# Whither Aquaculture R&D?

## Results from a Delphi study

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**Abstract**

In the summer of the year 2008 a worldwide online Delphi study on the future of R&D in aquaculture was conducted. The Delphi method is widely used to survey experts on the anticipated developments within a specific domain. We employ this method to ascertain the likely future directions of aquaculture research in developed, high-income countries. For the convenience of our respondents we conducted the survey on the web.
Results of the survey show that aquaculture experts agree that aquaculture research in general has made substantial achievements and will continue to make even more achievements in the future and also aquaculture research achievements will have very large impact on the productivity of the aquaculture farm as well as on the quality of fish produced in aquaculture systems. This paper presents the first descriptive results of the Delphi study.

### 1 Summary

In the summer of the year 2008 a worldwide online Delphi study on the future of aquaculture research was conducted. The purpose of the project was to contribute towards focussing better the nascent aquaculture research program of the Faculty of Agriculture and Nutritional Science of the University at Kiel. The study was conducted by the Department of Agricultural Economics (Prof. Dr. Mueller) and the Department of Animal Breeding and Husbandry (Prof. Dr. Schulz) of the University at Kiel in Germany.
The Delphi method is widely used to survey experts on the anticipated developments within a specific domain, such as aquaculture. We employ this method to ascertain the likely future directions of aquaculture research in developed, high-income countries. This study comprises three survey rounds. Goal of the initial round was to assess the current situation and anticipated future developments of research in aquaculture in the long run (until the year 2020), as seen by aquaculture experts. The second and third round focussed on finding consensus on specific fields as well as to discuss fields identified as promising for R&D investments in more detail. Our study focuses on aquaculture of finfish in advanced economies. This study was not concerned with other species than fish, such as crustaceans, molluscs, aquatic plants, etc. and it does not focus on countries and regions that are less advanced, such as China and Africa.
For the convenience of our respondents we conducted the survey on the web. For the first round of the survey 1,298 experts were reached. After the invitational email and two reminder emails, 272 (21 percent) aquaculture researchers participated in the first round. This is very

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high compared to other online surveys, where literature reports response rates as low as below one percent. The aquaculture experts participating in the survey were between 26 and 78 years old, their average age was 48 years. The vast majority of aquaculture experts hold a PhD title (73 percent). Aquaculture experts participating in the survey have an average of 19 years of experience in aquaculture. Nearly half of the respondents are employed by Universities, while nearly every fifth respondent works for a governmental agency. Most of the respondents are Professors or senior researchers and focus on applied or basic research. The respondents currently live in all parts of the world, most in Europe, USA/Canada, Norway and the United Kingdom.

Results of the survey show that aquaculture experts agree that aquaculture research in general has made substantial achievements and will continue to make even more achievements in the future and also aquaculture research achievements will have very large impact on the productivity of the aquaculture farm as well as on the quality of fish produced in aquaculture systems.

Fish nutrition was identified as the research area with the highest research achievements up to the time the study was conducted, while fish health and fish nutrition are the areas that experts anticipate to produce most research achievements until the year 2020. These two research areas were also identified to have the greatest impact on the quality of fish produced from aquaculture.

Aquaculture experts participating in the survey identified organic aquaculture as the research field having produced least results up to the time the study was conducted. Also,most experts agreed to the statement that organic aquaculture is generally overrated, still they think investments into organic aquaculture research will become considerably higher.

Norway was clearly identified as the current and future leading aquaculture research nation, while Taiwan, Spain and the USA are expected to become very much stronger until the year 2020. Among advanced economies, Germany and Italy were rated lowest for their general aquaculture research achievements and experts predict these nations to remain in the low position until the year 2020.

While the European Seabass and the Gilthead Seabream were identified as most promising for developing an aquaculture breeding program, aquaculture experts predict that the field "marker based selective breeding" will develop to produce most research achievements within the research area "breeding and reproduction".

Recirculating aquaculture systems were clearly identified as the most promising production system for investing research money. When conducting research on recirculating systems, aquaculture experts predict that research on energy efficiency, nutrient discharge, biological clarification systems as well as monitoring and controlling systems will produce most research achievements. In the section "fish husbandry and water management", research on IMTA (integrated multitrophic aquaculture) and research on the environmental impacts of aquaculture were named as further promising research areas for the investment of aquaculture research money.

Within the research area "fish health", the area that –in general- was predicted to produce most promising research achievements by the year 2020, "developing therapeutics and

vaccines", "disease gene mapping" and "early identification systems" were rated to be most promising research areas for investing R&D money.
Within the area "fish nutrition", research on the feed conversion ratio was rated highest for its past achievements, but aquaculture experts agree that research on finding fish meal and fish oil alternatives will develop to produce most research achievements by the year 2020. When finding alternative feed resources, vegetable resources and its derivates were rated to be most successful by the year 2020, research on leguminous plants being most important for finding fish meal alternatives, research on oleiferous fruits being most important for finding fish oil alternatives. The vast majority (82 percent) of aquaculture experts participating in the Delphi survey thinks, it will be possible to achieve Feed Conversion Ratios (FCRs) below one when feeding carnivorous species. Three quarters of which think that FCRs smaller than one will be reached by the year 2015.
Even though there is dissent among aquaculture experts surveyed about the current achievements of aquaculture fish marketing and quality management research, there is consensus that research within this area will substantially increase. Here research on traceability and supply chain management and research on the socioeconomic impacts of aquaculture are predicted to produce most research achievements.

