Survey on selective breeding programs implemented in the European aquaculture industry

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1. Objectives:

Selective breeding, or artificial selection, describes the methods by which humans produce organisms with desirable traits. It is opposed to natural selection where individuals being best adapted to their environment survive and transmit their genes to the next generation. Selective breeding began around 10,000 years ago in the Neolithic age, turning wild species into domesticated crops and livestock. In ancient time, it is thought that artificial selection was mostly unintentional. It became a scientific practice during the British Agricultural Revolution (works of Robert Bakewell in the 18th century) and progressed further in the middle of the 20th century thanks to major technological breakthroughs.

The aquaculture industry, as compared to its agriculture counterpart, is a relatively young production sector. The first selective breeding programs in aquaculture have been initiated in Europe with the emergence of the Norwegian salmon farming at the beginning of the 1970s. Since then, new aquaculture species have started to be selected across Europe. The carp, the first domesticated fish, is seen as a special case as it has undergone selective breeding for centuries (Vandeputte, 2003).

In AquaTrace, the main goal is to assess the genetic impact of aquaculture on wild populations. The present survey will contribute to this objective by depicting the European aquaculture seeds production sector, with a focus on the selective breeding programs implemented on the European seabass, the gilthead seabream, the turbot, the rainbow trout, the Atlantic salmon and the common carp.

2. Materials and methods:

2.1. Preparation and dispatch of the survey:

The AquaTrace survey has been prepared based on the work done in the previous industrial survey (AquaBreeding, 2008):

– a similar questionnaire template was used and enhanced to assess the share of the selected seeds in the market

– the lists of national contacts and breeding organisations were updated and enlarged so that more countries would be represented in the survey

The initial method of distribution has consisted in an online questionnaire accessible from the AquaTrace website (https://aquatrace.eu/qstr). In practice, we sent an email to the breeding organisations inviting them to take part to the survey. For security and confidentiality reasons, the questionnaire was configured to accept only relevant potential respondents having received personalised credentials. After 2 months, a reminder was sent out to the non-respondents with, in attached, an excel version of the questionnaire pre-filled for the relevant species and country.

2.2. *Processing of the answers*

The questionnaires have been collected between December 2013 and October 2014. Half were filled-in online while the other half were completed in Excel and sent back by email. Once received, they were forwarded to a restricted number of people authorised to access the data.
The terms of confidentiality were reported at the beginning of the survey in order to guarantee the anonymity of the answers. They state the non-disclosure of information directly linked to the breeding organisations. As a consequence the survey analysis uses aggregated data without making reference to single companies.
All the answers were checked for their reliability and consistency. In case of doubt or error the respondents were contacted again for verification.
In total 33 breeding programs were surveyed. For each question asked, at least one respondent failed to answer, which explains why the totals are never equal to 33 in the presented data: the number of answers obtained for one question ranges from 24 to 32.

2.3. *Questions related to the market seeds study*

The view of selective breeding as a means to increase productivity and competitiveness is perceived differently among the producing countries. As a consequence, the effective implementation of selection programs and the level of domestication of a given species varies between countries. So we designed the questionnaire in order to assess the penetration of selected seeds in the eggs and juveniles markets both at the national and European levels. To do so we asked each breeding organisation to:

– quantify its seeds production
– estimate its market share at the national and European (plus Turkey and Israel) levels

The term seeds is defined as the material (eggs, larvae and juveniles) obtained from the organisation's own selected broodstock (not imported), either sold or on-grown in the farm (excluding those discarded). For salmonids the term 'eggs' is intended as ova laid down for hatching.

The production and share market estimates were provided by the respondents within the ranges shown below:

Production (million) eggs or larvae	Production (million) Juveniles
<2	<2
2 – 10	2 – 5
10 – 30	5 – 10
30 – 60	10 – 20
60 – 100	20 – 40
100 – 200	40 – 60
200 – 400	60 – 100
>400	>100

Share of the market (%)
<5
5 – 15
15 – 30
30 – 50
50 – 70
70 – 90
>90

The share of the market was assessed by each organisation based on reference production values (common to all surveyed respondents) provided in the questionnaire. The latter were obtained from production reports released by producer associations or government bodies and, when the authoritative statistics were missing, by national contacts. The reference production year is 2012 for all species except for trout which is 2011.
For the seabass, seabream and turbot market study the reference production values concern the juveniles. Most of the estimates were retrieved from the FEAP European aquaculture production report 2004-2013 (FEAP, 2014). Instead, the reference values for salmonids concern the eggs. The different sources are indicated in the table below.

Country	Source	Web address
Austria	Statistik Austria	http://www.statistik.at/
France	Agriculture Ministry	http://agreste.agriculture.gouv.fr/
Norway	The Directorate of Fisheries	http://www.fiskeridir.no/english
Spain	MAGRAMA	www.magrama.gob.es/
Turkey	National producer associations, academic and industry representatives	
UK	Scottish Government & CEFAS	http://www.scotland.gov.uk/
Others	National contacts	

3. Results and discussions:

3.1. Surveyed organisations and selective breeding programs:

In total, we identified 40 organisations having a selective breeding program active on at least one of the 6 target species. The organisations taking part to the survey were 29, they are presented in Annex 1. Four of the respondents managed two selective breeding programs on two different species, so we received 33 out of the 44 expected questionnaires. With 11 missing answers the response rate of the survey was 75% (table 1).

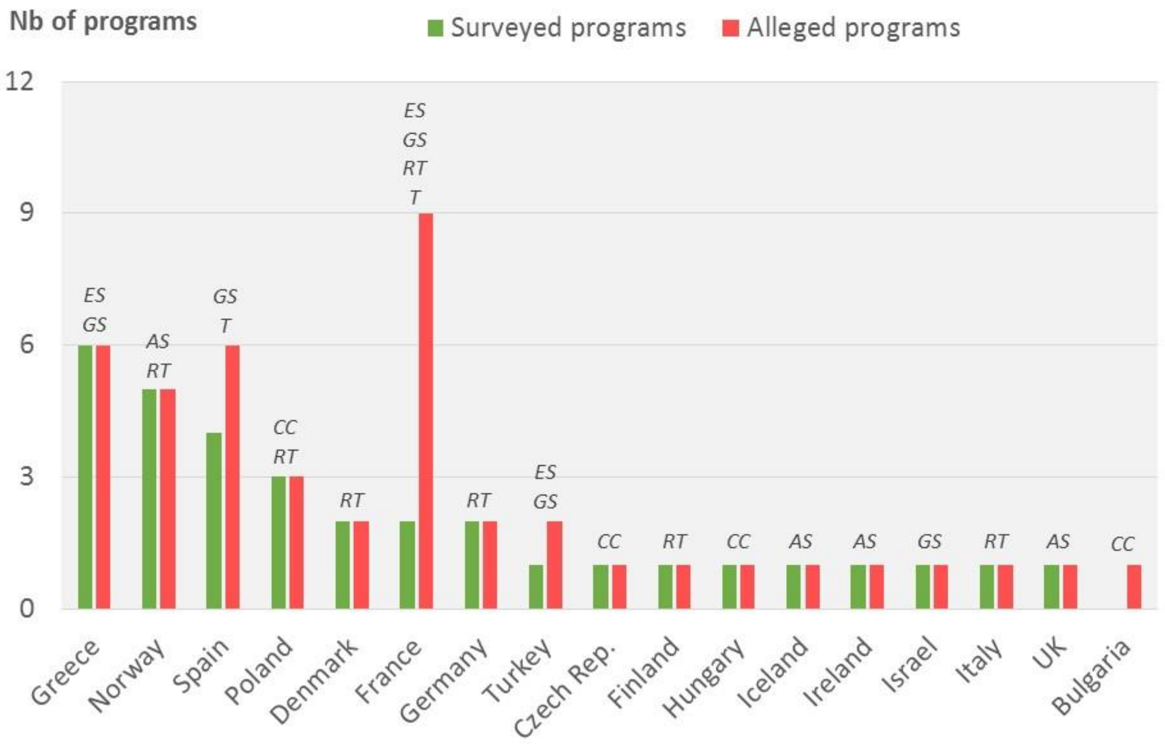
Table 1: Number of surveyed and alleged selective breeding programs for the 6 target species.

Species	Surveyed programs	Alleged programs
Gilthead seabream	6	8
European seabass	4	7
Turbot	2	4
Rainbow trout	10	13
Atlantic salmon	7	7
Common carp	4	5
Total	**33**	**44**

The species having the highest number of programs is rainbow trout, followed by seabream, salmon and seabass. Their geographical distribution is heterogeneous across countries, without showing clear relations with the seeds production or the tonnage at the European level (Annexes 2 to 6).

By ranking the countries according to the number of breeding programs implemented, a change occurs in the classification depending on whether or not we consider the non-respondents (figure 1). The change concerns mostly France and Spain whose position varies from the fifth and third place for the surveyed programs to the first and second place equally with Greece for the alleged programs, respectively.

Figure 1: Number of breeding programs implemented within the surveyed countries.



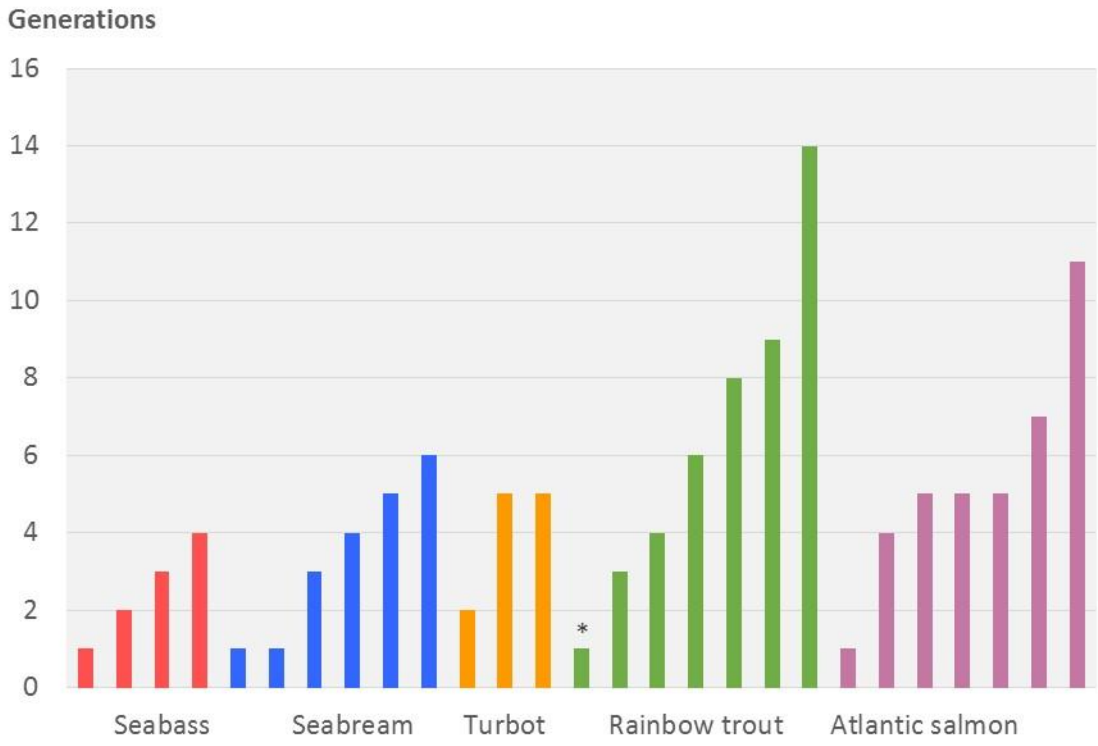
The letters above series correspond to the selected species in the alleged programs: *AS*: Atlantic Salmon, *CC*: Common Carp, *ES*: European Seabass, *GS*: Gilthead Seabream, *RT*: Rainbow Trout, *T*: Turbot.

