producers?

Statement	Completely disagree	Disagree	Indifferent	Agree	Completely agree	Don't know / don't wish to disclose
Producers (farmers) will accept this GM salmon worldwide.						
Producers will accept this GM salmon only in some countries.						

Please indicate where you believe producers' acceptance of GM salmon will be higher. [space for write-in answer]

To what level do you agree/disagree with the following statements about GM salmon producers?

Statement	Completely disagree	Disagree	Indifferent	Agree	Completely agree	Don't know / don't wish to disclose
Retailers will accept this GM salmon worldwide.						
Retailers will accept this GM salmon only in some countries.						

Please indicate where you believe retailers' acceptance for GM salmon will be higher. [space for write-in answer]

If AquaBounty's request is accepted and AquAdvantage® salmon reaches the market, …

Statement	Completely disagree	Disagree	Indifferent	Agree	Completely agree	Don't know / don't wish to disclose
…salmon farmers' production costs will likely decrease (better feed conversion).						
…salmon farmers' production costs will likely increase (land-based systems breeding).						
…salmon farmers' profits will likely increase.						
…profits from GM salmon introduction will be equally distributed along the supply chain.						
…salmon farmers will be more dependent on input suppliers.						
…salmon market price will likely decrease.						
…consumers' health will improve because of higher fish consumption.						
…consumers' health will be harmed (e.g., allergy, toxicity risks, etc.).						
…new regulations will be introduced (e.g., labeling, traceability, etc.).						
…the environment will benefit (e.g., less use of fish feed).						
…the environment will be damaged (e.g., possible non-sterile GM salmon escapes).						
…fish quality will improve.						
…fish health will improve.						
…fish safety will improve.						

Finally, if you could have the possibility to suggest any policy advice, what would you suggest? [space for write-in answer]

Any other comments? [space for write-in answer]