# 2 Survey design

The survey was conducted as an online Delphi study with three survey rounds in the time between May and November 2008. The participants received feedback about the results of the previous rounds in form of frequency counts which were printed in the subsequent questionnaires. Only questions were consensus criteria suggested dissent among respondents were reasked.

## 2.1 The Delphi method

The Delphi method was developed in the 1950ies by the Rand Corporation in the USA. Its name comes from the oracle of Delphi, which was asked before all important political decisions in ancient Greece. It is a group survey in written form. It was developed to make better use of expert judgements. The Delphi method was first made known by the publications of Dalkey and Helmer [1963]. From the United States, the use of the Delphi method then spread to Europe. A detailed presentation of the method can be found in Seeger [1979] and Woudenberg [1991]. A general definition of the method can be found in Linstone and Turoff [1975, page 3]: "Delphi may be characterized as a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem." The Delphi method is a well recognized instrument for long term prognosis of technological evolution and futures research and has found application in planning, decision making, and policy research. A discussion of the Delphi method as well as an overview over its various implementations can be found in Linstone and Turoff [1975] and Woudenberg [1991]. Participants are carefully chosen for their expertise in

aspect of the problem studied and are promised anonymity with respect to their answer. In general, Delphi studies involve feedback of information from one round to the next.
The process tends to move the group's responses towards consensus, although reaching consensus is not necessarily the central object of a Delphi study. It also produces a set of reasons behind the responses. The value of the Delphi method results from the ideas it generates, the arguments for the extreme positions also represent a useful product. Areas where dissent remains over several research rounds indicate that these fields need to be discussed in further detail.
Within Delphi studies, the criteria used for measuring consensus differ, they have in common though, that they are related to measures of statistical dispersion, such as the variance, the standard deviation, the median or quartiles. The consensus criteria are usually defined individually for a Delphi study, depending on the research goal, the participating experts and the data collected. As criteria for measuring consensus we used the standard deviation and the coefficient of variation. In our study experts were asked to rate various aquaculture research fields on five point lickert scales. Therefore we chose a standarddeviation of below one in combination with a coefficient of variation below 0.3 as criteria for consensus having been found among aquaculture experts. The coefficient of variation is defined as the ratio of the standard deviation to the mean.

## 2.2 Online implementation of the method

For the convenience of our respondents, we used an online survey tool to conduct the Delphi study. This survey tool was identified in a prestudy, in which we compared various online survey software by their functionality to be used in a Delphi study. The tool "EFSsurvey" by Unipark (see www.unipark.de) was identified as best suited for a Delphi study. The lean content management system of EFSsurvey made possible the fast html implementation of the aquaculture questionnaires.
The EFSsurvey content management system allowed the administration of the survey participants as well as the overview over and management of responses. Using this tool, aquaculture experts received an initial invitational mail to each round of the survey, those participants that had not answered the questionnaire within a specific time, received reminder emails. In each survey round, two reminder emails were sent. The aquaculture experts then participated in the survey by following the link in their invitational or reminder email.

## 2.3 The questions

The questions for this three round online Delphi survey were an excerpt of the research fields identified in a prestudy. The results of this prestudy are available as a working paper [Guettler 2008]. The prestudy identified, that past and current aquaculture research could be categorized into these five major research fields:

1. Fish breeding and reproduction
2. Fish husbandry and water management
3. Fish health

4. Fish nutrition
5. Marketing and quality management

From this prestudy, a set of questions to be asked in the survey were formulated and these questions were then discussed with well reckoned experts within these research fields. These personal interviews took place in May and June 2008. The experts received an interview guideline containing the potential questions to be asked in the survey as well as specific topics to be discussed with the expert in advance to the interview. In these interviews, the individual research areas as well as the questions to be asked in the survey were discussed in detail, identifying relevant research areas and consolidating the questions to ask in the survey.

### 2.4 Survey participants and response rates

Survey participants were identified from various sources, primary source was a bibliometric database, whose data was gathered in the frame of the PhD Thesis "Networks in International Aquaculture Research: a Bibliometric Analysis" [Seidel-Lass, 2009]. These data were enhanced by various other data sources, resulting in 1,486 names of aquaculture experts as potential survey participants. By searching the web and the use of personal and organizational networks, email addresses for 1,407 aquaculture experts were found. For 79 aquaculture experts it was not possible to find an email contact at all. Then, for the first round of the survey 1,407 potential aquaculture researchers were invited per email to participate in the first round of the Delphi survey. 1,298 experts were finally reached, because for 109 experts no valid email addresses could be found (delivery failures). After the invitational email and two reminder emails, 272 (21 percent) aquaculture researchers participated in the first round of which 12 answered only the general questions on the first page. Additionally we received 95 emails from researchers we invited to participate, stating that the people we invited are no real aquaculture experts. This calculates to a total response rate of 28 percent. This is very high compared to other online surveys, where literature reports response rates are as low as below one percent. We contribute this to the importance of the research field aquaculture.