3.2. *Selected generations performed*

A key point to assess the degree of divergence between wild and farmed stocks regards the number of selected generations performed in a selective breeding program. The higher the number of generations, the larger the divergence at the genetic and performance levels.

The survey results show that the implementation of selective breeding programs is a continuous and growing phenomenon for all target species (figure 2). Except for carp (data not shown) and turbot, at least one new program has been initiated during the last 3 years on each species. The oldest programs are on rainbow trout and salmon (14 and 11 generations, respectively), both species being cultivated in aquaculture since more than 40 years. Regarding rainbow trout, it should be noted that for at least 3 (only one appears in figure 2) out of the 9 surveyed programs, the broodstock has undergone for decades a 'home-made' selection process before being selected with the currently described breeding designs. In the oldest program the founder population dates back 53 years. The information available in the survey does not make it possible to understand whether these breeding populations were introgressed with novel breeders nor to make assumptions regarding their level of genetic variability.

Figure 2: Number of generations performed in each program, grouped by species. *: Program having undergone a 'home-made' selection for decades.



In the case of carp the number of selected generations performed is highly variable between and within programs (data not shown). The within program variation is due to the various lines maintained per program, from 2 to 19, with an average of 11, each having its own

history. The between program variation is attributable to the starting year of selection, some dating back to 1880's.

3.3. Control of inbreeding and effective population size:

Selective breeding programs are intrinsically long term investments. Throughout the years the genetic diversity is subject to a continuous erosion, leading to a progressive increase of the inbreeding level. The risk of inbreeding depression, associated with negative effects on fish performance, appears when the inbreeding level increases at an excessive rate, above 1% per generation (Meuwissen & Woolliams, 1994). Hence the need to maintain the rate of inbreeding at a low level.

The survey indicates that in most cases (71%) precautions are taken by the breeding companies to monitor the increase of inbreeding at each new generation. Even if the monitoring method is not documented in our survey, we can assume that a primary objective is to restrict the rate of inbreeding in the programs.
The table below shows that for the salmon and turbot programs the increase of inbreeding is systematically estimated, against roughly half for the other species' programs. These differences must be put in relation with the type of breeding schemes implemented, where the pedigree information is available or not.

Table 2: Estimation of inbreeding at each generation (number of programs grouped by species).

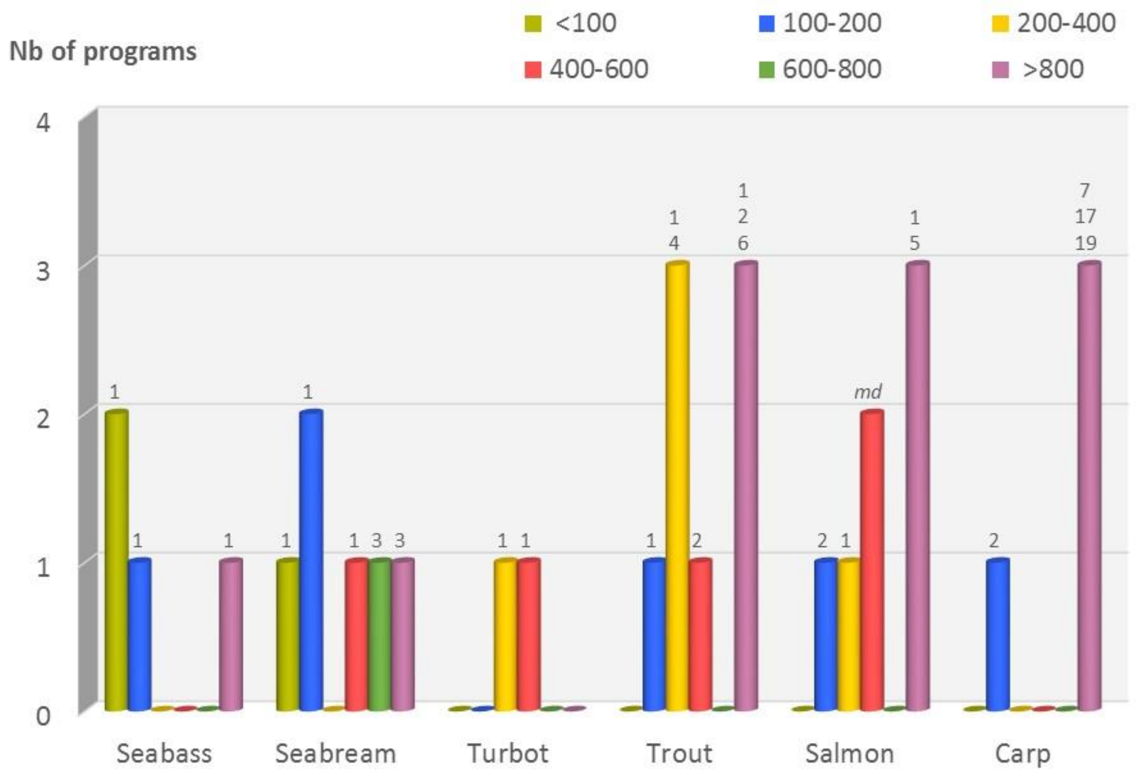
	Yes	**No**
European seabass	2	2
Gilthead seabream	4	2
Turbot	2	0
Rainbow trout	6	4
Atlantic salmon	7	0
Common carp	2	1
Total	**23**	**9**

A key means to control the increase of inbreeding is to ensure a sufficiently large effective population size *Ne* (above 50), the number of broodfish effectively contributing to the new generation. In the questionnaire we asked the breeding organisations to indicate the approximate number of parents used at each generation. This parameter differs from *Ne* as the latter depends also on the mating ratio males:females and on the variance of the contributing families. However, we propose to use it here as a trend indicator of the *Ne* level.

When asked to describe the reproduction pattern of their selected broodstock, the majority of the breeding organisations (71%) declared to use more than 200 broodfish per generation. It is on carp, salmon and trout that the number of parents is higher: for each species three programs declare more than 800 parents, and none is below 100. On the

contrary, the majority of the seabass and seabream programs use less than 200 parents. Turbot, with only 2 programs, is in between (figure 3).

Figure 3: Number of programs according to the number of broodfish involved at each generation, grouped by species.



The values above series represent the number of lines used in each program. *md*: missing data.

Different factors explain the various number of parents involved. Often, a higher number is associated with a family based breeding scheme, while a lower number tends to be found in programs where the pedigree of breeding candidates is unknown. Another factor is the capacity to fully control artificial fertilisation: this approach is common on salmonids but its practice becomes more complicated in the case of marine species. We also assume that the changing strategy occurring over time in a program, including the choice of the breeding scheme and the use of artificial fertilisation, tends to move the cursor towards an increasing number of parents.

In most programs the broodfish are produced over different year-classes or are maintained in separate lines (figure 3). 12 programs are managed with a unique line, while 17 others run different lines (up to 19 on carp).

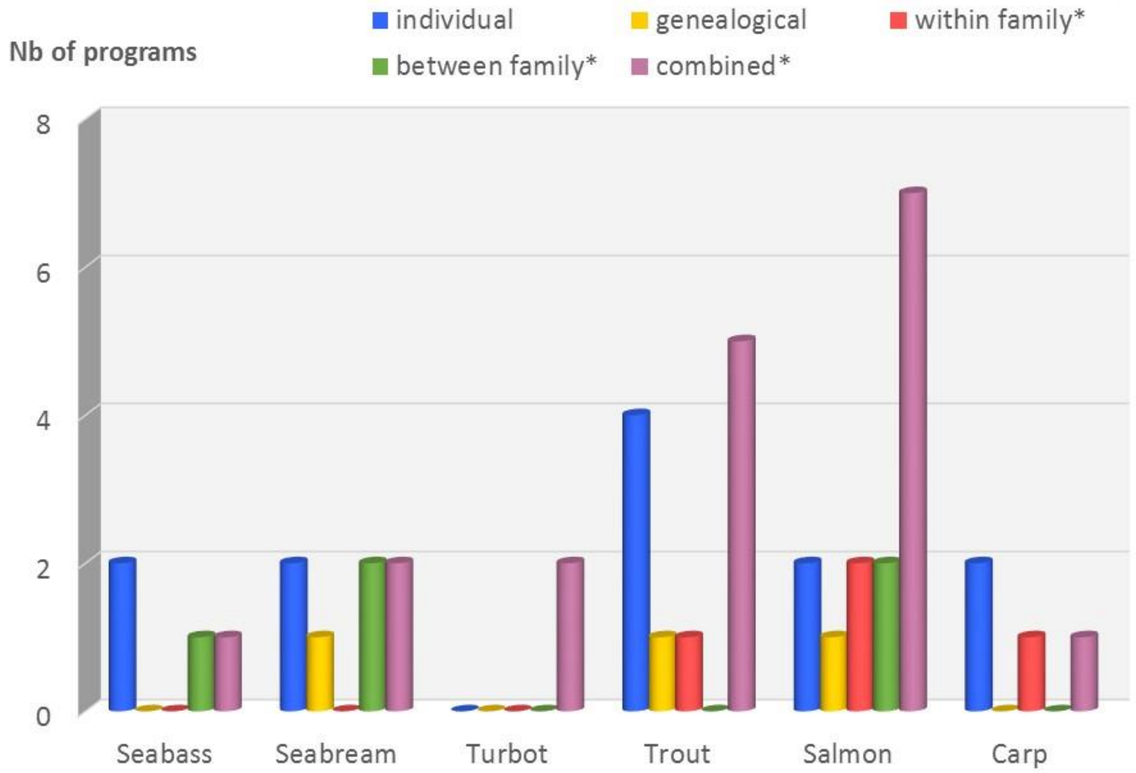
3.4. *Breeding schemes and molecular tools:*

One way to describe a selective breeding program is to define its breeding scheme. In the simplest designs, often less costly like individual selection, the pedigree information is not required and consequently the number of selected traits is limited. With such designs traits

like product quality or disease resistance, which are evaluated on the sibs of the candidates, cannot be selected or, at best, are improved in an indirect way. The so-called family-based designs, by contrast, require the family origin of the candidates to be traced, which make them more flexible regarding the number and the type of traits to select.

