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THE STATE
OF THE WORLD's
AQUATIC GENETIC RESOURCES FOR FOOD AND AGRICULTURE

COMMISSION ON GENETIC RESOURCES FOR FOOD AND AGRICULTURE
FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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ABBREVIATIONS AND ACRONYMS

ABS	access and benefit sharing
AqGR	aquatic genetic resources
ASFIS	Aquatic Sciences and Fisheries Information System
BAC	bacterial artificial chromosome
CBD	Convention on Biological Diversity
CCRF	Code of Conduct for Responsible Fisheries
CGRFA	Commission on Genetic Resources for Food and Agriculture
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CMS	Convention on the Conservation of Migratory Species of Wild Animals
COFI	FAO Committee on Fisheries
COFI AWG AqGR/T	COFI Advisory Working Group on Aquatic Genetic Resources and Technologies
CRISPR	clustered regulatory interspaced short palindromic repeats
CRISPR/Cas	clustered regularly interspaced short palindromic repeats-CRISPR associated
ddRADseq	DNA sequencing
DIAS	Database on Introductions of Aquatic Species
DNA	deoxyribonucleic acid
DPS	distinct population segment
EAF	Ecosystem Approach to Fisheries
ESA	Endangered Species Act
EST	expressed sequence tag
ESU	evolutionarily significant unit
EU	European Union
EUSDR	EU Strategy for the Danube Region
FAM	freshwater aquatic macrophyte
FAO	Food and Agriculture Organization of the United Nations
FAO/FI	FAO Fisheries and Aquaculture Department
FPA	freshwater protected area
GIFT	genetically improved farmed tilapia
GMAD	Global Marine Aquarium Database
GMO	genetically modified organism
GSI	genetic stock identification
ICES	International Council for the Exploration of the Sea
ICPR	International Commission for the Protection of the Rhine
IGO	intergovernmental organization or international governmental organization
INGA	International Network on Genetics in Aquaculture
ISSCAAP	International Standard Statistical Classification of Aquatic Animals and Plants
ITWG AqGR	Intergovernmental Technical Working Group on Aquatic Genetic Resources
IUCN	International Union for Conservation of Nature
MAS	marker-assisted selection
MPA	marine protected area
MTA	Material Transfer Agreement
mtDNA	mitochondrial DNA
nei	not elsewhere included
NGO	non-governmental organization
NFPA	National Framework for Priority Action
OIE	World Organisation for Animal Health
PPP	public-private partnership

QTL	Quantitative Trait Loci
RAPD	random amplified polymorphic DNA
RFLP	restriction fragment length polymorphism
RNA	ribonucleic acid
RNA-seq	ribonucleic acid sequencing
SADC	Southern African Development Community
SMS	single molecule sequences
SNP	single nucleotide polymorphism
SOFIA	State of World Fisheries and Aquaculture
SoW AqGR	State of the World's Aquatic Genetic Resources for Food and Agriculture
TALEN	transcription activator-like effector nuclease
UNCLOS	United Nations Convention on the Law of the Sea
UNFCCC	United Nations Framework Convention on Climate Change
USGS	United States Geological Service
ZFN	zinc finger nuclease

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The Report was prepared and finalized by a core team in the FAO Fisheries and Aquaculture Department under the overall coordination of Matthias Halwart. The Report is based on a questionnaire that was initially developed by Roger S.V. Pullin and Devin M. Bartley. Enrico Anello turned the questionnaire into a user friendly dynamic PDF that was distributed to all FAO Member Countries and key partners. This questionnaire formed the basis of the countries' reporting to FAO.

Capacity building workshops were organized mainly in collaboration with regional fishery bodies and aquaculture networks including Lake Victoria Fisheries Organization, African Union – Interafrican Bureau for Animal Resources, Network of Aquaculture Centres in Asia and the Pacific, Central America Fisheries and Aquaculture Organization, and partner institutions in the People's Republic of China. These workshops were essential in helping countries understand the type of information requested by the questionnaire. The Government of Germany was a key partner in this process providing both financial and technical support to the workshops.

The main body of information synthesized in the Report came from the Country Reports submitted by 92 governments. These governments, their national focal points and the numerous individuals who provided information to the country reports are especially acknowledged for their important contributions.

Once the Country Reports were received by FAO, Enrico Anello and Anthony Jarret incorporated the information into a database and developed a system to query the data. Ruth Garcia-Gomez and Zhiyi Zhang extracted and organized information from the database for use by the authors of the various chapters in the Report.

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Details of the authors of the individual chapters and the thematic background studies are provided in the table below. The technical editorial team of Matthias Halwart, Devin M. Bartley, Graham Mair and Austin Stankus is gratefully acknowledged for improving each chapter and the overall Report.

Section	Title	Author(s)
Introduction	Introduction	Matthias Halwart
Chapter 1	The state of world aquaculture and fisheries	Graham C. Mair, Xiaowei Zhou, Simon Funge-Smith
Chapter 2	The use and exchange of aquatic genetic resources of farmed aquatic species and their wild relatives within national jurisdiction	Devin M. Bartley
Chapter 3	Drivers and trends in aquaculture: consequences for aquatic genetic resources within national jurisdiction	Simon Funge-Smith
Chapter 4	*In situ* conservation of farmed aquatic species and their wild relatives within national jurisdiction	Devin M. Bartley
Chapter 5	*Ex situ* conservation of aquatic genetic resources of farmed aquatic species and their wild relatives within national jurisdiction	Ruth Garcia-Gomez
Chapter 6	Stakeholders with interests in aquatic genetic resources of farmed aquatic species and their wild relatives within national jurisdictions	Malcolm Beveridge
Chapter 7	National policies and legislation for aquatic genetic resources of farmed aquatic species and their wild relatives within national jurisdiction	Devin M. Bartley
Chapter 8	Research, education, training and extension on aquatic genetic resources within national jurisdiction: coordination, networking and information	Ruth Garcia-Gomez
Chapter 9	International collaboration on aquatic genetic resources of farmed aquatic species and their wild relatives	Matthias Halwart
Chapter 10	Synthesis of key findings and conclusions	Matthias Halwart, Graham Mair, Devin M. Bartley, Austin Stankus

Thematic Background Studies[1]	Author(s)
Incorporating genetic diversity and indicators into statistics and monitoring of farmed aquatic species and their wild relatives	Devin M. Bartley and Xiaowei Zhou
Genome based biotechnologies in aquaculture	Zhanjiang Liu
Genetic resources for farmed seaweeds	Anicia Q. Hurtado
Genetic resources for farmed freshwater macrophytes	William Leschen
Genetic resources for microorganisms of current and potential use in aquaculture	Russell T. Hill

[1] Available at http://www.fao.org/aquatic-genetic-resources/background/sow/background-studies/en/

INTRODUCTION

Background

Aquatic genetic resources (AqGR) for food and agriculture are a core function of the work of the Food and Agriculture Organization of the United Nations (FAO). The FAO Fisheries and Aquaculture Department (FAO/FI) has been requested by Member Countries, through the FAO Commission on Genetic Resources for Food and Agriculture (CGRFA), to lead the process towards production of the Report on *The State of the World's Aquatic Genetic Resources for Food and Agriculture* (the Report). Therefore, in 2007, the Commission called upon its Members to initiate steps for determining the current state of their AqGR for food and agriculture. Since then, this work has been supported by FAO/FI and by the Commission itself.

The Report will be the first global assessment on AqGR for food and agriculture based on national reporting. The scope of the Report, as decided at the Fourteenth Regular Session of the Commission, is farmed aquatic species and their wild relatives within national jurisdiction.[2]

Process

In 2012, following the process established by the Commission, FAO invited countries to nominate National Focal Points and to prepare and submit Country Reports, which would be the main source of information for the preparation of the Report. In 2012, FAO/FI provided guidelines to all National Focal Points, in the form of a structured questionnaire[3] and methodology, to aid in the preparation of these Country Reports.

It was envisaged that the development of the Country Reports would be an opportunity to conduct a national strategic exercise for assessing the status of AqGR at the national level, and to reflect on the needs and priorities for their sustainable management, development, conservation and use. In order to develop the capacity of National Focal Points and other national representatives on the preparation of the Country Reports, FAO/FI organized a series of regional workshops, in collaboration with partners in the aquaculture sector.

The Report was prepared as a country-driven process, which accomplished the following steps:

(i) Commission Members submitted their Country Reports on the status of AqGR to FAO;

(ii) FAO/FI reviewed these Country Reports and incorporated the information into a database;

(iii) data were analysed and incorporated into the Report;

(iv) FAO/FI compared, where appropriate, the data provided by countries in their Country Reports to official statistical data received from Members in order to identify information gaps, possible inconsistencies and limitations on the number of species reported as farmed within the aquaculture sector in each country;

(v) FAO/FI led the preparation of five Thematic Background Studies (TBS) (Table 1), which are intended to complement Country Reports in thematic areas where scientific and official data and information are missing, outdated or where significant knowledge gaps persist;

(vi) FAO/FI incorporated reports on the status of AqGR for food and agriculture from relevant international, regional and subregional organizations; and

(vii) FAO/FI incorporated guidance and revisions, as detailed hereafter.

[2] www.fao.org/docrep/meeting/028/mg538e.pdf, paragraph 76.
[3] www.fao.org/3/a-bp506e.pdf.

Table 1
Selected thematic background studies commissioned to complement data from Country Reports

Subject	Rationale
Incorporating genetic diversity and indicators into statistics and monitoring of farmed aquatic species and their wild relatives	Production and value statistics for farmed aquatic species and their wild relatives are highly aggregated to species or community levels, with many not even identifying the species used. Management of fish stocks, traceability of fish and fish products, and oversight and development of responsible aquaculture require management of genetic diversity linked to production. Increasingly, resource managers and development communities are asked to identify indicators of the status of aquatic genetic resources (AqGR). Once better production data are available, indicators can be developed for monitoring and assessment.
Biotechnology and genomics in aquaculture	Aquaculture is making increasing use of biotechnology and application of genomic research for domestication, increased production, improved management, and better traceability of fish and fish products in the supply chain. With advances often outpacing the development of policy and regulatory frameworks and consumer awareness, the key is to harness biotechnology for beneficial ends, with biosecurity ensured through precaution and sound management of risks and through understanding consumers' attitudes.
Genetic resources for farmed seaweeds	The farming of seaweeds to produce material for food processing and other industries, as well as products for direct consumption as human food, is one of the world's largest aquaculture subsectors. Because of their increasing relevance as genetic resources for food security, they require coverage in a *State of the World Report*, as they have often been omitted from other reports.
Genetic resources for farmed freshwater aquatic macrophytes (FAMs)	The cultivation and consumption of FAMs and their impact on food security has long been unrecognized and under-recorded despite their significant contribution to food production and nutrient recycling. This study is focused on the main FAMs cultivated for provision of human food and other uses as the treatment of wastewater or the production of supplementary feed in a number of farming systems.
Genetic resources of microorganisms of current and potential use in aquaculture	Bacteria, cyanobacteria, microalgae and fungi are cultured extensively as feed sources in aquaculture. Some bacteria are used as probiotics to enhance fish growth and health. Many species and strains of microalgae are kept as *ex situ* culture collections. The genetic resources of these important microorganisms for food and agriculture require coverage in a *State of the World Report*.

Fifty-seven Country Reports had been received as of May 2016; forty-seven of which were reviewed and analysed in the *First Draft State of the World's Aquatic Genetic Resources for Food and Agriculture* (the First Draft Report). During the First Session of the Ad Hoc Intergovernmental Technical Working Group on Aquatic Genetic Resources (ITWG AqGR), held in Rome in June 2016, the First Draft Report was discussed and reviewed. The recommendations from this first session included the following:

- identify individual countries in the analysis in addition to the summaries by region or subregion, as appropriate;
- include specific country examples and case studies to illustrate issues, where relevant;
- provide an analysis by developing versus developed countries, as appropriate;
- include some examples of new species and farmed types identified from Country Reports that have not been previously been reported to FAO;
- revise the references to all countries to ensure they accurately reflect the information provided in Country Reports, in particular in the last part of sub-chapter 7.2 of Chapter 7;

- revise the conclusions of sub-chapter 7.4 of Chapter 7 that cannot be inferred from the information contained in the Report, in particular on access and benefit-sharing regimes;
- streamline the quotation in the last paragraph of sub-chapter 6.5 of Chapter 6;
- use additional information (e.g. from scientific literature, international, regional and national organizations and networks, and advanced scientific institutions) to complement Country Reports and contribute to a more comprehensive assessment;
- harmonize definitions throughout the Report and provide a full glossary of key terms;
- clearly identify all sources of information, including in tables and figures;
- provide an in-depth analysis of findings, including, *inter alia*, on climate change, habitat change and invasive species, as drivers impacting AqGR;
- distinguish between policies and strategies and include soft law instruments, such as codes of conduct and voluntary guidelines;
- clarify some of the concepts referred to in the chapters (e.g. *in situ* conservation and access and benefit-sharing regimes);
- acknowledge the challenges of collaboration for the management of AqGR, especially for the transboundary conservation of migratory species;
- include some specific examples of successful AqGR *ex situ* and *in situ* conservation programmes and strategies, and stress the complementarity of the two conservation approaches;
- acknowledge the value of aquatic protected areas in conserving AqGR; a balance between conservation and development must be maintained, accounting for conditions in different areas;
- demonstrate the close linkages between aquaculture and capture fisheries systems that depend on wild AqGR;
- ensure that information provided complements the information contained in *The State of World Fisheries and Aquaculture* (SOFIA);
- include an analysis of how effectively the various networks contribute to the sustainable use and conservation of AqGR; and
- highlight key findings and gaps requiring a policy response to improve the sustainable use and conservation of AqGR.

The reports of the First Session of the COFI Advisory Working Group on Aquatic Genetic Resources and Technologies (COFI AWG AqGR/T) and the CGRFA ITWG AqGR were presented to the Sixteenth Session of the Commission. During that session, the Commission invited countries that had not yet done so to submit their reports by 30 June 2017 and invited countries that had already submitted a Country Report to submit a revised version by the same date.

By the end of June 2017, 35 new Country Reports had been submitted. In the Revised Draft Report, all the 92 submitted Country Reports were reviewed and considered (Table 2). Recommendations from the Committee on Fisheries (COFI) subsidiary bodies, the thematic background studies, and reports from international organizations were considered in the preparation of this Revised Draft Report.

In this Revised Draft Report, the analysis by region was adjusted to be consistent with FAO's analyses of fisheries and aquaculture statistics. The relative response was indicative of how representative the Country Reports are per region. Countries in all six regions responded, with greatest levels of response from North America (100% of countries) and Asia (64%) (Table 3).

Table 2
Country Reports received from FAO Members as of July 2017 by region (number of countries in region)

Africa (27)	**Asia (21)**	**Europe (17)**	**Latin America & the Caribbean (18)**	**North America (2)**	**Oceania (7)**
Algeria	Armenia	Belgium	Argentina	Canada	Australia
Benin	Bangladesh	Bulgaria	Belize	United States of America	Fiji
Burkina Faso	Bhutan	Croatia	Brazil		Kiribati
Burundi	Cambodia	Czechia	Chile		Palau
Cabo Verde	China	Denmark	Colombia		Samoa
Cameroon	Cyprus	Estonia	Costa Rica		Tonga
Chad	Georgia	Finland	Cuba		Vanuatu
Democratic Republic of the Congo	India	Germany	Dominican Republic		
Djibouti	Indonesia	Hungary	Ecuador		
Egypt	Iran (Islamic Republic of)	Latvia	El Salvador		
Ghana	Iraq	Netherlands	Guatemala		
Kenya	Japan	Norway	Honduras		
Madagascar	Kazakhstan	Poland	Mexico		
Malawi	Lao People’s Democratic Republic	Romania	Nicaragua		
Morocco	Malaysia	Slovenia	Panama		
Mozambique	the Philippines	Sweden	Paraguay		
Niger	Republic of Korea	Ukraine	Peru		
Nigeria	Sri Lanka		Venezuela (Bolivarian Republic of)		
Senegal	Thailand				
Sierra Leone	Turkey				
South Africa	Viet Nam				
Sudan					
United Republic of Tanzania					
Togo					
Tunisia					
Uganda					
Zambia					

Table 3
Number and percentage of countries per region that have submitted Country Reports

Region	Total number of countries	Number of responding countries	Percentage
Africa	54	27	50
Asia	33	21	64
Europe	43	17	40
Latin America & the Caribbean	47	18	38
North America	2	2	100
Oceania	17	7	41

The reporting countries were also categorized by economic class. The definition of the categories used in this report is consistent with the economic class categories used by the statistics unit of the FAO Fisheries and Aquaculture Department.[4] Ninety-two Members (47% of the total Member Countries of FAO) responded, with the largest proportion of the 92 responses coming from countries categorized as "other developing countries" (50%). Although the fewest responses (23) came from least developed countries, it was developed countries that had proportionally the lowest response rate (Table 4).

Table 4
Number of countries submitting Country Reports in each economic class

Economic class	Number of countries	Number of responding countries	Percentage
Least Developed Countries	50	23	46
Other Developing Countries	88	44	50
Developed Countries	58	25	43

The COFI Sub-Committee on Aquaculture, at its Ninth Session, welcomed the forthcoming report on *The State of the World's Aquatic Genetic Resources for Food and Agriculture* and recognized that it will facilitate identification of challenges and opportunities in the development, management and conservation of AqGR.[5] The Report was discussed during the Second Session of the COFI AWG AqGR/T, which was held in Rome in October 2017. Among the recommendations was that analyses be conducted according to a country's level of aquaculture production. Countries were therefore grouped into:

(i) Major producing countries that produced more than 1 percent of global aquaculture production; and
(ii) Minor producing countries that produced less than 1 percent.

Eleven countries were identified as Major producing countries, namely China, Indonesia, India, Viet Nam, the Philippines, Bangladesh, the Republic of Korea, Norway, Egypt, Japan and Chile. These countries collectively produced 91 percent of global aquaculture production. All the Major producing countries submitted Country Reports, while 44 percent of the Minor producing countries responded (81) (Table 5). Altogether, the 92 Country Reports represent approximately 96 percent of global aquaculture production.

[4] www.fao.org/faostat/en/#definitions
[5] www.fao.org/3/i8886t/I8886T.pdf, paragraph 46.

Table 5
Number and percentage of countries by level of aquaculture production that have submitted Country Reports

Category	Total number of countries	Number of respondents	Percentage
Major Producing Countries	11	11	100
Minor Producing Countries	185	81	44

The primary basis for reporting of AqGR in the Country Reports was at the level of species and below that, at the level of farmed types. FAO, as a repository for global statistics on fisheries and aquaculture, strives for accurate and consistent information that is necessary and useful to Member Countries and concerned parties for monitoring the status and development trend in species. Towards that end, an ASFIS (Aquatic Sciences and Fisheries Information System) List of Species for Fishery Statistics Purposes was previously developed to maintain and promote a standard system of nomenclature for and to provide analysis of the world's aquatic species that are produced in fisheries and aquaculture. Both the questionnaire on which Country Reports are based and this Report have adopted the ASFIS nomenclature.

However, it is recognized that the field of taxonomy is not static and that some groups or individuals have adopted different nomenclature for certain groups of aquatic species, e.g. the taxonomic revision of the genus *Penaeus* (Flegal, 2007). The ASFIS, with its long list of species items maintained and annually updated by FAO, is primarily for statistical purposes. Therefore, although striving for correctness, FAO adopts a conservative approach in general to changing nomenclature because of fear that such changes would cause confusion among users of the databases. The list is reviewed regularly, and some names have been changed, such as the case of rainbow trout, where *Salmo gairdneri* became *Oncorhynchus mykiss*. Notably, this change occurred only after it was widely accepted by the fishery/aquaculture community. The ASFIS list is a living document and users can help keep the list useful by adhering to accepted nomenclature and by alerting FAO to widely accepted changes to that nomenclature. For the purposes of consultation, the latest edition of the published ASFIS list can be downloaded from the link: www.fao.org/fishery/collection/asfis/en.

During the Second Session of the ITWG AqGR, which was held in Rome in April 2018, the Revised Draft Report was discussed and reviewed. The ITWG AqGR reiterated that the scope of the Report is farmed species and their wild relatives within national jurisdiction. It recognized that the focus and data availability on production do not reflect the diversity of AqGR at global and national levels. It noted that data and information are often provided at the species level and suggested that future assessments and related capacity development in characterization and monitoring of AqGR should provide more detailed information below the species level (e.g. farmed types).

The ITWG AqGR stressed the importance of selective breeding, cross-breeding and other approaches to aquatic genetic improvement, particularly in response to drivers such as disease resistance and suitability for intensive production methods, and recommended that this be highlighted in the Report. The Working Group also recommended that the Report reflect more comprehensively the impacts of non-native species on wild relatives and ecosystems.

While highlighting the importance of *in situ* and *ex situ* conservation, specifically live gene banking, the ITWG AqGR also noted the importance of maintaining appropriate levels of genetic diversity in conservation schemes to minimize, for example, inbreeding. The ITWG AqGR discussed conservation methods used for stock enhancement, noting the importance of minimizing selection for farm conditions to prevent potential adverse effects in the wild population. It requested that these topics be addressed in the Report and its key messages.

The ITWG AqGR noted the need for clarification in the Report of the concepts of *in situ* and *ex situ* conservation, especially with regard to on-farm and *in situ* conservation and through stock enhancement. The ITWG AqGR also noted the challenges of some countries carrying out *in situ* and *ex situ* conservation programmes. It recommended that the CGRFA request FAO to support countries, upon request and subject to the availability of financial resources, through technology transfer and capacity development.

The ITWG AqGR noted the importance of open source, peer-reviewed scientific literature as a cost-effective mechanism for sharing information related to AqGR among stakeholders. The ITWG AqGR recommended the inclusion in the Report of information on networks that address AqGR, e.g. the International Network on Genetics in Aquaculture and the General Fisheries Commission for the Mediterranean.

The ITWG AqGR recommended that the impact of international agreements on stakeholders be more fully elaborated, either in the form of a text or within a table.

The ITWG AqGR recommended that FAO review the Revised Draft Report to ensure clarity and accuracy. More specifically, it recommended that:

- terms be harmonized throughout the Report, and that the Report adhere to established definitions, where they exist;
- linguistic issues be addressed through copy-editing;
- usage of descriptive categories be harmonized throughout the Report;
- text, figures and table titles are accurate and match with their contents and original country reports; and
- findings are attributed correctly to farmed species, wild relatives or the broader AqGR.

The ITWG AqGR recommended that the Report be finalized and presented to the CGRFA at its next regular session. Additionally, a brief summary of the Report should be prepared in all FAO languages and widely distributed, including to policy-makers in particular.

A word on the process of producing the Report

The questionnaire provided significant new and useful information on the state of the world's AqGR. However, upon analysis of the Country Reports, it became clear that some of the inter-country variability in responses results from the composition of the country teams completing the questionnaires, how much they know about specific terms, how they have defined those terms, and their understanding of the different AqGR of interest. In addition to the regional capacity-building workshops, the guidance provided was for National Focal Points to consult with or involve stakeholders in completing questionnaires. Taken together, all the factors mentioned above introduce an unquantifiable but nonetheless substantive degree of variability, which means the results from the Report should be viewed as indicative and frequently in need of further clarification and investigation.

The published Country Reports will represent a valuable resource both for the countries themselves, as well as for other countries and regions. Along with continued interaction among FAO, the National Focal Points, the Commission and other experts on AqGR, it is hoped that the process of analysing the Country Reports and the database created from them will continue.

References

Flegal, T. 2007. The right to refuse revision in the genus Penaeus. *Aquaculture*, 280: 2–8.

CHAPTER 1

THE STATE OF WORLD AQUACULTURE AND FISHERIES

PURPOSE: Present an overview of the state of the world's aquaculture and fisheries production, detailed by species, regional distribution and production system. In aquaculture particularly, the species farmed has implications for the intensity of the production systems, both whether and how a feeding regime is applied, in which environment they are grown, their economic value, the source of seed/broodstock, and the extent to which the system has domesticated its stock.

KEY MESSAGES:

- Aquaculture represents 54 percent of total production from aquaculture and capture fisheries and 47 percent of food fish production (i.e. excluding aquatic plants, mammals and reptiles).
- Though growth in aquaculture production has slowed in recent decades, it continues to grow at 5.8 percent per annum, a trend that is likely to continue.
- The majority of aquaculture production (64 percent) comes from inland aquaculture.
- Aquaculture production systems are highly diversified in terms of species and systems.
- Capture fisheries production has plateaued over the past two decades, although production from inland fisheries continues to grow.
- Despite stagnant growth, marine fisheries still make up 87.2 percent of global fisheries production with almost half of this production coming from temperate areas.
- More than 90 percent of marine fish stocks are considered overfished or maximally sustainably fished.
- The abundance of wild relatives of cultured species, as indicated by catch records, is depleted or decreasing in many areas.
- A significant component of aquaculture production remains dependent on wild relatives and thus aquaculture and fisheries are closely linked production systems.
- A wide diversity of aquatic organisms for food and agriculture is derived from multiple phyla and encompasses around 2 000 species.
- Developing countries account for the majority of production from both aquaculture and capture fisheries.
- Marine and coastal areas contain the highest number of farmed species and their wild relatives due to the presence of several phyla that are not present in inland waters.

The Food and Agriculture Organization of the United Nations (FAO) reports every two years on *The State of World Fisheries and Aquaculture* (SOFIA).[6] This publication covers issues of, *inter alia*, production, trade, consumption and sustainability, as well as special topics of importance to fisheries and aquaculture and a summary of recent highlights of the Fisheries and Aquaculture Department of FAO.

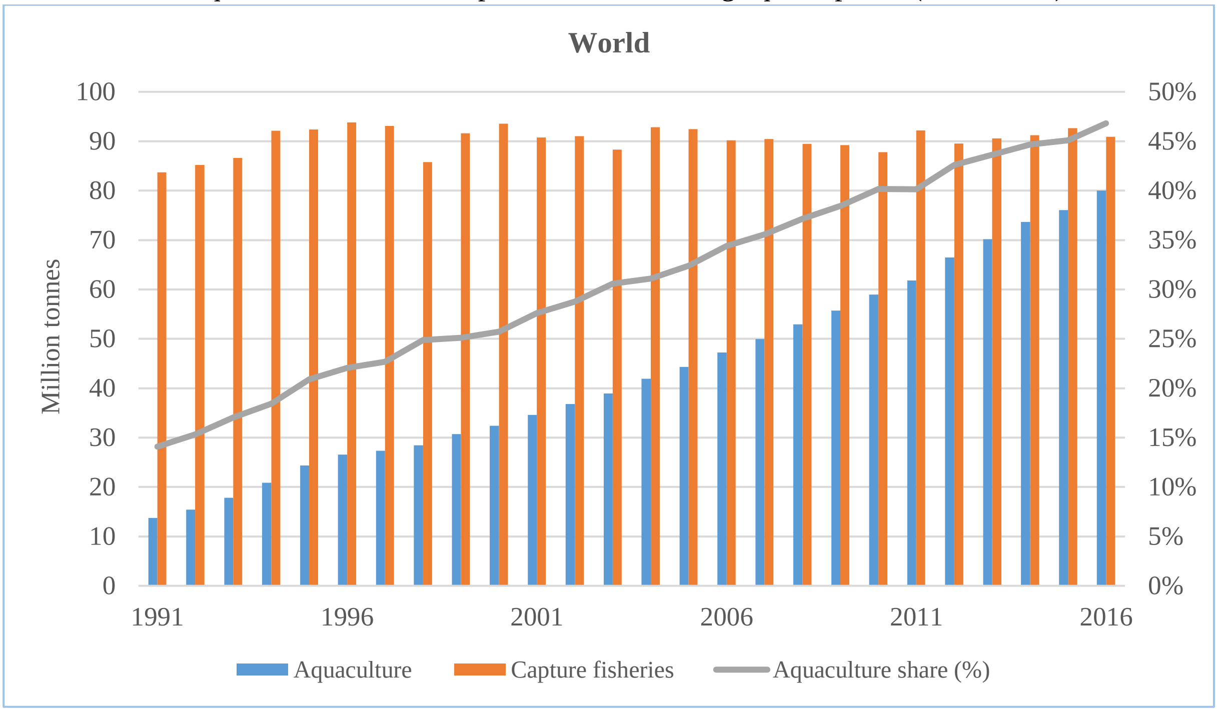
The processes to create SOFIA and *The State of the World's Aquatic Genetic Resources for Food and Agriculture* are complementary and will help facilitate the responsible use of fishery and aquaculture resources.

[6] www.fao.org/fishery/sofia/en.

1.1 Global trend in fisheries and aquaculture production

The contribution of aquaculture (excluding aquatic plants, mammals and reptiles) to the global fish production (capture fisheries and aquaculture combined) has risen continuously, reaching 46.8 percent in 2016, up from 25.7 percent in 2000 (Figure 1). If China is excluded, aquaculture's share reached 29.6 percent in 2016, up from 12.7 percent in 2000 (data not shown). If all production is included, aquaculture now exceeds capture fisheries production (Figure 2). In 2016, 37 countries were producing more farmed than wild-caught fish.

Figure 1
Contribution of aquaculture to total fish production, excluding aquatic plants (1991–2016)



Source: FAO, 2018b.

Production from capture fisheries has plateaued, while aquaculture has experienced growth of about 6 percent per year over the past several decades (Figure 1). More aquatic species are being farmed now than ever before. According to general consensus, marine capture fisheries have reached a point whereby they will no longer provide more fish than they do at present. This indicates that the predicted substantial increase in future demand for fish will need to be met by fish culture systems (World Bank, 2013; FAO, 2014a; FAO, 2016a). By 2016, global fish production had risen to a level of around 171 million tonnes, with aquaculture representing nearly 47 percent of the total, and 53 percent if non-food uses are excluded.

Production from inland capture fisheries is not well known, and the majority of the catch is not identified to species level when reported to FAO (Bartley *et al.*, 2015). This lack of information on what and how much is being harvested from the world's freshwater ecosystems is all the more problematic for conservation efforts, as freshwater fish are the most threatened group of vertebrates used by humans (Ricciardi and Rasmussen, 1999; IUCN, 2010). Inland fisheries are threatened by loss of habitat and competition for freshwater from sectors outside the fishery sector (FAO, 2012; FAO, 2014a).

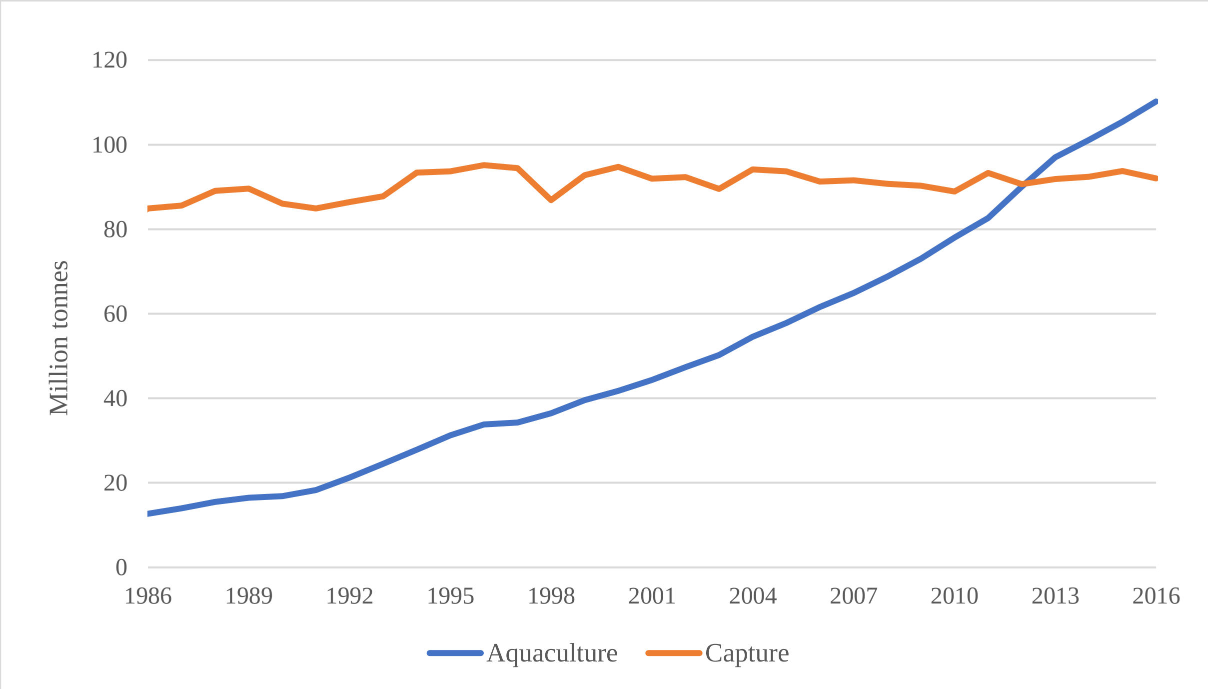
At the same time that pressure is placed on the expansion of aquaculture production to meet increased demands for seafood, existing aquaculture production systems are facing significant challenges in terms of available space, competition for water and feed resources alongside health and genetic concerns.