## 3 Results

According to the research areas identified and summarized in the above mentioned project part and related working paper [Guettler, 2008] and further narrowed through expert interviews, the questionnaire of the first round comprised 45 questions which were organized into the following sections:

1. General questions
2. Fish breeding and reproduction
3. Fish husbandry and water management
4. Fish health
5. Fish nutrition
6. Marketing and quality management

7. About the respondents

The questionnaire of the second round was much shorter, comprising only 14 questions, while the third round questionnaire contained 10 questions. The following sections present the descriptive results of all three rounds of the Delphi study.

## 3.1 General questions

A set of general questions that were identified as being of interest in the prestudy were asked at the beginning of the survey.
In the first round of the survey there was consensus among aquaculture experts about the past and current achievements in aquaculture research in general; three quarters of the respondents thinking that it has made substantial or even very substantial achievement until the year 2008. While there was dissent among experts concerning the development of achievements until the year 2020. Therefore this part of the question was reasked in the second round of the survey (see Figure 1). Figure 1 also shows an example of how the results of the previous rounds of the survey were presented to the aquaculture experts participating in the survey.

Figure 1: Question 1 in survey round 2

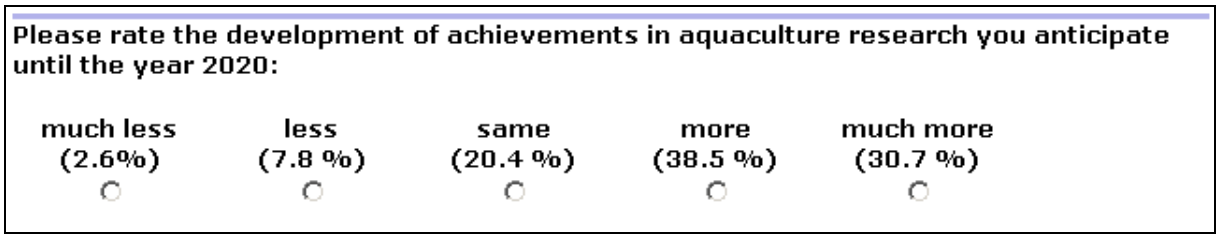
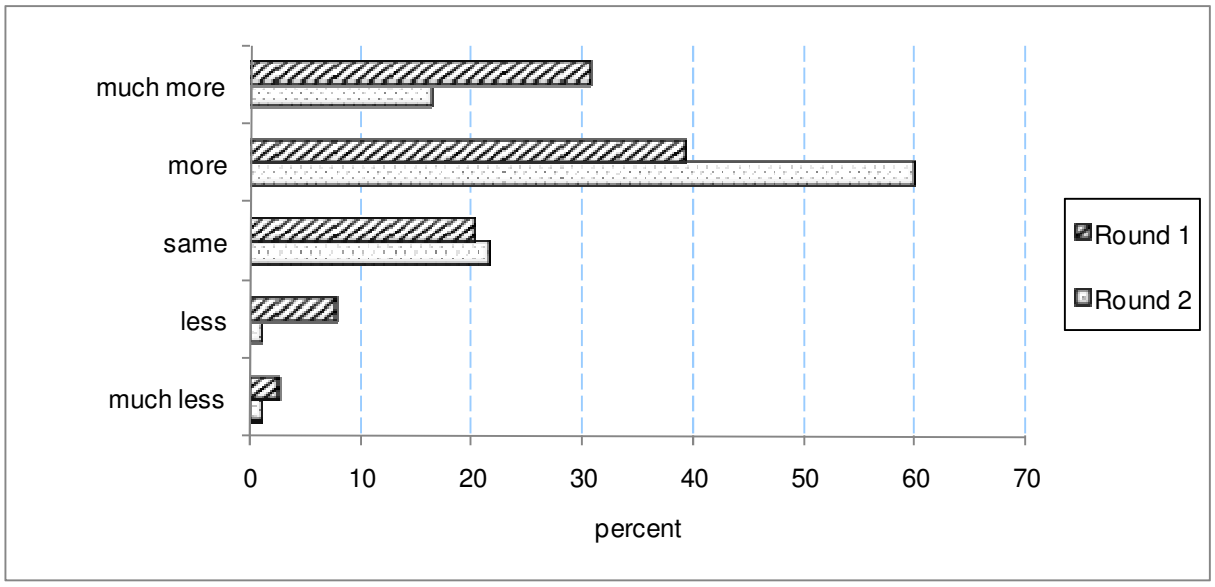



Figure 2: Rating of overall aquaculture R&D achievements in rounds 1 and 2 (n=272)




In the second round there was consensus among aquaculture experts participating in the survey that aquaculture research in general will develop to make more achievements by the year 2020 (see Figure 2).