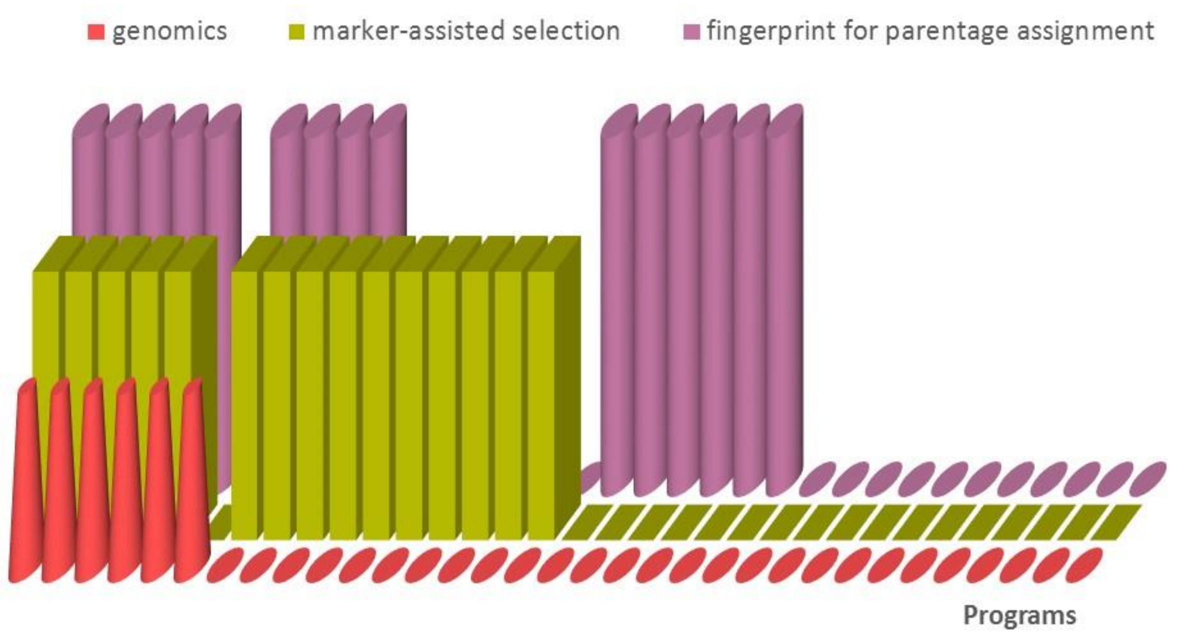
The survey shows a higher proportion of family-based designs on salmonids and turbot as compared to the other species (figure 4). Different designs can be used in the same program, which is the case for all species except turbot. In concrete terms, this means that certain traits can be improved by using the only phenotypic record (the fish are kept or culled based on a threshold value) or by crossbreeding different lines, while others will be selected based on parameters taking into account the pedigree information like the BLUP breeding value.

Figure 4: Number of programs according to the type of breeding scheme, grouped by species. *: family-based designs.



More specifically, when looking at the use of molecular tools in the familiy-based breeding programs, we note that all those that are running a genomic selection except one have also implemented a marker assisted selection (MAS) and use the DNA fingerprinting to assign parentage (figure 5). Seeing the number of marker-assisted selection programs (15), and provided that sufficient genomic ressources is developped, we can expect an increase of the number of genomic selection programs in the coming years. But the use of molecular markers is not limited to the family-based selection, they serve also to monitor the genetic variability in three individual programs on carp, trout and seabass (data not shown).

Figure 5: Use of molecular tools in each program.

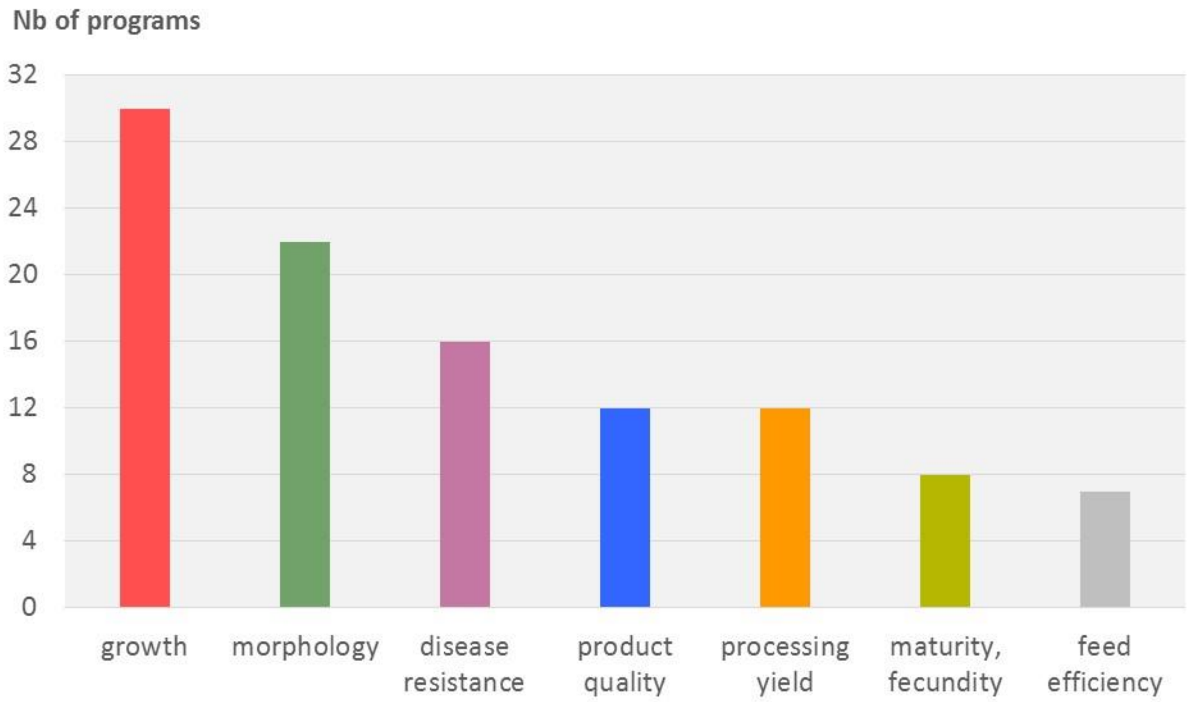


3.5. Selected traits and research priorities:

Commercial breeding programs differ from one another in the number and the type of selected traits. When several traits are improved simultaneously they are combined in an index, each trait being weighted according to its economic value. The trait itself can be recorded directly on the candidates (e.g. growth, morphology and reproduction related traits) or on the sibs of the candidates for more complex traits like disease resistance, processing yield or quality.

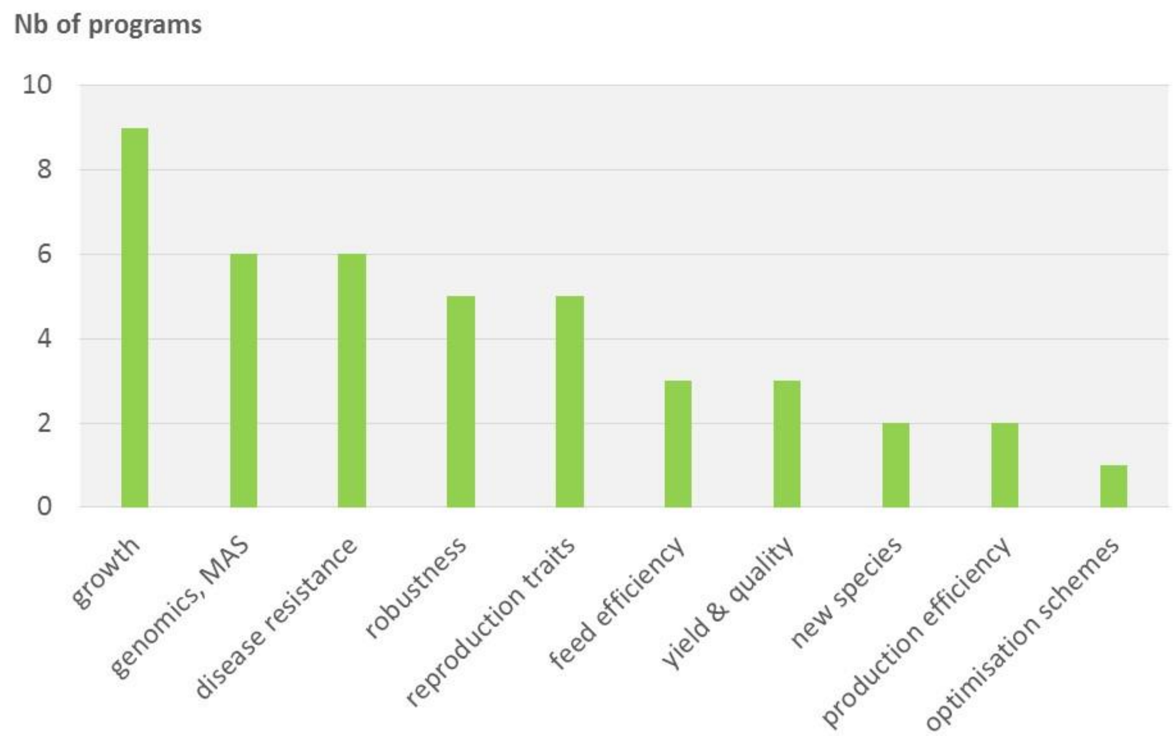
Growth is an easy to select trait of prime importance for the industry. It comes as no surprise that it is present in all surveyed programs (figure 6), except one focused on morphology (seabream). It is selected either alone (4 programs) or in combination with other traits (26 programs). Growth is also quoted first among the research priorities expressed by the surveyed organisations (figure 7). Morphology is the second most selected trait, followed by disease resistance, the latter being improved via family-based selection (data not shown). Product quality, ranked equally with processing yield, is improved in 12 programs. Product quality, as morphology, are traits aimed at satisfying the consumer demand. Their ranking among the breeding priorities indicates a higher consideration by the aquaculture industry to the consumers' expectations. More detailed figures of selected traits are presented in Annex 7.

Figure 6: Number of programs according to the selected traits, all species included.



When asked to indicate their research priorities in the fields of breeding and reproduction, the respondents favoured the breeding goals in most cases (33 over 45 expressed priorities). The other topics relate to the development and the optimisation of more advanced breeding schemes like MAS and genomic selection (figure 7).

Figure 7: Research priorities expressed by the surveyed organisations to address breeding and reproduction challenges.

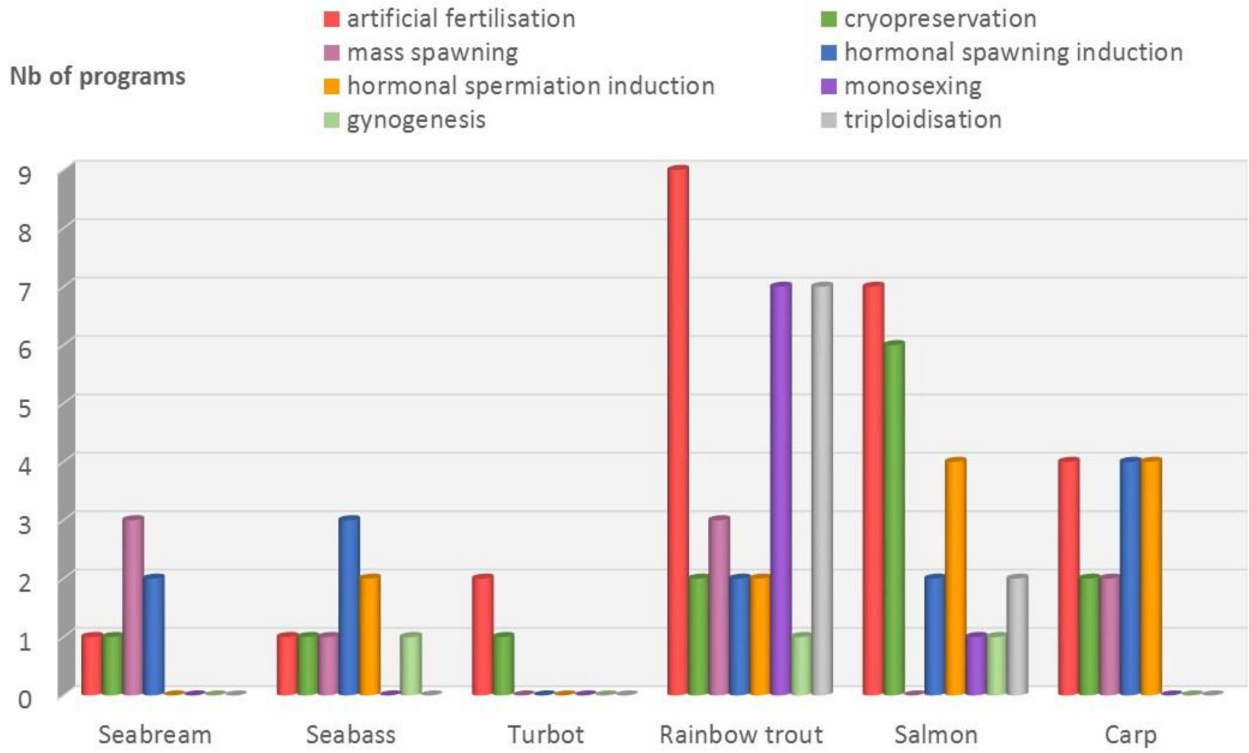


3.6. Reproduction and alternative genetic improvement technologies:

The control of reproduction techniques is essential for the development and management of selective breeding programs. However, their correct implementation often varies according to the biology of the species and the practical constraints on the ground.