Despite these constraints, aquaculture continues to grow and in fact represents the world's fastest growing food production sector (FAO, 2016a).

Between 1961 and 2016, the average annual increase in global food fish consumption (3.2%) outpaced population growth (1.6%) (Table 6) and exceeded that of meat from all terrestrial animals combined (2.8%). In per capita terms, food fish consumption grew from 9.0 kg in 1961 to 20.2 kg in 2015, at an average rate of about 1.5 percent per year.

Figure 2

Total global fisheries and aquaculture production, including aquatic plants and non-food production (million tonnes)



Source: FAO, 2018a.

Table 6
World fisheries and aquaculture production and utilization (million tonnes)[1]

	2011	2012	2013	2014	2015	2016
Production system						
Capture						
Inland	10.7	11.2	11.2	11.3	11.4	11.6
Marine	81.5	78.4	79.4	79.9	81.2	79.3
Total capture	92.2	89.5	90.6	91.2	92.7	90.9
Aquaculture						
Inland	38.6	42.0	44.8	46.9	48.6	51.4
Marine	23.2	24.4	25.4	26.8	27.5	28.7
Total aquaculture	61.8	66.4	70.2	73.7	76.1	80.0
Total world fisheries and aquaculture	154.0	156.0	160.7	164.9	168.7	170.9
Utilization[2]						
Human consumption	130.0	136.4	140.1	144.8	148.4	151.2
Non-food uses	24.0	19.6	20.6	20	20.3	19.7
Population (billions)[3]	7.0	7.1	7.2	7.3	7.3	7.4
Per capita food fish supply (kg)	18.5	19.2	19.5	19.9	20.2	20.3

Source: FAO, 2018b.
[1]Excludes aquatic mammals, reptiles, seaweeds and other aquatic plants.
[2]Utilization data for 2014–2016 are provisional estimates.
[3]Source of population figures: United Nations, 2017.

1.2 Diversity of aquatic genetic resources used in aquaculture and fisheries

The world's fisheries harvested over 1 800 species in 2016, including fish, crustaceans, molluscs, echinoderms, coelenterates and aquatic plants (FAO, 2018a). Though the number of farmed aquatic species is smaller, it remains extremely diverse compared to other food production sectors. In 2016, over 550 species and/or species items were farmed (Table 7). A species item refers to a single species, a group of species (where identification to the species level is not possible), or one of a small number of hybrids. Since record-keeping began, a total of 598 species have been reported to FAO as having been farmed around the world.

Table 7
Diversity of aquatic species identified in the wild and the number of farmed and fished species items and families represented

Taxon	Wild species (marine)	Wild species (freshwater)	Number of farmed species[a]	Number of farmed families[a]	Number of captured species	Number of captured families
Finfish	18 768	12 834	344	80	1 452	237
Molluscs	47 844	4 998	95	27	151	37
Crustaceans	52 412	11 990	60	13	181	34
Other aquatic animals	*	*	15	10	26	13
Aquatic plants	12 128	2 614	40	21	29	14
Total	131 152	32 436	554	151	1 839	335

*These include echinoderms, coelenterates and tunicates too numerous to list, many of which have no potential as food and are all marine species, as well as a few amphibians and reptiles.

Sources: Balian *et al*., 2008; Chambers *et al*., 2008; FAO, 2018a; Lévêque *et al*., 2008; WoRMs Editorial Board, 2018.
Note [a]: based on 2016 production data

According to the latest available fisheries and aquaculture statistics published by the FAO Fisheries and Aquaculture Department, the total production in 2016 from capture fisheries and aquaculture was 202.2 million tonnes (Table 8).

Table 8
World capture fisheries and aquaculture production in 2016 (unit: thousand tonnes, in live weight)

Taxon	Capture fisheries	Aquaculture	Total
Finfish	77 267	54 091	131 359
Molluscs (edible)	6 326	17 139	23 465
Molluscs (pearls and ornamental shells)	9	38	47
Crustaceans	6 711	7 862	14 573
Aquatic invertebrates	608	443	1 051
Frogs and turtles	2	495	497
Aquatic plants	1 091	30 139	31 230
Total	92 015	110 208	202 223

Source: FAO, 2018a.

The species diversity of aquatic genetic resources (AqGR) for food and agriculture is extensive and includes several phyla. AqGR can be split into major components according to phyla and/or taxa (Table 9).

Table 9
Aquatic genetic resources for fisheries and aquaculture categorization according to phyla

Phylum	Examples
Aquatic plants (multiple phyla)	Algae (seaweeds and microalgae), vascular plants
Phylum Chordata	Finfish, amphibians, reptiles
Phylum Mollusca	Bivalves (clams, mussels, oysters), gastropods (snails, abalone), cephalopods (octopus, squid)
Phylum Arthropoda	Crabs, shrimps, lobsters, cladocerans, brine shrimp
Phylum Cnidaria	Jellyfish, corals
Phylum Echinodermata	Sea urchins and sea cucumbers

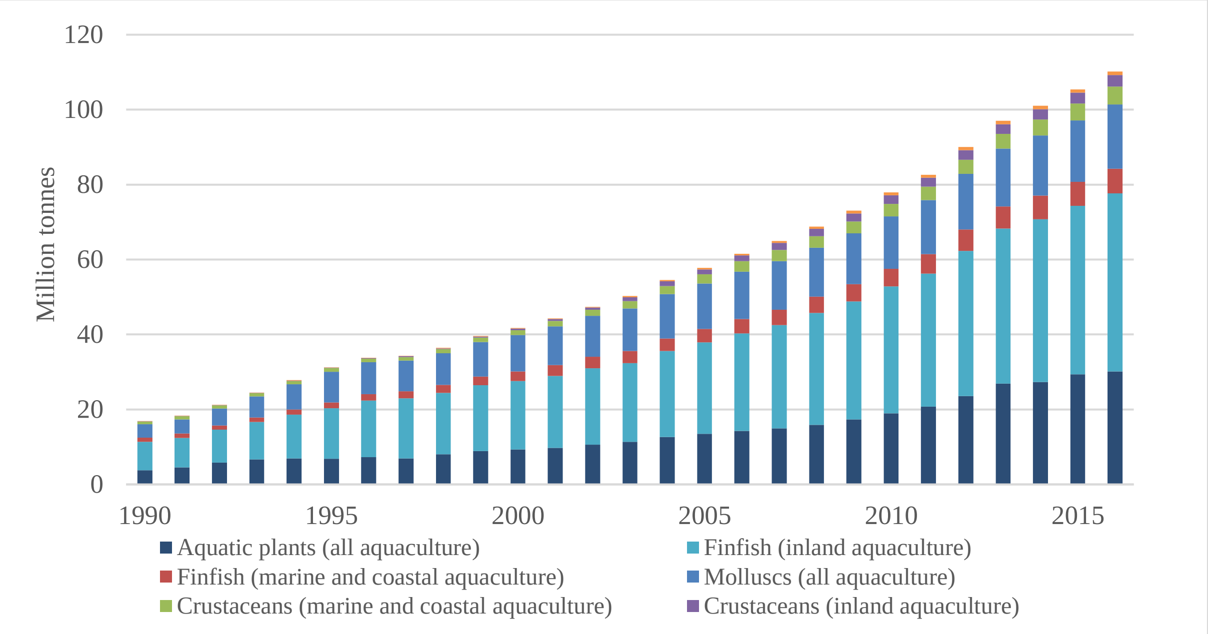
1.3 The state of world aquaculture

In 2016, global aquaculture production of aquatic living genetic resources reached a total of 110 million tonnes, including 80 million tonnes of food fish and 30 million tonnes of aquatic plants.[7] There was a further 38 000 tonnes of non-food production. Aquaculture food production had an estimated first sale value of USD 232 billion.

This production is derived from aquaculture operations conducted in freshwater, brackish water and marine waters. Farmed food production in 2016 comprised 54.1 million tonnes of finfish (USD 138.5 billion), 17.1 million tonnes of molluscs (USD 29.2 billion), 7.9 million tonnes of crustaceans (USD 57.1 billion), and 0.9 million tonnes (USD 6.8 billion) of other aquatic animals, including amphibians (FAO, 2018a) (Figure 3).

Figure 3

World aquaculture production of food fish and aquatic plants (1990–2016)



Source: FAO, 2018b.

Aquaculture production shows significant differences between regions. The Asian region is the predominant producer, accounting for about 89 percent of world food fish production in 2016 (Table 10).

World production of farmed food fish relies increasingly on inland aquaculture, which is typically practised in a freshwater environment in most countries. Earthen ponds remain the most commonly used type of facility for inland aquaculture production, although raceway tanks, above-ground tanks, pens and cages are also widely used if local conditions permit. Rice-fish culture remains important in areas where the practice is traditional, but it is also expanding rapidly, especially in Asia. In 2016, inland aquaculture was the source of 51.4 million tonnes of food fish, or 64.2 percent of the world's farmed food fish production, as compared with 57.9 percent in 2000. Finfish farming still dominates inland aquaculture, accounting for 92.5 percent (47.5 million tonnes) of total production from inland aquaculture.

[7] The term "food fish" includes finfishes, crustaceans, molluscs and other aquatic animals, such as frogs and sea cucumbers for human food, excluding aquatic mammals and crocodiles.

Marine aquaculture, also known as mariculture, takes place in the sea, in a marine water environment, while coastal aquaculture occurs within completely or partially human-made structures in areas adjacent to the sea, such as coastal ponds and gated lagoons. Salinity is less stable in coastal aquaculture with saline water than in mariculture because of rainfall or evaporation, depending on the season and location. At a global level, it is hard to distinguish between mariculture and coastal aquaculture production, mainly because of the aggregation of production data from several major producing countries. Most of the finfish production reported under marine and coastal aquaculture in Africa, the Americas, Europe and Oceania is produced through mariculture. FAO recorded 28.7 million tonnes (USD 67.4 billion) of food fish production from mariculture and coastal aquaculture combined in 2016. In sharp contrast to the dominance of finfish in inland aquaculture, shelled molluscs (16.9 million tonnes) constitute 58.8 percent of the combined production of marine and coastal aquaculture. Finfish (6.6 million tonnes) and crustaceans (4.8 million tonnes) together were responsible for 39.9 percent.

Table 10
Aquaculture production of main groups of food fish species, by continent, in 2016 (thousand tonnes, live weight)

	Africa	Asia	Europe	Latin America & the Caribbean	North America	Oceania	World
Inland aquaculture							
Finfish	1 954	43 983	502	879	194	5	47 516
Crustaceans	0	2 965	0	0	68	0	3 033
Molluscs	…	286	…	…	…	…	286
Other aquatic animals	…	531	…	1	…	…	531
Subtotal	1 954	47 765	502	879	262	5	51 367
Marine and coastal aquaculture							
Finfish	17	3 739	1 830	739	168	82	6 575
Crustaceans	5	4 091	0	726	1	6	4 829
Molluscs	6	15 550	613	360	214	112	16 853
Other aquatic animals	0	402	0	…	…	5	407
Subtotal	28	23 781	2 443	1824	383	205	28 664
All aquaculture							
Finfish	1 972	47 722	2 332	1 617	362	87	54 091
Crustaceans	5	7 055	0	726	69	7	7 862
Molluscs	6	15 835	613	360	214	112	17 139
Other aquatic animals	0	933	0	1	…	5	939
Total	1 982	71 546	2 945	2 703	645	210	80 031

Source: FAO, 2018b.
Note: Symbols "0" represents production quantity below 500 tonnes; "…" represents production or production data unavailable.

The rate of growth of aquaculture production has declined since the 1980s and 1990s (10.8% and 9.5% percent annually, respectively). Nevertheless, aquaculture continues to grow faster than other major food production sectors. Annual growth declined to 5.8 percent during the period 2001–2016, although double-digit growth still occurred in a small number of individual countries. Table 11 illustrates that, over the five-year period from 2012–2016, growth was highest in the African continent, albeit from a low base, with Asia continuing to grow at approximately 5 percent per annum. Europe has the lowest rate of growth of aquaculture of this period at just over 1 percent per annum.

Table 11
Annual growth rate (in percent) of total aquaculture for the period 2012–2016 (by continent)

	2012	2013	2014	2015	2016	Average rate of growth
Africa	7.1	5.7	7.0	5.8	7.7	6.7
Asia	9.1	8.5	3.7	4.7	4.6	6.1
Europe	6.9	-3.5	6.4	1.3	0.1	2.2
Latin America & the Caribbean	7.5	0.4	16.7	-4.5	1.7	4.4
North America	6.8	-1.4	-6.0	9.4	5.2	2.8
Oceania	-3.0	-2.4	4.8	-1.0	10.5	1.8

Source: FAO, 2018a.

Declining production in some industrialized countries that were previously major regional producers (most notably France, Italy, Japan and the United States of America) (FAO, 2016b) is driven mainly by the availability of fish imported from other countries, where production costs are relatively low.

The majority of aquaculture production is destined for direct human consumption, although some by-products may be used for non-food purposes and a few farmed types are expressly produced for processing for industrial purposes (e.g. aquatic plants used to produce phycocolloids such as agar and carrageenan). These may or may not be subsequently used for food purposes.

1.3.1 Diversity and production of farmed species

The diversity of species farmed is one reason for the growing production in aquaculture. A breakdown of global aquaculture production by each of the major groups and the number of species and families represented is shown in Table 12. Finfish are the largest category of farmed aquatic species by volume in all regions.

Table 7 summarizes the species reported as being farmed in 2016 totalling 554. However, a total of 598 species items have been farmed up to and including 2016 (i.e. since FAO records began). Total recorded species items reported as cultured to date include 369 finfishes (including five hybrids), 109 molluscs, 64 crustaceans, 7 amphibians and reptiles (excluding alligators, caimans or crocodiles), 9 other aquatic invertebrates, and 40 aquatic algae. These numbers do not include those species, known or unknown to FAO, produced from research, cultivated as live feed in aquaculture hatcheries, or ornamental species produced in captivity. From 2006 to 2016, the total number of commercially farmed species items historically recorded by FAO increased by 26.7 percent, from 472 in 2006 to 598 in 2016. However, the data reported to FAO do not keep pace with the actual speed of species diversification in aquaculture. Numerous single species items registered in the official statistics of many countries consist, in reality, of multiple species and sometimes hybrids. Despite the great diversity in the species raised, aquaculture production by volume is dominated by a small number of “staple” species or species items at national, regional and global levels. Table 12 illustrates the diversity of species farmed within each major taxonomic grouping by continent.

Table 12: Number of species or species items reported to FAO as under production in 2016 (by continent and culture environment)

	Africa	Asia	Europe	Latin America & the Caribbean	North America	Oceania
Inland aquaculture						
Finfish	66	112	73	76	14	20
Molluscs	0	5	0	1	0	0
Crustaceans	7	16	7	7	2	5
Other animals	0	8	3	4	0	0
Algae	3	4	4	5	0	0
Subtotal inland	76	145	87	93	16	25
Marine and coastal aquaculture						
Finfish	26	107	48	28	11	14
Molluscs	17	26	31	27	16	24
Crustaceans	8	27	15	7	3	10
Other animals	3	9	4	0	0	3
Algae	5	19	14	10	0	4
Subtotal marine and coastal	59	188	112	72	30	55
All aquaculture						
Finfish	81	192	108	97	24	28
Molluscs	17	30	31	28	16	24
Crustaceans	13	39	20	14	5	15
Other animals	3	15	6	4	0	3
Algae	8	23	17	15	0	4
Total – all aquaculture taxa	122	299	182	158	45	74

Source: FAO, 2018a.

Table 12 illustrates that Asia farms the most species of aquatic organisms, in part due to having the longest tradition of aquaculture. That relatively few species are farmed in Africa (in relation to the size, habitat diversity of the continent and the potential number of species available for farming) demonstrates the potential for further use of AqGR in African aquaculture.

1.3.1.1. Finfish aquaculture

The importance of a small number of species within the large diversity is well illustrated if finfish farming is considered. This most diverse subsector relied on 27 species and species items for over 90 percent of the total production in 2016, while the 20 most produced species accounted for 84.2 percent of total production (Table 13).

Freshwater/diadromous finfish are the largest group in terms of families and species cultured (53 families and 215 species); this group is the largest in terms of total volume of all of the types of aquaculture production. Inland finfish aquaculture has been the most important driver for the global increase in annual output of farmed fish, representing 65 percent of the annual fish production increase between 2005 and 2014 (FAO, 2016b).

This high level of aquaculture production from freshwater emphasizes the importance of access to adequate quality and quantity of water for both farmed types and wild relatives, as well as the vulnerability of these systems to external impacts on freshwater resources and land (see Chapter 3). The

species used range from low trophic level species (e.g. carps, barbs, tilapia, pacu) to highly carnivorous species (e.g. salmon, eel, snakehead). The majority of production volume is based on the lower trophic level species. This underscores the contribution of these species to global food security and their relatively efficient production of high-quality protein relative to other livestock systems. The salmonids are a carnivorous species and are highly significant in value terms; even these production systems are now being developed to a point where they are becoming much more efficient users of feed resources.

Despite marine finfish representing a much lower proportion of the total volume of finfish produced, they are nevertheless represented by 33 different families (and 129 species/species items). The species tend to be carnivorous (e.g. snappers, groupers, pompano, tuna), but are also represented by a few species that are omnivorous or herbivorous (e.g. mullet, scats, rabbitfish).

Compared with finfish, fewer species of crustaceans and molluscs are farmed (Table 12).

Table 13
Major finfish species under aquaculture production and their relative contribution to global finfish production (2010–2016) (thousand tonnes)

Species/species item	**2010**	**2012**	**2014**	**2016**	**2016 share (%)**
Grass carp (*Ctenopharyngodon idellus*)	4 362	5 018	5 539	6 068	11.2
Silver carp (*Hypophthalmichthys molitrix*)	4 100	4 193	4 968	5 301	9.8
Common carp (*Cyprinus carpio*)	3 421	3 753	4 161	4 557	8.4
Nile tilapia (*Oreochromis niloticus*)	2 537	3 260	3 677	4 200	7.8
Bighead carp (*Hypophthalmichthys nobilis*)	2 587	2 901	3 255	3 527	6.5
Carassius spp.	2 216	2 451	2 769	3 006	5.6
Catla (*Catla catla)*	2 977	2 761	2 770	2 961	5.5
Freshwater fishes nei, Osteichthyes	1 378	1 942	2 063	2 362	4.4
Atlantic salmon (*Salmo salar*)	1 437	2 074	2 348	2 248	4.2
Roho labeo (*Labeo rohita*)	1 133	1 566	1 670	1 843	3.4
Pangas catfishes nei, *Pangasius* spp.	1 307	1 575	1 616	1 741	3.2
Milkfish (*Chanos chanos*)	809	943	1 041	1 188	2.2
Tilapias nei, *Oreochromis* (= tilapia) spp.	628	876	1 163	1 177	2.2
Torpedo-shaped catfishes nei, *Clarias* spp.	353	554	809	979	1.8
Marine fishes nei, Osteichthyes	477	585	684	844	1.6
Wuchang bream (*Megalobrama amblycephala*)	652	706	783	826	1.5
Rainbow trout (*Oncorhynchus mykiss*)	752	883	796	814	1.5
Cyprinids nei, Cyprinidae	719	620	724	670	1.2
Black carp (*Mylopharyngodon piceus*)	424	495	557	632	1.2
Snakehead (*Channa argus*)	377	481	511	518	1.0
Other finfishes	5 849	6 815	7 774	8 629	16.0
Finfish total	38 494	44 453	49 679	54 091	100

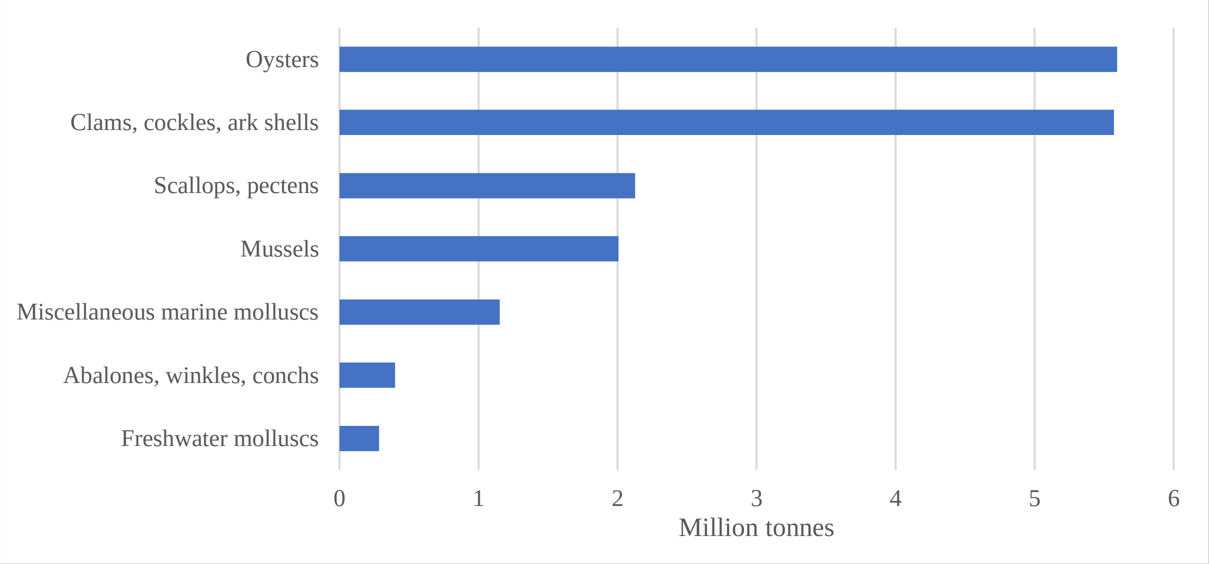
Source: FAO, 2018b.
Note: nei = not elsewhere included.

1.3.1.2. Mollusc aquaculture

Farmed molluscs can be broadly split into bivalves and gastropods, with 2016 production including 95 species in 27 families (FAO, 2018a). The overwhelming majority are cultured in marine systems (Figure 4). Bivalve molluscs are produced in systems using natural water fertility, and therefore unfed. Some gastropod systems (abalone, conch, *Babylonia* spp.) can be relatively intensive and utilize feeds. There is a minor production of cephalopods (octopus).

Figure 4

Global aquaculture production of major mollusc species items in 2016 (million tonnes)



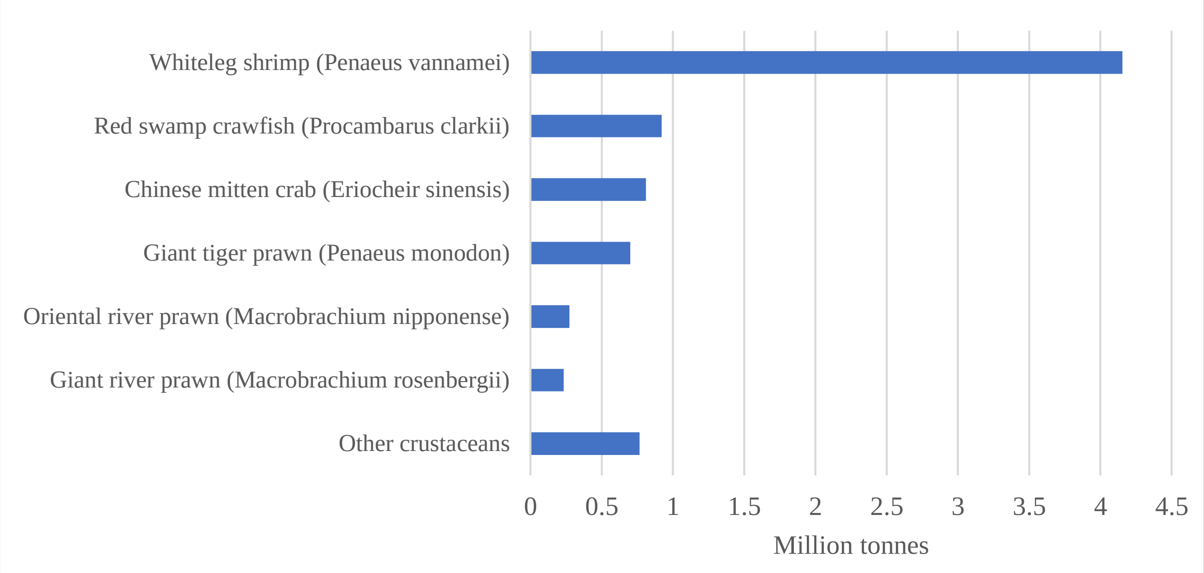
Source: FAO, 2018a.

1.3.1.3. Crustacean aquaculture

Crustaceans can be split between marine/brackish and freshwater production systems, comprising 13 families and 60 reported species. Marine/brackish-water production is dominated by the penaeid shrimp, with minor contributions from other families such as lobsters and metapenaeids. Freshwater production is comprised of the Chinese mitten crab (*Eriocheir sinensis*), different crayfish/crawfish species and the *Macrobrachium* freshwater prawns.

Some production of *Penaeus vannamei* is also recorded as undertaken in freshwater inland areas, although this may not be strictly freshwater, but extremely low-salinity brackish water instead. The majority of production is from warm-water systems (Figure 5).

Figure 5
Global production of major crustacean species items and groups in 2016 (million tonnes)

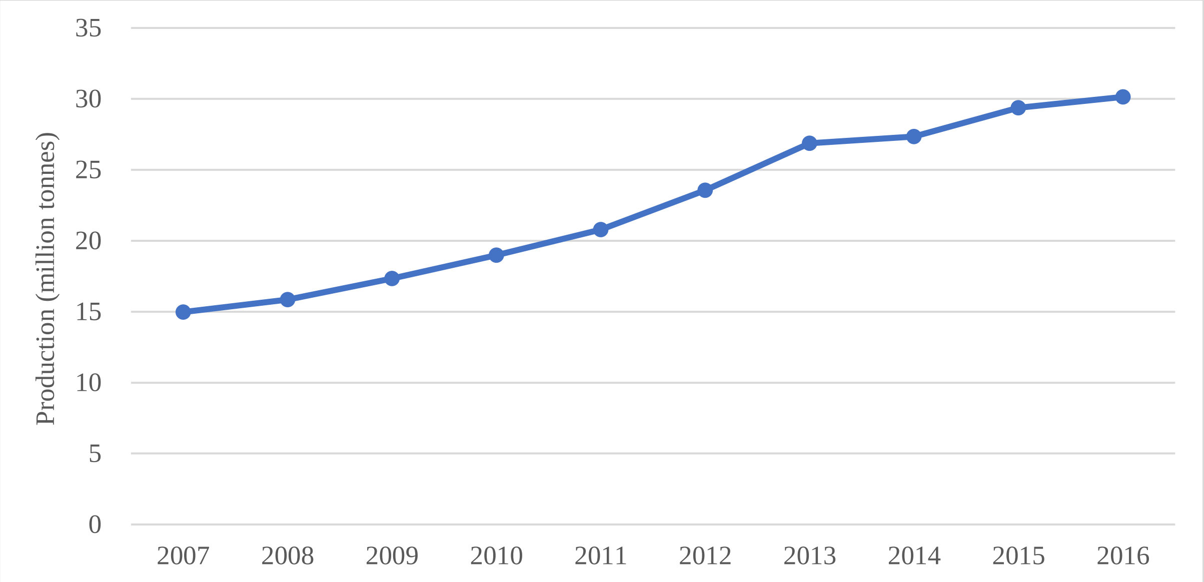


Source: FAO, 2018a.

1.3.1.4 Aquatic plant and microorganism aquaculture

Aquatic plants are largely produced in marine and brackish waters, but some microalgae are cultured in freshwaters. Aquatic plant aquaculture systems typically rely on natural productivity and are not fertilized; there are, however, managed culture systems. Farming of aquatic plants is undertaken in more than 50 countries and over the past decade has grown by 8 percent per year (FAO, 2018a) (Figure 6)

Figure 6
Aquatic macrophyte production from 2007 to 2016



Source: FAO, 2018a.

Information on microalgae is not well reported in available aquaculture statistics despite being of increasing economic importance both as a food supplement (e.g. *Spirulina* spp.) and as an important base for the hatchery production of many species (especially marine species). There are more than 17 genera of microalgae commonly cultivated for aquaculture purposes, but there are many more species used both commercially and within research collections.

Owing to the relative paucity of information, aquatic plant aquaculture warrants more specific attention and has been covered in two separate thematic background papers, with information on farmed seaweeds and freshwater macrophytes summarized below.[8]

1.3.1.4.1 Farmed seaweeds

The genetic resources of farmed seaweeds are often omitted from regular reporting to FAO despite the significance of these seaweeds as sources of human food, natural colloids as food ingredients, cosmetics, biofuels, pharmaceuticals and neutraceuticals, and feed ingredients in aquaculture. They are a mixture of food plants consumed directly and those produced for processing to extract phycocolloids such as agar and carrageenans. Seaweeds are also being used as bioremediation agents or for phyto-mitigation in integrated multi-trophic level aquaculture as a means to recycle aquaculture effluents by absorbing nutrients from other parts of the aquaculture system.

Higher-level taxonomic classification of algae is notoriously difficult and frequent changes appear in the literature. For the purposes of this document, algae are included as aquatic plants, in full recognition that some algae are indeed not included in the Kingdom Plantae. It is more useful to consider the taxa at the family level. There are 38 species reported to FAO, representing 27 families in the following four classes:

- Green algae (Chlorophyceae – 7 species items);
- Brown algae (Phaeophyceae – 11 species items);
- Red algae (Rhodophyceae – 17 species items); and
- Cyanobacteria (Cyanophyceae – 3 species items).

Seaweed farming is predominantly carried out in Asia both for the brown (*Saccharina* and *Undaria*) and red seaweeds (*Eucheuma, Gelidium, Gracilaria, Kappaphycus* and *Pyropia* [*Porphyra*]). European seaweed culture is still small in scale and can be found in countries such as Denmark, France, Spain, Portugal, Ireland and Norway. Previously, brown seaweeds (*Saccharina* and *Undaria*) dominated global seaweed production, until they were overtaken by red seaweeds (*Kappaphycus* and *Eucheuma*) around 2010.

The brown seaweeds are farmed normally in subtemperate to temperate countries such as China, Japan and the Republic of Korea, while red seaweeds such as *Kappaphycus* and *Eucheuma* are farmed in subtropical to tropical countries with production dominated by Indonesia, the Philippines and Malaysia.

There are other red seaweeds that are currently farmed in the open seas, brackish-water ponds or land-based tanks. These are *Asparagopsis, Chondrus crispus, Gelidium, Gracilaria, Hydropuntia, Palmaria palmata* and *Pyropia.* Among the green seaweeds, *Caulerpa, Codium, Monostroma* and *Ulva* are the main taxa farmed for commercial purposes.

Traditional selection of strains based on growth performance and resistance to disease is still used in propagating farmed seaweeds. The breakthrough in the hybridization of *Laminaria japonica* in China paved the way for massive expansion in cultivation of this species. The development of plantlets from spores for outplanting purposes is still practised to the present in some brown (*Laminaria, Saccharina, Undaria),* red *(Palmaria, Pyropia),* and green seaweeds *(Codium, Monostroma, Ulva).* Micropropagation through tissue and callus culture is becoming a popular method in generating new and improved strains in *Eucheuma* and *Kappaphycus,* though vegetative propagation is still widely used.

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[8] *Genetic resources for farmed seaweeds* (www.fao.org/cofi/46056-0e272e19f4b0051d1e1c3b679e5ca8ada.pdf) and *Genetic resources for farmed freshwater macrophytes* (www.fao.org/cofi/46220-0c01d74940144a468674c816958a1889f.pdf).

The main driver for the continued interest in seaweed cultivation has been the potential for the production of large volumes of a renewable biomass that is rich in carbohydrates and therefore attractive for biofuel production. Seaweed biomass has a wide range of applications as:

- bio-based and high-value compounds in edible food, food and feed ingredients, biopolymers, fine and bulk chemicals, agrichemicals, cosmetics, bio-actives, pharmaceuticals, nutraceuticals and botanicals;
- lower-value commodity bioenergy compounds in biofuels, biodiesels, biogases, bio-alcohols and biomaterials; and
- a nutritional food source; global consumption of sea vegetables is rising as consumers become more aware of their health benefits.

1.3.1.4.2 Aquatic plants – freshwater macrophytes

Freshwater macrophytes are relatively under-researched and underdocumented. In fact, they have not been well covered in previous Reports of *The State of the World's Plant Genetic Resources*. However, they play important roles in rural economic development, particularly in Asia, where they have both historical and cultural significance in providing healthy food and also employment while often recycling valuable nutrients in what are essentially low-input systems, which benefits millions of lower income, primarily peri-urban, stakeholders (Box 1).