### 3.1.1 R&D impact

Three out of every four (75.6 percent) aquaculture researchers participating in the survey believe that aquaculture research will have large or very large impact on the aquaculture farm productivity. Nearly all (98.0 percent) survey participants believe it will have at least some impact on farm productivity. Aquaculture experts also think that aquaculture research will have substantial impact on fish quality and on the general methodological improvements.

### 3.1.2 Achievements by research areas

The respondents were asked to rate selected aquaculture research areas by their past and current research achievements. For past and current research achievements the area “Fish nutrition” was rated highest by the respondents, followed by “Breeding” and “Reproduction”, “Fish husbandry” and “Fish health”. The most future research achievements are anticipated to be in the area “Fish health”, followed by “Fish nutrition”, “Quality management” and “Water management”. Research achievements in the past and current were averagely rated between “some” and “substantial”, while future achievements are anticipated to be “more” than current. There was no consensus in the rating of areas "Fish marketing" and "Organic aquaculture" in the first round, therefore these sections were reasked in the second round where there then was consensus at fairly lower scores compared to the first round.

Table 1: Average scores of expert rating of past and current achievements as well as future development of aquaculture research by areas (n=272)

| | Average score | | Rank | Rank |
|---|---|---|---|---|
| Research area | Past and current* | Development until 2020** | past and current | 2020 |
| Fish nutrition | 2.51 | 3.87 | 1 | 2 |
| Breeding | 3.75 | 3.59 | 2 | 7 |
| Reproduction | 3.71 | 4.06 | 3 | 8 |
| Fish husbandry | 3.58 | 3.93 | 4 | 9 |
| Fish health | 3.00 | 3.81 | 5 | 1 |
| Water management | 3.22 | 3.93 | 6 | 4 |
| Quality management | 0.00 | 0.00 | 7 | 3 |
| Fish marketing | 0.00 | 0.00 | 8 | 6 |
| Organic aquaculture | 0.00 | 0.00 | 9 | 5 |

* scale from 1 = poor to 5 = very substantial

** scale from 1 = much less to 5 = much more

### 3.1.3 Fish quality

Aquaculture experts came to the consensus that fish nutrition, fish health, as well as quality and water management are the most important factors influencing fish quality and that research within these areas will be very important until the year 2020 (see Table 2).

Table 2: Importance of research areas towards increasing fish quality by 2020 (n=272)

| Research area | Average score* |
|---|---|
| Fish nutrition | 4.55 |
| Fish health | 4.40 |
| Quality management | 4.31 |
| Water management | 4.17 |
| Fish husbandry | 3.97 |
| Breeding | 3.83 |
| Organic aquaculture | 3.57 |
| Reproduction | 3.39 |

* scale from 1 = not important to 5 = very important

### 3.1.4 Advanced economies and their current strength in aquaculture R&D

Norway was by far rated as the current and future leading aquaculture research nation. Taiwan, Spain and USA are expected to become very much stronger in aquaculture research. Germany and Italy are expected to stay in lower positions (see Table 3). Interestingly, the mean ratings of the future development of the nations' strengths in aquaculture research lie very much closer together than the average ratings of current strengths.

Table 3: Advanced economies and their current strength in aquaculture R&D (n=272)

| Country | Mean current strength* | Anticipated future strength** | Rank current | Rank future |
|---|---|---|---|---|
| Norway | 4.64 | 3.75 | 1 | 1 |
| Israel | 3.68 | 3.55 | 2 | 6 |
| United Kingdom | 3.63 | 3.39 | 3 | 9 |
| Canada | 3.57 | 3.56 | 4 | 5 |
| USA | 3.50 | 3.58 | 5 | 3 |
| France | 3.45 | 3.40 | 6 | 8 |
| Taiwan | 3.43 | 3.70 | 7 | 2 |
| Denmark | 3.34 | 3.33 | 8 | 11 |
| Spain | 3.28 | 3.58 | 9 | 3 |
| The Netherlands | 3.26 | 3.35 | 10 | 10 |
| Greece | 2.92 | 3.46 | 11 | 7 |
| Germany | 2.76 | 3.31 | 12 | 12 |
| Italy | 2.74 | 3.27 | 13 | 13 |

* scale from 1 = very weak to 5 = very strong

**scale from 1 = much less to 5 = much more

## 3.2 Fish breeding and reproduction

There was consensus among almost all (98%) aquaculture experts that developing breeding programs comparable to breeding programs in livestock production for fish species would be

"useful" or "very useful". The aquaculture experts were then asked to rate how promising they think the development of breeding programs for particular species would be.
This question was asked over all three survey rounds, adding most often named additional fish species to the questionnaire for rating. Over all three survey rounds "European Seabass", "Gilthead Seabream" and "Turbot" were rated highest (see Table 4).