Artificial fertilisation is systematically implemented on salmon, trout, carp and turbot programs, and it is often combined with the cryopreservation, in particular on salmon (figure 8). In the case of seabass and seabream, whose control of reproduction is known to be problematic, the technique of mass spawning is preferred, even if artificial fertilisation is implemented in two programs. The hormonal induction of both males and females is commonly used across species: it is primarily used on carp and seabass and less present in the trout programs.

Figure 8: Number of programs according to the reproduction techniques implemented, grouped by species.

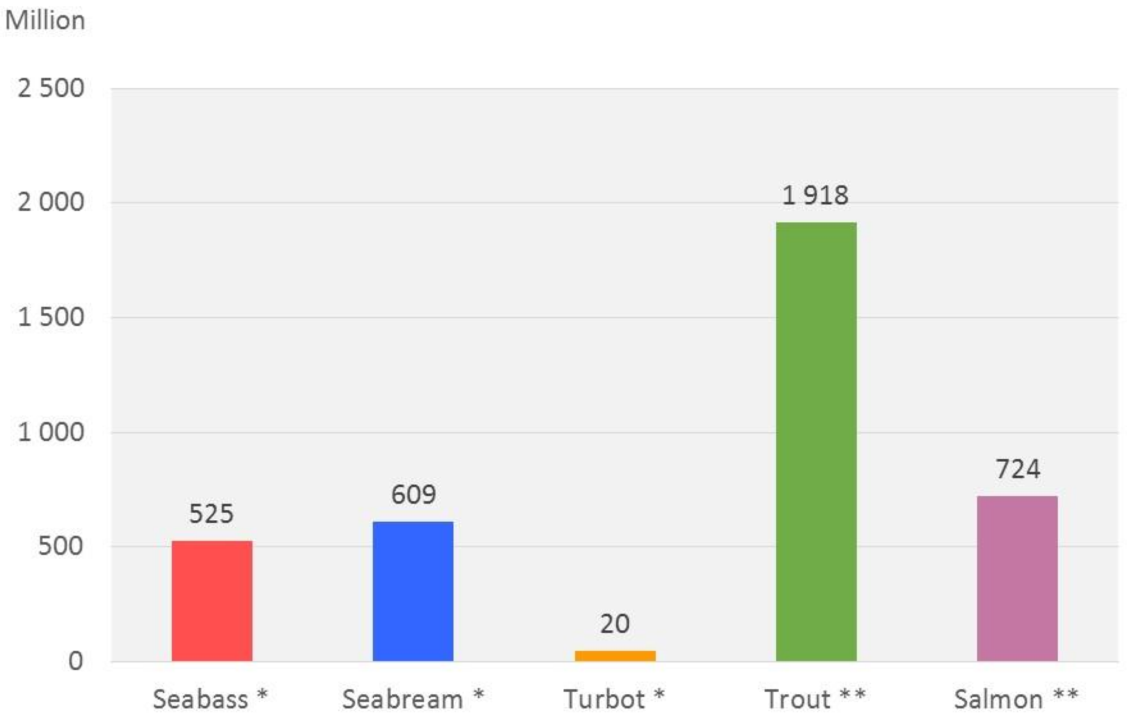


The production of sterile fish through the induction of triploidy is seen on salmonids exclusively, mainly on rainbow trout (seven programs) and in two salmon programs. Alternatively, the approach of using tetraploid lines to successively produce triploids is implemented in three rainbow trout programs (data not shown). The monosex technology is used to avoid early sexual maturation and produce larger and more valuable fish. Here again this approach is reported in salmonids only, where the culture of monosex female fish populations is desirable. In the survey, seven rainbow trout and one salmon programs use this technology. Finally, gynogenesis is reported in three programs on salmon, seabass and trout programs, and for the last two species it is used in combination with hybridisation.

3.7. *Seeds production:*

The seeds production estimates are shown in Annex 8 and summarized in figure 9. No value is provided for brown trout and carp due to insufficient reliable data. Although a seabass eggs market exists it was not considered in our analysis because of the fragmented structure of the retrieved data. Finally, the rainbow trout eggs production may be underestimated due to missing data from potential producer countries (Poland, Sweden).

Figure 9: Seeds production estimates in Europe plus Israel and Turkey in 2012 (2011 for rainbow trout). *: juveniles; **: eggs laid down to hatch.



The dominant market players are Spain, Greece and Turkey for turbot, seabream and seabass juveniles productions, respectively. For the eggs of salmon and rainbow trout the major producers are Norway and Turkey, respectively. These countries are also the major producers (in tons) for the respective species (table 3).

Table 3: Shares of the seeds and tonnage markets for the major producer countries. [1]: juveniles; [2]: eggs laid down to hatch. [3]: source FEAP; [4]: source FEAP and Turkish industry.

Species		Turbot	Seabream	Seabass	Salmon	Trout
	dominant country	Spain	Greece	Turkey	Norway	Turkey
Market:	**Seeds**	94%[1,3]	40%[1]	39%[1,3]	84%[2]	31%[2]
	Tonnage	61%[3]	50%[3]	48%[3]	83%[3]	22%[4]

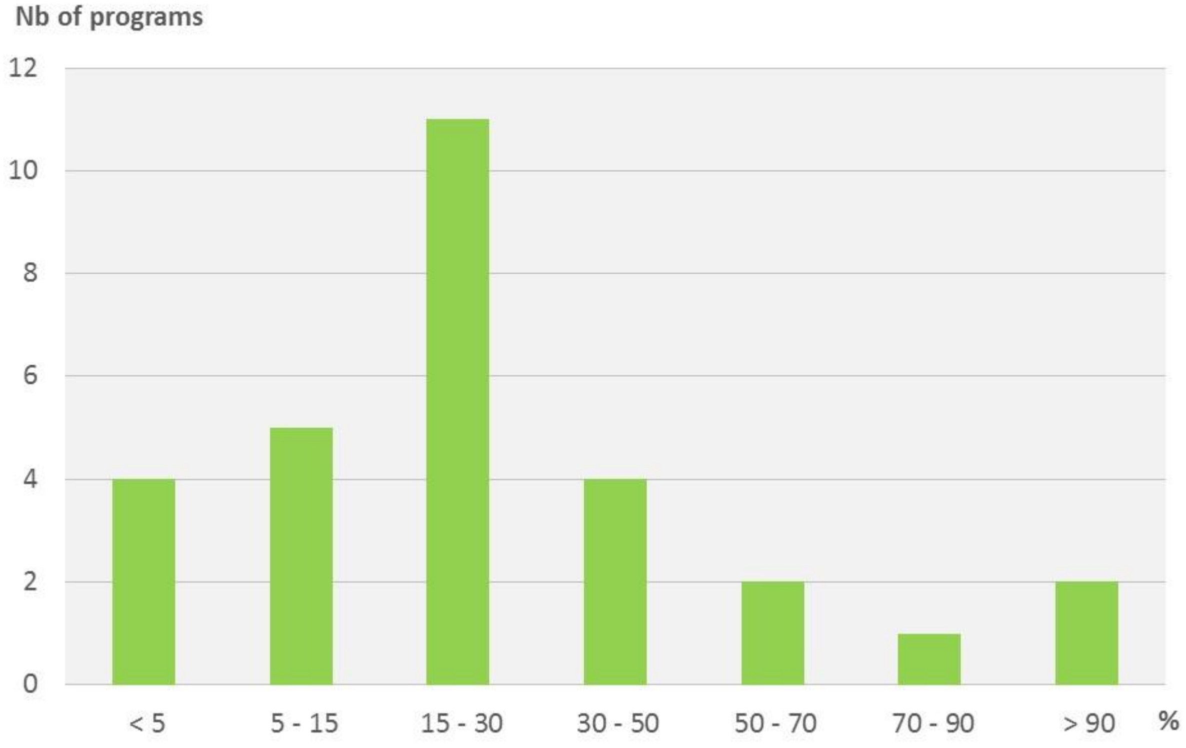
Regarding the country diversification of seeds production, France and Spain breed 4 of the 5 studied species each, followed by Italy and Turkey with 3 species. With regard to the geographic distribution of seeds production, rainbow trout heads the list with 10 countries, followed by seabream (9), seabass (8), salmon (5) and finally turbot with 2 producer countries.

3.8. Selected seeds in the market:

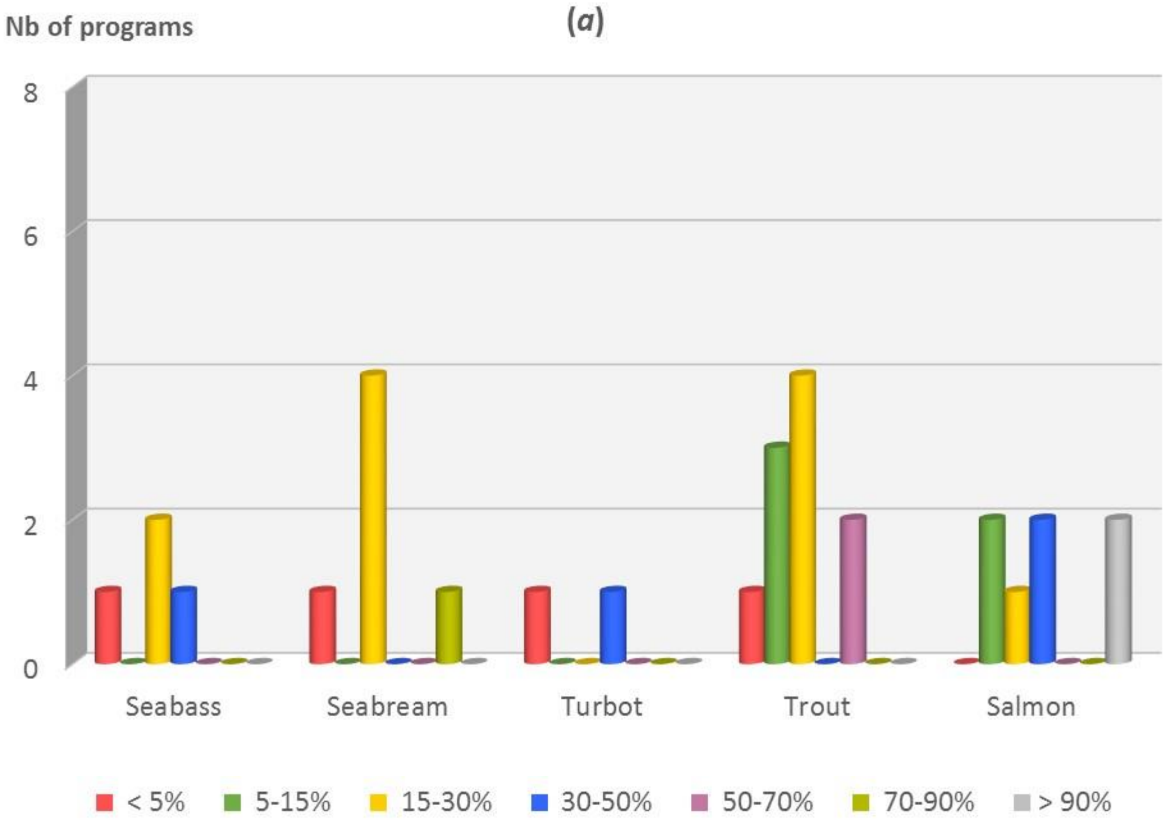
Based on the seeds production values provided by the survey respondents we have estimated the penetration of the selected seeds in the market both at the national and the European levels.