Box 1

Freshwater aquatic macrophytes for food and agriculture

The cultivation and consumption of edible cultivated freshwater macrophytes and their impact on food security has long been under-recognized and under-recorded in both scientific and grey literature. In a geographical context, they have largely been unrecognized outside South and Southeast Asia, where for centuries they have provided millions of often lower-income communities with a low-cost, nutritious foodstuff for both themselves and their associated livestock, including cultured fish. Freshwater macrophytes are often used to recycle "waste" nutrients, but they also provide significant employment and incomes. Freshwater aquatic macrophytes (FAMs) continually remain unrecorded in most government and (inter-) national agriculture and/or aquaculture statistics and planning documents despite their significant contribution to food production and nutrient recycling. In terms of the global aquaculture development community, the range and scale of edible cultivated aquatic plant production is little known or practised outside South and Southeast Asia; it is rarely taught in curricula or addressed in the research agenda of the major academic aquaculture schools and agriculture and international non-governmental research organizations.

Aquatic plants form an ecological rather than taxonomic group and cannot be defined with any degree of precision. Though there are no standard definitions for freshwater macrophytes in the literature, they are generally considered plants that either require a fairly continuous supply of freshwater or are present in soils that are covered in freshwater for a significant proportion of their growing cycle. They are distinguished as macrophytes by their size compared with phytoplankton, but can also include filamentous algae, which sometimes grow into larger floating mats and can then be harvested. FAMs can be categorized broadly into three groups, or categories, by their methods of growth within the water column, although some species at different stages in their life cycle can move between the different categories. The three categories are: (i) emergent species; (ii) submersed species; and (iii) floating species.

It is estimated that there are more than 40 species of edible FAMs, of which around 25 percent either are already being cultivated for food at a scalable level or have the potential to be developed into commercially viable cultivation species. In terms of their genetic improvement and species selection for improvements in growth performance, productivity, phytoremediation of wastewater, and even disease resistance despite the significant translocation of germplasm between countries or regions over the last 600 years, there is relatively little information either in the research literature or at the grassroots production level to indicate the occurrence of selective breeding programmes and/or selection or genetic modification towards improved strains. However, owing to their scale and their importance, particularly in Southeast Asia, FAMs can be considered a key tropical and subtropical cultivatable crop that can contribute to sustainable food production in developing countries in the future in a financially viable and environmentally responsible way.

There are many other roles that FAMs do and can fulfil, including being key components in multipurpose integrated production systems. Their incorporation and use in aquaculture and other wastewater treatment and remediation continue to be developed. They also have potential as aquaculture feed ingredients. There is often a close relationship in aquatic plant production between aquaculture and agriculture/horticulture. As an example, there is a large global market for ornamental aquatic plants. Thus, there is a need for clear differentiation and clarity in the future collection and presentation of global production statistics for diverse use categories of FAMs. This data collection is further complicated with particular species such as water morning glory (*Ipomoea aquatica*) being cultivated in different geographical locations for various purposes with different beneficial outcomes.

1.3.1.4.3 Microorganisms

Microorganisms, feed organisms and aquatic plants have not been comprehensively reported to FAO, yet they are a valuable component of AqGR (Box 2).

Box 2
Microorganisms in fisheries and aquaculture

Aquatic microorganisms are indispensable resources for growth of shellfish and finfish in natural aquatic ecosystems and in aquaculture. Many microalgal species are important in aquaculture, with different species being suitable as feed for shellfish and finfish larviculture, as components of "green water" widely used to enhance survival and growth of larval and adult fish, and as feeds to enhance the nutritional quality of *Artemia* and rotifers. These microorganisms fall into the microbial groups of: (i) microalgae and fungal-like organisms; (ii) bacteria, including cyanobacteria; and (iii) zooplankton.

Microalgae are also grown in aquaculture to produce pigments and fatty acids of importance in fish aquaculture and as human nutraceuticals. Bacteria that are used in aquaculture include cyanobacteria such as *Spirulina* used for human diet supplements and a rapidly growing suite of probiotic bacteria. These probiotic bacteria include species that improve survival and growth of fish and shellfish larval and adult stages.

Probiotic bacteria are expected to become increasingly important for disease prevention in aquaculture as antibiotic use is further curtailed and species are grown in more intensive aquaculture systems. Bacteria also play an important role in filtration systems needed in recirculating aquaculture systems.

Zooplankton, specifically *Artemia* and rotifers, have a long history and wide application as feed for the aquaculture industry. Several species of *Artemia* are used, with *Artemia franciscana* being the most important. Of more than 2 000 species of rotifers, *Brachionus plicatilis* and *Brachionus rotundiformis* are most commonly used. Other zooplankton used in aquaculture include copepods, which are growing in importance, and cladocerans such as *Daphnia* that are widely used in freshwater larviculture.

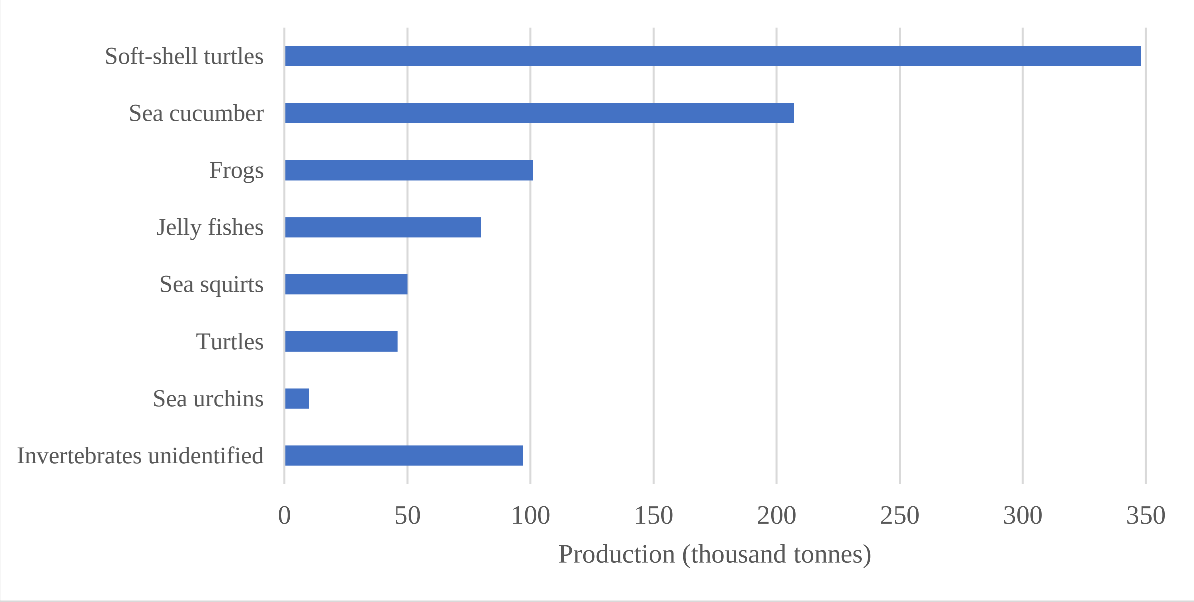
The future success and growth of aquaculture depends on the continued availability and more efficient culture of these important microbes, as well as conservation and expansion of the biological diversity and genetic resources of microbes used in aquaculture. Important issues include the ability to achieve long-term storage of important organisms without subjecting them to genetic drift, the role of commercial and public culture collections, and the need for increased use of genomics to characterize all key microbial species used in aquaculture.

1.3.1.5 Other species

A range of niche species are also produced comprising seven families of sea cucumbers (*Holothuria*), sea urchins (Echinodermata) and other invertebrates, and two families of amphibians (two species of frog) and reptiles (two species or groups of freshwater turtles; note that crocodiles/alligators are not included) (Figure 7). Ornamental invertebrates (including corals) are also not included, nor are those produced for shell (pearl, mother of pearl).

Crocodile production is growing quickly in the Asian region with export of juvenile crocodiles to producing countries. China, Cambodia, Papua New Guinea, Thailand and Viet Nam all have crocodile farms; however, this production is rarely, if ever, reported in fishery or aquaculture statistics.

Figure 7
Aquaculture production of other aquatic animals in 2016 (thousand tonnes)



Source: FAO, 2018a.

1.3.2 Diversity of production systems

With the wide diversity of farmed species items, global aquaculture production systems are highly diverse. They cover a range of systems, from extensive to intensive, across all types of aquatic environment (fresh-, brackish- and marine waters) and in every inhabited continent of the world.

These systems also have different characteristics with respect to the diversity and use of AqGR, ranging from the use of wild seed to domesticated and improved strains. The diversity of aquaculture systems, the species or species items typically produced in these systems, and the common sources of broodstock and/or seed are summarized in Table 14.

Table 14
The diversity of aquaculture systems, the species or species items typically cultured in these systems and the common sources of broodstock and/or seed

System type	Typical species/species items	Source of seed stock	Source of broodstock
Industrial/high-technology systems, including recirculating aquaculture systems	**Marine finfish:** Atlantic salmon, pompano **Marine crustaceans:** *Penaeus vannamei*	Hatcheries	Captive broodstock; selective breeding and other genetic improvements; domestication programmes
	Freshwater finfish: rainbow trout, *Pangasius*, tilapia, common carp, sturgeon, channel catfish		
Higher-value species fattening systems	**Marine:** bluefin tuna, groupers, lobster, mangrove crab, yellowtail **Freshwater:** European and Japanese eel, marbled sand goby	Wild captured from targeted fisheries	Wild relatives
Lower-value species fattening systems	**Marine/brackish water:** mullet, milkfish		
	Freshwater: giant snakehead, African catfish		
Medium technological level commercial finfish and crustacean fed systems	**Marine/brackish-water fish:** turbot, seabream, European seabass, Asian seabass, milkfish, snappers, cobia **Marine crustaceans:** *Penaeus monodon*	Hatchery	Captive broodstock used from grow-out systems;no/limited selective breeding; some genetic material from wild relatives used for broodstock
	Freshwater finfish: tilapia, *Pangasius*, Indian major carp, Chinese carp, mandarin fish		

System type	Typical species/species items	Source of seed stock	Source of broodstock
	Crustaceans: *Macrobrachium* spp., crayfish spp., Chinese mitten crab		
Higher-value mollusc systems	**Marine/brackish water:** **Fed systems:** abalone, *Babylonia* **Unfed systems:** Lantern net systems: scallop Lines: green-lipped mussel Racks/poles: Pacific and European oyster systems Open water: giant clam	Hatchery-produced seed	Captive broodstock
Low technology/ artisanal and backyard systems	**Marine:** rabbitfish, milkfish, scats	Hatchery	Broodstock maintained on-farm or held in hatchery; quality of strain ranges between highly inbred on-farm strain to genetically well-managed national broodstock systems
	Freshwater: Indian carp, common carp, Chinese carp, tilapia, catfish, snakehead, climbing perch, silver barb, snakeskin gourami, giant gourami, pacu		
Integrated or mixed systems	**Marine/brackish water:** mangrove/ aqua-silviculture (crab/shrimp/trap pond systems)	Trapped wild species ongrown; hatchery culture species introduced	Wild broodstock; hatchery-maintained broodstock
	Freshwater: rice-fish (common carp, barbs, tilapia, channel catfish); rice-crayfish, rice-crab, rice-turtle		
	Freshwater/brackish water: rice-fish/rice-prawn rotation systems (tilapia; mixed brackish-water fish; penaeid shrimp; *Macrobrachium* spp.)		
	Freshwater: wastewater improvement systems (aquatic plants and/or molluscs/herbivorous fish)	Mainly hatchery	Hatchery-maintained broodstock
	Marine: integrated, multi-trophic systems (seaweeds; invertebrates – scallops, mussels, sea cucumber, sea urchin; finfish cages)	Mostly hatchery raised or vegetative growth (e.g. seaweed)	Mainly on-farm stock or hatchery-maintained broodstock
Lower-value mollusc systems	Extensive stake systems (oyster, mussels) Extensive bottom systems (blood cockle, manila clam)	Natural spatfall; spat collectors	Wild broodstock on-farm or wild relatives
Aquaculture feed species	Invertebrates (e.g. polychaete worms)	Hatchery	Hatchery-maintained strains or use of farm stock (in the case of worms)
	Zooplankton (e.g. *Moina*)		
	Phytoplankton (e.g. *Chaetoceros*, *Chlorella*, *Skeletonema*, *Tetraselmis*, *Isochrysis*)		
	Zooplankton (*Artemia*)	Wild collection	Inoculation of open waters with maintained strains; wild relatives naturally recruited
Food supplements	Spirulina	Hatchery	Maintained strains
Seaweeds/aquatic plants	**Marine:** seaweeds (e.g. *Eucheuma*, *Gracilaria*, *Laminaria*, *Porphyra*)	Hatchery and vegetative reproduction	Maintained stock or hatchery-held strains
	Freshwater: aquatic plants (e.g. *Ipomoea*, water cress), including ornamental/aquarium plants		
Aquarium fish and other species	Indicative number of marine species. Indicative number of freshwater species. Also significant use of exotic species outside of their natural range.	Hatchery	Hatchery-maintained broodstock

1.3.3 Marine and freshwater ornamental fish in the aquarium trade

In 2000, the Global Marine Aquarium Database (GMAD) was created, and by August 2003 the data set contained trade records covering a total of 2 393 species of fish, corals and invertebrates and spanning the years 1988 to 2003. Asia provided more than 50 percent of the global total ornamental fish supply (FAO, 2000).

A total of 1 471 species of marine fish are traded worldwide, but the ten "most traded" species account for about 36 percent of all fish traded for the years 1997 to 2002 (Wabnitz *et al*., 2003).

A total of 140 species of stony coral, nearly all scleractinians, are traded worldwide. Coral species from several genera (particularly *Euphyllia, Goniopora, Acropora, Plerogyra, Catalaphyllia*) are the most popular, accounting for approximately 56 percent of the live coral trade between 1988 and 2002. There were also 61 species of soft coral traded.

More than 500 species of invertebrates (other than corals) are traded as marine ornamentals, though the lack of a standard taxonomy makes it difficult to establish a precise figure.

There is no equivalent database for the freshwater aquarium trade, and the diversity of species being produced and traded is not readily available. However, various aquarium guides list 650 (Sakurai *et al*., 1993) to 850 (Baensch and Riehl, 1997) common freshwater aquarium species.

An important distinction that can be made between the freshwater and marine aquarium trades is the level of reliance on capture of animals rather than culture. It is roughly estimated that the freshwater aquarium trade relies on cultured animals for 98 percent; only 2 percent of the products are captured.

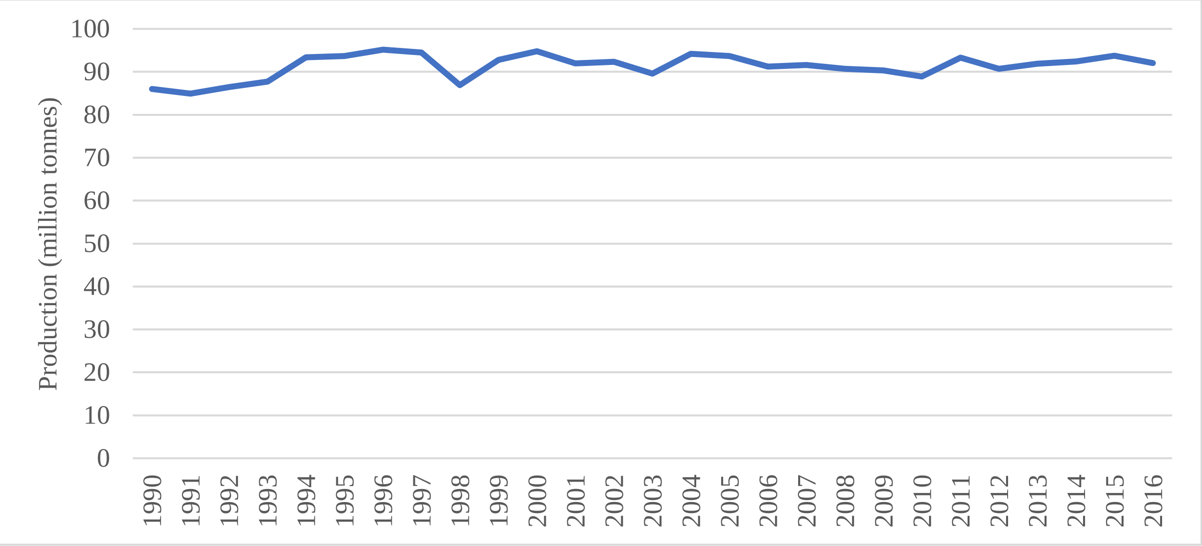
The marine aquarium trade relies on capture for 98 percent of its production versus 2 percent culture (Wabnitz *et al*., 2003) with only a small number of species currently being bred in captivity (e.g. some clownfish – *Amphiprion* spp.). Significant potential exists for increasing the contribution of aquaculture to the marine aquarium trade; the freshwater aquarium trade is also a significant contributor to the value of aquaculture production in some countries.

1.4 The state of world fisheries

The harvest from marine and inland capture fisheries was about 91 million tonnes in 2016 and appears to have plateaued at approximately this level over the past two decades (Figure 8).

Figure 8

Production in volume (million tonnes) from marine and inland capture fisheries (1990–2016)



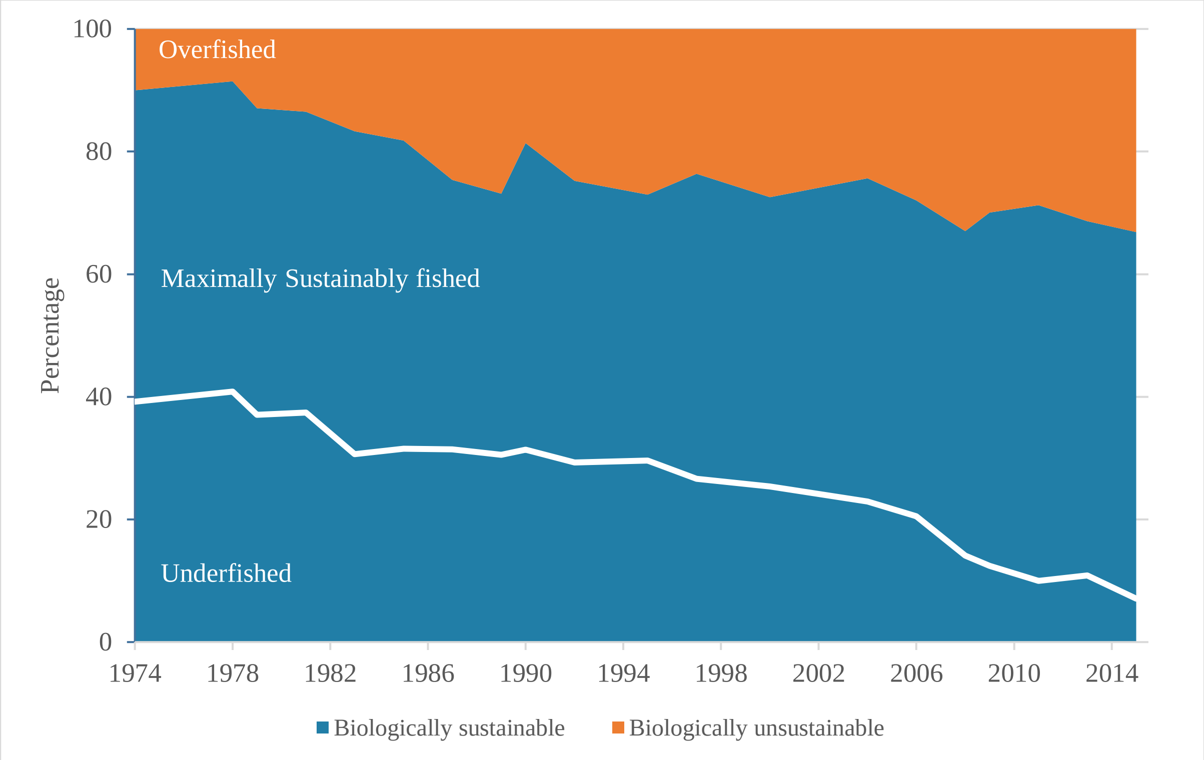
Source: FAO, 2018a.

1.4.1 Marine fisheries

The status of marine fisheries is based on an in-depth analysis of over 450 fish stocks (FAO, 2018b). Though the world's marine fisheries expanded continuously to a production peak of 86.4 million tonnes in 1996, they have since exhibited a general declining trend, sitting at 79.3 million tonnes in 2016. This still represents 87.2 percent of global fisheries production, with almost half of this production coming from temperate areas (FAO, 2018b). The fraction of assessed stocks fished within biologically

sustainable levels has exhibited a decreasing trend, declining from 90 percent in 1974 to 66.9 percent in 2015 (Figure 9). In 2015, 33.1 percent of fish stocks were estimated as fished at a biologically unsustainable level, and therefore overfished. Of the total number of stocks assessed in 2015, fully fished stocks accounted for 59.9 percent and underfished stocks have declined to just 7.0 percent.

Figure 9
The global trends in the state of world marine fish stocks (1974–2015)



Source: FAO, 2018b.

Asia harvests the majority of marine fish stocks (54%), followed by Europe and Latin America and the Caribbean (Table 15). As is the case with global aquaculture, there are a relatively small number of species or species items that make up the majority of marine fishery yields. Table 16 lists fifteen species or species items that yield a million tonnes or more per annum, including the highest yielding Alaska pollock (*Theragra chalcogramma*) and the anchoveta (*Engraulis ringens)*.

Table 15
Production of global marine capture fisheries by region in 2016, excluding aquatic plants

Geographical region	Production (tonnes)	Percentage of global total
Africa	6 415 217	8.1
Asia	42 531 179	53.6
Europe	13 259 301	16.7
Latin America & the Caribbean	9 658 257	12.2
North America	6 007 511	7.6
Oceania	1 413 776	1.8
Total	79 285 242	100

Source: FAO, 2018a.

Table 16
Main species harvested from marine fisheries and production in volume from 2011 to 2016 (tonnes)

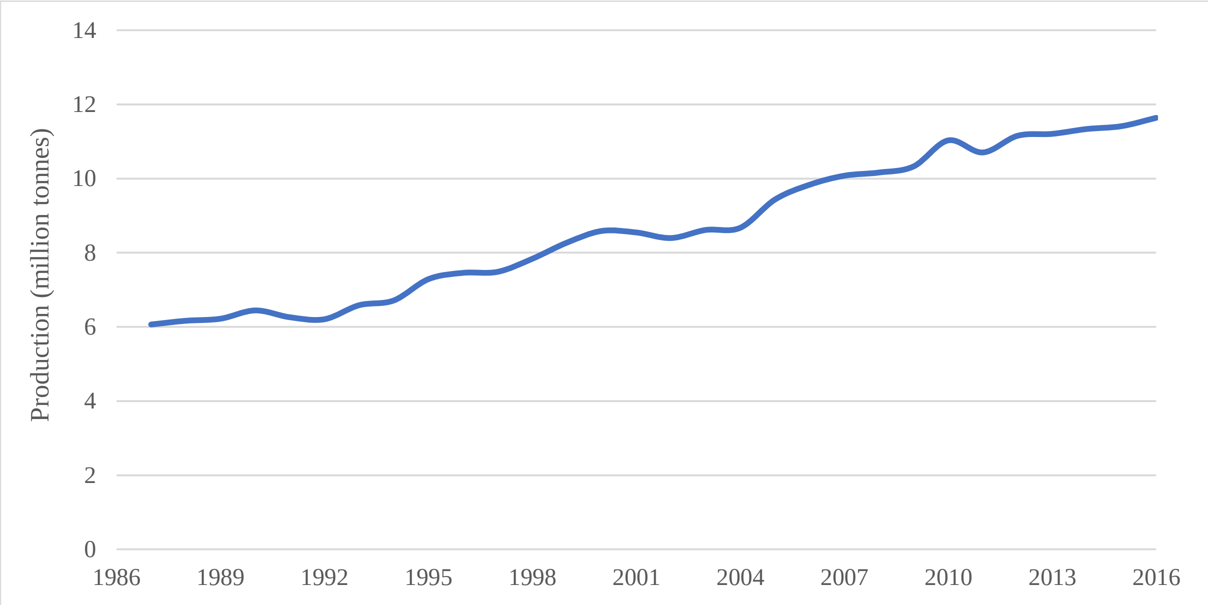
Species (ASFIS species)	2011	2012	2013	2014	2015	2016
Marine fishes nei	9 451 060	9 612 031	9 350 107	9 494 495	10 211 242	10 433 019
Alaska pollock (= walleye pollock) *(Theragra chalcogramma)*	3 210 513	3 271 726	3 247 756	3 245 082	3 372 752	3 476 149
Anchoveta (= Peruvian anchovy) *(Engraulis ringens)*	8 319 597	4 692 855	5 674 036	3 140 029	4 310 015	3 192 476
Skipjack tuna *(Katsuwonus pelamis)*	2 529 147	2 702 484	2 909 408	2 990 915	2 809 954	2 829 929
Atlantic herring *(Clupea harengus)*	1 780 268	1 773 235	1 817 333	1 630 629	1 512 174	1 639 760
Pacific chub mackerel *(Scomber japonicus)*	1 309 141	1 269 642	1 259 861	1 397 453	1 484 780	1 598 950
Yellowfin tuna *(Thunnus albacares)*	1 144 618	1 304 439	1 260 913	1 347 135	1 356 883	1 462 540
Atlantic cod *(Gadus morhua)*	1 051 778	1 114 352	1 359 136	1 374 168	1 303 726	1 329 450
Japanese anchovy *(Engraulis japonicus)*	1 321 662	1 291 905	1 324 504	1 395 807	1 336 218	1 304 484
European pilchard (= sardine) *(Sardina pilchardus)*	1 037 161	1 021 129	1 003 097	1 208 478	1 174 611	1 281 391
Largehead hairtail *(Trichiurus lepturus)*	1 260 602	1 238 125	1 263 883	1 264 731	1 269 525	1 280 214
Blue whiting (= Poutassou) *(Micromesistius poutassou)*	108 077	378 841	631 534	1 160 884	1 414 131	1 190 282
Atlantic mackerel *(Scomber scombrus)*	950 226	914 993	986 950	1 424 042	1 247 666	1 138 053
Sardinellas nei *(Sardinella spp.)*	966 955	1 017 368	932 523	1 020 461	1 042 801	1 088 980
Scads nei *(Decapterus)*	1 231 999	1 267 235	1 229 636	1 260 835	984 090	998 289

Source: FAO, 2018a.
Notes: ASFIS = Aquatic Sciences and Fisheries Information System; nei = not elsewhere included.

1.4.2 Inland fisheries

Unlike in marine fisheries, global inland fishery harvests have risen steadily since 1988, and were close to 12 million tonnes in 2016 (Figure 10). FAO does not have a system for tracking the status of inland fisheries in the way that is feasible for marine fisheries, in part given the predominance of the catch within developing countries and the absence of monitoring of individual fisheries. There are, however, credible reasons to believe that the production figures reported by FAO are underestimated (FAO, 2018b). Asia harvests the most from inland fisheries, producing 64 percent of the global production; Africa produces 26 percent of the production (Table 17).

Figure 10
Inland capture fisheries production by volume from 1987 to 2016



Source: FAO, 2018a.

Table 17
Global production from inland capture fisheries (freshwater and diadromous fish) by region (2016)

Geographical region	Production (tonnes)	Percentage of global total
Asia	6 850 021	64.1
Africa	2 814 121	26.3
Europe	424 886	4.0
Latin America & the Caribbean	538 026	5.0
North America	47 321	0.4
Oceania	13 530	0.1
Total	10 687 905	100

Source: FAO, 2018a.

Again, there are a number of species or species items that dominate production, as shown in Table 18 (note that a large volume of catch is not identified at the species level).

Table 18
Main species or species items harvested from inland fisheries in 2016

Species	**Production (tonnes)**	**Percentage of total global inland harvest**
Freshwater fishes nei	6 193 313	53
Cyprinids nei	774 893	7
Tilapias nei	436 998	4
Freshwater molluscs nei	326 154	3
Silver cyprinid (*Rastrineobola argentea*)	273 764	2
Nile tilapia (*Oreochromis niloticus*)	232 129	2
Nile perch (*Lates niloticus*)	217 444	2
Snakeheads (= murrels) nei	161 430	1
Hilsa shad (*Tenualosa ilisha*)	145 606	1
Oriental river prawn (*Macrobrachium nipponese*)	132 422	1
Siberian prawn (*Exopalaemon modestus*)	132 422	1
Freshwater siluroids nei	119 879	1
Common carp (*Cyprinus carpio*)	115 412	1
Lake Malawi sardine (*Engraulicypris sardella*)	109 387	1
Torpedo-shaped catfishes nei	101 442	1

Source: FAO, 2018a.
Note: nei = not elsewhere included.

Unlike marine fisheries where fishing pressure is a major determinant of the status, other factors external to the fishery sector exert a major influence on status (FAO, 2016a). Habitat condition, water quality and connectivity of waterbodies often influence inland fisheries more than fishing pressure. Complicating the determination of the status of inland fisheries is the fact that much of the harvest is unreported or not reported to species (FAO, 2018a; FAO, 2018b; Bartley *et al*., 2015).

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CHAPTER 2

THE USE AND EXCHANGE OF AQUATIC GENETIC RESOURCES OF FARMED AQUATIC SPECIES AND THEIR WILD RELATIVES WITHIN NATIONAL JURISDICTION

PURPOSE: The purpose of this chapter is to provide annotated inventories on and the status of aquatic genetic resources (AqGR) of farmed aquatic species and their wild relatives.

KEY MESSAGES:

- Aquatic genetic resources for food and agriculture include DNA, genes, chromosomes, tissues, gametes, embryos and other early life history stages, individuals, strains, stocks and communities of organisms. Unlike domesticated crops and livestock where many breeds, varieties and cultivars have been well established and recognized for centuries or millennia, aquatic species have a much smaller number of traditionally recognized strains and stocks of a few species.
- Naming of aquatic species and farmed types was reported to be generally accurate and up to date for most countries, although there are inconsistencies in naming farmed types below the species level.
- Current information systems such as the Aquatic Sciences and Fisheries Information System (ASFIS) often lack the capacity to record information on strains or stocks, or other kinds of genetically improved aquatic species.
- The use of genetic information in management depends on accurate information and baseline data. Although a global information system does not yet exist, potential elements of such a system have been developed.
- The information contained in the Country Reports could contribute to a new information system on AqGR.
- Countries reported farming of 694 species, or species items. Asia farms the most aquatic species and North America the fewest, although this is partially attributable to more countries practicing aquaculture in Asia than in North America.
- The two most commonly reported species being farmed were common carp (*Cyprinus carpio*) and Nile tilapia (*Oreochromis niloticus)*, followed by rainbow trout (*Oncorhynchus mykiss)*, grass carp *(Ctenopharyngodon idellus)* and North African catfish (*Clarias gariepinus*).
- Based on the Country Reports, the 11 major producing countries (i.e. those countries that contribute more than 1 percent to global aquaculture production) on average farmed a higher number of species (26 species/country) than the 79 other countries (7 species farmed/country).
- Introduced species (also known as non-native or alien species) are important in aquaculture, with approximately 200 species, or species items, farmed in areas where they are non-native, as reported by countries.
- Nine of the ten most widely cultured species were farmed in more countries where they are non-native than in countries where they are native.
- In most areas, aquaculture production is increasing, and is expected to continue for most species. Countries reported over 640 cases where aquaculture is currently increasing, while only reporting about 175 cases where it was decreasing or had stopped. As for the future trend in production, in about 800 cases aquaculture production was expected to increase.
- Coordination of national statistics on AqGR and aquaculture production is needed in some countries; the Country Reports identified over 250 species and species items that have not previously been reported with their production statistics to the Food and Agriculture Organization of the United Nations (FAO).
- Many of the species not previously reported were ornamental fish (29 percent) and microalgae (25 percent), or had limited production, were primarily used in research, have localized niche markets, were microorganisms or were new species being farmed. These groups are not sufficiently covered by the current FAO global data collection systems.