Table 4: Average rating over all three survey rounds of fish species for developing aquaculture breeding programs

| Fish species | Average rating |
|---|---|
| European Seabass *(Dicentrarchus labrax)* | 4.10 |
| Gilthead seabream *(Sparus aurata)* | 4.05 |
| Turbot *(Psetta maxima)* | 3.95 |
| Cod *(Gadus morhua)* | 3.82 |
| Tilapia *(Oreochromis sp.)* | 3.74 |
| Cobia *(Rachycentron canadum)* | 3.70 |
| Sturgeon *(Acipenseridae)* | 3.56 |
| Rainbow trout *(Oncorhynchus mykiss)* | 3.55 |
| Tuna *(Thunnus Thynnus)* | 3.48 |
| Pangasius *(Pangasianodon hypophthalmus)* | 3.39 |

* scale from 1 = not promising to 5 = very promising

Table 5: Achievements in aquaculture fish breeding and reproduction by research areas (n=166)

| Research area | Average score | | Rank past and current | Rank 2020 |
|---|---|---|---|---|
| | Past and current* | Development until 2020** | | |
| Conventional selective breeding | 3.73 | 3.63 | 1 | 2 |
| Chromosomeset and sex manipulation | 3.16 | 3.56 | 2 | 3 |
| Crossbreeding | 2.98 | 3.19 | 3 | 5 |
| Marker based selective breeding | 2.93 | 4.28 | 4 | 1 |
| Hybridization | 2.90 | 3.15 | 5 | 6 |
| Transgenesis | 2.32 | 3.32 | 6 | 4 |

* scale from 1 = poor to 5 = very substantial
** scale from 1 = much less to 5 = much more

When rating research achievements within fish breeding and reproduction by research areas, there was consensus among aquaculture experts participating in the survey that achievements within the research area "Conventional selective breeding" were most substantial (see Table 5).

## 3.3 Fish husbandry and water management

Aquaculture experts agree that research expenditures on recirculating systems will increase most substantially, followed by research investments into cage systems. The majority of aquaculture experts participating in the survey think research investments into pond and flow-through systems will stay the same (see Table 6).

Table 6: Average rating of research expenditures by aquaculture systems in survey round 1 and 2

| Aquaculture systems | Average scores* | |
|---|---|---|
| | Round 1 | Round 2 |
| Recirculating systems | 4.45 | 4.57 |
| Cage systems | 3.86 | 3.84 |
| Flow through systems | 3.03 | 2.99 |
| Pond systems | 2.94 | 2.97 |
| n | 197 | 175 |

* scale from 1 = will decrease to 5 = very large increase

Table 7: Rating of research areas on recirculating systems aquaculture (n=138)

| Research area | Mean score* |
|---|---|
| Energy efficiency | 4.26 |
| Nutrient discharge | 4.21 |
| Biological clarification systems | 4.19 |
| Monitoring and controlling systems | 4.08 |
| Impacts of interactions of all research areas | 4.01 |
| Feeding strategies | 4.00 |
| Gassing and degassing systems | 3.89 |
| Feeding techniques | 3.77 |
| Water desinfection | 3.62 |
| Mechanical clarification systems | 3.59 |
| Hydraulic management | 3.56 |
| Stocking rate | 3.39 |
| Material of fish rearing unit | 2.76 |
| Shape of fish rearing unit | 2.76 |

* scale from 1 = not promising to 5 = very promising

Since results of the first two rounds showed that aquaculture experts agree on the importance of research of recirculating systems, we decided to ask a question further differentiating research on recirculting systems.

By far, aquaculture experts participating in the survey rated "Energy efficiency", "Nutrient discharge" and "Biological clarification systems" as most promising research areas (see Table 7). Interestingly the consensus was stronger the higher the rating of research area.

R&D expenditures on research on the material and shape of the fish rearing unit were clearly rated lowest with an average score of 2.76, lying between "little" and "some potential".

In the first round of the survey aquaculture experts were asked: "In which other areas do you expect to receive considerable attention and funding on research and development over the next 12 years?" Here IMTA (Integrated Multitrophic Aquaculture) as well as the environmental impact of aquaculture were named most often. Therefore two new questions were integrated in the second round of the survey.
The first question asked was “How promising the experts think research investments into research on IMTA would be?”. The experts were asked to rate IMTA research investments from 1 (="not promising") to 5 (="very promising"). There was consensus at an average score of 3.63, indicating that they think investing into IMTA is promising.
In the first round of the survey, besides IMTA, research on the environmental impacts of aquaculture was often named as a field receiving considerable attention and funding within the next 12 years. Here aquaculture experts were asked to rate past and current achievement in research on the environmental impacts of aquaculture in terms of “Carbon dioxide”, “Nitrogen”, “Phosphorus”, and “Carbon”. Research achievements measured in terms of Nitrogen and Phosphorus were -at average- rated much higher than research achievements concerning Carbon dioxide and carbon (see Table 8).