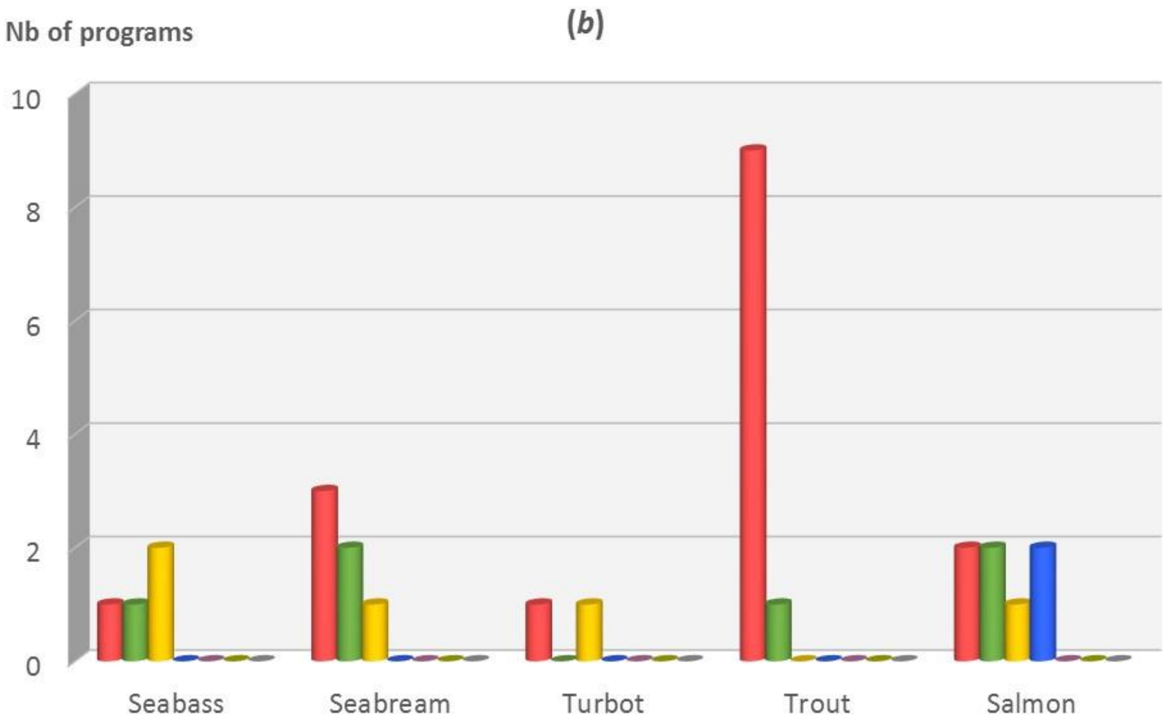
For a majority of the programs the supplied seeds represent less than 30% of the national market (figure 10). We also observe three cases characterized by dominant positions, above 70%, one for seabream and two for salmon (figure 11.a). At the European level the market share of single companies decreases below 30%, except for two salmon breeding programs, and become more homogeneous among species (figure 11.b).

Figure 10: Number of programs according to their seeds market shares at the national level, all species included.



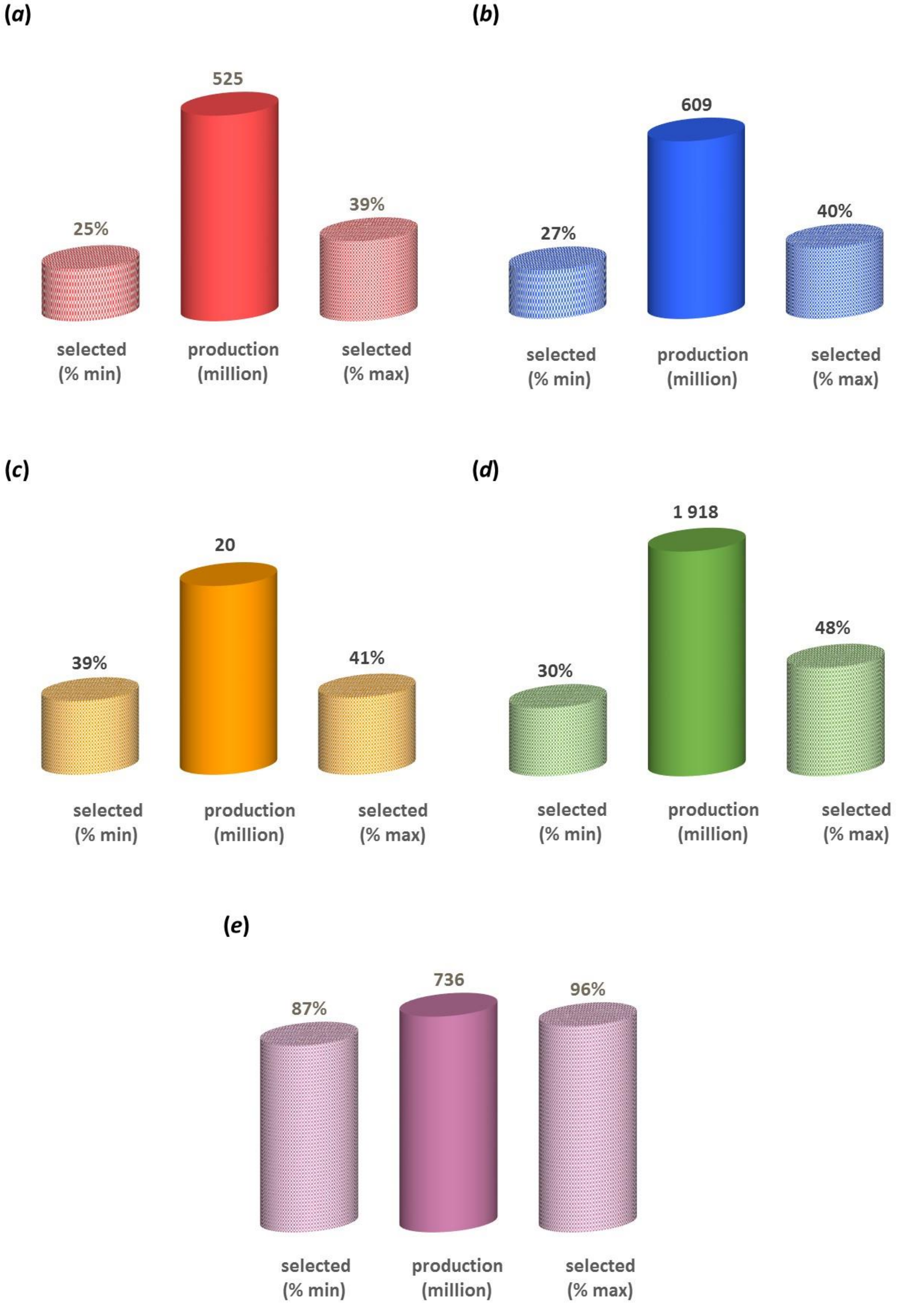
Figures 11 *a* and *b*: Number of programs according to their seeds market shares at the national (*a*) and European (*b*) levels, grouped by species.





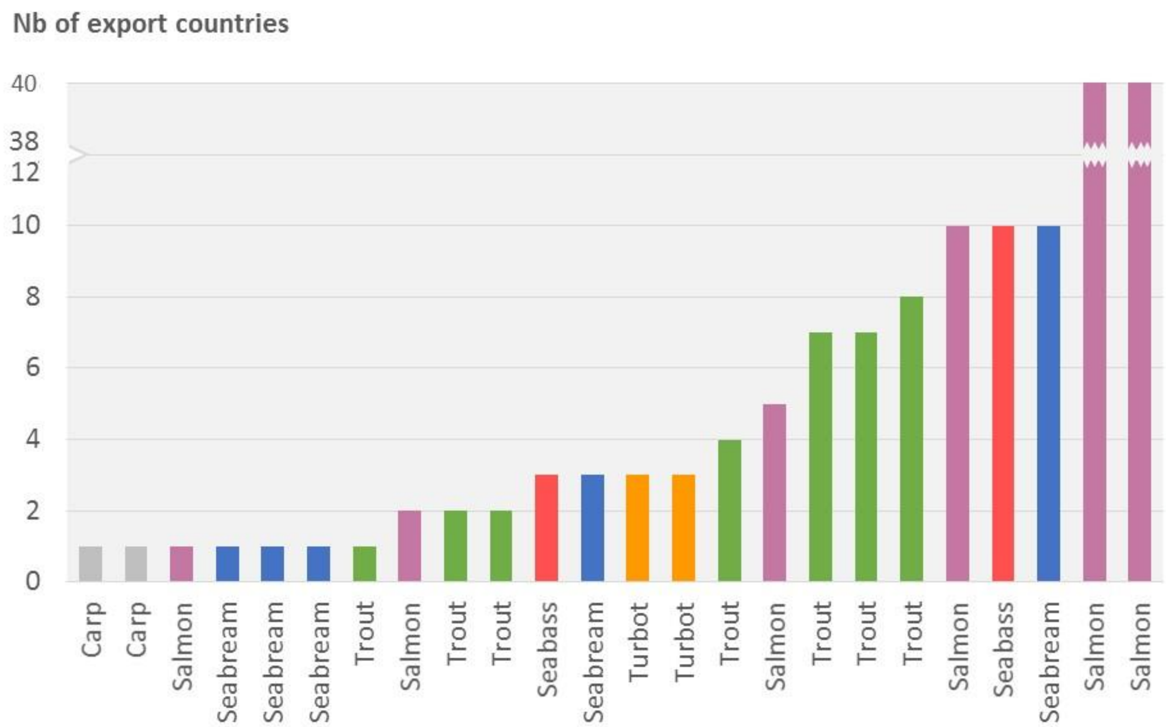
We also analysed the data in an aggregated way, without distinction between the countries or the breeding companies providing the selected seeds. In this way we could estimate, for each target species, the minimum and maximum percentage of selected material in the European seeds market. The results are presented in figures 12 (*a*) to (*e*). They show two broad trends with, on one hand the salmon production being highly penetrated by genetically improved fish (at least 87% of the market) and, on the other hand, the other species characterized by low to medium levels of selection (25 to 48% of the market). Such values reflect the situation depicted by the surveyed respondents. They are likely to underestimate the real situation due to the missing questionnaires (the non-respondents are 11 for a total of 40 contacted organisations), the eventual unidentified breeding organisations and, in the case of seabass, for considering only the juveniles market to the detriment of the parallel market of eggs.