- The top 10 listed species reported as candidates for domestication and use in aquaculture were flathead grey mullet (*Mugil cephalus*); pike perch (*Sander lucioperca*); European perch (*Perca fluviatilis*); Nile perch (*Lates niloticus*); milkfish (*Chanos chanos*); African bonytongue (*Heterotis niloticus*); cobia (*Rachycentron canadum*); North African catfish (*Clarias gariepinus*); common sole (*Solea solea*); and turbot (*Psetta maxima*).
- It was reported in nearly 60 percent of responses that the cultured species, instead of being the wild type, are subject to some form of genetic change.
- There is a large range of genetic technologies useful in improving production in aquaculture, including selective breeding, hybridization, polyploidization, chromosome set manipulation, monosex production, marker-assisted selection, transgenesis, and gynogenesis and androgenesis. However, transgenesis was not reported by any country.
- Although the wild type was the most common farmed type used in aquaculture (in about 41 percent of responses), selective breeding was the technology most often used to improve certain desirable traits in aquatic species.
- Major producing countries reported a higher use of genetically improved organisms than minor producing countries.
- Countries reported that, in general, genetic data were available and used in aquaculture, with major producing countries using the information more than the minor producing countries; least developed countries used information on AqGR to a lesser degree than other countries.
- Most of the programmes on selective breeding were funded by the public sector, but the private sector was the main funder of all other technologies.
- Public support was an important source of funds for genetic improvement programmes. Public financing of genetic improvement programmes was more prevalent in the major producing countries than in the minor producing countries.
- Aquaculture depends on AqGR from the wild in the form of early life history stages or broodstock to at least some extent in almost 90 percent of the responses from the Country Reports.
- Wild relatives play a significant role in fisheries and aquaculture, with rivers and coastal areas being the habitats from where most wild relatives were reported.
- The abundance of many wild relatives is declining. For most wild relatives that are fished, a management plan exists; however, over 200 cases were reported where wild relatives are declining, and an additional 27 cases reported that they were depleted.
- The main reason cited for the change in abundance of wild relatives was habitat loss and degradation, followed by pollution.
- Habitat for most wild relatives was reported to be decreasing in the majority of Country Reports; however, there were a number of reports where the trend in changes of habitat were not known.
- As with farmed aquatic species, genetic data may exist for wild relatives, but these data are often not used in management.
- Of the wild relatives ranked on the basis of frequency of reports of declining catch, only three of the top 10 are listed as having any conservation concerns in the International Union for Conservation of Nature (IUCN) Red List, and for only two of these species has IUCN identified any trend in population numbers.
- Production from non-native species was reported to be increasing in fisheries for wild relatives and in aquaculture, especially in minor producing countries.
- Over 200 aquatic species were reported to have been exchanged (import and export), with Nile tilapia (*Oreochromis niloticus*) and North African catfish (*Clarias gariepinus*) the most exchanged species globally; Latin America and the Caribbean reported the most exchanges by region.
- Living specimens were the most often exchanged type of AqGR, accounting for about 77 percent of the reported exchanges.

2.1 Background

The use and exchange of aquatic genetic resources (AqGR) of farmed aquatic species and their wild relatives has been practised for millennia. The earliest humans gathered fish, shellfish and aquatic plants from wetlands and coastal areas in Africa and continued this practice as early humans migrated out of Africa; evidence from around the world of prehistoric fishing is found in middens, i.e. artifacts and ecofacts associated with past human occupation (Sahrhage and Lundbeck, 1992).

Early evidence of fish farming is found over two thousand years ago in China, as well as in ancient Rome, where Romans held marine species in special coastal enclosures not only for eventual consumption, but also as an indicator of wealth and status. European monks farmed and transferred the common carp from its native range in Asia and the Danube River to many parts of Europe; the scientific name for common carp, *Cyprinus carpio*, is derived from the fact that the fish was introduced to Western Europe through Cyprus (Nash, 2011).

While an incredible amount of biodiversity is used in fisheries and aquaculture (Bartley and Halwart, 2017), most information on this biodiversity, in terms of production and number of farmed organisms and their wild relatives, is at the species level. Little information is available on the genetic diversity of farmed organisms and their wild relatives.

2.2 Definitions and nomenclature

Aquatic genetic resources for food and agriculture include DNA, genes, chromosomes, tissues, gametes, embryos and other early life history stages, individuals, strains, stocks, and communities of organisms. Unlike domesticated crops and livestock (FAO, 2007; Scherf and Pilling, 2015), where many breeds, varieties and cultivars have been well established and recognized for centuries or millennia, aquatic species have few recognized strains and stocks (i.e. the equivalent to breeds in livestock or cultivars in crops). Box 3 explains the operational definitions used in this Report and proposed for standard usage in the description of aquatic genetic resources.

Box 3
Standardizing nomenclature in aquatic genetic resources

In 2016, FAO held an Expert Workshop on Incorporating Genetic Diversity and Indicators into Statistics and Monitoring of Farmed Aquatic Species and Their Wild Relatives (FAO, 2016a). This workshop recognized that there was a lack of standardization of terms used to describe aquatic genetic resources (AqGR), and recommended a number of operational descriptors as applicable to AqGR. In general, the nomenclature follows the custom in naming plant cultivars and animal breeds. The following descriptors used throughout this Report are based on these.

Term	**Definition**
Cultivar or variety	A plant or grouping of plants (including aquatic plants) selected for desirable characteristics that can be maintained by propagation and have characteristics that easily distinguish it from any other known cultivar; the cultivar must retain these characteristics under repeated propagation.
Farmed type	Farmed aquatic organisms that could be a strain, hybrid, triploid, monosex group, other genetically altered form, cultivar, variety or wild type. Note: a “species” is a higher level classification than a “farmed type”. A farmed type would normally be a species (unless it is a hybrid or introgressed strain) being cultured, but requires a further level of definition beyond just the species name, e.g. wild type or triploid, such that every species in culture would have a farmed type associated with it to provide more information on the genetic resource.
Strain	A farmed type of aquatic species having homogeneous appearance (phenotype), homogeneous behaviour and/or other characteristics that distinguish it from other organisms of the same species and that can be maintained by propagation.
Stock	A group of similar organisms in the wild that share a common characteristic that distinguishes them from other organisms at a given scale of resolution.
Wild relative	An organism of the same species as a farmed organism (conspecific) found and established in the wild, i.e. not in aquaculture facilities.

Unlike the terrestrial agriculture sector, all wild relatives of farmed aquatic species can still be found in nature, although wild types of some species are becoming threatened through, *inter alia*, introgression with farmed types and non-native genotypes (see below). The term “wild relative” signifies an organism found in nature that is the same species (conspecific) as one being farmed. This natural reserve of genetic diversity not only supports capture fisheries and helps the species adapt to anthropogenic and natural impacts, but it also provides a source of individuals and genes for use in aquaculture.

2.3 Information on fisheries and aquaculture

Accurate and timely information lies at the heart of documenting the use and status of genetic resources of farmed species and their wild relatives. The Food and Agriculture Organization of the United Nations (FAO) serves as the global repository for national statistics on fisheries and aquaculture production.

The international standard for collecting and reporting fisheries and aquaculture production includes the Aquatic Sciences and Fisheries Information System (ASFIS) list and the classification system of the International Standard Statistical Classification of Aquatic Animals and Plants (ISSCAAP). Members of FAO are recommended to utilize and align with the ASFIS nomenclature for collecting national fisheries and aquaculture statistics both in the case of their own use and when reporting to FAO.

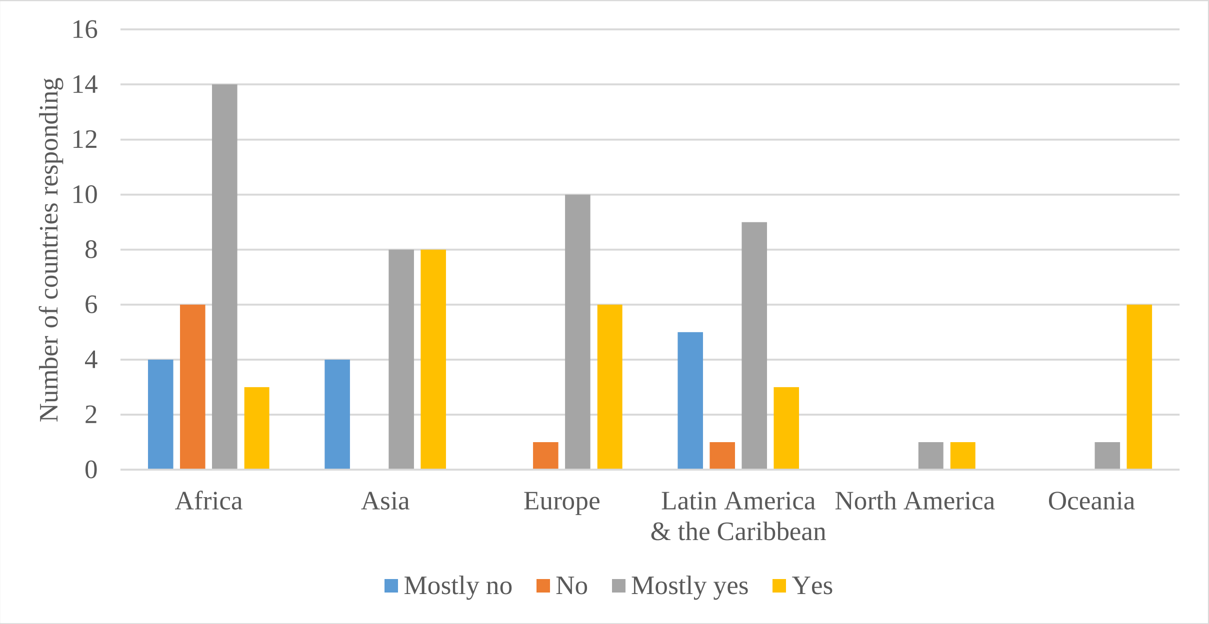
Responses in Country Reports indicated that the naming of species was generally accurate and up to date (Figure 11). This finding was seen when countries were grouped by economic status (Figure 12) and by level of aquaculture production (data not shown). However, there are still inconsistencies in nomenclature below the species level.

As of 2017, the ASFIS[9] list contains 12 700 species items.[10] The nomenclature includes only 12 species items below the species level (i.e. "farmed types"), with these currently being limited to commercially produced hybrids. The list does not include any other farmed types, such as subspecies, stocks, strains or varieties of farmed species or their wild relatives. It is possible to include more farmed types within ASFIS if and when FAO Members report production data of clearly identified and properly described types.

Information about AqGR below the species level can be extremely useful to resource managers, policy-makers, private industry and the general public. Genetic diversity is the basic building block for selective breeding programmes and other genetic improvement technologies in aquaculture. Also, it is key for natural populations to adapt to changing environments and to evolve. Information on genetic diversity can be used, *inter alia*, to help meet production and consumer demands, to prevent and diagnose disease, to trace fish and fish products in the production chain, to monitor impacts of introduced species on native species, to differentiate cryptic species, to manage broodstock, and to design more effective conservation and species recovery programmes.

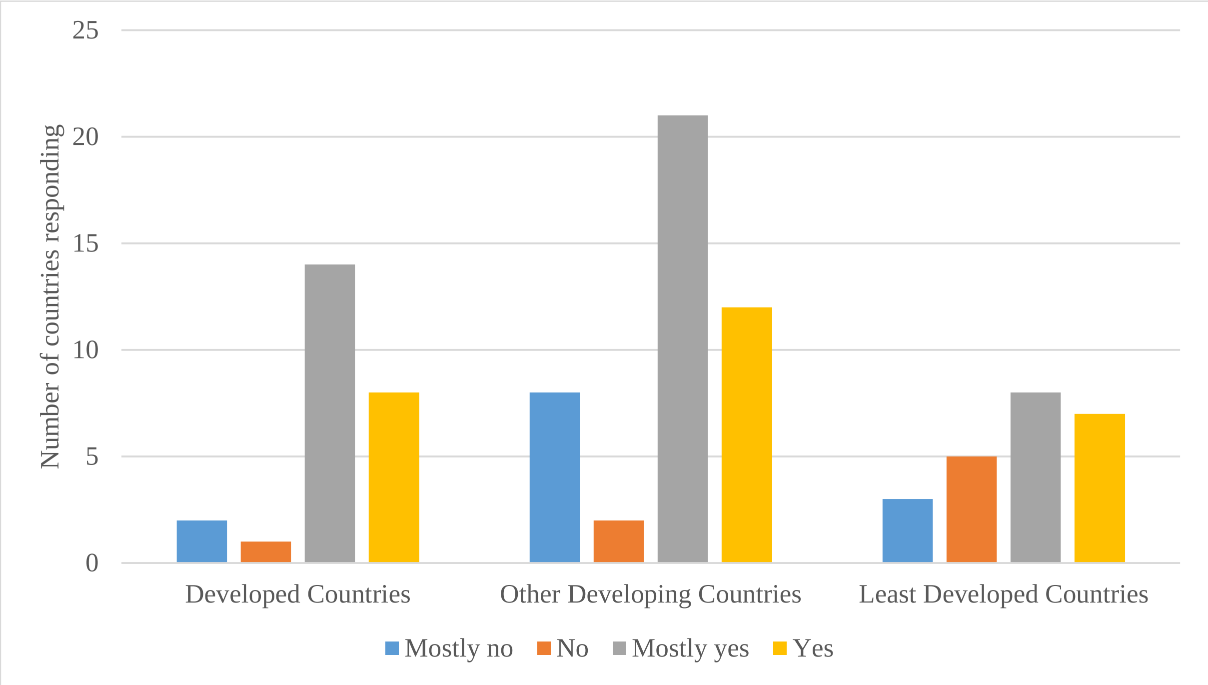
However, the majority of resource managers and those government officials who have routinely submitted information to FAO either do not use or cannot command sufficient access to information on aquatic genetic diversity of farmed species and their wild relatives to report below the level of the species, e.g. stocks and strains.[11]

Figure 11
The naming of aquatic species and farmed types accurate and up to date (by region)



[9] www.fao.org/fishery/collection/asfis/en.
[10] The ASFIS list and Country Reports contain entries that are not species, e.g. *Oreochromis* spp., hybrids or higher level taxa such as Cichlidae. Therefore, in the analyses presented here, "species" also includes "species items."
[11] The National Focal Points for AqGR have helped provide information below the species level for this report and are gratefully acknowledged.

Figure 12
The naming of aquatic species and farmed types accurate and up to date (by economic level)



2.4 Incorporating genetic diversity and indicators into national statistics and monitoring of farmed aquatic species and their wild relatives

The FAO Commission on Genetic Resources for Food and Agriculture realized that substantial production from aquaculture and capture fisheries is based on groups below the level of the species and that genetic information has a variety of uses in fishery management. Therefore, the Commission requested FAO to undertake a thematic study to explore the means to incorporate genetic diversity and indicators into statistics and monitoring of AqGR of farmed aquatic species and their wild relatives.

Examples of incorporating genetic diversity into national and global reporting and monitoring do exist; however, they appear primarily in the terrestrial agriculture sector, where the nomenclature for breeds and varieties has been standardized and used for centuries. In the aquaculture sector, the establishment of strains of most species is a much more recent practice, and thus the nomenclature and characterization of strains are not standardized.

In capture fisheries, genetic diversity is sometimes used in fishery management of high-value species, but this is dependent on the establishment of baseline data and on regular sampling, monitoring and analyses of the fish stocks, which is often beyond the financial and technical capacities for many species and areas. Stock identification in capture fisheries has traditionally been based on geographic location; production has been reported and monitored accordingly.

Some countries maintain registries of nationally important aquatic species, but production information is not routinely included unless the stock or species is considered threatened or endangered.

Significant constraints exist to developing an information system below the species level for AqGR, including:

- the absence of a standardized genotypic and phenotypic description or definition of a “strain” or “stock”;
- the lack of complete baseline data that genetically characterize a strain or stock; and
- the private aquaculture industry’s view that genetic information for their products is proprietary (FAO, 2016a).

Nonetheless, an information system was designed (Table 19) that would complement FAO's current work on fishery and aquaculture statistics (FAO, 2016a).

Table 19. Data structure for an information system on aquatic genetic resources of farmed types and their wild relatives

Information for farmed types	Information for wild relatives
Respondent – name of person providing information	Respondent – name of person providing information
Taxonomic status, genus, species, and farmed type or strain	Taxonomic status, genus and species
Genetic characteristics of the farmed type	Genetic status and characteristics of the wild relative
Source of farmed type, from wild or aquaculture	Source of wild relative, native or introduced
Breeding history	Migratory pattern
Distinguishing characteristics and common name	Designation of stock name and distinguishing characters
Where farmed	Records of occurrence
Farming system(s)	Habitat(s), distribution and range
Time series of production	Exploitation or use
Abundance	Status, presence and abundance
Source of further information	Source of further information

Source: FAO, 2016a.

Given the complexity and resources required, incentives would need to be developed to motivate governments, resource managers and private industry to participate and contribute to the information system. Incentives could include, among others:

- countries accessing funds to meet international commitments, e.g. from funding mechanisms of the Convention on Biological Diversity or the Global Environment Facility;
- private industry accessing markets through improved traceability and certification schemes; and
- international and national organizations becoming centres of excellence in information on AgGR.

To address costs and complexities, options exist for incorporating genetic diversity into statistics and monitoring programmes. As a first step, an inventory of farmed types and strains of wild relatives could be created that would not involve monitoring and assessment. This inventory would provide an accessible system for documenting the aquatic genetic diversity in fisheries and aquaculture. For an information system that would permit monitoring, options also exist for the time interval between data input. The cost of inputs to and maintenance of the information system would be lower with less frequent input.

The Country Reports are being incorporated into a database that would allow some monitoring on the status and trends of AqGR through the process of producing this Report. Rapid advances in genetic technologies and growing need for sustainably produced seafood suggest an imperative exists for monitoring at regular intervals to provide current information on change, opportunities and threats. Reporting at this level would further promote capacity building and continuity, i.e. a body of experts, resource managers, industry representatives and other interested stakeholders who would provide, analyse and use the information.

International organizations, private industry and national governments must commit to contributing to the information system. In light of the necessity for efficiently feeding a growing human population, these stakeholders would be well served by incorporating genetic diversity information into national management, reporting and monitoring programmes and then reporting this information to the global community.

A global information system on AqGR does not yet exist, and at national levels where it does exist, it is not comprehensive and only includes information on the species that dominate production. Therefore, a

new information system with input from countries needs to be established, one which will require human and financial resources as well as significant capacity building in many areas.

2.5 The use of aquatic genetic resources in food production

2.5.1 Aquaculture

As the fastest growing food production sector, aquaculture is expected to play a major role in providing seafood in the future, as production from many capture fisheries has plateaued (Figure 1 and Figure 2). Currently, 46.8 percent of global fish production (i.e. excluding aquatic plants) comes from aquaculture (FAO, 2016b). In order for aquaculture to fulfil its expected role in meeting future increases in demand for seafood, the sustainable management, development, conservation and use of AqGR and the application of useful genetic technologies will be essential.

The wide use of AqGR in aquaculture is a relatively recent activity for all but a few species, such as the common carp, *Cyprinus carpio* (Balon, 1995). Unlike the plant and livestock sectors, where farmers have been domesticating and maintaining hundreds of useful breeds and varieties with distinct characteristics for millennia, domestication of aquatic species only became widespread during the last century (Nash, 2011).

2.5.1.1 Diversity of farmed aquatic species

The current list of farmed aquatic species reported to FAO contains over 550 species items from inland, marine and coastal waters (see Table 7). Farmed aquatic species are derived from a wide taxonomic diversity that includes multiple phyla (Table 9).

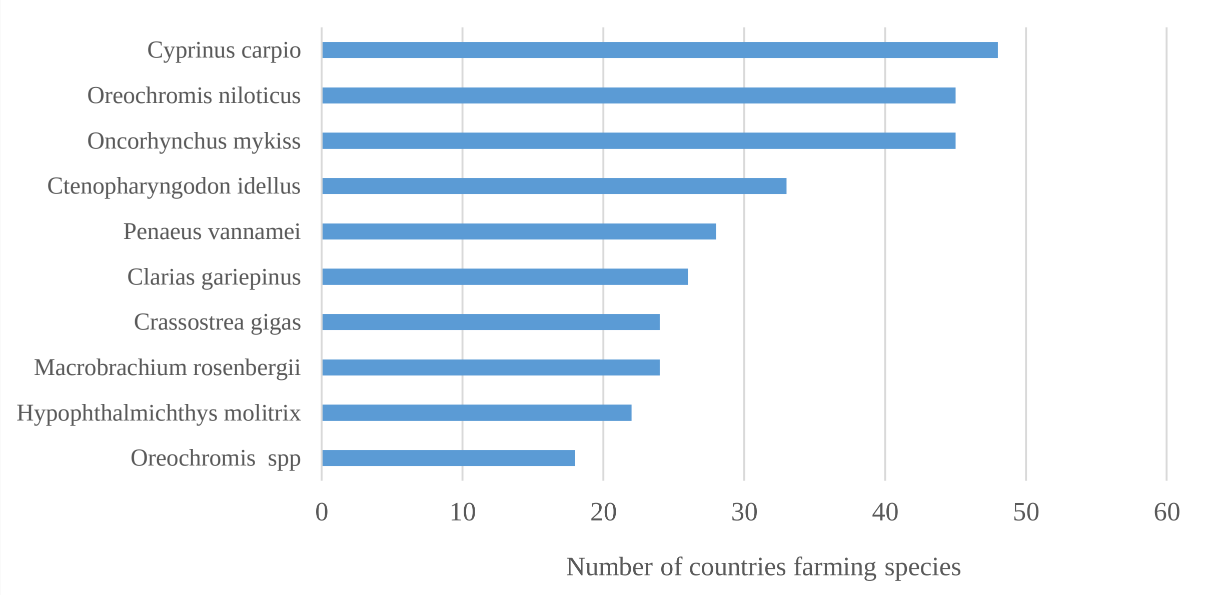
Aquatic species are farmed throughout the world, with approximately 130 countries traditionally reporting to FAO through the annual submission of statistics by Member Countries (FAO, 2018a).

Information from the Country Reports, a separate process from the traditional reporting, revealed that, of the ten most commonly farmed species/species items (Figure 13), eight are from freshwater habitats with one crustacean and one mollusc from the marine environment.

The two most commonly reported species being farmed were common carp (*Cyprinus carpio*) and Nile tilapia (*Oreochromis niloticus*). Both of these species have been widely introduced around the world. In fact, many of the commonly farmed species are not native to many (most) of the countries that farm them (Table 20).

Figure 13

Top 10 aquatic species by number of Country Reports in which they are reported as farmed



Countries reported farming of 694 species, or species items. Asia farms the most species (Figure 14a), with North America farming the fewest. By economic classification, other developing countries reported farming the most species. These results are partially a result of differences in the number of countries reporting from the different regions. However, the 11 major producing countries on average farmed a higher number of species than the 79 other countries that reported (Figure 14b). Thus, it appears that whereas little correlation appears between level of economic development and number of species farmed, there is an indication of a positive relationship existing between level of aquaculture production and number of species farmed (Figure 14b). This is consistent with other information on the advantages of farming a diversity of aquatic species (Harvey *et al.*, 2017).

In the preparation of this Report, FAO requested feedback from international organizations working with AqGR in a development context. Input was received from six organizations and included several species being prioritized in regional cooperation (Box 4).[12]

Box 4

Key focal species for international cooperation

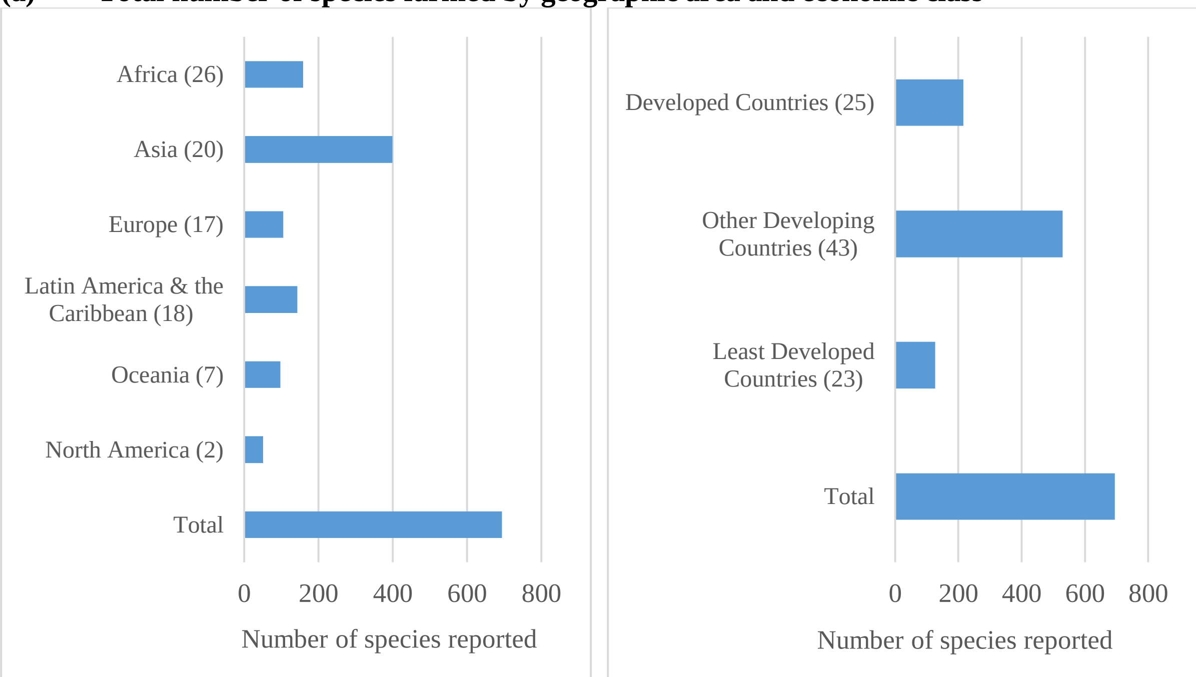
Tilapias	For example, *Oreochromis niloticus*, *O. aureus*, *O. shiranus*, *O. tanganicae*, *O. andersonii*, *O. esculentus*, *O. mossambicus*, *O. variaiblis*, and hybrid farmed types
Catfishes	*Clarias gariepinus*, *C. macrocephalus*
Cyprinids/carps	*Cyprinus carpio*, *Labeo rohita*, *L. vitorianus*, *Catla catla*, *Hypophthalmichthys molitrix*, *H. nobilis*, *Amblypharyngodon mola*
Salmonids	*Salmo trutta*
Freshwater prawns	*Macrobrachium rosenbergii*
Brackish water/marine crustaceans	*Penaeus monodon*,* *P. vannamei*, *P. stylirostris*, *Portunus pelagicus*, *Scylla* spp.
Molluscs	*Crassostrea gigas*, *Tridacna* spp., *Pinctada margaritifera*,

[12] The organizations were the Lake Victoria Fisheries Organization, Mekong River Commission, Network of Aquaculture Centres in Asia-Pacific, the Pacific Community, Southeast Asian Fisheries Development Center, and WorldFish Center.

	Haliotis sp.
Brackish water/marine finfish	*Lates calcarifer*, *Chanos chanos*, *Epinephelus* spp., *Siganid* spp.
*It is recognized that some groups have split the genus *Penaeus* to other genera, e.g. *Litopenaeus*. For consistency with the Aquatic Sciences and Fisheries Information System (ASFIS) and FishStatJ, this Report maintains the genus *Penaeus* for many of these marine shrimp.	

Figure 14
Number of species farmed by region (number of countries in group). Note that the total is the number of unique species, or species items, reported and not the sum of above groups, as the same species could be farmed in different regions.

(a) Total number of species farmed by geographic area and economic class



(b) Average number of species farmed by level of aquaculture production

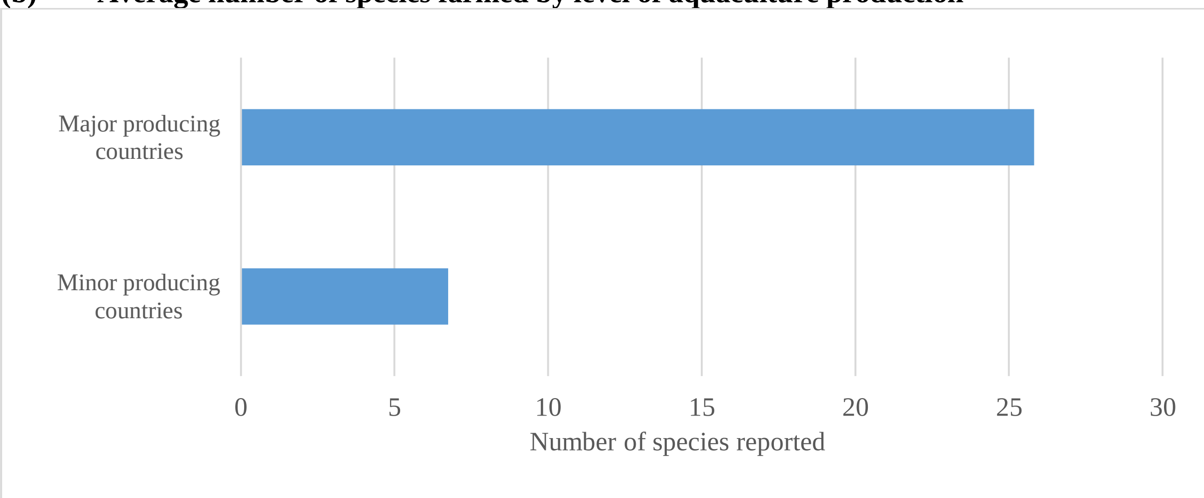


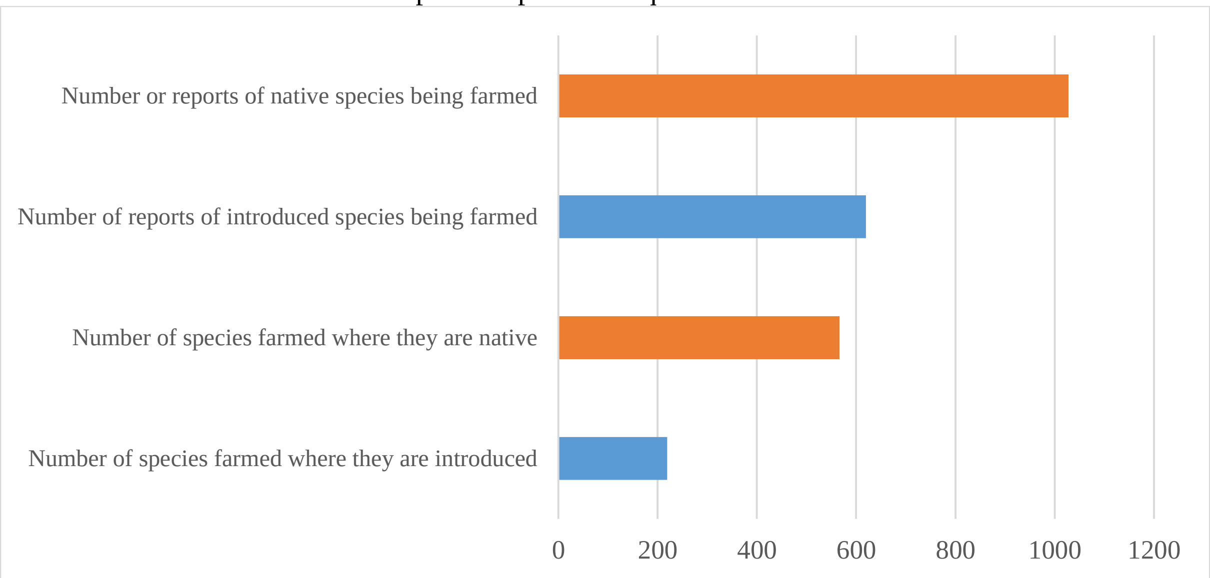
Table 20
For the ten most commonly farmed species reported, the number of countries where the farmed species is native or introduced

Species	Native	Introduced
Cyprinus carpio	11	37
Oreochromis niloticus	12	33
Oncorhynchus mykiss	5	40
Ctenopharyngodon idellus	3	30
Clarias gariepinus	14	12
Penaeus vannamei	9	19
Hypophthalmichthys molitrix	3	19
Crassostrea gigas	4	20
Macrobrachium rosenbergii	11	13
Oreochromis (= tilapia) spp.*	3	15

**Oreochromis* spp. would probably also contain *O. niloticus.*

Introduced species play a significant role in aquaculture production (see also section 2.5.4). Approximately 200 species items were reported farmed in countries where they are introduced, i.e. non-native, and almost 600 species items were reported farmed where they are native (Figure 15). There were over 1 000 reports of farming native species or species items and over 600 reports of farming introduced species or species items (Figure 15). Although there were more reports of farming native species, nine of the ten most productive species are mostly farmed in areas where they are non-native.