Table 8: Average rating of research achievements concerning the environmental impacts of aquaculture (n= 151)

| | Research achievements | |
|---|---|---|
| | Past and current* | Development until 2020** |
| Nitrogen (N) | 3.60 | 3.82 |
| Phosphorus (P) | 3.54 | 3.81 |
| Carbon dioxide (CO2) | 2.50 | 3.74 |
| Carbon (C) | 2.90 | 3.69 |

* scale from 1 = poor to 5 = very substantial
** scale from 1 = much less to 5 = much more

While there was consensus among aquaculture experts about the rating of past and current achievements concerning Nitrogen and Phosphorus, there was dissent among experts when rating past and current achievements concerning research on Carbon dioxide and carbon. Therefore these two areas were reasked in the third round, where there was consensus at slightly lower average scores (2.4 for Carbon dioxide and 2.8 for Carbon).

## 3.4 Fish health

Within the research fields concerning fish health, aquaculture experts assume a dynamic change in research fields with the greatest achievements. While research areas "Bacteria" and "Parasites" were rated highest for their past and current research achievements, "Developing therapeutics and vaccines", "Disease gene mapping", and "Early identification systems" are predicted to be the research areas with much more achievements in the future (see Table 9).

Table 9: Achievements in aquaculture fish health research by areas (n=178)

| Research area | Average score | | Rank | Rank |
|---|---|---|---|---|
| | Past and current* | Development until 2020** | past and current | future 2020 |
| Bacteria | 3.80 | 3.83 | 1 | 8 |
| Parasites | 3.52 | 3.73 | 2 | 9 |
| Nutritional deficiencies | 3.47 | 3.90 | 3 | 7 |
| Developing therapeutics and vaccines | 3.47 | 4.32 | 4 | 1 |
| Viruses | 3.44 | 4.05 | 5 | 4 |
| Hygiene and prophylaxis | 3.24 | 3.91 | 6 | 6 |
| Environmental diseases | 3.12 | 3.93 | 7 | 5 |
| Fungi | 3.04 | 3.52 | 8 | 10 |
| Early identification systems | 2.87 | 4.11 | 9 | 3 |
| Disease gene mapping | 2.67 | 4.24 | 10 | 2 |

* scale from 1 = poor to 5 = very substantial

** scale from 1 = much less to 5 = much more

Interestingly, consensus scores were very high when rating the development of achievements until the year 2020, while consensus was low when rating the past and current achievements in some areas. They were lowest for "Viruses" and "Disease gene mapping" therefore aquaculture experts were asked to rerate these two areas in the second round of the survey. In the second round past and current achievements in the area "Disease gene mapping" was rated at an average of 2.5, while past and current research achievement in the area "Viruses" received an average score of 3.3, which is slightly lower than the average rating within the first survey round. The average scores for anticipated development were the same as in the first round, consensus scores being even higher.

## 3.5 Fish nutrition

There is consensus among aquaculture experts that research on finding fish meal and fish oil substitutes will produce much more achievements until the year 2020. While past and current achievements on all research areas were rated between 3 (="some") and 4 (="substantial"), 4 research areas -at average- are assumed to generate "more" or even "much more" research achievements. Besides research on fish meal and -oil substitutes, these are the areas "Nutrient discharge" and "Larvae nutrition" (see Table 10).

Aquaculture experts think that vegetable resources and derivates will have the highest probability of being successful for finding fish meal and fish oil alternatives until the year 2020. Consensus scores were low in the first round of the Delphi survey, therefore the whole question was reasked in the second round. Then there was consensus among aquaculture experts, delivering the average scores listed in Table 11.

Table 10: Average rating of fish nutrition research areas (n= 187).

| Research area | Average score | | Rank | Rank |
|---|---|---|---|---|
| | Past and current* | Development until 2020** | past and current | Development until 2020 |
| Feed conversion ratio | 3.76 | 3.78 | 1 | 6 |
| Larvae nutrition | 3.64 | 4.16 | 2 | 4 |
| Feed processing | 3.64 | 3.75 | 3 | 7 |
| Feeding techniques | 3.58 | 3.68 | 4 | 8 |
| Fish meal substitutes | 3.57 | 4.45 | 5 | 1 |
| Feeding strategies | 3.55 | 3.87 | 6 | 5 |
| Fish oil substitutes | 3.44 | 4.40 | 7 | 2 |
| Nutrient discharge | 3.29 | 4.18 | 8 | 3 |

* scale from 1 = poor to 5 = very substantial

** scale from 1 = much less to 5 = much more

Table 11: Average rating in the second round of the survey when rating the probability of being successful in finding alternative feed resources for fish meal and fish oil (n=167).

| | Fish Meal Alternatives | Fish Oil Alternatives |
|---|---|---|
| | Average scores* | |
| Vegetable resources and derivates | 4.08 | 4.00 |
| Single cell proteins | 3.66 | 3.24 |
| Aquatic plants | 3.55 | 3.52 |
| Aquatic animals | 3.33 | 3.34 |
| Land living animal resources and derivates | 3.04 | 2.82 |

*scale from 1 = success very unlikely to 5 = success very likely

Since vegetable resources and derivates were -by far- rated to have the highest probability of being successful until the year 2020 in finding alternative feed resources for fish meal and fish oil, we decided to include a question asking for which vegetable resources and derivates the experts think to be successful as providing alternative feed resources.