Figure 12: Seeds production, minimum and maximum estimates of selected seeds in the European market (plus Israel and Turkey). (*a*), (*b*) and (*c*): juveniles of seabass, seabream and turbot, respectively. (*d*) and (*e*): eggs of rainbow trout and salmon, respectively.



We also examined the number of seeds export countries associated with the surveyed program. Two salmon programs outpace the others by trading their seeds in 40 countries (figure 13). They are followed by three programs whose seeds are exported in 10 countries. For these programs the owner companies are large aquaculture firms, with a turnover exceeding €10 million, characterised by either the vertical integration of their activities or by consolidated commercial partnerships with leading fish producers. At the other end are companies whose breeding programs have been implemented to serve first their production needs, and secondarily for customers located in a limited number of countries. These companies have heterogeneous profiles, being either small (<€0.1 million turnover; 2 employees) or large (>€100 million turnover; more than 500 employees) enterprises and operating small to large production capacities.

Figure 13: Number of export countries of the seeds derived from the surveyed breeding programs.



3.9. *Trends since the last survey:*

In 2008, a first survey was conducted to describe the European aquaculture breeding sector (AquaBreeding survey, 2008). By comparing the AquaBreeding results with the current survey we can analyse the main changes of the sector over the past years.

First, our data show a higher number of breeding organisations and programs (table 4). This can be explained by the newly identified entities (17), but also by the implementation of new programs by six companies, and despite one program was not pursued on trout.

Table 4: New surveyed and alleged breeding programs for the 6 target species as compared to the 2008 AquaBreeding survey.

Species	Surveyed programs	Alleged programs
Gilthead seabream	1	3
European seabass	2	5
Turbot	0	2
Rainbow trout	1	4
Atlantic salmon	1	1
Common carp	0	1
Total	**8**	**17**

When we look at the breeding goals we observe an increase in the number of selected traits in most programs (table 5). Of the 20 programs having the requisites to be compared (programs present in both surveys with answers provided for the relevant questions), 15 have added new traits (24 in total) in their breeding goals and 5 remained unchanged. Feed efficiency has spurred greatest interest among the breeding companies as it is now present in 7 programs (on all species except carp) while it was not mentioned in the 2008 survey. Morphology comes second, followed by disease resistance and processing yield. Finally, we count two programs, on salmon, whose some formerly selected traits have been removed (4 in total).

Table 5: Number of programs whose selected traits have been added and/or removed as compared to the 2008 AquaBreeding survey.

Traits	Added	Removed
Feed efficiency	7	-
Morphology	5	1
Disease resistance	4	0
Processing yield	3	0
Maturity, fecundity	3	2
Product quality	2	1
Total	**15**	**2**

Another positive trend concerns the integration of molecular tools in the breeding programs. The major changes regard the genomic selection, a new design now implemented in 6 programs (table 6). The application of marker assisted selection and parentage assignment in 15 programs (against two and eight before, respectively) represent the most common use of markers. It is followed by the genetic traceability implemented in 13 programs. Finally, in at least three programs the molecular markers are specifically used to evaluate the genetic variation in the breeding population (data not shown).

Table 6: Number of programs using the molecular tools as reported in the AquaTrace (first number) and AquaBreeding (second number) surveys, grouped by species.

Species	Genomic selection	Marker assisted selection	Molecular fingerprinting	Genetic traceability
Gilthead seabream	0 - 0	4 - 0	2 - 2	2 - 2
European seabass	0 - 0	2 - 0	0 - 1	2 - 1
Turbot	1 - 0	0 - 0	1 - 0	1 - 0
Rainbow trout	0 - 0	2 - 0	6 - 1	3 - 0
Atlantic salmon	5 - 0	6 - 2	6 - 4	5 - 3
Common carp	0 - 0	1 - 0	0 - 0	0 - 1
Total	**6 - 0**	**15 - 2**	**15 - 8**	**13 - 7**

4. Conclusion:

Looking at the development of selective breeding across Europe, it appears clearly that a great heterogeneity exists between species and countries. Most salmons that are produced today derive from selected stocks, while over half the cultivated fish of the other species are of wild origin. Instead on carp, even if it is recognized that the species has been selected for centuries, the missing data on seeds production do not point to a conclusive trend in the fish origin. The differences between countries show no factor influencing predominantly the implementation of breeding programs, even if the strategic long-term vision of development in larger companies may play a facilitating role.

The survey data clearly put forward the key role of molecular tools in selection, in particular with the emergence of the genomic selection and the multiplication of marker-assisted selection programs, and by seeing the greater use of molecular fingerprinting to reconstruct the pedigree. Alternative genetic improvement technologies are also implemented to increase the production quality and performance, like chromosome-set manipulation (triploidy, tetraploidy), monosex populations or interspecific hybrids.

Based on the number of generations performed we show that for all species the built-up of new breeding programs is a continuous process. Once implemented, the programs evolve with new traits being added over time to increase the productivity (growth, disease resistance, processing yield) but also to answer to the consumer demands (fish morphology, product quality).

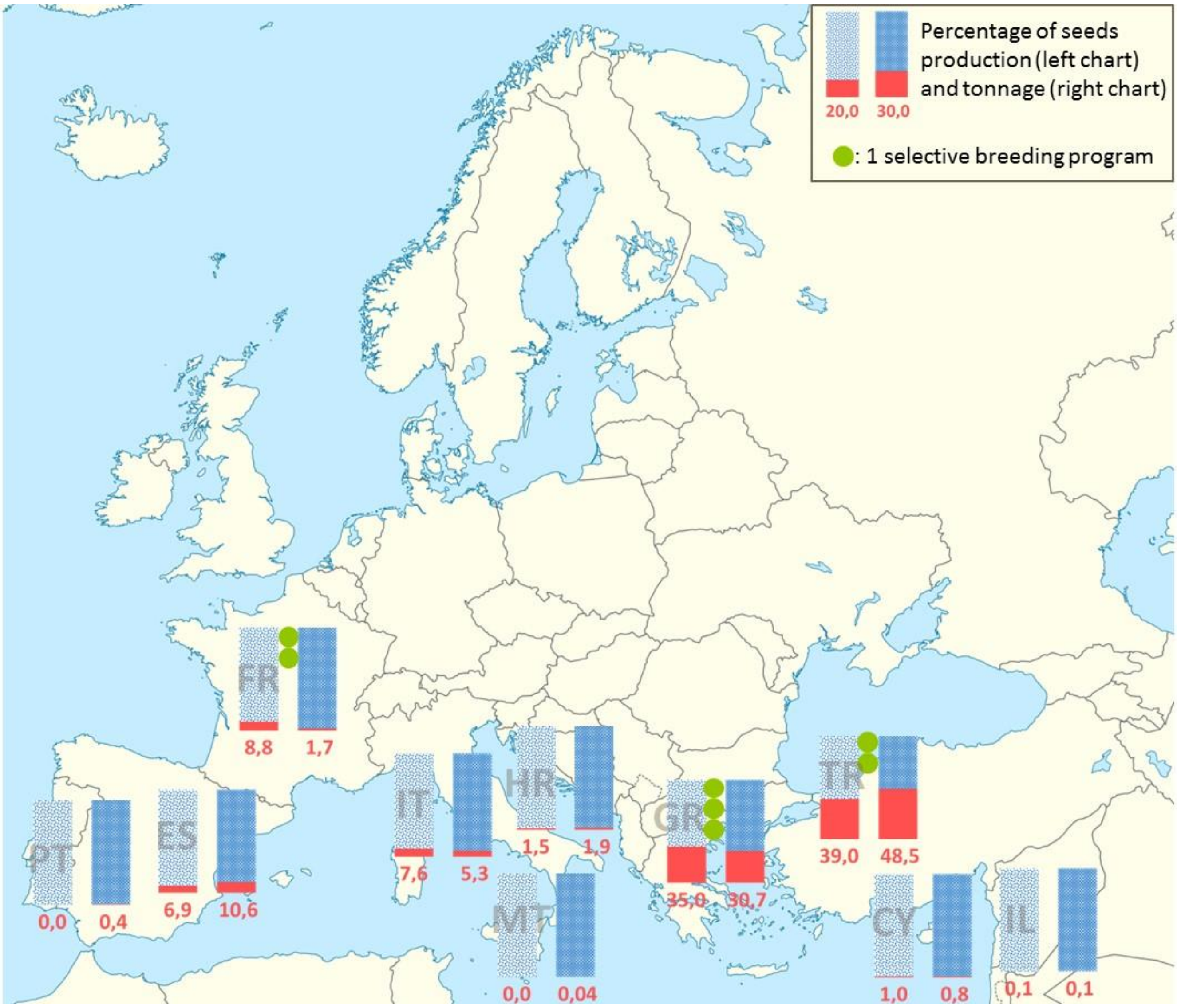
For most breeding companies the transnational trade of seeds is part of an overall effort to reach new customers and increase their market share. If some producers have become major players both in terms of traded seeds and number of export countries, like in the salmon sector, others are still producing seeds for their own needs or for a limited number of customers, in particular for the marine fish species where the genetic added-value of selected seeds is not fully recognized yet.

To this day, two models of hatcheries subsist and differentiate according to the species. The salmon model is where the selected candidates are transferred to the multiplier stations to provide sufficient commercial seeds for smolts production and final grow-out. The transfer of the genetic progress is so deferred of one generation in production for seeds dissemination. On the other side the marine fish hatcheries are characterized by a horizontal organisation: the breeding company is most often combined with a commercial farm and no intermediate multipliers are required. In these two models the key factor is biological, and more specifically it is linked to the fecundity which varies by a factor of 100 between salmonids (2-3.000 eggs/kg body weight) and marine fish species (up to 2-400.000 eggs/kg body weight). So a legitimate question may be raised as to whether both models can subsist or if one of them will prevail. Based on the present survey collected data on the seeds market, but also by observing the basic trend of merging of companies giving rise to larger players, it appears that the need to adopt a multiplier strategy may emerge for the biggest marine fish hatcheries. It will then be necessary to draw attention against the risks of a large dissemination of homogenous seeds, with reduced genetic diversity. And, for the marine fishes having large ranges of distribution and production, to remain vigilant to ensure that the genetic by environment interactions are properly taken into account.

Annex 1: List of the surveyed organisations.