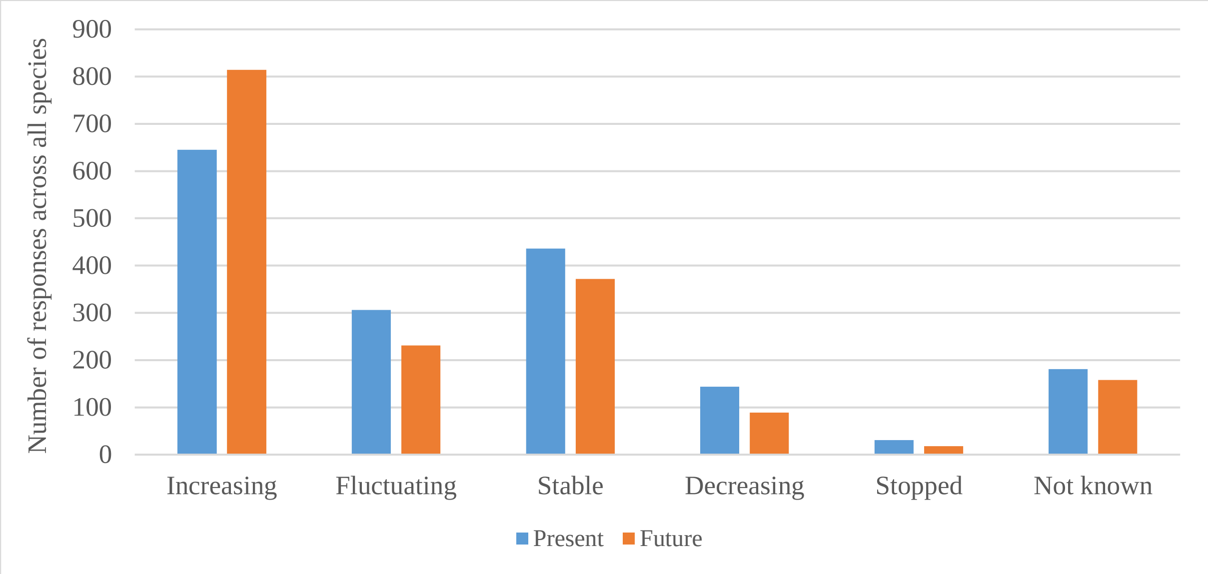
Figure 15
Numbers of native and introduced species reported in aquaculture



Aquaculture production is increasing, a trend which is expected to continue (FAO, 2018b). Additionally, production has been and is expected to continue increasing for the vast majority of species included in the Country Reports (Figure 16).

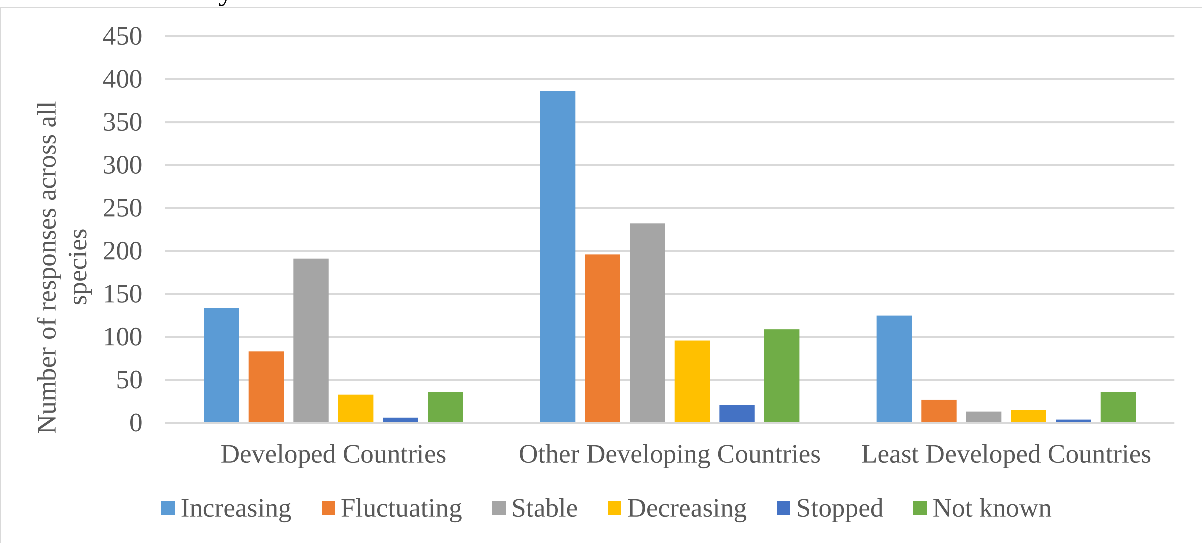
A few countries have discontinued the farming of certain species (e.g. *Argopecten ventricosus*, *Cherax quadricarinatus*, *Rachycentron canadum*, *Crassostrea gigas*, *Ctenopharyngodon idellus*, *Hypophthalmichthys molitrix*, *H. nobilis*, *Isochrysis galbana*, *Metapenaeus affinis*, *Oreochromis aureus*). However, the farming of these species was only reported as stopped in no more than one country.

Figure 16
Reported present and expected future trends in production of farmed aquatic species



Analysis of production trends by economic level of the countries indicated that aquaculture is mostly increasing in developing and least developed countries, but in developed countries the production of most species is stable (Figure 17).

Figure 17
Production trend by economic classification of countries



The Country Reports reflect the current national reporting (as appears in the FAO FishstatJ database; FAO, 2018a), but also contain additional information not previously reported to FAO (Table 21). Numerous countries reported farming more species and "species items" than they inform through the regular FAO statistic survey and mentioned species items not currently listed in ASFIS (Table 22, Figure 18 and Figure 19).

Table 21
Summary of species and farmed types reported in Country Reports

Item	Count	Examples	Notes
Number of Country Reports recording more species cultured than recorded in FishstatJ	44	See below	Based on species reported in Country Reports that have not been reported (in FishstatJ) as produced in that country since 2000.
Number of Country Reports recording fewer species than recorded in FishstatJ	44	See below	Based on FishstatJ reports going back to 2000.
Number of reports of cultured species that have never been previously reported as production to FAO (i.e. in FishstatJ)	253 (records); 207 (species)	**Finfish** *Clarias jaensis* (Cameroon – catfish); *Clarias magur* (India – catfish) **Molluscs** *Haliotis discus hannai* (China/Republic of Korea – abalone) **Crustaceans** *Cherax cainii (*Australia – freshwater crayfish) **Plants** *Cymodocea rotundata* and *C. serrulata* (Kenya – seagrass) *Eucheuma spinosum* (Philippines – red algae) **Microalgae** *Isochrysis galbana (*Argentina, Belgium, Egypt, Kiribati, Morocco, Netherlands, Panama, Tonga) **Other** *Heliocidaris erythrogramma* (Australia – sea urchin); *Xenia* sp. (Madagascar – coral)	This represents the total number of species records across all reporting countries. Several newly reported species were duplicated in more than one country.
Number of farmed types reported as significant	532	see Box 5	Any genetic differentiation or intervention recorded for a species in a Country Report. Includes strains/varieties, selected strains, hybrids, crossbreds, monosex and polyploid (based on question 8).
Total number of farmed types reported	1 085	See Box 5	Any genetic differentiation or intervention recorded for a species in a Country Report. Includes strains/varieties, selected strains, hybrids, crossbreds, monosex (based on question 9).

The largest groups of species not previously reported to FAO were ornamental fish species (29 percent) and microalgae (25 percent). Since FishstatJ focuses reporting on species cultured for food, it would not normally list species that are only cultured as ornamental fish. There was nevertheless a significant proportion of edible finfish and crustacean species not previously reported as produced (12.6 and 6.3 percent, respectively).

Species items reported for this Report may not be on the ASFIS list or not have been reported previously because they may:

- have limited production;
- be primarily used in research;
- have localized niche markets;
- be ornamental species;
- be microorganisms;
- have been misnamed or reported as strains or other type of non-standard nomenclature; and
- be new species being farmed.

Figure 18
Number of species reported that are not included in the Aquatic Sciences and Fisheries Information System (ASFIS) list

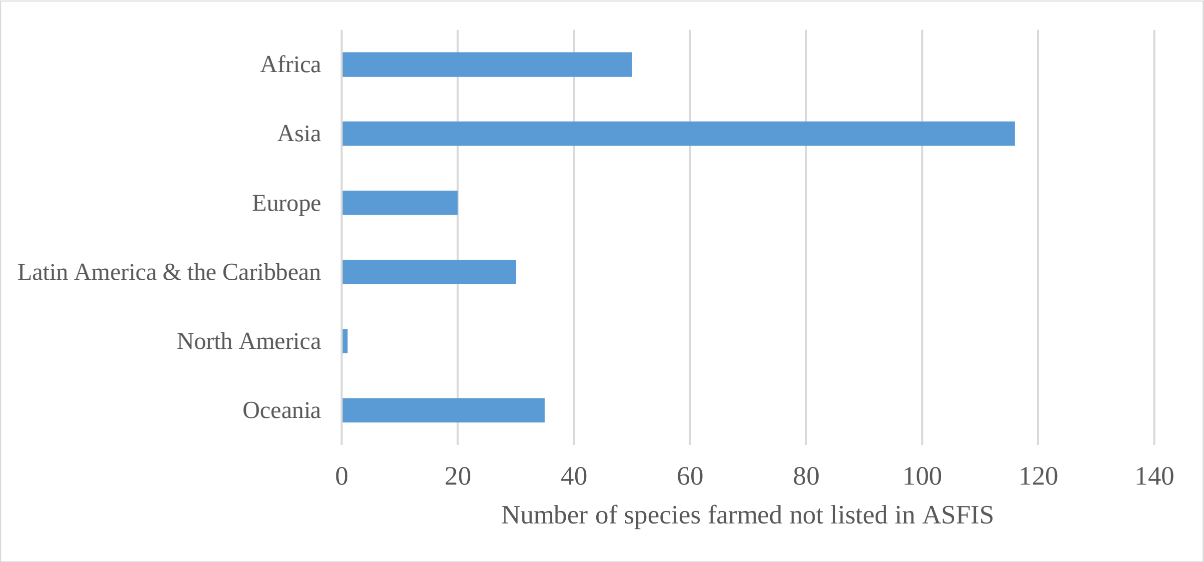


Figure 19
Identification of 253 species reported in Country Reports that have not previously been reported as produced (i.e. never previously reported in the FishstatJ database)

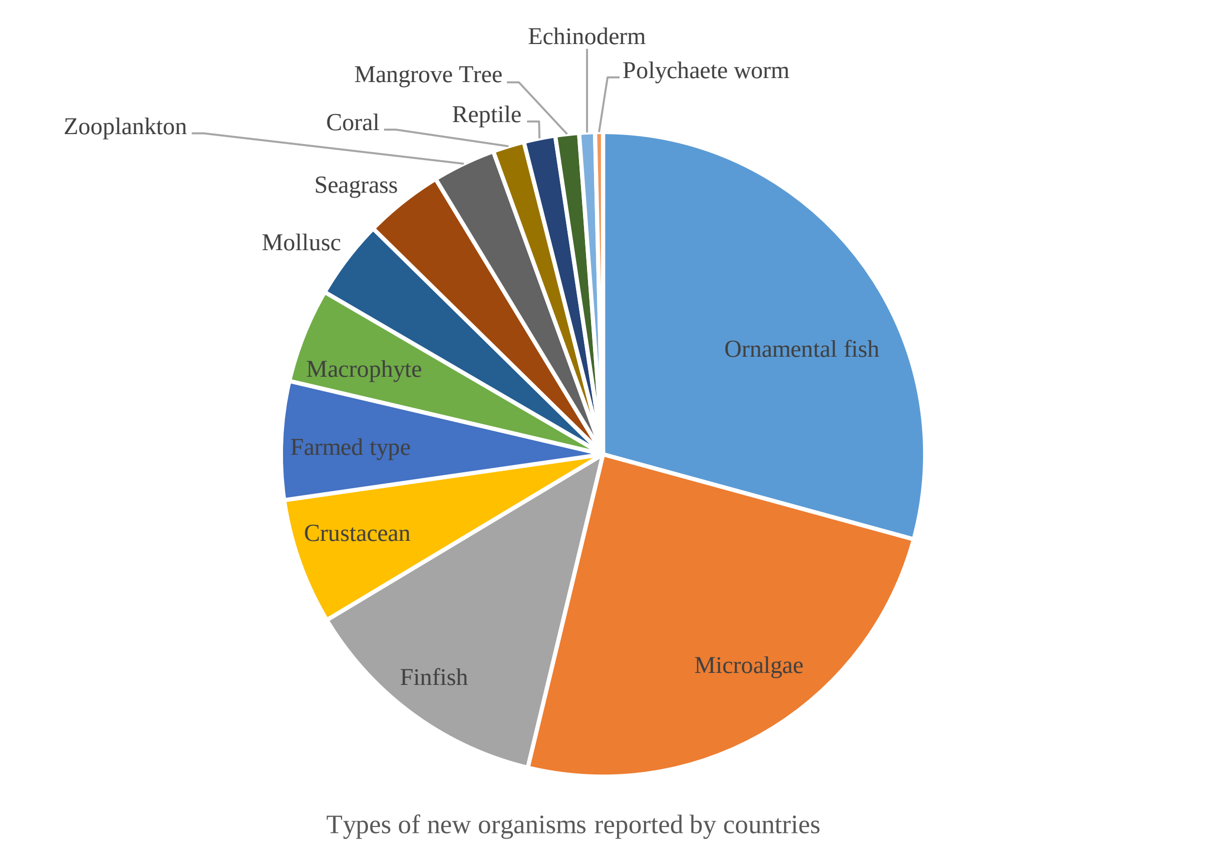


Table 22
The ten countries reporting the most species items not included in the Aquatic Sciences and Fisheries Information System (ASFIS)

Country	Number of species reported	Number of reported species in ASFIS	Number of reported species not in ASFIS
Panama	32	26	6
Guatemala	17	10	7
Indonesia	41	34	7
Japan	22	15	7
Madagascar	26	15	11
Viet Nam	67	55	12
Philippines	54	39	15
Sri Lanka	39	24	15
Kenya	33	14	19
Thailand	117	70	47

Country Reports included hybrid species items (Table 23). Currently, the ASFIS contains 11 hybrids (Table 24); however, countries do not always provide production information on the farming of these hybrids.

Table 23
Hybrids reported in Country Reports, but not in the Aquatic Sciences and Fisheries Information System (ASFIS) list. The female parent listed first and reciprocal cross signifies mating of the same species with the other species as the female parent.

Country	General name	Scientific name
Brazil	Catfish	*Pseudoplatystoma reticulatum* × *P. corruscans* and reciprocal cross
	Catfish	*P. reticulatum* × *P. hemioliopterus*
Philippines	Tilapia	*Oreochromis mossambicus* × *O. niloticus*
Germany	Char	*Salvelinus alpinus* × *S. fontinalis*
Japan	Trout	*Oncorhynchus mykiss* × *Salmo trutta*
Viet Nam and Malaysia	Grouper	*Epinephelus lanceolatus* × *E. coides* and reciprocal cross
	Grouper	*E. lanceolatus* × *E. fuscoguttatus*
Thailand	Catfish	*Clarias batrachus* × *C. macrocephalus*
Lao People's Democratic Republic	Snakehead	*Channa micropeltes* × *C. striata*
Canada	Scallop	*Patinopecten caurinus* × *P. yessoensis*

Table 24
Hybrids in the Aquatic Sciences and Fisheries Information System (ASFIS) list and indication of whether the data were previously reported to FAO and included in FishStatJ

Family	Scientific name	FAO English name	Production data registered in FAO database
Characidae	*Piaractus mesopotamicus* × *Colossoma macropomum*	Tambacu, hybrid	Yes
Characidae	*Colossoma macropomum* × *Piaractus brachypomus*	Tambatinga, hybrid	Yes
Characidae	*Piaractus mesopotamicus* × *P. brachypomus*	Patinga, hybrid	No
Channidae	*Channa maculata*×*C. argus*		No
Cichlidae	*Oreochromis aureus* × *O. niloticus*	Blue-Nile tilapia, hybrid	Yes
Moronidae	*Morone chrysops* × *M. saxatilis*	Striped bass, hybrid	Yes
Cichlidae	*Oreochromis andersonii* × *O. niloticus*		No
Clariidae	*Clarias gariepinus* × *C. macrocephalus*	Africa-bighead catfish, hybrid	Yes
Ictaluridae	*Ictalurus punctatus* × *I. furcatus*	Channel-blue catfish, hybrid	No
Pimelodidae	*Pseudoplatystoma corruscans* × *P. reticulatum*		No
Pimelodidae	*Leiarius marmoratus* × *Pseudoplatystoma reticulatum*		No

Nonetheless, the Country Reports clearly demonstrated that more aquatic genetic diversity is being used than has been previously recognized. However, discrepancies in many Country Reports to FAO, through the state of the world process and through the routine submission of statistics for FishStatJ, indicate that improved coordination of aquaculture statistics within a country would be important.

The ASFIS list does not include strains; however, some Country Reports listed numerous intraspecific genetic diversity (see Box 5 on strains).

Box 5
Strains in aquaculture

In terrestrial agriculture, animals and plants have been domesticated into recognizable breeds and varieties, e.g. Angus beef, Bantu swine, Jasmine rice and iceberg lettuce. The *Second Report of the State of the World's Animal Genetic Resources* states that there are over 7 000 breeds of animals (mammals and birds) (Scherf and Pilling, 2015).

For plant genetic resources, there are even more breeds. According to FAO (1997):

> Estimates of the number of distinct varieties of the rice species, *Oryza sativa*, range from tens of thousands to more than 100 000. At least seven different vegetables derive from the single wild cabbage species *Brassica oleracea* (kale, cauliflower, cabbage, Brussels sprouts, kohlrabi, broccoli calabrese, [and] savoy cabbage).

Although there are examples of fish farmers using and even developing their own strains, in aquaculture there are few standardized strains that are globally recognized. The common carp, *Cyprinus carpio,* is a notable exception, with the mirror carp, scaled carp, leather carp and wild type widely recognized (Bakos and Gorda, 2001). The genetic basis for the different strains of carp is also known.

A strain in aquaculture should be distinct, stable and reproducible. That is, if a mirror carp breeds with a mirror carp, the offspring are more mirror carps. Therefore, monosex populations, hybrids and triploids would not be considered strains, even if they were distinct because they could not be bred and yield the same strain. The Country Reports listed numerous "farmed types" that would not be designated "strains" by this definition, e.g. monosex tilapia, hybrid cold-tolerant tilapia, genetically male tilapia, all-female Atlantic salmon and hybrid catfish.

Countries also reported on farmed types that could be considered as strains. Not unexpectedly, common carp was often listed. Strains of common carp from China included "Feng Li" (Li means common carp in Chinese), "Heyuan Li", "Baiyuan Li", "Furong Li", "Yue Li", "Jin Li", "Huabai mirror carp", "Songpu mirror carp" and "Furui Li". Indonesia reported seven strains of common carp for human consumption, namely Rajadanu, Jaya Sakti, Mantap, Marwana, Najawa, Majalaya and Sinyonya; each strain has specific superior traits such as disease resistance, fast growth rate or high fecundity. Czechia reported that there are 20 registered strains of common carp in the country.

Nile tilapia, *Oreochromis niloticus,* was another species for which countries identified strains. The Philippines reported on the genetically improved farmed tilapia (GIFT) and other selected strains of Nile tilapia named FAST, GET-Excel, BEST 200, the GenoMar Supreme Tilapia and the SEAFDEC Supreme Tilapia. These strains were reported to have superior growth rate or environmental tolerances compared to unimproved strains. The Philippines also reported using a red tilapia strain, salt-tolerant "Molobicus" and "iBEST", and a cold-tolerant tilapia derived from cross-breeding or hybridizing tilapia strains/species.

Czechia reported using not only strains of common carp, but also seven strains of tench (*Tinca tinca)* and a strain of albino catfish (*Silurus glanis*).

The *State of the World* Reports on plants and animals rely on standardized and recognized description of breeds and varieties for the assessment of genetic resources for food and agriculture. The aquatic sector lags far behind in establishing, recognizing and promoting strains of aquatic species. A system that recognizes strains with known characteristics would be an asset to help aquaculture grow in a sustainable and efficient manner. A registry of strains with their distinguishing characters has been proposed as a possible first step toward more accurate information on and increased production from aquatic genetic resources (see section 2.4).

Countries reported numerous farmed types, species and hybrids not currently listed in ASFIS. However, FAO, as developer and curator of the ASFIS nomenclature, is reluctant to add additional items to the list unless it can be demonstrated that the new listing, i.e. new hybrid or species, would be reported in a reliable and consistent manner by Members of FAO. No mechanism exists within the structure of the ASFIS list to include strains, stocks or subspecies. An analysis of the Country Reports revealed that several new species and hybrids are being farmed that are currently not on the ASFIS list. Several of these species items were reported by more than one country and will be added to the ASFIS list.

Some Country Reports listed subspecies as being farmed or as a wild relative. Current taxonomists have recommended the abolishment of this latter term (N. Baily, FishBase coordinator, personal communication, 2016).

There were several species that countries identified as having aquaculture potential. Some of these are wild relatives of species that are farmed in other countries, but are not yet in a specific country; other species are currently being developed in research stations or by private industry in pilot programmes.

The most often reported species for future domestication and use in aquaculture was the flathead grey mullet (*Mugil cephalus*). The ten species most often reported as candidates for domestication and use in aquaculture were (number of countries reporting):

- flathead grey mullet (*Mugil cephalus*) (19);
- pike perch (*Sander lucioperca*) (12);
- European perch (*Perca fluviatilis*) (11);
- Nile perch (*Lates niloticus*) (9);
- milkfish (*Chanos chanos*) (8);
- African bonytongue (*Heterotis niloticus*) (8);
- cobia (*Rachycentron canadum*) (8);
- North African catfish (*Clarias gariepinus*) (7);
- common sole (*Solea solea*) (7); and
- turbot (*Psetta maxima*).

These organisms are all finfish and come from marine, coastal and inland areas. Country Reports often listed just a genus of interest without listing a specific species. For example, *Epinephelus* spp. was reported as having future potential by fourteen countries, *Lutjanus* spp. was mentioned by seven countries, *Macrobrachium* spp. in six countries, and *Centropomus* spp. in five countries.

Pullin (2016) reviewed models for establishing priorities for future domestication that included growth and economic parameters of importance when considering the farming of a new species. However, the models the author reviewed were not extremely good at predicting future use of a species in aquaculture. Pullin incorporated other criteria to identify species suitable for culture, such as maximum length, growth performance, indicative trophic level, water(s) inhabited, temperature tolerance and other general considerations, e.g. ease of culture. Interestingly, several of the papers reviewed by Pullin according to his own prioritization identified species of river mullet – although not the same species identified in the Country Reports – as having future farming potential.

2.5.2 Technologies

Genetic technologies, both in developing and in developed countries, can be applied in aquaculture for increased production, control of reproduction, improved marketability, more accurate and effective traceability in the supply chain, better disease and parasite resistance, more efficient utilization of resources, and better identification and characterization of aquatic genetic resources (Table 25). Ethical, regulatory and legislative considerations regarding some of these technologies are presented in the

Thematic Background Study on Genome-based Biotechnologies in Aquaculture.[13]

Some technologies can be used for immediate short-term gain, whereas others are for longer-term gain with genetic improvements accumulating each generation. Although new gene editing techniques are emerging (Wargelius *et al*., 2016) for cultured species, they have not yet been widely applied in commercial aquaculture. The basic requirement for the application of all genetic technologies is the ability to reproduce the species under controlled conditions, i.e. under farm or hatchery conditions.

Table 25

Genetic technologies for improving culture performance of farmed types and indicative responses in farmed aquatic species

Long-term objectives using selective breeding	
Growth rate of salmon	Around 50 percent improvement in time to market after ten generations in coho salmon (*Oncorhynchus kisutch*); gilthead seabream (*Sparus aurata*) mass selection gave 20 percent increase per generation; about 5 percent per generation improvement in Atlantic salmon (*Salmo salar*), where feed efficiency was also increased (Hulata, 1995; Tave, 1989; Thodesen *et al*., 1999).
	Mass selection for live weight and shell length in Chilean oysters (*Ostrea chilensis*) found 10–13 percent gain in one generation (Toro, Aguila and Vergara, 1996).
Body confirmation	High heritability in common carp (*Cyprinus carpio),* catfish (*Ictalurus punctatus*) and trout (*Oncorhynchus mykiss*) (Tave, 1995).
Physiological tolerance (stress)	Rainbow trout (*Oncorhynchus mykiss*) showed increased levels of plasma cortisol levels (reviewed in Overli *et al.*, 2002).
	Increased resistance to dropsy in common carp (*Cyprinus carpio*) (Kirpichnikov, 1981).
Disease resistance	Increased survival after selection for resistance to Taura syndrome in whiteleg shrimp (*Penaeus vannamei*) (Fjalestad *et al.*, 1997); a Quantitative Trait Loci (QTL) marker-assisted selection programme resulted in a 50 percent decrease in infectious pancreatic necrosis in Norwegian Atlantic salmon (*Salmo salar*) (Moen *et al*., 2009).
Maturity and time of spawning	Sixty days advance in spawning date in rainbow trout (*Oncorhynchus mykiss*) (Dunham, 1995).
Resistance to pollution	Tilapia progeny (*Oreochromis niloticus*) from lines selected for resistance to heavy metals survived three to five times better than progeny from unexposed lines (Lourdes, Cuvin-Aralar and Aralar, 1995).
Short-term strategies	
Crossbreeding (intraspecific mating – see Box 6)	Improved growth seen in 55 and 22 percent of channel catfish (*Ictalurus punctatus*) and rainbow trout (*Oncorhynchus mykiss*) crosses, respectively (Dunham, 1995).
	Improved growth wild × hatchery gilthead seabream (*Sparus aurata*) crosses (Hulata, 1995).
	Crossbreeds of channel catfish (*Ictalurus punctatus*) and common carp (*Cyprinus carpio*) showed 30–60 percent improved growth.
	Increased salinity tolerance and colour in tilapia crossbreeds (*Oreochromis* spp.) (Pongthana, Nguyen and Ponzoni, 2010).
	Oreochromis niloticus × *O. aureus* hybrids show a skewed male sex-ratio (Rosenstein and Hulata, 1993).
Hybridization (interspecific mating)	Sunshine bass hybrids (*Morone chrysops*× *M. saxatilis*) grew faster and had better overall culture characteristics than either parental species (Smith, 1988).
	Walking catfish hybrids (*Clarias macrocephalus* × *C. gariepinus)* exhibit morphological features that increase consumer acceptance (Dunham, 2011).
	All male tilapia (*Oreochromis niloticus*) show improvements in yield of almost 60 percent depending on farming system and little unwanted reproduction and stunting (Beardmore, Mair and Lewis, 2001; Lind *et al.*, 2015).
Sex reversal and breeding	All female rainbow trout (*Oncorhynchus mykiss*) grew faster and had better flesh quality (Sheehan *et al.*, 1999).

[13] Much of the section on genetic technologies was taken from the draft Thematic Background Study by Zhanjiang Liu in 2016: *Genome-based biotechnologies in aquaculture*. Available at www.fao.org/3/a-bt490e.pdf.

	Improved growth and conversion efficiency in triploid rainbow trout (*Oncorhynchus mykiss)* and channel catfish (*Ictalurus punctatus*); triploid Nile tilapia (*Oreochromis niloticus*) grew 66–90 percent better than diploids and showed decreased sex-dimorphism (Dunham, 1995).
Chromosome manipulation	Triploid Pacific oysters (*Crassostrea gigas*) show 13–51 percent growth improvement over diploids and better marketability due to reduced gonads (Guo *et al.*, 2009).
	Polyploidization makes certain interspecific crosses produce sterile offspring (Wilkins *et al*., 1995).
Gene transfer/transgenesis	Coho salmon (*Oncorhynchus kisutch*) with a growth hormone gene and promoter from sockeye salmon (*O. nerka*) grew 11 times (0–37 range) as fast as non-transgenic fish (Devlin *et al.*, 1994).
	Atlantic salmon (*Salmo salar*) containing a gene encoding growth hormone from Chinook salmon; (*Oncorhynchus tshawytscha*) grows twice as fast as selectively bred fish (Fox, 2010).

Box 6
Hybridization terminology

Hybridization is a term that can often generate confusion. This box attempts to introduce a degree of standardization of terminology. Definitions of the terms discussed here are included in the definitions within the glossary associated with this publication. Hybrids and crossbreds are often used synonymously, but are most usefully defined and distinguished as referring to interspecific and intraspecific crosses, respectively. A cross between two species (hybrids) or two strains of the same species (crossbreds) is known as an F_1 (hybrid or crossbred). Crosses between F_1s are known as F_2s, between F_2s as F_3s, and so on. In F_1s, F_2s and F_3s, the average genetic contribution within the line remains at 50 percent from each of the original parental species, but as the number of hybrid/crossbred generations progresses, the phenotypes of the hybrids or crossbreds become less predictable and more variable. Also, hybrids or crossbreds may be backcrossed or crossed to another species or strain, changing the relative genetic contributions from the source species/strains and making the phenotypes even less predictable and more variable. It can thus be confusing to continue to refer to these subsequent generations within the lines as hybrids or crossbreds, and it is proposed here that anything beyond an F_2 hybrid or crossbred be referred to as an introgressed species or strain.

2.5.2.1 Farmed types

Several farmed types of aquatic organisms are available to aquaculturists. These farmed types include, in addition to selectively bred organisms, polyploids (Tiwary, Kirubagran and Ray, 2004), hybrids (Wohlfarth, 1994; Bartley, Rana and Immink, 2001) and monosex groups (Mair *et al.*, 1995). The general term "farmed type" has been suggested (FAO, 2016a) as an inclusive term to include the diversity of genetically altered (or non-wild type) organisms available for aquaculture. Many aquatic farmed types are similar to the wild type, i.e. the wild relative, and their genetic resources are not managed systematically. It has been stated that less than 10 percent of aquaculture production is based on genetically improved stocks resulting from family-based selective breeding programmes (Gjedrem and Robinson, 2014). This has often been misinterpreted in various forums to mean that either 90 percent of farmed aquatic species genetic resources are not managed and are essentially of the "wild type" or that 90 percent of production is from the "wild type".

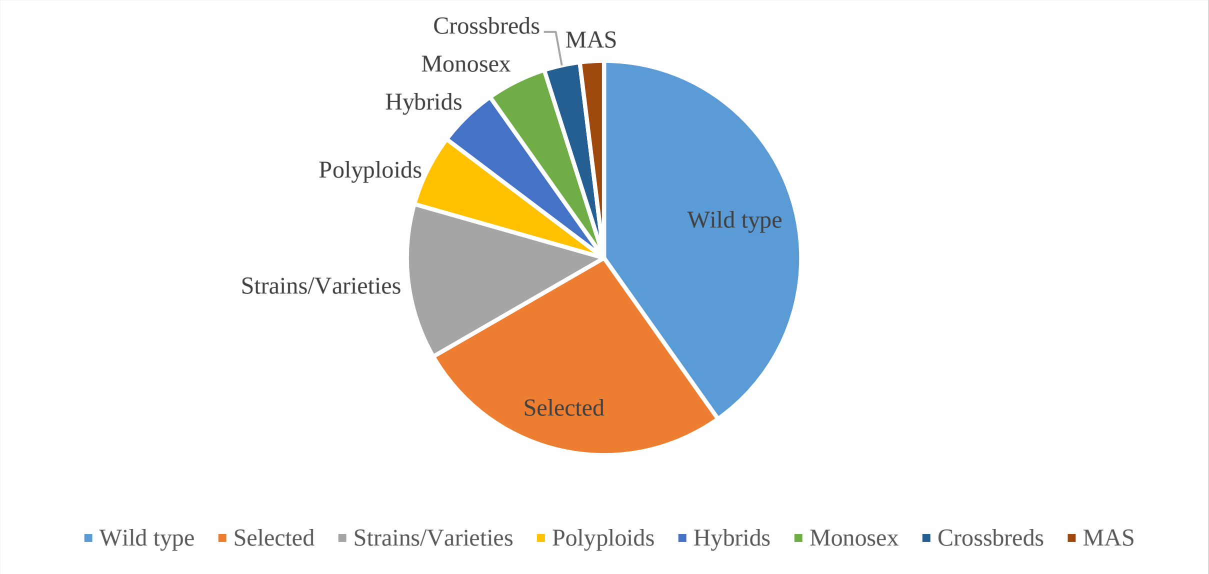
The Country Reports indicate that in fact genetic resources are being managed at some level in about 60 percent of the responses relating to species, i.e. only about 40 percent of species reported as cultured are of the wild and farmed type (Figure 20). While these data are not directly comparable, one dealing with a proportion of production and the other with the proportion of cultured species, this finding from the Country Reports would appear to represent a substantial increase in the misquoted figure that only 10 percent of aquaculture is using genetically improved or managed organisms. Unfortunately, neither the Country Reports nor the data routinely reported to FAO allow analysis of how much production

comes from wild types versus genetically improved types.

Selective breeding has the longest history of use in aquaculture and was the most common form of genetic technology application reported by countries (Figure 20). Selective breeding permits the accumulation of genetic gain in each generation. It is therefore a good long-term, and often a highly cost-effective, strategy for strain improvement and domestication.

Selective breeding has proven to be effective in enhancing traits of agricultural plants and animals through the application of quantitative genetic principles; selective breeding has also benefited aquaculture species. For instance, the genetic gain has been greater than 12 percent per generation for growth rate and for disease resistance when challenge tests are applied (Gjedrem and Robinson, 2014). The main reasons for the large genetic gains observed for aquatic species relative to plants and livestock are their relatively high fertility and high levels of genetic variation for economically important traits.