Aquaculture experts think that for finding fish meal alternatives, research on leguminous plants is most important, while they think research on oleiferous fruits is most important for finding fish oil alternatives. Aquaculture experts rate research on potatoes as fish meal or fish oil alternative least promising (see Table 12).

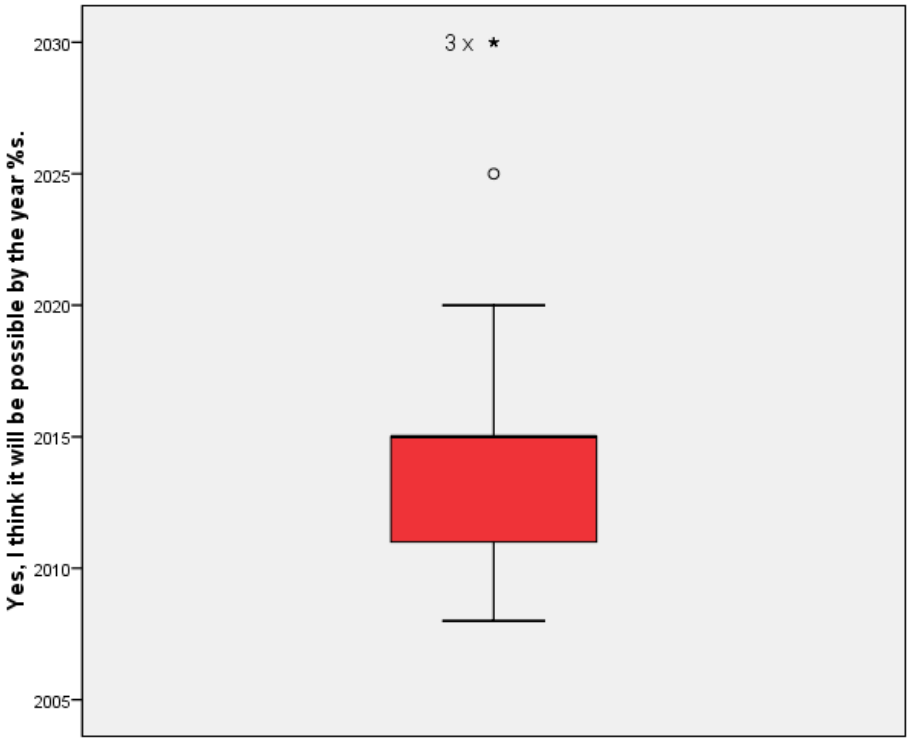
Table 12: Average rating of vegetable feed as fish meal and fish oil alternatives (n=116)

| | Fish Meal Alternatives | Fish Oil Alternatives |
|---|---|---|
| | Average scores* | |
| leguminous plants | 3.59 | 3.08 |
| grain | 3.36 | 2.82 |
| oleiferous fruits | 3.00 | 3.33 |
| potatoes | 2.34 | 1.97 |

*scale from 1 = success very unlikely to 5 = success very likely

Two thirds (82) of the aquaculture experts participating in the survey think it will be possible to achieve Feed Conversion Ratios (FCRs) below one when feeding carnivorous species. Three quarters of the respondents think FCRs below one will be achieved by 2015, of which half think it will be achieved in 2015 (median). The mean lies at the year 2016, while the standard deviation is 8.8 years (see Figure 3).

Figure 3: Boxplot when FCR of below one will be achieved (n=82).




## 3.6 Marketing, quality management and economics of aquaculture

Most aquaculture experts think that current advances in research on fish and fish products is less or even much less advanced that research on meat and meat products. This is the only question that was asked three times and where consensus was not reached after three survey rounds. The average rating of research on fish marketing lies close to 2 (="less advanced") dropping somewhat from round to round (Round 1: 2.25; Round 2: 2.15; and Round 3: 2.11)
Quality Management was rated little better, even though the average of all rating indicates that research on aquaculture fish quality management has not reached the same status as quality management research on meat and meat products (Round 1: 2.57; Round 2: 2.62; Round 3: 2.49). An average score of 3 would have indicated that experts think that aquaculture research advances are the same as research advances in research on meat and meat products.
Even though there is dissent among the aquaculture experts surveyed, about the current achievements, there is consensus that research on fish marketing and fish quality management will substantially increase until the year 2020.

Aquaculture experts think that past and current achievements on "aquaculture farm business management" were highest, while they assume that the development of achievements will be highest in "traceability and supply-chain-management". In the first round the consensus scores were bad, indicating dissent among aquaculture experts, so this question was reasked in the second round. In the second round aquaculture experts reached consensus at almost the same average rating scores, ranks also stayed the same (see Table 13).