Survey respondents	Country	Selected species
Andromeda Group	Greece	European seabass & Gilthead seabream
AquaGen AS	Norway	Rainbow trout & Atlantic salmon
AquaSearch	Denmark	Rainbow trout
Ardag Ltd	Israel	Gilthead seabream
Azienda Agricola Grossi	Italy	Rainbow trout
Bretagne Aquaculture	France	Rainbow trout
Cluster de la Acuicultura de Galicia	Spain	Turbot
Culmasur	Spain	Gilthead seabream
Ege University & Akvatek	Turkey	European seabass
Finnish Game and Fisheries Research Institute	Finland	Rainbow trout
Fischzucht Peter Störk	Germany	Rainbow trout
Hofer Forellen GmbH	Germany	Rainbow trout
Inland Fisheries Institute	Poland	Rainbow trout
Institute of Ichthyobiology and Aquaculture	Poland	Common carp
Landcatch	United Kingdom	Atlantic salmon
Marine Harvest	Ireland	Atlantic salmon
Marine Harvest	Norway	Atlantic salmon
Murgat	France	Rainbow trout
Nireus Aquaculture SA	Greece	European seabass & Gilthead seabream
Rauma Stamfisk AS	Norway	Atlantic salmon
Research Institute for Fisheries and Aquaculture	Hungary	Common carp
Salmobreed	Norway	Atlantic salmon
Selonda A.S.	Greece	European seabass & Gilthead seabream
South Bohemia University	Czech Republic	Common carp
Stofnfiskur	Iceland	Atlantic salmon
TroutEX	Denmark	Rainbow trout
Warsaw University of Life Sciences	Poland	Common carp
plus some others …		

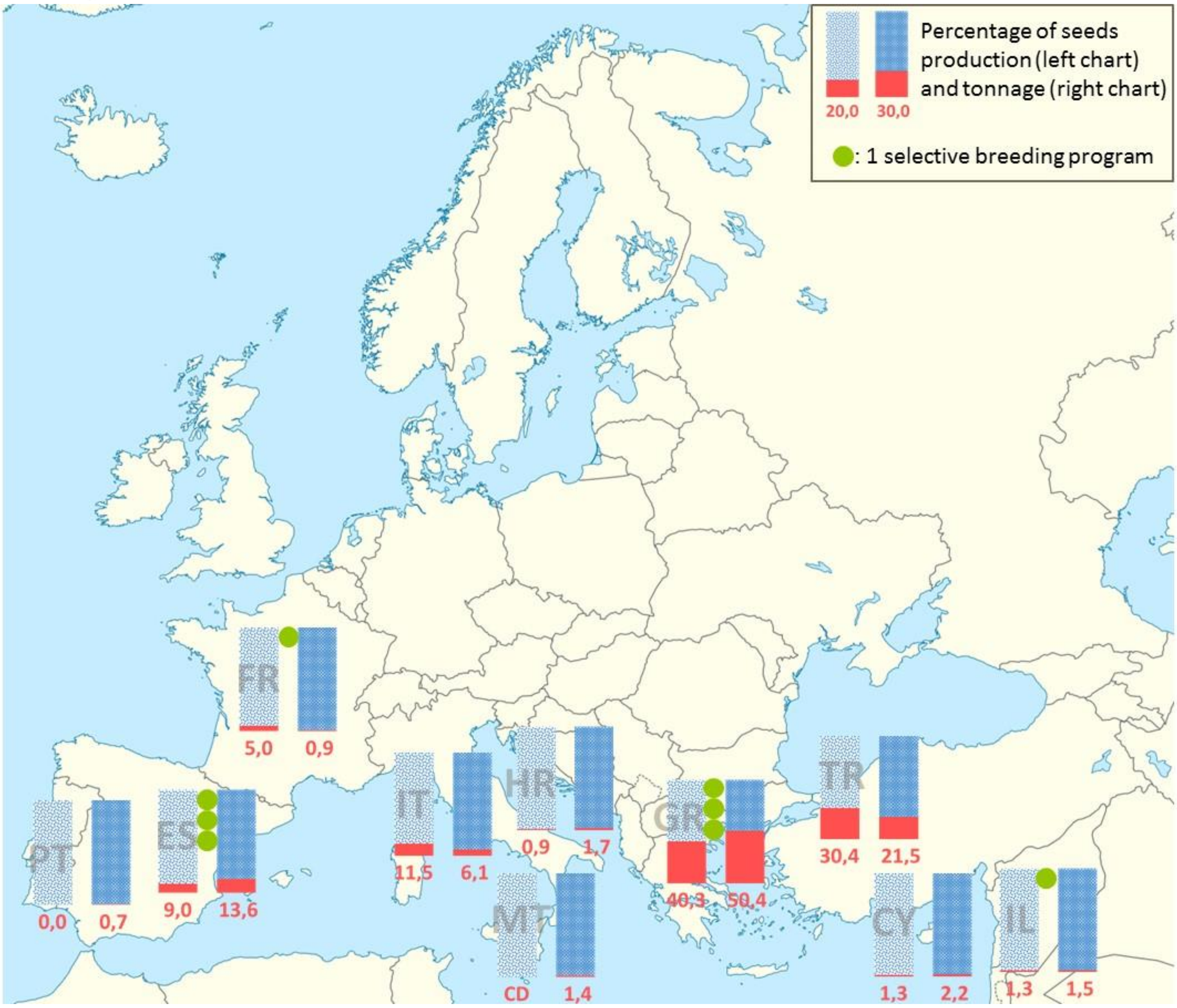
Annex 2: Geographical distribution of surveyed and alleged selective breeding programs on European seabass in relation with the percentage of the juveniles production and the tonnage at the European level (plus Israel and Turkey).



CY: Cyprus; ES: Spain; FR: France; GR: Greece; HR: Croatia; IL: Israel; IT: Italy; MT: Malta; PT: Portugal; TR: Turkey.

Sources: see paragraph 'Questions related to the market seeds study'.

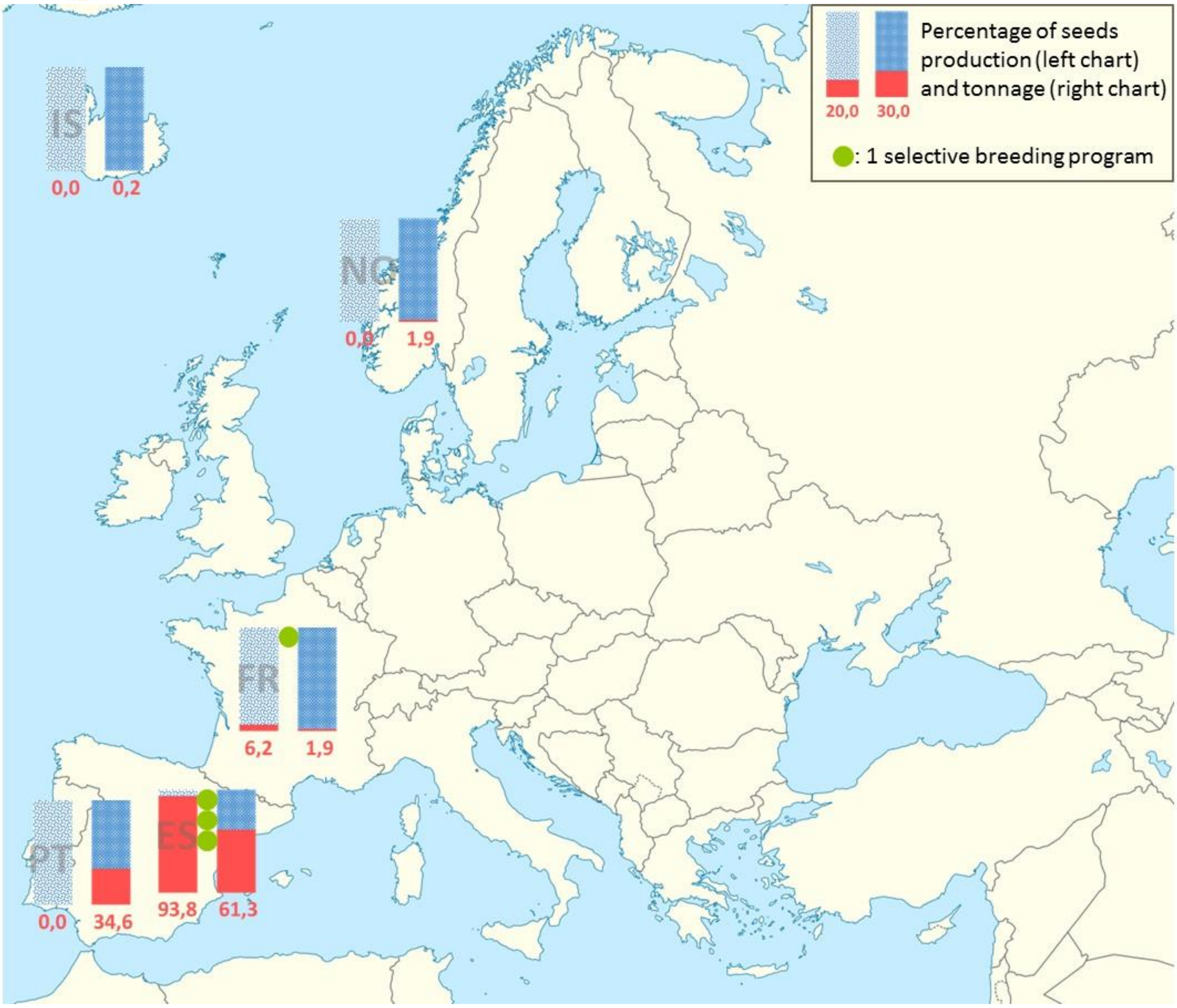
Annex 3: Geographical distribution of surveyed and alleged selective breeding programs on gilthead seabream in relation with the percentage of the juveniles production and the tonnage at the European level (plus Israel and Turkey).



CY: Cyprus; ES: Spain; FR: France; GR: Greece; HR: Croatia; IL: Israel; IT: Italy; MT: Malta; PT: Portugal; TR: Turkey. CD: confidential data.

Sources: see paragraph ‘Questions related to the market seeds study’.

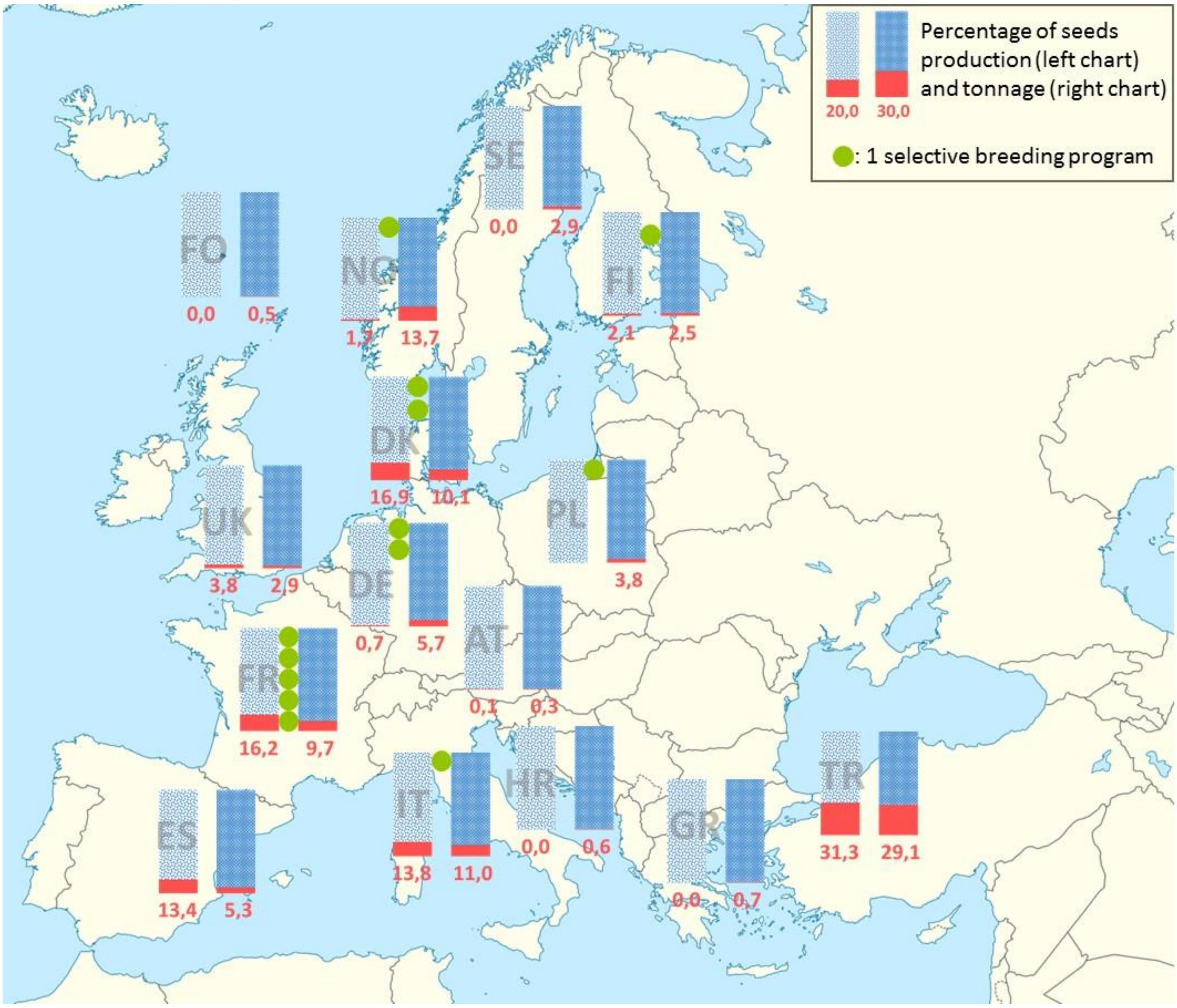
Annex 4: Geographical distribution of surveyed and alleged selective breeding programs on turbot in relation with the percentage of the juveniles production and the tonnage at the European level (plus Israel and Turkey).