Figure 20
Genetic improvement used in aquaculture (number of responses)

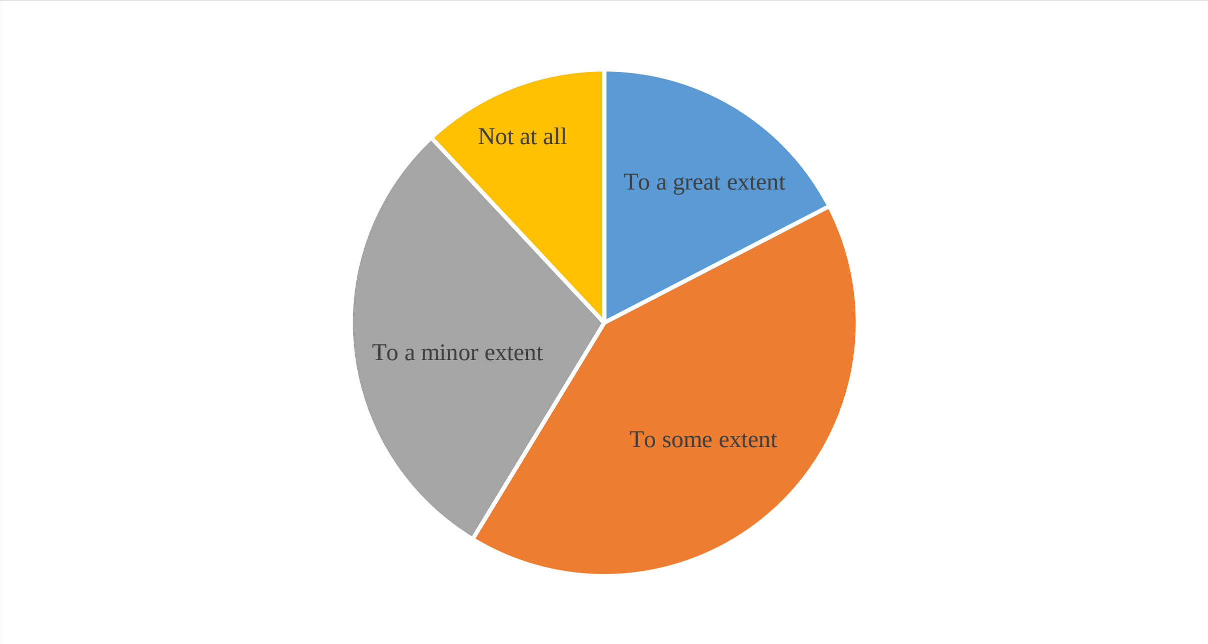


Note: MAS = marker-assisted selection.

In addition to farming wild types that may not be domesticated, many aquaculture or hatchery facilities depend on organisms from the wild for a supply of seed, juveniles and broodstock.[14] Overall, 89 percent of countries reported that aquaculture depended on aquatic organisms collected from the wild to some extent (Figure 21).

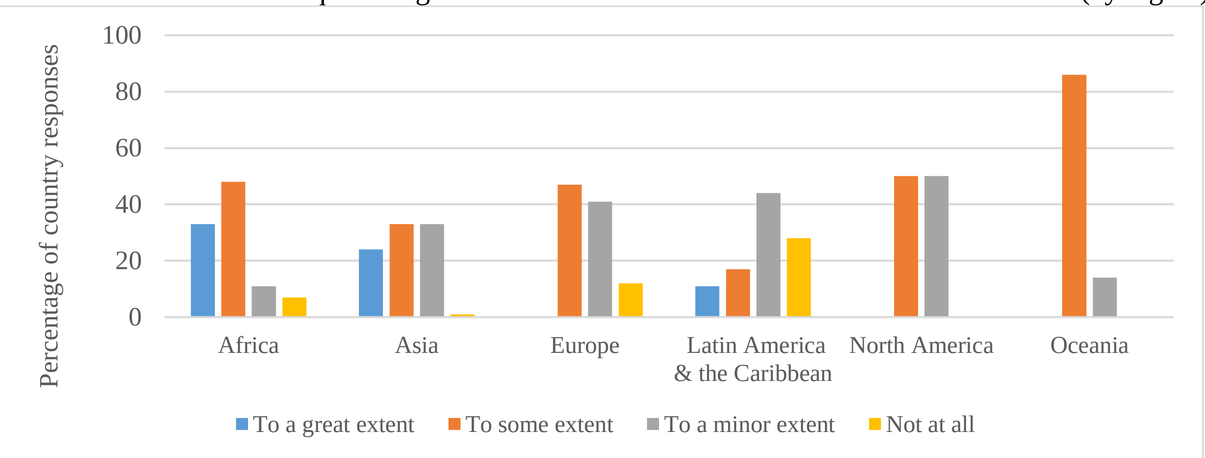
[14] Following Bilio (2008), three generations of mating under farm or hatchery conditions are required for an organism to be considered “domesticated”.

Figure 21
Extent to which aquatic organisms farmed in your country are derived from wild seed or wild broodstock (number of countries)



Analysis by region confirmed the importance of using AgGR derived from the wild (Figure 22). Analysis by economic and production level of countries did not reveal important differences in the extent that AqGR were derived from the wild (data not shown).

Figure 22
Extent to which farmed aquatic organisms are derived from wild seed or wild broodstock (by region)



In spite of the reliance on wild types in aquaculture, almost 90 percent of the countries reported that genetically improved aquatic organisms contributed at least somewhat to national aquaculture production (Figure 23). Analyses by region and economic development revealed the same general result, i.e. that genetic resource management is occurring at some level in most cases. Analysis by level of aquaculture production revealed that genetically improved organisms contributed to production more in the major producing countries, but contribution at least to some extent was reported in all countries (Figure 24, Figure 25 and Figure 26).

Figure 23
Extent to which genetically improved aquatic organisms contribute to national aquaculture production

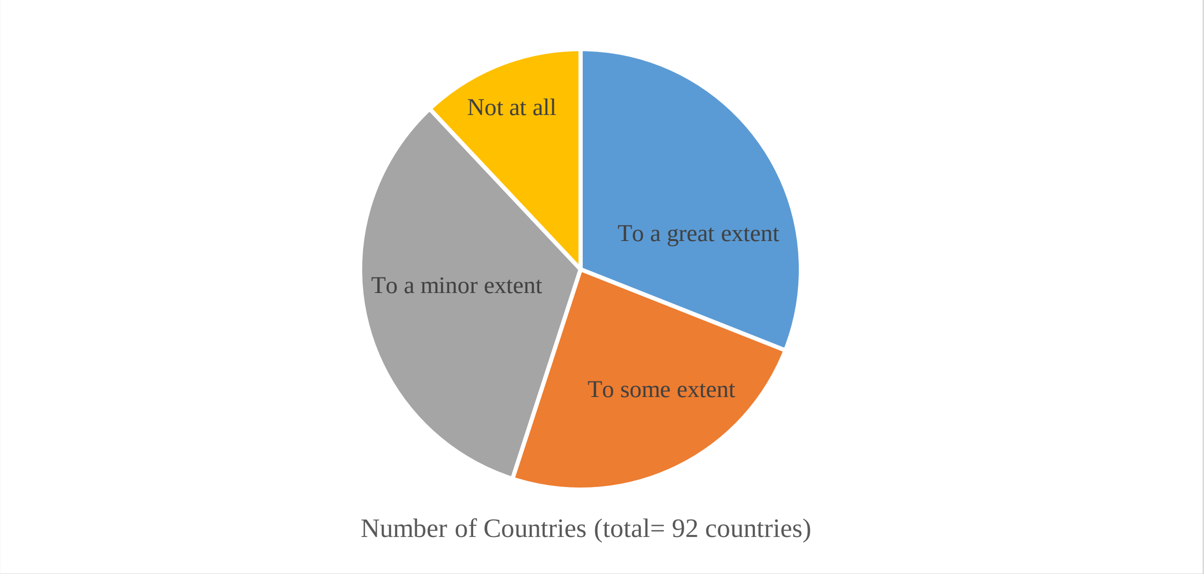


Figure 24
Extent to which genetically improved aquatic organisms contribute to national aquaculture production by region

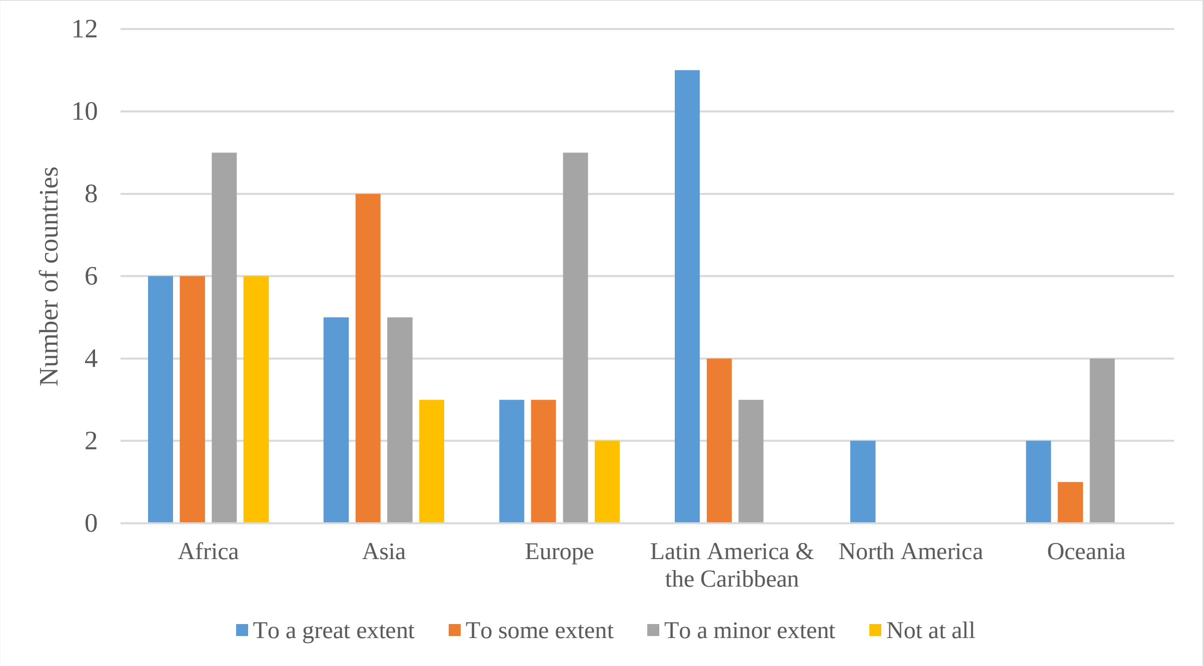


Figure 25
Extent to which genetically improved aquatic organisms contribute to national aquaculture production by economic level

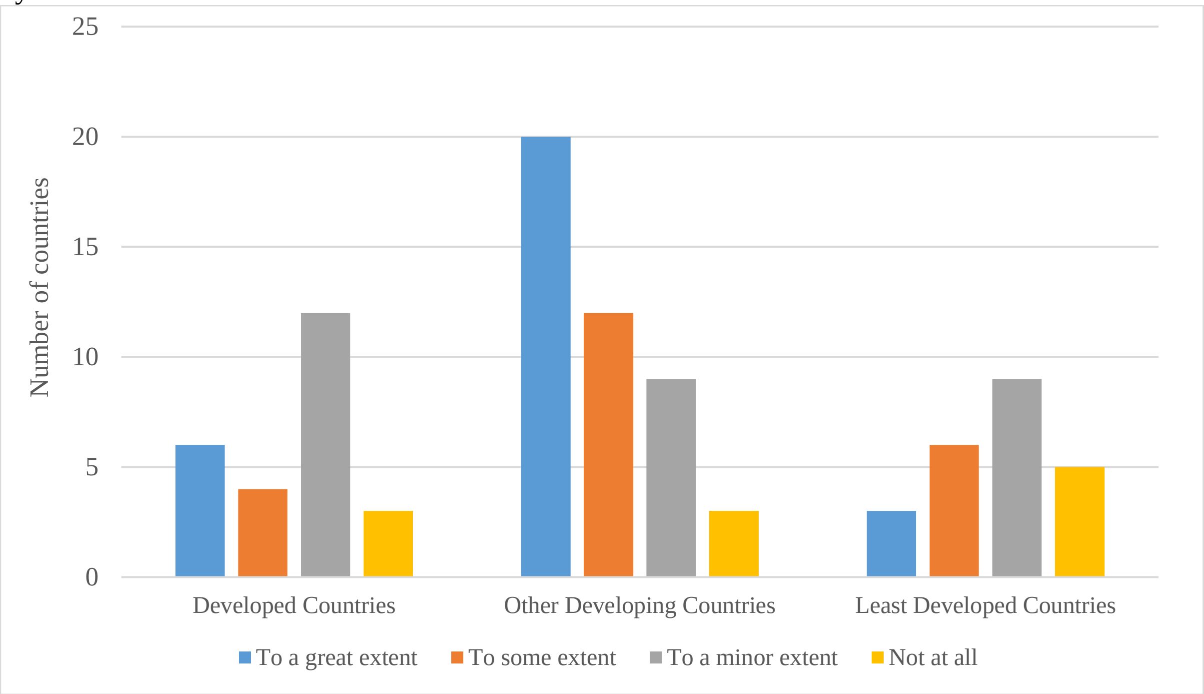
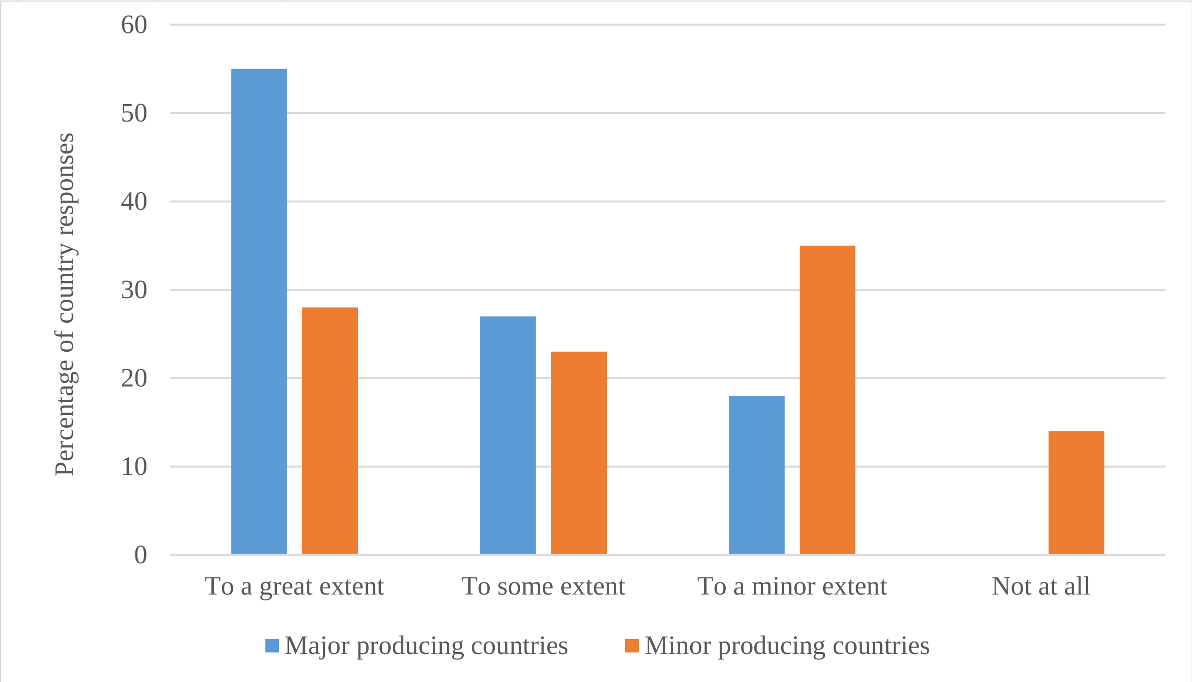


Figure 26
Extent to which genetically improved aquatic organisms contribute to national aquaculture production by level of aquaculture production



2.5.2.2 Extent of the use of genetics in aquaculture

The world's demand for seafood is expected to increase by about 2 percent per year over the next decades (World Bank, 2013). Genetic improvements from selective breeding produce increases of about 10 percent per generation. Aquaculture geneticists have stated that if all farmed aquatic species were in traditional selective breeding programmes, aquaculture production could double by 2050, thus meeting the additional need for seafood with little extra land, water, feed or other inputs (Gjedrem, 1997; Gjedrem, Robinson and Rye, 2012).

Clearly, tremendous opportunities exist to increase food production through the use of genetic technologies. However, challenges persist, including capacity and financial needs, and the question of how to handle information (see Chapter 8).

Genetic data are more technically demanding and costly to collect and therefore may not often be available or used in management of farmed aquatic species. However, countries reported that in general genetic data were available and used in aquaculture (Figure 27). Analysis of the "use" of genetic information revealed that only a few countries in Asia and Latin America and the Caribbean used genetic information to a great extent (Figure 28). Major producing countries used the information more than minor producing countries (Figure 29), and least developed countries used information on AqGR to a lesser degree than other countries (Figure 30).

Figure 27

Availability and use of information on aquatic genetic resources of farmed types

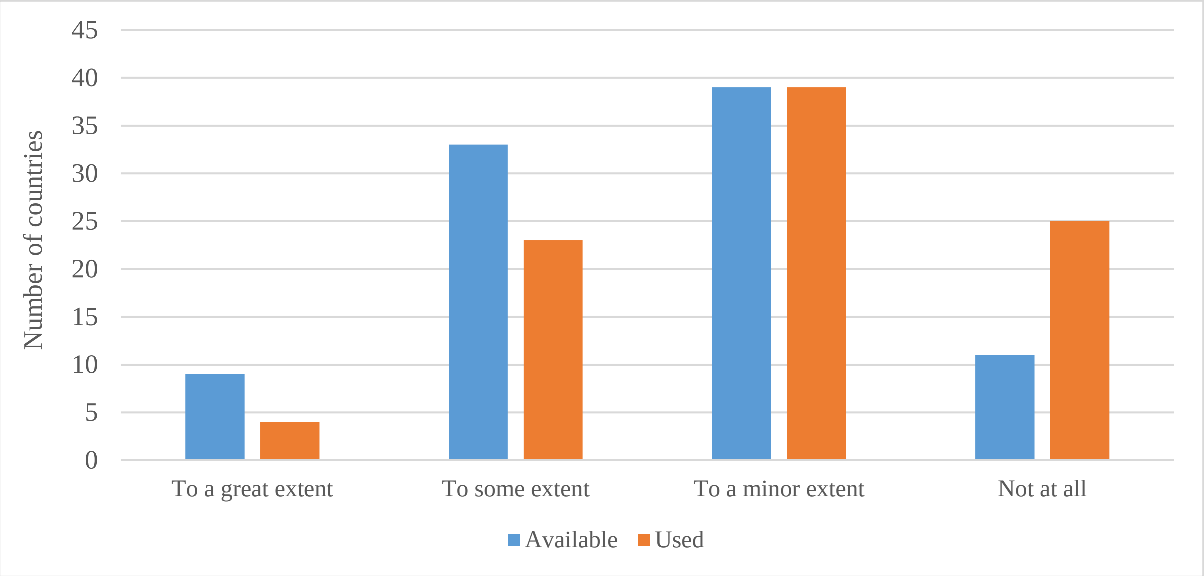


Figure 28
Use of information on aquatic genetic resources of farmed types by region

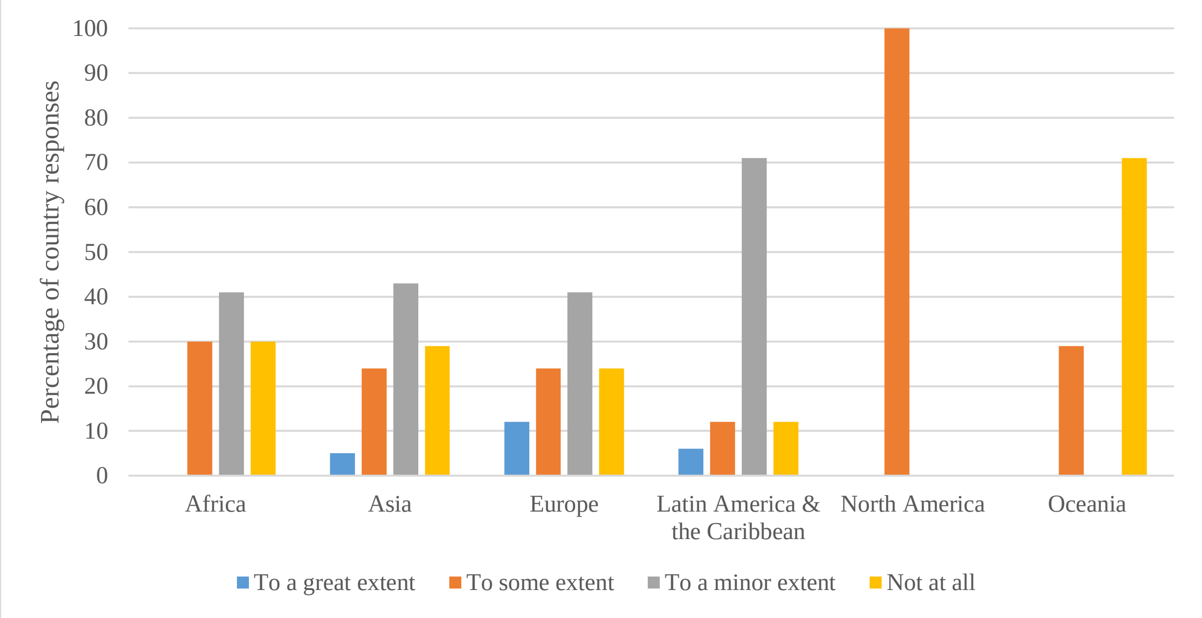


Figure 29
Use of information on aquatic genetic resources of farmed types by level of aquaculture production

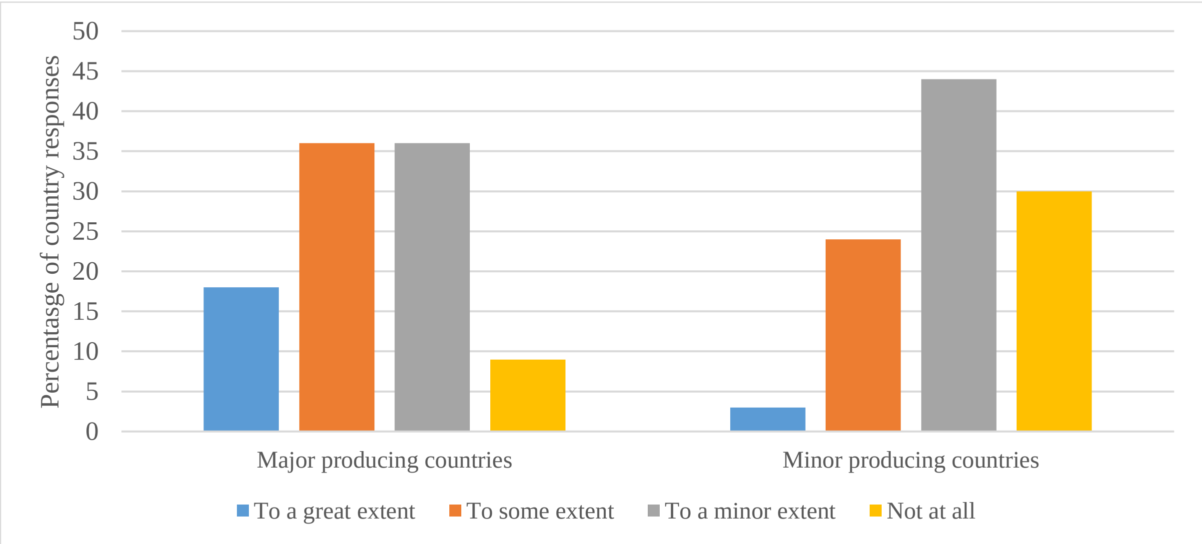
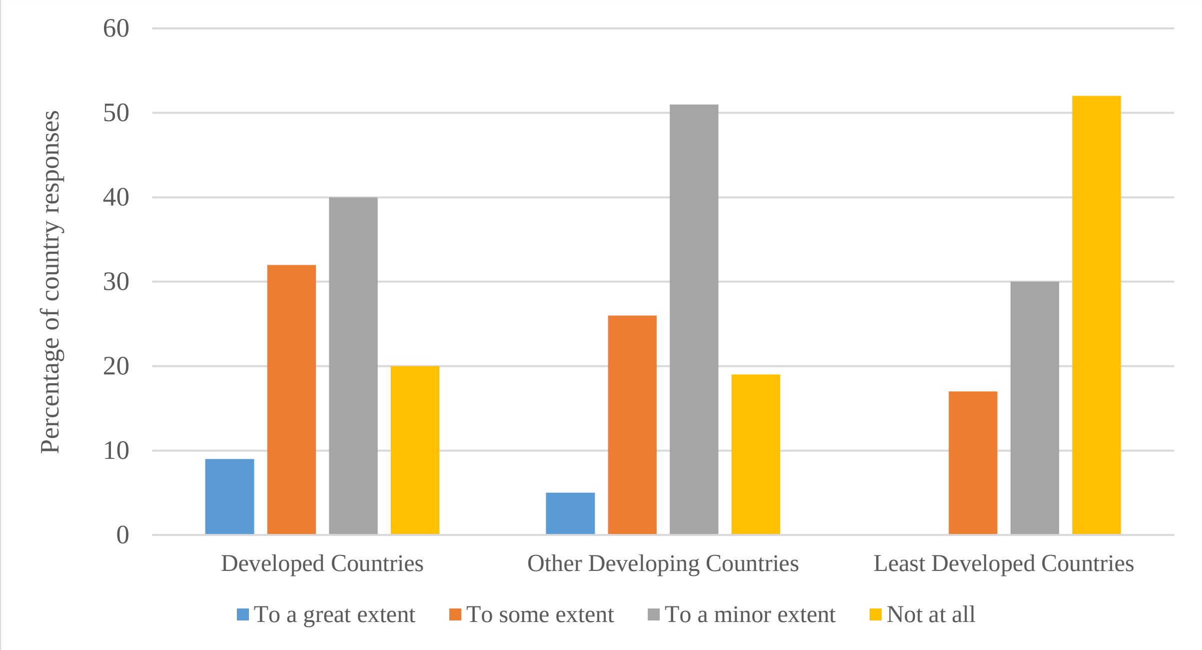


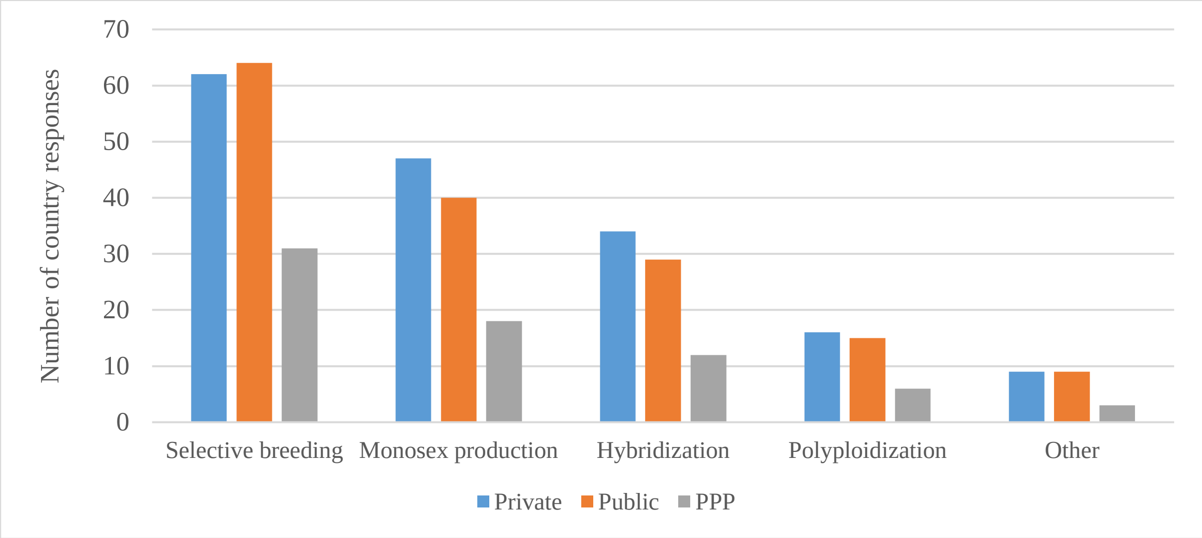
Figure 30
Use of information on aquatic genetic resources of farmed types by economic level



Although genetic resource management and breeding programmes provide increased production and profit, they are often difficult to fund and often require partnerships. The International Center for Living Aquatic Resources Management (now the WorldFish Center) developed the genetically improved farmed tilapia (GIFT) in partnership with the Asian Development Bank, the Government of the Philippines, the United Nations Development Programme, and advanced scientific institutions (ADB, 2005; Ponzoni *et al*., 2011). The impressive gains in Atlantic salmon in Norway were due in large part to private-public partnerships that involved a government research group (Akvaforsk, now NOFIMA) and private companies.

The Country Reports revealed that the majority of strain improvement programmes in aquaculture dealt with selective breeding. For selective breeding, most of the programmes were funded by the public sector, but the private sector was the main funder of all other technologies (Figure 31), although the differences between the numbers of responses for public and private funding were slight. The fewest programmes were funded through public-private partnerships. Analysis by region indicated that Asia reported the most public-funded improvement programmes, both in relative and absolute terms (Figure 32). Analysis by production level indicated that public support, i.e. finances for genetic improvement programmes, was much more prevalent in the major producing countries (Figure 33). Given that 55 percent of the reported cases of genetic improvement were supported by the public sector (Figure 33), the success of the GIFT programme (ADB, 2005) and the Norwegian Atlantic salmon programme, countries wanting to genetically improve aquatic genetic resources could consider wider use of public funding and public-private partnerships.

Figure 31
Source of funding for genetic improvement programmes by improvement strategy



Note: PPP = public-private partnership.

Figure 32
Source of funding for genetic improvement programmes by region

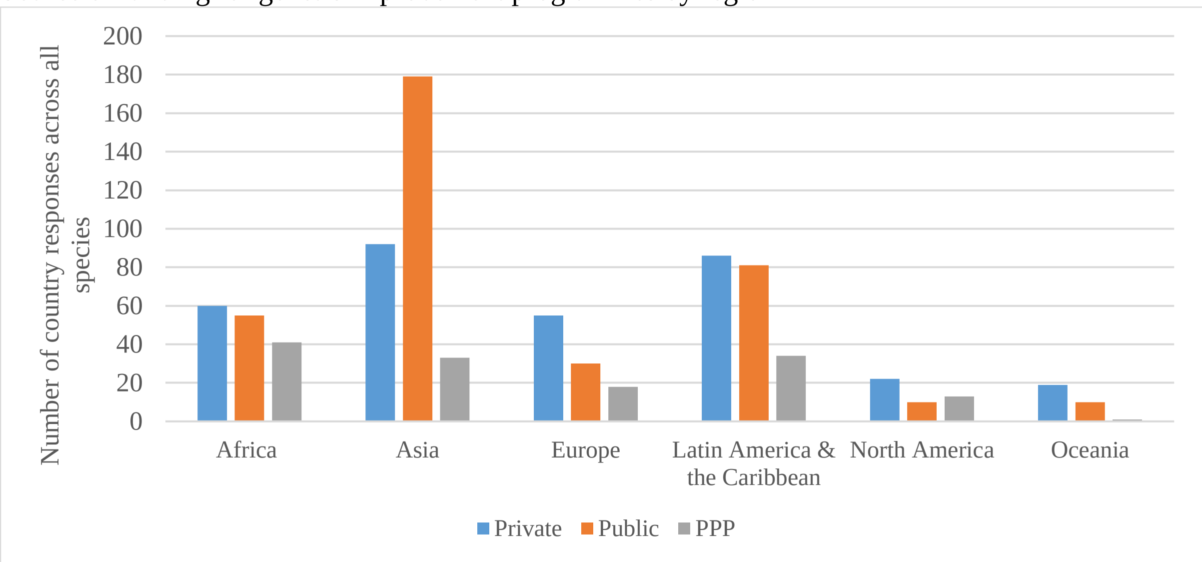
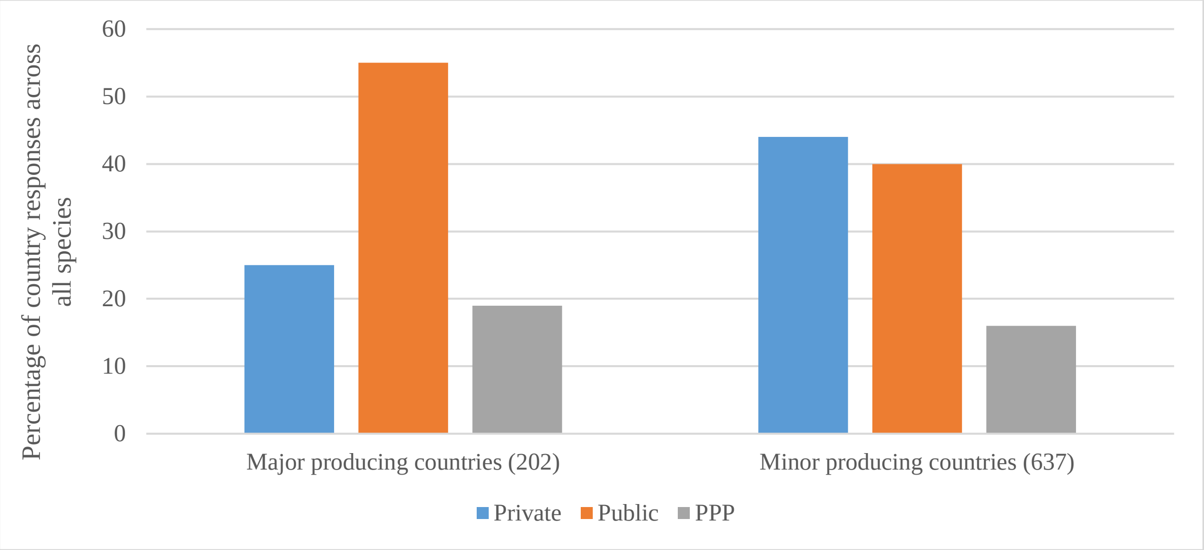


Figure 33
Source of funding for genetic improvement programmes by level of aquaculture production (number of responses)



2.5.2.3 Biotechnologies for improved characterization of AqGR

Biotechnologies can be used to increase performance under farming conditions, but can also be important in characterizing AqGR in farmed types and wild relatives (Ruane and Sonnino, 2006).[15] Improved characterization will facilitate monitoring and management of AqGR and will be necessary for incorporating genetic diversity into national reporting and monitoring programmes (see section 2.4).