Table 13: Rating of fish economic research areas in survey round 2 (n= 166).

| Research area | Average score | | Rank past and current | Rank 2020 |
|---|---|---|---|---|
| | Past and current* | Development until 2020** | | |
| Aquaculture farm business management | 3.02 | 3.79 | 1 | 5 |
| Traceability and supply-chain-management | 2.82 | 4.28 | 2 | 1 |
| Fish market research | 2.73 | 4.01 | 3 | 3 |
| Impacts of globalization | 2.62 | 4.06 | 4 | 4 |
| Socioeconomic impacts of aquaculture | 2.66 | 4.07 | 5 | 2 |

* scale from 1 = poor to 5 = very substantial

** scale from 1 = much less to 5 = much more

### 3.7 Demographics of the participants

The vast majority of the respondents were male (82.5 percent) aquaculture experts, only 45 (17.5 percent) of the respondents were females. The aquaculture experts were between 26 and 78 years old, their average age was 48.4 years. The standard deviation of age was 9.5 years. The vast majority of aquaculture experts hold al PhD title (73.2 percent). Aquaculture experts participating in the survey have an average of 19 years of experience in aquaculture. Half have at least 20 years of aquaculture research experience, while three fourths of the responding experts have between 11 and 25 years of experience. Nearly half of the respondents are employed by Universities, while nearly every fifth respondent works for a governmental agency. Most of the respondents are Professors or senior researchers and focus on applied or basic research. The respondents currently live in all parts of the world; most in Europe, USA/Canada, Norway and United Kingdom.

# 4 Discussion of results

Results of the survey show that aquaculture experts agree that aquaculture research in general has made substantial achievements and will continue to make even more achievements in the future, Further on, they predict aquaculture research achievements will have very large impact on the productivity of the aquaculture farm as well as on the quality of fish produced in aquaculture systems. This finding indicates that the investment of research money will result in higher productivity within aquaculture farms as well as in increases quality of the fish produced from aquaculture.

Fish nutrition was identified as the research area with the highest research achievements up to the time the study was conducted, while fish health and fish nutrition are the areas that experts anticipate to produce most research achievements until the year 2020. These two research areas were also identified to have the greatest impact on the quality of fish produced from aquaculture.

Within the research area "fish health", developing therapeutics and vaccines, disease gene mapping and early identification systems were rated to be most promising research areas for investing R&D money. Within the area "fish nutrition", research on the feed conversion ratio was rated highest for its past achievements, but aquaculture experts agree that research on finding fish meal and fish oil alternatives will develop to produce most research achievements by the year 2020. When finding alternative feed resources, vegetable resources and its derivates were rated to be most successful by the year 2020, research on leguminous plants being most important for finding fish meal alternatives, research on oleiferous fruits being most important for finding fish oil alternatives. The vast majority (82 percent) of aquaculture experts participating in the Delphi survey thinks, it will be possible to achieve Feed Conversion Ratios (FCRs) below one when feeding carnivorous species, three quarters of which think that FCRs smaller than one will be reached by the year 2015. These results indicate that investments into fish health and fish nutrition will produce substantial research achievement, which in turn have positive impact on aquaculture farm productivity and fish quality.

Although aquaculture experts participating in the survey identified organic aquaculture as the research field having produced least results up to the time the study was conducted and most agreed to the statement that organic aquaculture is generally overrated, they think investments into organic aquaculture research will become considerably higher. This sets investments into research on organic aquaculture in a critical light, as these are not predicted to bring forward substantial results by the year 2020.

While the European Seabass and the Gilthead Seabream were identified as most promising for developing an aquaculture breeding program, aquaculture experts predict that the field "marker based selective breeding" will develop to produce most research achievements within the research area "Breeding and reproduction".

Recirculating aquaculture systems were clearly identified as the most promising production system for investing research money. When conducting research on recirculating systems, aquaculture experts predict that research on energy efficiency, nutrient discharge, biological clarification systems as well as monitoring and controlling systems will produce most research achievements. In the section "Fish husbandry and water management", research on IMTA (integrated multitrophic aquaculture) and research on the environmental impacts of aquaculture were named as further promising research areas for the investment of aquaculture research money.

Even though there is dissent among aquaculture experts surveyed about the current achievements of aquaculture fish marketing and quality management research, there is consensus that research within this area will substantially increase. Here research on traceability and supply chain management and research on the socioeconomic impacts of aquaculture are predicted to produce most research achievements.

Norway was clearly identified as the current and future leading aquaculture research nation, while Taiwan, Spain and the USA are expected to become very much stronger until the year 2020. Among advanced economies, Germany and Italy were rated lowest for their general aquaculture research achievements and experts predict these nations to remain in the low position until the year 2020. This indicates that the German aquaculture research community is underdeveloped in comparison to other nations, indicating the necessity to invest into R&D in aquaculture in order to move to a more advanced position in international comparison.
The demographic characteristics we can assume that we have found a round of aquaculture with a wide background representing the global aquaculture research community. This study cannot be seen as representative for the total population of aquaculture experts. This is the case in all Delphi studies, as the universe of experts usually is unknown.

# 5 Literature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