ES: Spain; FR: France; IS: Iceland; NO: Norway; PT: Portugal.

Sources: see paragraph 'Questions related to the market seeds study'.

Annex 5: Geographical distribution of surveyed and alleged selective breeding programs on rainbow trout in relation with the percentage of the eggs production and the tonnage at the European level (plus Israel and Turkey).

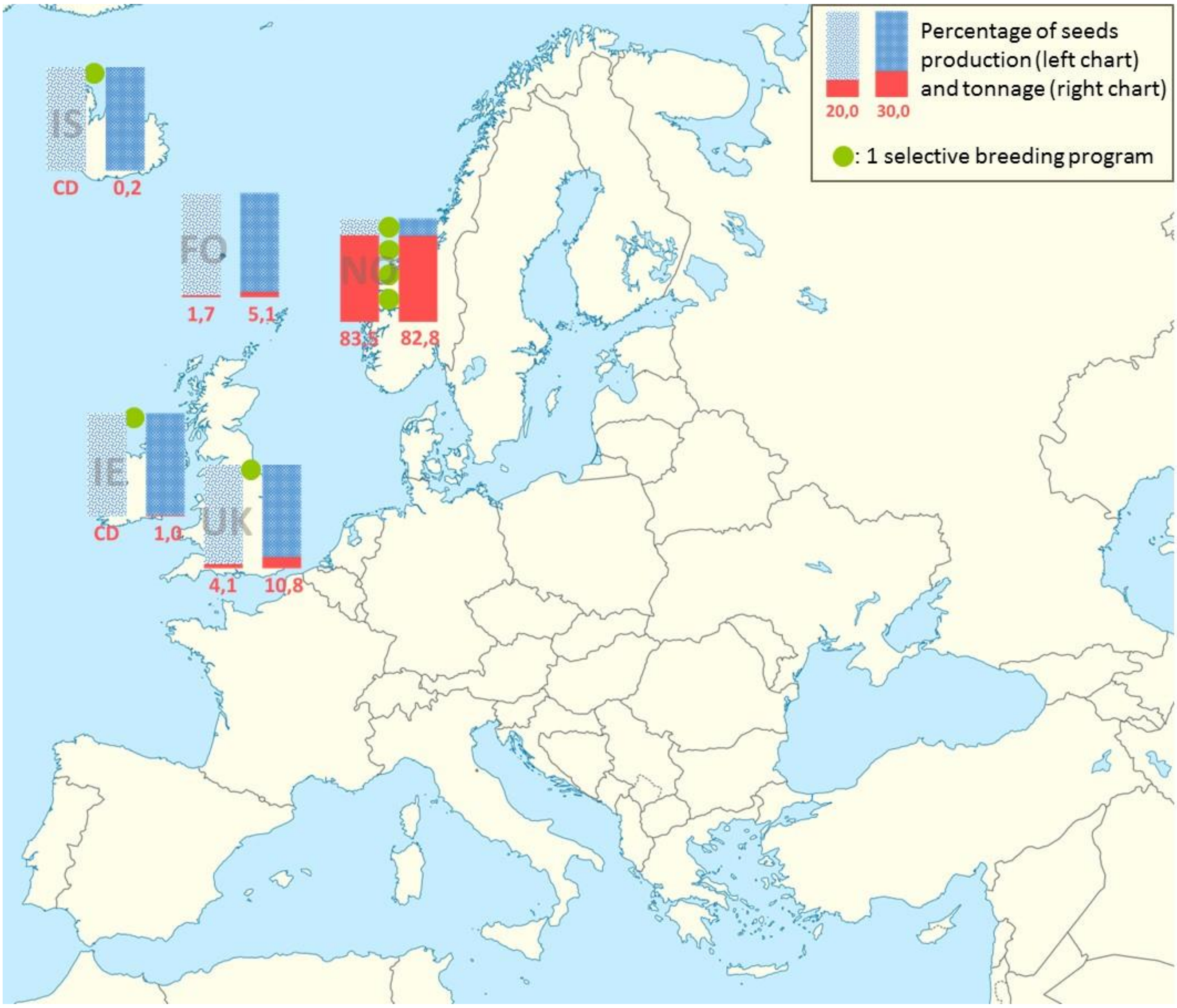


AT: Austria; DE: Germany; DK: Denmark; ES: Spain; FR: France; FI: Finland; FO: Faroe Islands; GR: Greece; HR: Croatia; IT: Italy; NO: Norway; PL: Poland; SE: Sweden; TR: Turkey; UK: United Kingdom.

Countries with a tonnage production lower than 0.5% are not represented in the map: Cyprus (0.02%), Czech Republic (0.2%), Hungary (0.02%), Iceland (0.1%), Ireland (0.4%), Israel (0.1%), The Netherlands (0.01%) and Portugal (0.2%).

Sources: see paragraph 'Questions related to the market seeds study'.

Annex 6: Geographical distribution of surveyed selective breeding programs on Atlantic salmon in relation with the percentage of the eggs production and the tonnage at the European level.

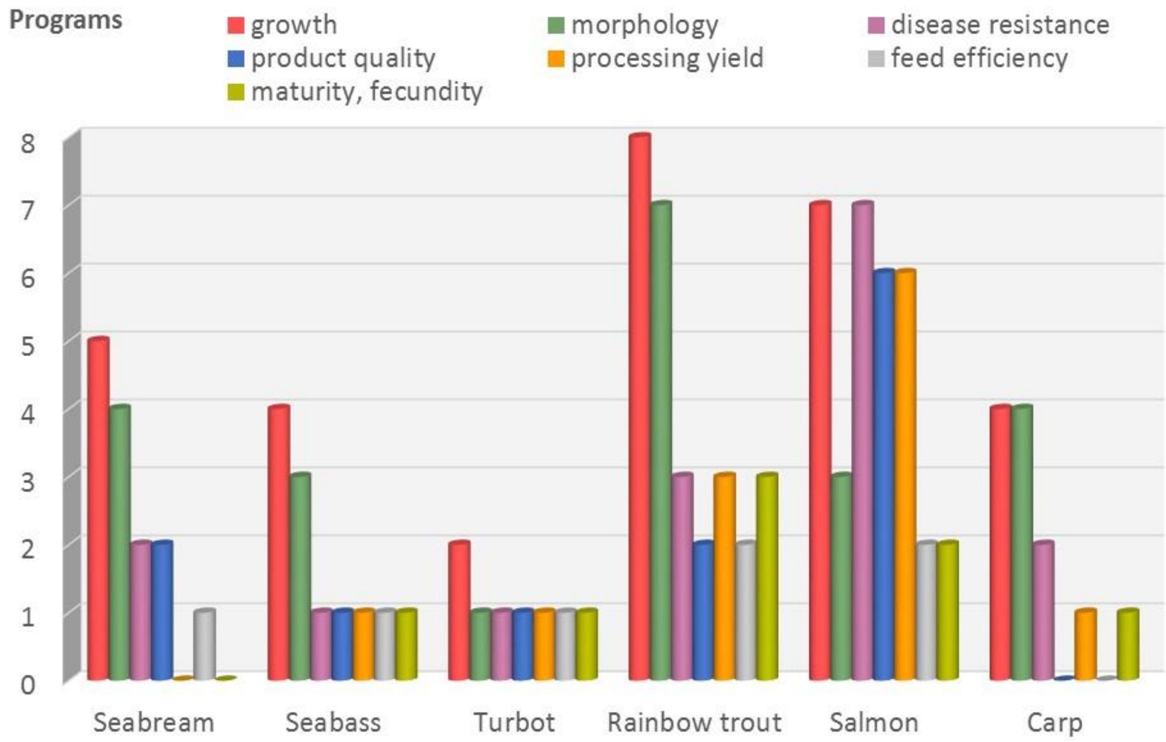


FO: Faroe Islands; IE: Ireland; IS: Iceland; NO: Norway; UK: United Kingdom. CD: confidential data.

Sources: see paragraph 'Questions related to the market seeds study'.

<u>Annex 7</u>:

7.1. Number of programs according to the selected traits, grouped by species



7.2. Number of selected traits by species and program.

Number of selected traits	Species	Number of programs
1	Seabass	1
	Seabream	3
	Turbot	1
2	Carp	1
	Rainbow trout	3
	Salmon	1
	Seabass	1
3	Carp	1
	Rainbow trout	1
	Seabass	1
	Seabream	2
4	Carp	2
	Rainbow trout	2
	Salmon	3
5	Rainbow trout	1
	Seabream	1
6	Salmon	2
	Seabass	1
7	Rainbow trout	1
	Salmon	1
	Turbot	1

Annex 8: Seeds production in the European aquaculture (thousands). [1]: juveniles; [2]: eggs laid down to hatch. *md*: missing data; *cd*: confidential data.

	European seabass[1]	**Gilthead seabream[1]**	**Turbot[1]**	**Rainbow trout[2]**	**Atlantic salmon[2]**
Austria				2.448	
Bulgaria					
Croatia	8.100	5.400			
Cyprus	5.280	7.976			
Czech Republic					
Denmark				323.810	
Faroe Islands					12.500
Finland				40.000	
France	46.000	30.400	1.262	310.000	
Germany				13.300	
Greece	184.000	**245.000**			
Hungary					
Iceland					*cd*
Ireland					*cd*
Israel	427	7.659			
Italy	40.000	70.000		265.000	
Malta		*cd*			
The Netherlands					
Norway				31.899	**604.245**
Poland				*md*	
Portugal					
Spain	36.423	54.985	**18.950**	257.831	
Sweden				*md*	
Turkey	**205.000**	185.000		**600.000**	
UK				73.840	30.000
Total	525.230	608.638	20.212	1.918.128	723.615

Sources: see paragraph 'Questions related to the market seeds study'.

Acknowledgments:

This work is the result of the collaborative effort of researchers in the FP7 projects AquaTrace and FishBoost. A report including a more extensive review of the seeds market will be delivered by the Fishboost project.

The AquaTrace project acknowledges with appreciation the many people who helped in the preparation and follow-up of the survey, in particular the national contacts who contributed in providing national production statistics when authoritative statistics were missing.

The AquaTrace project also gratefully acknowledges the survey's respondents for providing extensive technical information, which was crucial to fine-tune our survey on a wider range of issues.

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