Genome technologies have been developed to study genome structure, organization, expression and function, and to select and modify genomes of interest to increase benefits to humans. Of these genome technologies, DNA marker technologies have been intensely used to map the genome to understand genome structure and organization. These DNA marker technologies include:

- restriction fragment length polymorphism (RFLP) markers;
- mitochondrial DNA markers;
- DNA barcoding;
- random amplified polymorphic DNA (RAPD) markers;
- amplified fragment length polymorphism (AFLP) markers;
- microsatellite markers;
- single nucleotide polymorphism (SNP) markers; and
- restriction site-associated DNA sequencing (RAD-seq) markers (SNP markers *per se*).

Although these marker systems were used at various levels for various purposes, the microsatellite markers and SNP markers are currently the most important to characterize and monitor AqGR.

Various genome mapping technologies were developed, including both genetic mapping and physical mapping methods. Genetic mapping is based on recombination during meiosis, while physical mapping is based on fingerprints of DNA segments. Although several variations of physical mapping methods are available, such as radiation hybrid mapping and optical mapping, the most popular physical mapping method is the bacterial artificial chromosome (BAC)-based fingerprinting.

[15] *Cfr.* footnote 1 in Box 8. Fermentation and bioremediation are excluded, except when genetic alteration of the microorganisms has occurred. Selective breeding is also excluded as a biotechnology because it is covered elsewhere.

The next-generation sequencing technologies are especially powerful. The second and third generation sequencing technologies literally revolutionized the way science is conducted. These technologies now allow sequencing of the whole genome *de novo*, or mass sequencing of genomes of populations. Extension of their application allows characterization of the transcriptomes and the non-coding portions of the genome and their functions.

Technologies for improved characterization of aquatic species are listed below in approximate time and level of resolution, i.e. the earliest technologies and those that have the least resolving power are listed first.

- DNA marker technologies: Genetic markers assist in the identification of useful stocks, strains, genes, pedigrees and even individuals. The markers differ in their sensitivity, i.e. some may only work at the species level, while others can distinguish individual pedigrees. The DNA markers include the following:
  - allozyme markers: identification of species, strains and stocks based on protein analysis;
  - restriction fragment length polymorphism (RFLP) markers: analysis of genetic variation based on DNA fragment length differences after digesting genomic DNA with one or more restriction enzymes;
  - mitochondrial DNA markers: studies of genetic divergence within and among populations;
  - DNA barcoding: standard for species identification, especially in international trade and seafood labelling;
  - random amplified polymorphic DNA (RAPD): polymerase chain reaction-based multilocus DNA fingerprinting technique for species identification, hybrid identification, strain differentiation and, to a much lesser extent, genetic analysis such as mapping;
  - RAD-seq markers: identification of genetic variants, phylogenetic analysis, germplasm assessment, analysis of population structure, linkage and Quantitative Trait Loci (QTL) mapping, and whole genome-based selection;
  - microsatellite markers: microsatellites are simple sequence repeats of 1–6 base pairs; they are highly abundant in various eukaryotic genomes, including all aquaculture species studied to date; and
  - SNPs: base substitutions along the DNA chain that reveal abundant genetic variations at the individual and population levels to be used for pedigree analysis, stock/strain identification, high-density linkage mapping, fine QTL mapping, and whole genome-based selection.
- Genome mapping technologies: The genomes of farmed fish vary from several hundreds of millions of base pairs to several billion base pairs. It is difficult to study such large genomes without first breaking them into smaller pieces and then sorting out their relationships, which is the task of genome mapping. Genetic maps assist in knowing the location of sequences, markers or genes on the chromosome and how they may be inherited or manipulated. Some mapping technologies include:
  - genetic linkage mapping: identification of the position of known genes or genetic markers relative to each other in terms of recombination frequency;
  - physical mapping: identification of the position of known genes or genetic markers relative to each other in terms of physical distance on the chromosome;
  - radiation hybrid mapping: production of high-resolution maps of DNA markers on all chromosomes;
  - optical mapping: construction of high-resolution restriction maps of a whole genome; and
  - QTL mapping: allows for locating genes underlining performance and production traits important for aquaculture.
- Genome sequencing technologies: Facilitates the complete description of the molecular structure of DNA. Genomes of at least two dozen aquaculture species have been sequenced, or are now being sequenced, including, *inter alia*, Nile tilapia, *Oreochromis niloticus*, rainbow

trout, *Oncorhynchus mykiss*, Atlantic salmon, *Salmo salar*, channel catfish, *Ictalurus punctatus*, striped bass, *Morone saxatilis,* Pacific oysters, *Crassostrea gigas*, and marine shrimps, *Penaeus* spp. Among others, sequencing technologies include:
    - first- and second-generation DNA sequencers: identification of the precise base pairs along the strands of DNA and genes of potential interest, for example, in marker development for the identification of microsatellites or SNP markers and for the identification of differentially expressed genes or co-induced genes; and
    - third-generation DNA sequencers: identification of single molecule sequences.
- Transcriptome analysis: Gene expression analysis for identifying differentially expressed genes under different environmental conditions and gene expression regulation, shedding light on gene functions. The complete sequence or composition of ribonucleic acid (RNA) of an organism can be determined for genome level expression profiling and for identification of differentially expressed genes or co-induced genes.
    - Expressed sequence tags (ESTs): ESTs can be generated for aquaculture species to rapidly identify which genes are being expressed and under what conditions.
- RNA-seq technologies analyse gene expression profiling and identification of differentially expressed genes and gene-associated markers.

2.5.2.4 Biotechnologies for improved performance in aquaculture

Numerous genetic biotechnologies exist for improving performance in aquaculture and for addressing consumer preferences in the marketplace (Figure 20, Table 25 and Box 7).

Box 7
Biotechnologies in aquaculture

A brief summary of the most important genetic biotechnologies for improved performance in aquaculture follows in hopes of promoting wider awareness and acceptance.[1] Specific technologies in addition to selective breeding for improved performance include the following.

- **Polyploidy.** Although polyploidy is lethal in mammals and birds, it has led to the development of many productive plant varieties such as domesticated wheat. Triploid fish are viable and are usually sterile, while tetraploid fish, if viable, can be fertile. The performance of triploid fish varies. Triploidy can affect growth, feed conversion efficiency, disease resistance and other traits. For growth, triploid fish can grow faster, at a similar rate, or slower than normal diploids. However, even for those that grow faster, this advantage is not obvious until sexual maturity. It is apparent that in many triploids metabolic energy is diverted from reproduction into somatic growth, enabling faster growth of the animal.
- **Gynogenesis.** Gynogenesis is a form of all-female inheritance. In fish species, ultraviolet or gamma irradiation has been used to denature the DNA in sperm. Such inactivated sperm are used to trigger gynogenetic development without contributing the paternal genome to the progeny. A further physical shock is required to restore the diploidy complement of the zygote. One of the practical goals of gynogenesis is the production of clonal lines. Clonal lines have been produced with aquaculture species, such as ayu (*Plecoglossus altivelis)* and hirame (*Paralichthys olivaceus*), although their large-scale aquaculture has not been realistic. The major purpose of gynogen production has been for research.
- **Androgenesis.** Androgenesis refers to all-paternal inheritance. Androgens can be produced by irradiating eggs and then duplicating the paternal genome. Androgens are more difficult to produce than gynogens, presumably because of the extremely low survival rate of irradiated eggs. Like gynogenesis, it can be used to produce clonal populations or monosex populations for the purpose of breeding programmes or to elucidate sex-determining mechanisms. Production of novel YY male fish through androgenesis, followed by regular mating with a normal XX female fish, can be used to produce all-male populations in fish.
- **Sex reversal.** Sexual dimorphism for growth is common with fish species. In some cases, males grow faster, while in other cases females grow faster. Monosex populations can be created by

hormonal treatment. Although genotypic sex is established at the time of fertilization, the phenotypic sex can be altered by administration of oestrogens or androgens during the critical period of sex determination. For instance, 17α-methyltestosterone is widely used for sex reversal in fish, especially in tilapia. Several estrogenic compounds have been used to produce monosex female populations, of which 3-estradiol is the most commonly used hormone for feminization. Females of soles, eels and many other species grow much faster than the males. In contrast, males grow much faster for tilapia and catfish, among many other species. In addition to growth rate, sex also affects body shape, colouration and carcass composition.

- **Gene transfer.** Gene transfer or transgenesis is a process to transfer one or a few foreign gene(s) into an organism. However, the foreign gene can be from other species or from the same species. A number of techniques have been developed for transferring genes of interest into fish, including microinjection and electroporation. Transgenic technologies, however, suffer from several major shortcomings: (i) the doses of genes transferred cannot be controlled; (ii) the integration sites are random and such sites can be within a functional gene; and (iii) the pleiotropic effect of genes cannot be controlled. Significantly enhanced growth rates and other characters were observed in goldfish (*Carassius auratus),* channel catfish (*Ictalurus punctatus),* northern pike (*Esox lucius),* Atlantic salmon (*Salmo salar),* rainbow trout *(Oncorhynchus mykiss),* tilapia (*Oreochromis* spp*.)* and common carp *(Cyprinus carpio),* among many other species. In addition to enhancing performance traits of aquaculture species, fish have been considered for the production of pharmaceuticals as biological factories. To date, there is only one transgenic fish that is known to be farmed commercially.[2]
- **Marker-assisted selection** (MAS) is a process whereby a selection decision is made based on the genotypes of DNA markers. MAS is especially useful for traits that are difficult or lethal to measure, exhibit low heritability and/or are expressed late in development. MAS requires information of DNA markers that are tightly linked to Quantitative Trait Loci (QTL) for traits of interest based on QTL mapping or association studies. For example, in the Japanese flounder (*Paralichthys olivaceus*), a microsatellite locus was near the major QTL for resistance to lymphocystis disease and another marker was near an infectious pancreatic necrosis resistance gene in salmon; in both cases resistant populations were created that were favourably received in the market. Although MAS is theoretically sound and attractive, little is known about the economic benefits gained from MAS in aquaculture species, with the exception of the above cases where the phenotypes were controlled by a single gene rather than by many genes.
- **Sex-linked markers** have been mapped for common carp, tilapia, catfish, Zhikong scallop (*Chlamys farreri*), half-smooth tongue sole (*Cynoglossus semilaevis*), white shrimps *(Penaeus vannamei* and kuruma prawns, *P. japonicas*), and rainbow trout (*Oncorhynchus mykiss)*. These markers can help identify the desired sex for breeding or for grow-out to take advantage of sexual dimorphism. Sex-linked markers have been useful for the identification of sex without phenotypic data.
- **Genome selection** uses the estimated effect of many loci across the entire genome at once, not just the small number of linked loci as done with MAS. Although genomic selection has been successfully used in dairy cow and beef cattle and other livestock species, its use in aquaculture species has been slow.
- **Genome editing technologies** refer to the ability to make specific changes at targeted genomic sites. Zinc finger nuclease (ZFN), transcription activator-like effector nuclease (TALEN), or clustered regulatory interspaced short palindromic repeats (CRISPR) technologies allow introduction or disabling of any gene without much difficulty in any fish or shellfish species. The altered genome is able to pass on the genetic material to future generations. While it is clear that the genome editing technologies are different from gene transfer technologies, it is widely believed that government agencies should be regulating any commercial products generated using gene editing technologies. The techniques offer promise, with TALEN and CRISPR being used more than ZFN, for example, in experimental studies on Atlantic salmon, carp, marine shrimp, tilapia and zebrafish (*Danio rerio*).
    - CRISPR and CRISPR associated (CRISPR/Cas; bacterial DNA that cuts DNA to help with immunity against invading viruses or plasmids. Cas9 is an enzyme that cuts

DNA, and CRISPR is a collection of DNA sequences that tells Cas9 where to cut).
- TALENs are restriction enzymes that can be engineered to cut specific sequences of DNA. The restriction enzymes, when being introduced into cells, can be used for gene editing or genome editing.

An advantage of genetic biotechnologies is that they may be used in combination to increase their effectiveness in aquaculture. For example, sterilization by triploidization has been proposed for use with selective breeding and gene transfer for reducing the chance of escaped fish breeding.

[1]*Cfr.* footnote 1 in Box 8.
[2]https://www.biographic.com/posts/sto/one-fish-two-fish-strange-fish-new-fish and http://theconversation.com/gm-salmon-may-be-safe-but-theyre-not-coming-to-a-store-near-you-just-yet-51893.

Genetic biotechnology is also often referred to as genomics when it involves the study of gene identification and gene action. The fundamental goal of aquaculture genomics in the practical sense is to understand the genomic basis for performance and production traits. Because most aquaculture traits are complex traits that are likely controlled by multiple genes, QTL mapping is the core of applied aquaculture genomics. By coupling genome mapping technologies with aquaculture trait evaluations, QTL mapping allows the identification of genes underlining the performance and production traits. Following mapping of QTLs, marker-assisted selection or genome selection can be conducted. Genomes can be edited or modified almost any way now as designed by scientists. Therefore, technologies are ready to make large contributions for improving aquaculture traits.

There are a number of challenges to the wider adoption of genetic biotechnologies in aquaculture, including bioinformatics (i.e. how to collect and manage large amounts of genetic information), lack of resources in some parts of the world, difficulties in working with individual farmers, and ethical and legislative challenges that must be overcome in order to have broad applications of genome technologies. In spite of the challenges, a range of biotechnologies was used to improve AqGR according to Country Reports (Table 26 and Figure 34). An overall index of use for some selected genetic technologies was developed by assigning a score to each "extent of use" and then multiplying by the percentage and summing for each biotechnology (Table 26).

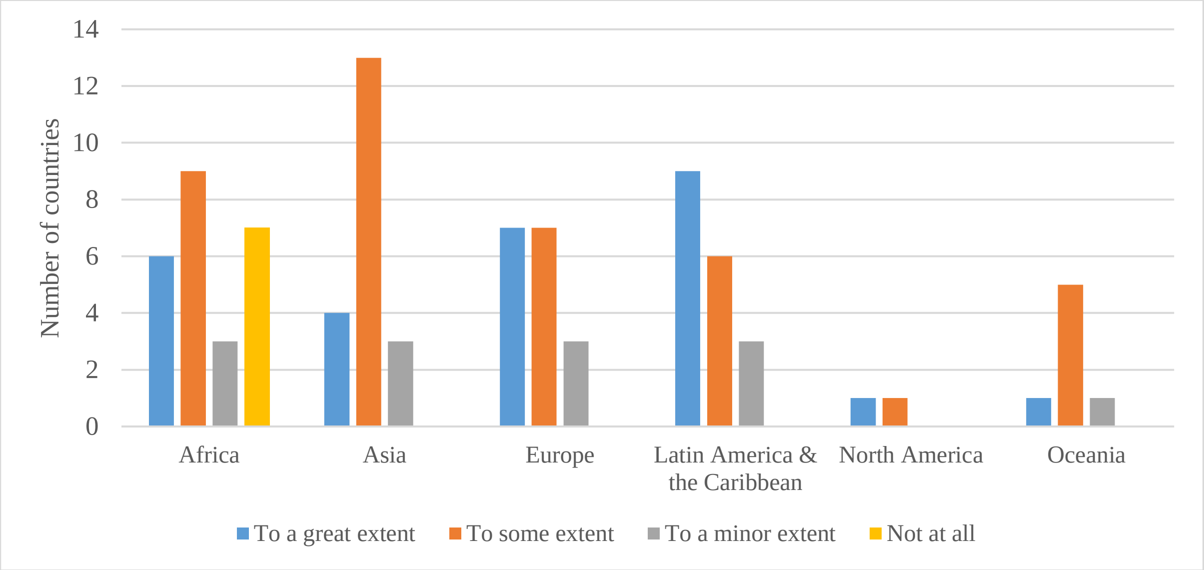
Table 26
Extent of use of selected biotechnologies (number of responses)

Extent of use	Selective breeding	Hybridization	Polyploidization	Monosex production	Marker-assisted selection	Gynogenesis/ androgenesis
To a great extent	30	5	0	22	1	0
To some extent	41	22	4	20	7	1
To a minor extent	13	27	26	23	19	18
Not at all	7	35	58	26	62	70
Index of use	3.0	1.9	1.3	2.4	1.4	1.2

Selective breeding was the most widely used biotechnology, with 84 countries reporting its use to at least some extent (Table 26). The trend was evident when countries were analysed by region, although the application of selective breeding was uneven within regions (Figure 34). The index of use indicated that after selective breeding, production of monosex animals and hybridization were the most commonly used biotechnologies (Table 26). The more complex technical techniques of marker-assisted selection and gynogenesis/androgenesis were not used at all in 62 and 70 of the countries surveyed, respectively.

Figure 34

Use of selective breeding by region



2.5.3 Wild relatives

Wild relatives of farmed species are defined here to be the same species living in the wild as the species being farmed, i.e. they are conspecifics (see Box 8). There are other species living in the wild that are closely related to farmed species, e.g. the same genus or family, and some of these have been identified as having aquaculture potential, or are important in capture fisheries. Wild relatives, in addition to being useful in aquaculture, are important components of many aquatic ecosystems and capture fisheries and perform beneficial ecosystem services.

Box 8
Wild relatives and interpretations of the term

Wild relatives of farmed species are defined for this report as a species that occurs in the wild within a country that is a conspecific of a species that is cultured anywhere in the world, including within the country itself. It is not intended to include closely related species, only conspecifics. Given that the FAO FishstatJ database on aquaculture production statistics reports 591 species cultured worldwide, there is a large pool of cultured species from which wild relatives should be reported. This broad definition is applied to assist in building a picture of the genetic resources of cultured species that occur in the wild, irrespective of where they are cultured.

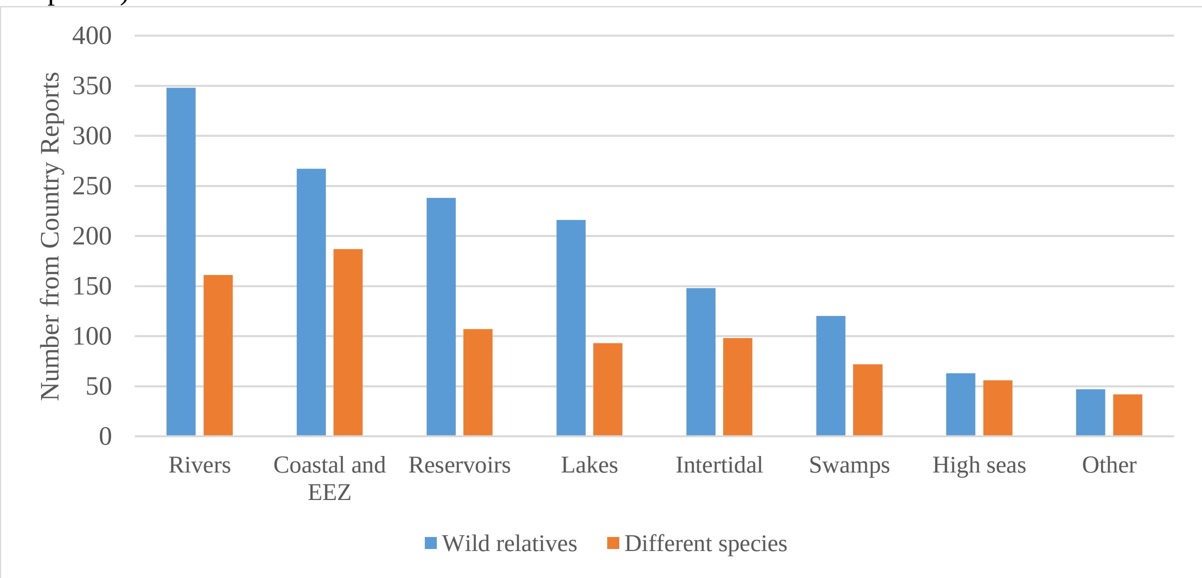
Three questions in the questionnaire that formed the basis of the Country Reports refer directly to wild relatives.[1] Question 12 requested a list of wild relatives for cultured species excluding those cultured in the country; question 1 concerned transfer and exchange of wild relatives; and question 14 requested countries to complete a table of all wild relatives in the country with details on their management and utilization.

The questionnaire did not clearly and fully define wild relatives; it is apparent that there was some ambiguity in the definition, and thus some variation in the way in which countries have interpreted the term. It is further apparent that the numbers of wild relatives have been underreported in the majority of Country Reports. For question 12, a third of reporting countries did not attempt to list wild relatives that are not cultured in their country. For question 14, nearly 90 percent of countries did report species, but again numbers were low (averaging only 8.1) and nearly 40 percent of countries reported only wild relatives of species cultured within their country.

Thus, there is a clearly identified issue with the accuracy of reporting of wild relatives, a fact which has been taken into account in this Report in the interpretation of the data relating to questions 12–14.

[1]www.fao.org/3/a-bp506e.pdf.

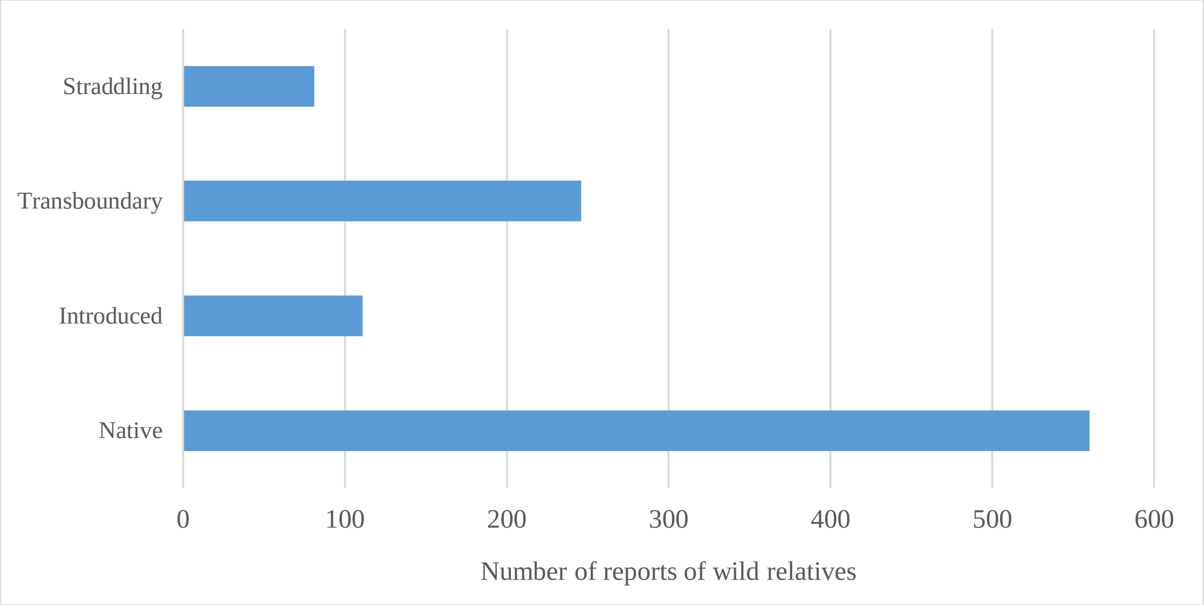
Figure 35
Habitats of wild relatives of farmed aquatic species within national jurisdiction (number of responses for all species)



Note: EEZ = exclusive economic zone.

Wild relatives are found throughout aquatic ecosystems (Figure 35 and Figure 36). River and coastal habitats were the places where most wild relatives were reported and where the highest diversity of taxa were found (Figure 35). For example, 187 different species of wild relatives were reported as living in coastal waters within the exclusive economic zone, and 267 examples across all species considered to be wild relatives were reported from coastal zones. The majority of wild relatives reported were native (83.4 percent); countries reported 560 cases where the wild relatives were native. Several wild relatives were reported to be transboundary and straddling stocks; a wild relative could be native and straddling or transboundary (Figure 36).

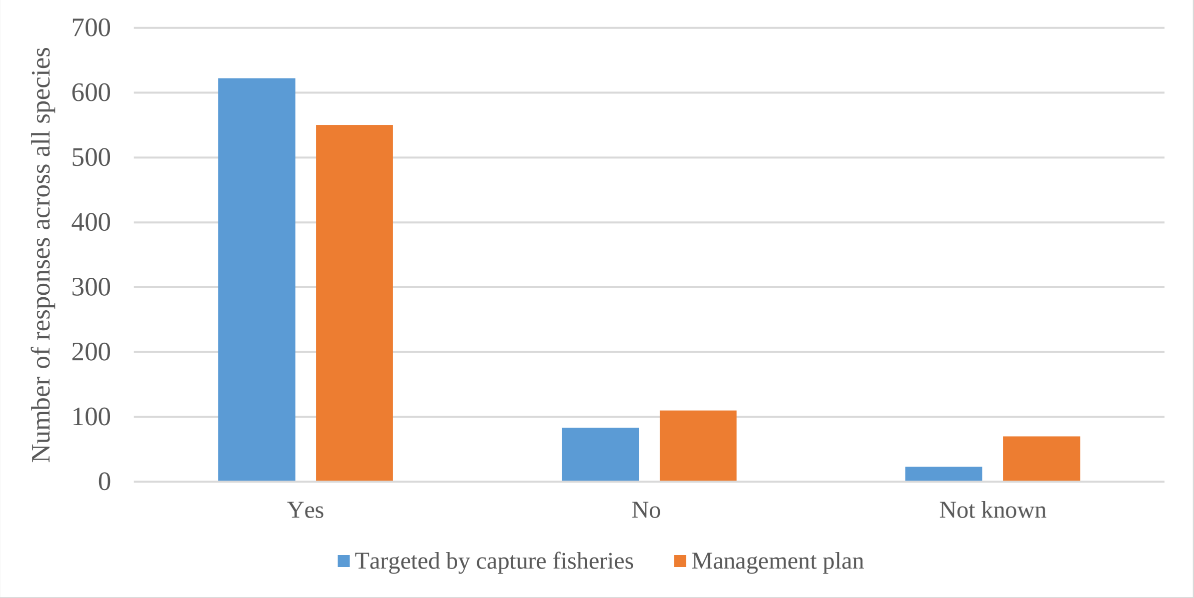
Figure 36
Geographic description of wild relatives of farmed aquatic species



2.5.3.1 Use of wild relatives in fisheries

The vast majority of the reports on wild relatives (622 out of 705) indicated that wild relatives contribute to capture fishery production and have fishery management plans (Figure 37). Many of the wild relatives not fished were species introduced for aquaculture purposes, or fish for which capture fisheries were highly regulated, e.g. sturgeons, owing to their listing on the appendices of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Though it is encouraging that so many fishery management plans exist, the fact that populations of many wild relatives are declining (see section below, which calls into question both the efficacy of management plans and the ability to enforce them).

Figure 37
Occurrence of wild relatives in capture fisheries and whether a fishery management plan exists



2.5.3.2 Trends in abundance of wild relatives

Figure 21 and Figure 22 reveal how dependent aquaculture still is on aquatic species found in natural ecosystems. However, countries reported numerous cases where the abundance of wild relatives was currently decreasing and is expected to decrease in the future (Figure 38). The top five species reported with decreasing catch trends were Nile tilapia (*Oreochromis niloticus*), European eel (*Anguilla Anguilla),* common carp (*Cyprinus carpio*), giant river prawn (*Macrobrachium rosenbergii*) and brown trout (*Salmo trutta*). The wild relatives most often reported as being depleted in a country were Russian sturgeon (*Acipenser gueldenstaedtii*), huchen (*Hucho hucho*), beluga sturgeon (*Huso huso*), Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*). For the depleted species, the sturgeons are prominent along with large salmonids. There were reports of increasing catch trends, and the top five species with an increasing catch trend were Nile tilapia (*Oreochromis niloticus*), North African catfish (*Clarias gariepinus*), Mediterranean mussel (*Mytilus galloprovincialis*), milkfish (*Chanos chanos*) and Pacific oyster (*Crassostrea gigas*). Interestingly, Nile tilapia (*O. niloticus*) populations are seen as both increasing in some areas and decreasing in others. Across all species, habitat was the most often cited cause for a change in abundance of wild relatives (Figure 39).

Figure 38
Current and expected catch trends in wild relatives

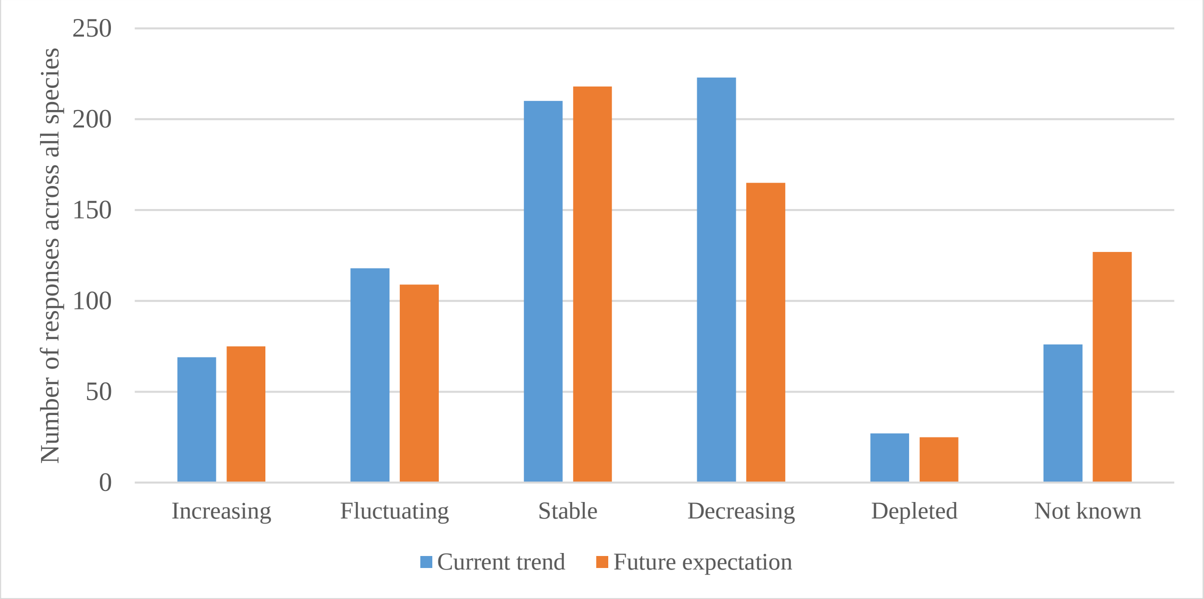
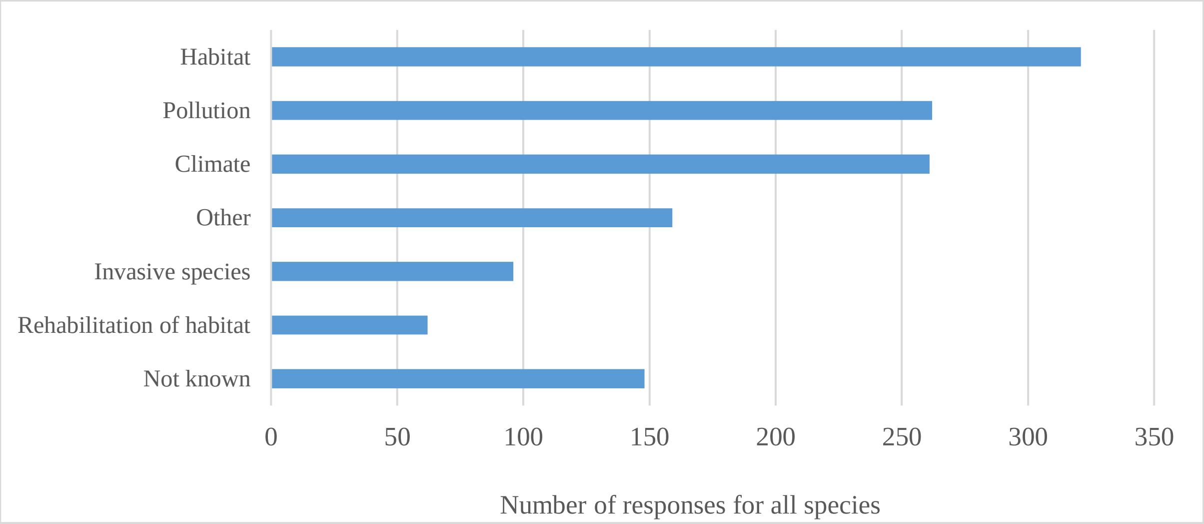


Figure 39
Reasons for change in abundance of wild relatives



Countries reported that the habitat for most wild relatives of farmed aquatic species was decreasing (Figure 40), and in only a few cases was habitat reported as increasing. Analysis by region indicated that a higher percentage of reports citing habitat as a determinant of change in numbers of wild relatives came from Asia (Figure 41a) and from least developed countries (Figure 41b). These findings reinforce the need to protect natural populations of aquatic genetic resources and suggest that protecting habitats would be an effective strategy.

Figure 40
Trends in changes of habitat of wild relatives

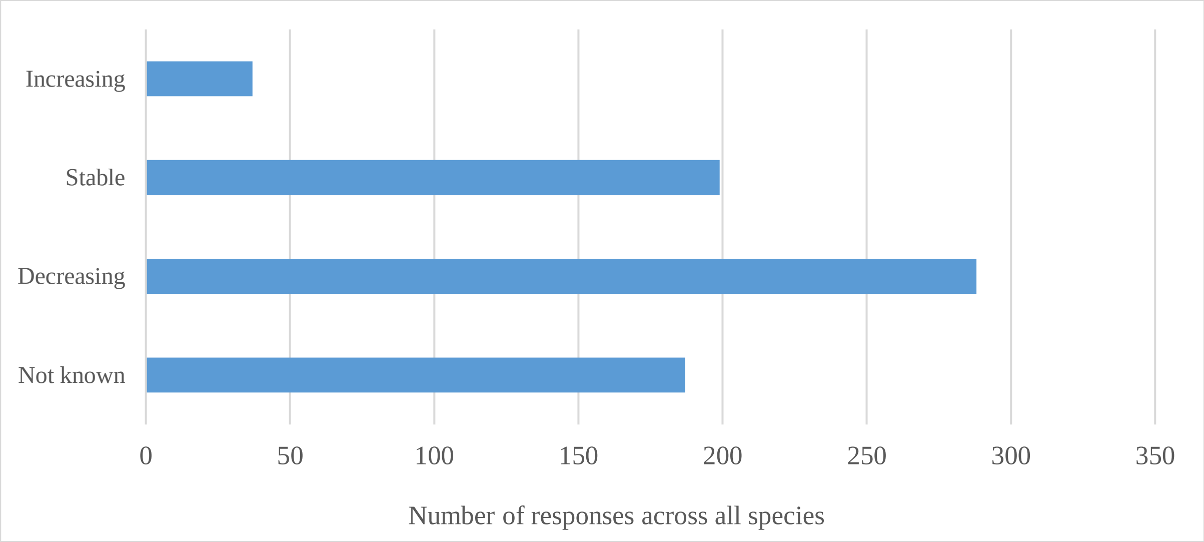
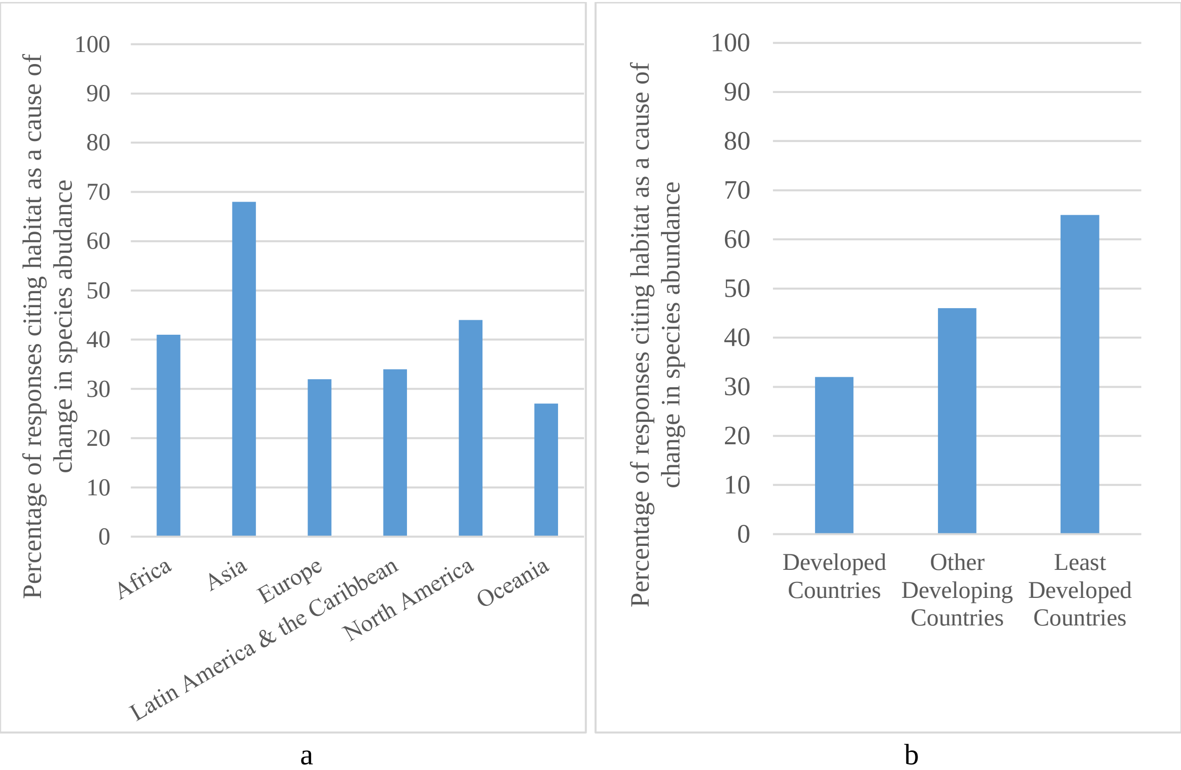


Figure 41
Changes in abundance of wild relatives due to habitat change

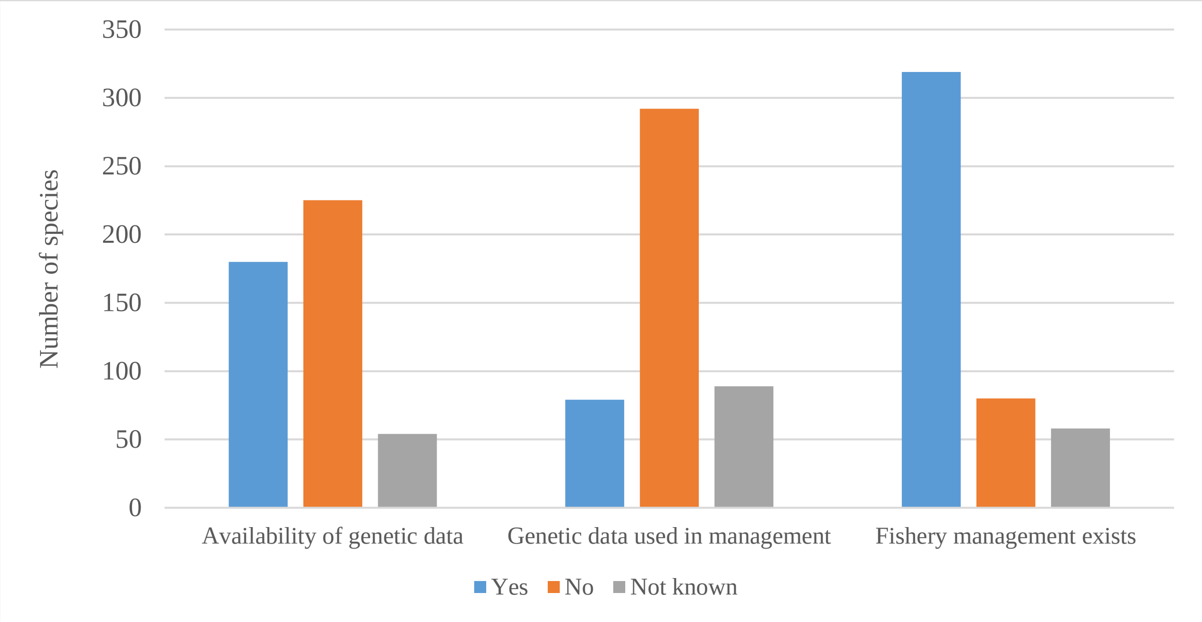


About one-third of the responses from developed countries cited habitat as a cause of change in the numbers of wild relatives (Figure 41b). Comparisons of the importance of habitat loss by economic classification of countries can be misleading. In many developed countries, the aquatic habitat for wild relatives was lost or degraded centuries ago because of economic development, and human communities became accustomed to this lack of fishery resources and lack of alternative food sources. This phenomenon is called the "shifting baseline" (Pauly, 1995) and is used to explain peoples' short-term perspective on managing natural resources. That is, people tend to forget how things were in the past because they accept and have become familiar with the current situation.

The Country Reports did not indicate that fishing pressure was a major cause for the change in abundance of wild relatives of farmed species. For many inland capture fisheries, factors outside of the fishing sector, e.g. draining wetlands and damming of rivers, have a much larger impact (FAO, 2014). For many coastal areas, a similar condition could occur where loss of a coastal spawning or nursery habitat or land-based pollution could impact fisheries more than fishing pressure, especially in small-scale fisheries. Nonetheless, for many wild relatives that are fished, fishery management plans exist. However, genetic data are used to only a limited extent for most species (Figure 42).

Figure 42

Fishery management of wild relatives and the use of genetic information



Examples do exist where genetic data are used in management of high-value species or iconic species, such as Atlantic cod (*Gadus morhua*), Pacific salmon, *Oncorhynchus* spp., and Atlantic salmon, *Salmo salar* (Ruane and Sonnino, 2006). For example, genetic stock identification (GSI) helps set the season, area and catch limits on commercially important species in North America and Europe based on the genetic profile of the fishery (Beacham *et al*., 2006).

However, GSI depends on an accurate genetic analysis of the potential stocks contributing to a fishery, as well as real time sampling and analysis of the fishery. As such, fishery management based on GSI may be beyond the financial and technical capacity of many government resource agencies.

2.5.3.3 Conservation of wild relatives

In light of the reports that many populations of wild relatives are decreasing, information on the conservation status will be important in identifying future actions for conservation. A decreasing fishery yield combined with a decreasing habitat could provide a proxy indicator for the level of endangerment for wild relatives. The level of endangerment would be even higher if the species had a restricted distribution or was limited to a specific habitat type, e.g. salt marshes or vernal pools.

Table 27 lists the top 10 wild relatives whose habitat is decreasing. A comparison with the International Union for Conservation of Nature (IUCN) Red List[16] shows that only one species, European eel (*Anguilla anguilla*) was listed as critically endangered; one as near threatened, the clown knifefish (*Chitala chitala*); while one was listed as vulnerable, the common carp (*Cyprinus carpio*). Several are of least concern and the majority have not been assessed and the population trend is unknown. The

[16] www.iucnredlist.org.

majority of these species are freshwater fishes or diadromous, e.g. European and Japanese eels (*Anguilla* spp.). The European seabass (*Dicentrarchus labrax*) is the only marine species in this group of top 10 species.

Table 27

Top 10 species for which catch was reported to be declining, number of reports of habitat decrease and status on the International Union for Conservation of Nature Red List

Species name	Common name	Number of reports of population decrease	Number of reports of habitat decrease	Red List	Population trend from Red List
Oreochromis niloticus	Nile tilapia	7	9	NA	U
Anguilla anguilla	European eel	6	4	CE	D
Cyprinus carpio	Common carp	4	5	V	U
Macrobrachium rosenbergii	Giant river prawn	4	3	LC	U
Salmo trutta	Brown trout	4	8	LC	U
Channa striata	Striped snakehead	3	3	LC	U
Chitala chitala	Clown knifefish	3	3	NT	D
Colossoma macropomum	Cachama	3	2	NA	U
Dicentrarchus labrax	European seabass	3	Not listed	LC	U
Lates calcarifer	Barramundi	3	2	NA	U

NA = not assessed; LC = least concern; DD = data deficient to assess; V = vulnerable; NT = near threatened; CE = critically endangered. For population trend: D = declining; U = unknown.

Although at the species level *Oreochromis niloticus* is not threatened, the concern has been raised that many natural populations are being introgressed with genes from other stocks and species (ADB, 2005). Thus, the genetic differences between stocks of natural Nile tilapia may be lost. Brazil and Colombia reported populations of *Arapaima giga*s as declining. This species is listed in Appendix II of CITES, which includes species that are not necessarily now threatened with extinction, but may become so unless trade is closely controlled. CITES had data to suggest listing of *Arapaima*, whereas IUCN said that data were deficient. An improved global information system would help communicate authoritative information to help resolve such issues (see Table 19).

2.5.4 Use of non-native species in fisheries and aquaculture

As in terrestrial agriculture, introduced aquatic species (also called non-native, alien or exotic species) contribute significantly to production and value in fisheries and aquaculture (Gozlan, 2008; Bartley and Casal, 1998; Bartley and Halwart, 2006). Although Country Reports did not contain production statistics, production from non-native species was reported to be increasing in fisheries for wild relatives and in aquaculture (Figure 43). Production from non-native species was reported to be increasing substantially in the minor producing countries, but none of the major producing countries indicated an increasing trend in production from non-native species (Figure 44). This result may be contrary to information provided to FAO; however, for example, China and Viet Nam reported increasing production from non-native species (X. Zhou, FAO Aquaculture Information Officer, personal communication, March, 2018).

Figure 43
Current production trends in non-native species in fisheries and aquaculture overall

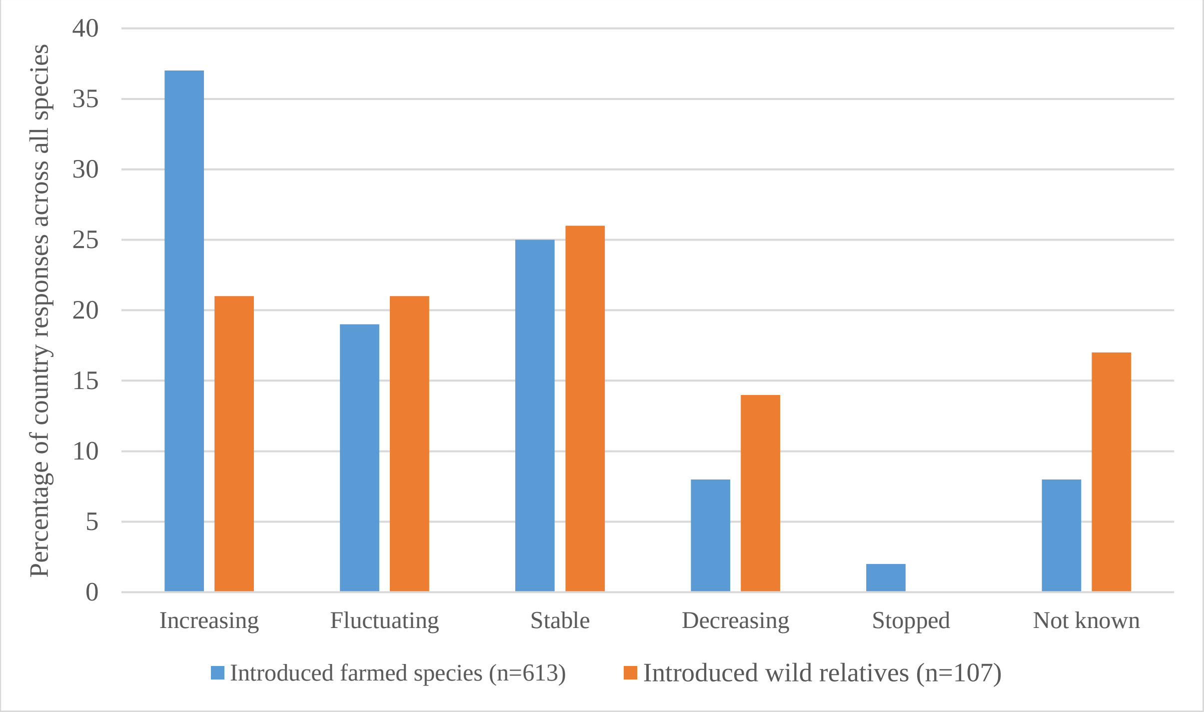
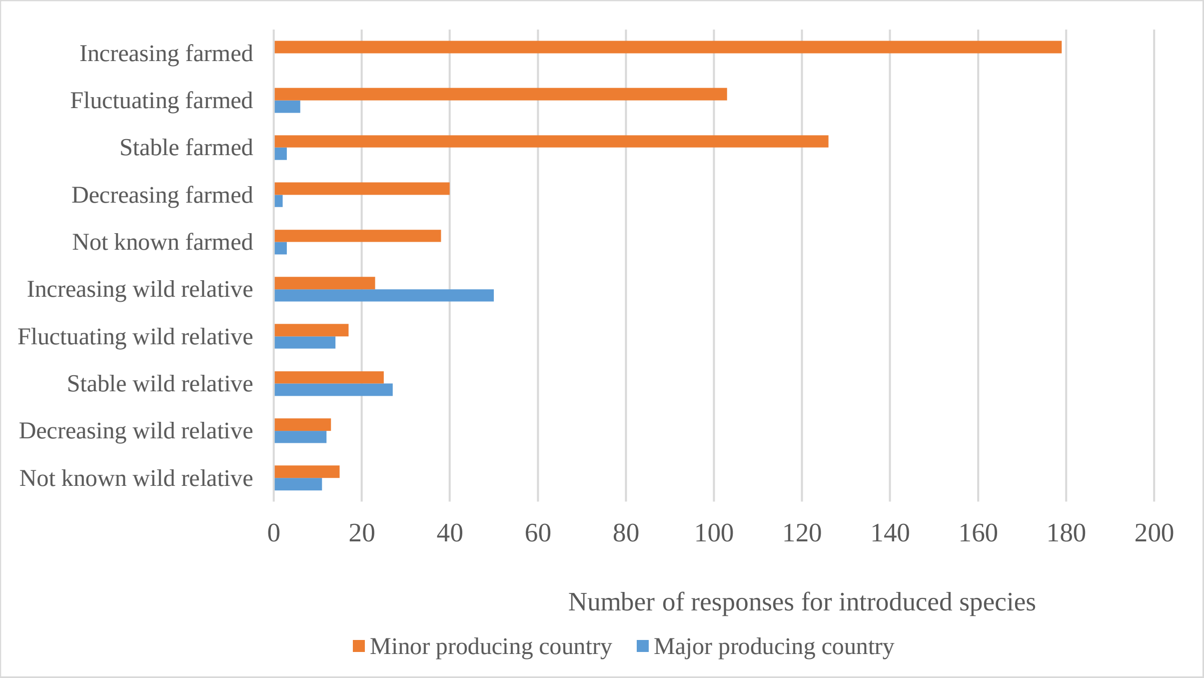


Figure 44
Current production trends in non-native species in fisheries and aquaculture by country level of aquaculture production



FAO maintains the Database on Introductions of Aquatic Species (DIAS) that contains records of introductions across national boundaries. The database may be accessed online[17] and is linked to FAO production figures and species fact sheets.[18] Analysis of DIAS revealed that carps, trout, tilapia and oysters were the most widely introduced aquatic species. Country Reports generally confirmed this analysis, with the most often exchanged species (import and export) being Nile tilapia (*Oreochromis niloticus*) followed by North African catfish (*Clarias gariepinus*) (Table 28). Countries reported that over 200 species had been exchanged across international borders (data not shown).

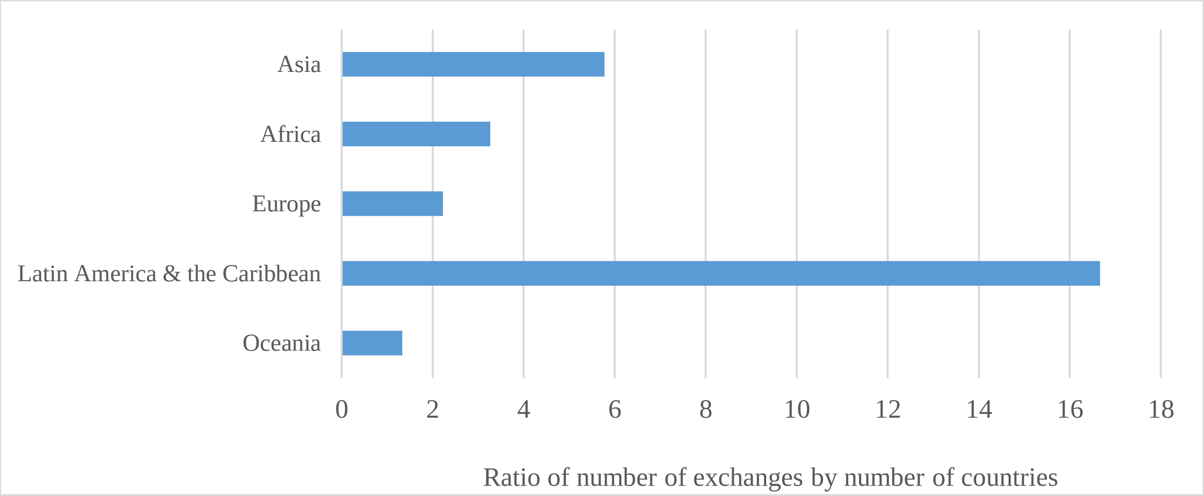
Table 28
Top 12 wild relatives exchanged by countries (includes both import and export)*

Species name	Common name	Exchanges
Oreochromis niloticus	Nile tilapia	39
Clarias gariepinus	North African catfish	25
Piaractus brachypomus	Red-bellied pacu	9
Colossoma macropomum	Cachama (black pacu)	8
Eucheuma spp.	Red algae	8
Crassostrea gigas	Pacific oyster	7
Salmo salar	Atlantic salmon	7
Mytilus edulis	Blue mussel	6
Penaeus monodon	Asian tiger shrimp	6
Ctenopharyngodon idellus	Grass carp	5
Cyprinus carpio	Common carp	5
Anguilla anguilla	European eel	5

*Common carp and European eel were included to allow comparison with Table 27.

Latin America and the Caribbean was the region exchanging the most AqGR (Figure 45), whereas other developing countries (Figure 46) and minor producing countries (Figure 47) reported most exchanges on a per country basis. Generalizations from the results are difficult to make at present. The low ratio of exchange in major producing countries and in developed countries where aquaculture is generally declining could indicate that there is no more need to import or export AqGR, but this assumption would not explain the low rate of exchange in Africa where aquaculture is developing.

Figure 45
Exchange of aquatic genetic resources by region



[17] www.fao.org/fishery/introsp/search/en.
[18] www.fao.org/fishery/factsheets/en.

Figure 46
Exchange of aquatic genetic resources by economic status of countries

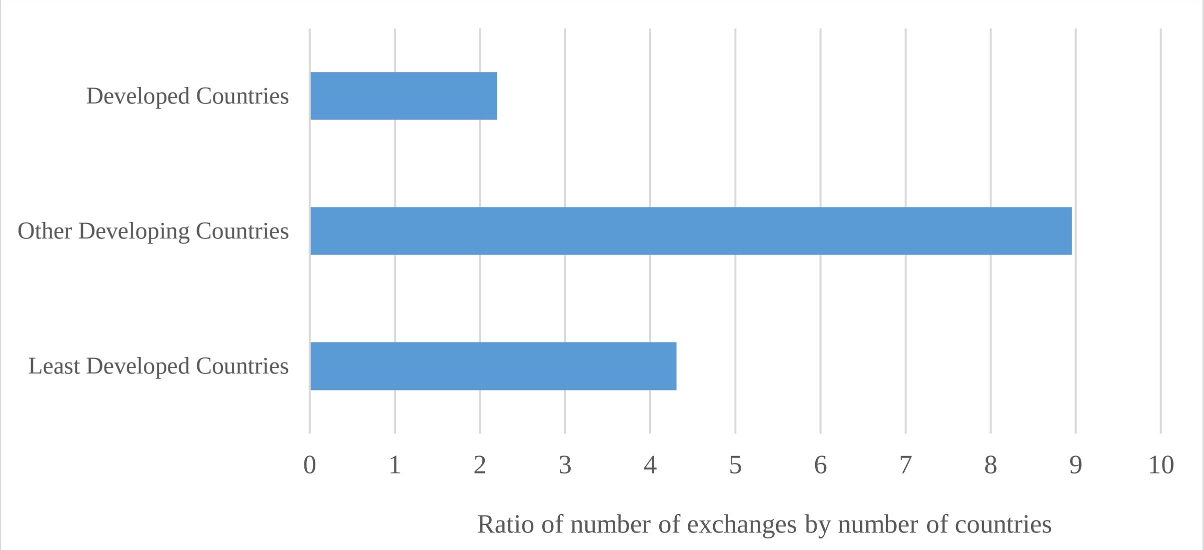
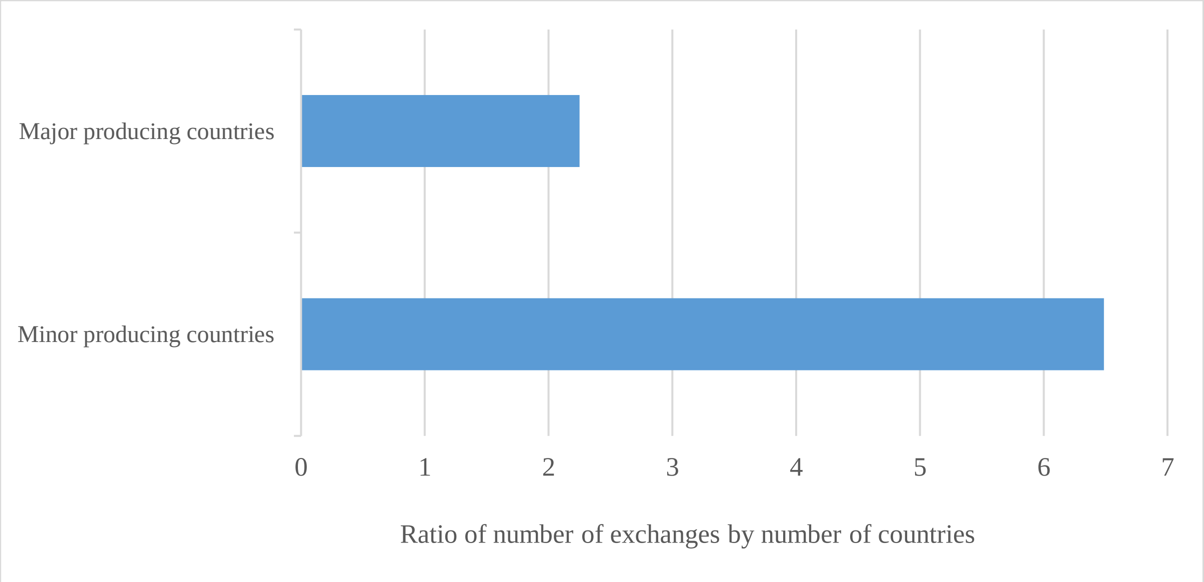
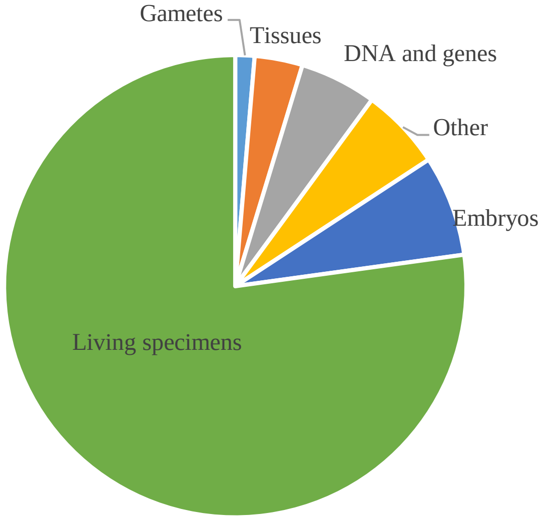


Figure 47
Exchange of aquatic genetic resources by level of aquaculture production



As expected, the most common form of genetic material exchanged was living specimens. Of the nearly 300 reported exchanges, about 77 percent were of living specimens, with about 7 percent exchanging embryos and only a few countries reporting the exchange of other genetic material (Figure 48). The "other" category included various unspecified items and teeth.

Figure 48
Types of genetic material exchanged, both imports and exports, across all countries and species



An analysis of DIAS (Bartley and Casal, 1998; Gozlan, 2008) revealed that the majority of introductions of aquatic species have had negligible environmental impact on the surrounding ecosystem or biodiversity. Although some introductions have had serious adverse impacts, e.g. the golden apple snail (*Pomacea canaliculata*) in the Philippines (Halwart, 1994) or the crayfish plague (*Aphanomyces astaci*) in Europe that arrived with an introduced crayfish from North America (Holdich *et al*., 2009), the records in DIAS further demonstrated that there have been more positive social and economic benefits from the introductions than negative environmental impacts (Bartley and Casal, 1998). More recent analysis with more records in DIAS supports the earlier findings, although the difference between positive social and economic impacts and negative environmental impacts was not as large as in the earlier work (FAO, 2018c). The Country Reports did not indicate whether or not the introductions had positive or negative impacts.

However, non-native species can become invasive and have been identified as one of the major threats to biodiversity throughout the world. In order to minimize the risks and optimize the benefits from non-native species, the international community promotes codes of practice and risk analysis before an introduction is made (ICES, 2005; Chapter 7). The codes of practice and risk analysis include social and economic benefits as well as environmental risk (see Bartley and Halwart, 2006, for a collection of documents and international guidelines on non-native species, including DIAS).

References and key documents

Online resources

- FAO Aquatic Sciences and Fishery Information System: www.fao.org/fishery/collection/asfis/en
- FAO Database on Introductions of Aquatic Species (DIAS): www.fao.org/fishery/topic/14786/en and www.fao.org/fishery/dias/en
- FishStatJ (2018): www.fao.org/fishery/statistics/software/fishstatj/en
- FAOSTAT (2016): http://faostat3.fao.org/home/E
- FAO Commission on Genetic Resources for Food and Agriculture: www.fao.org/nr/cgrfa/cgrfa-home/en
- IUCN Red List of Threatened Species: www.iucnredlist.org
- Global Invasive Species Database: www.iucngisd.org/gisd
- Baltic Sea Alien species database: www.corpi.ku.lt/nemo
- USDA invasive species: www.invasivespeciesinfo.gov/aquatics/databases.shtml

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CHAPTER 3

DRIVERS AND TRENDS IN AQUACULTURE: CONSEQUENCES FOR AQUATIC GENETIC RESOURCES WITHIN NATIONAL JURISDICTION

PURPOSE: The chapter explores the effects of different drivers on farmed aquatic genetic resources (AqGR) and their wild relatives. These drivers are human population increase; competition for resources; strength of governance; increased wealth and development of economies; and changing consumer food preferences and ethical considerations. The chapter also considers the effect of the drivers that affect ecosystems and thus have implications for both wild relatives and farmed types. These drivers are habitat loss and degradation; pollution of waters; direct and indirect effects of climate change; and establishment of invasive species.

KEY MESSAGES:

Human population increase

- Population increase will continue to drive demand for seafood, especially aquaculture products, as capture fishery resources become limited. This will drive efforts to expand and diversify the farmed species produced and therefore AqGR.
- This will also exert pressure on fisheries for wild relatives, either as broodstock or directly as food.

Competition for resources

- A significant proportion of aquaculture production occurs in freshwater. Demand for freshwater for agriculture, urban supply, energy production and other uses will challenge aquaculture to become more efficient in its resource use and reduce its discharges. This will require species adapted to such systems.
- Expansion into brackish water will drive demand for new brackish-water AqGR for culture.
- Wild relatives will be threatened by changes in priorities related to the use of water and competition from escaped aquaculture species.
- Pollution from industry, agriculture and urban sources threatens the quality of water used both for aquaculture and to sustain wild relatives.
- Overfishing, including targeting seed for capture-based aquaculture, will negatively affect AqGR.

Governance

- Increasing levels of good governance are observed as having an overall beneficial effect on AqGR in both farmed types and wild relatives.
- Impacts range from improved regulation of farms and their operations to greater professionalization within the sector.
- Impacts on wild relatives pertain to improved environmental management, better control over stocking and movements, risk management to prevent escapes from aquaculture and higher levels of conservation and protection.

Increased wealth and development of economies

- Accompanying increasing wealth in developing economies are greater intraregional and interregional trade and increasing urbanization and industrialization, all of which drive demand and preference for AqGR.
- There will be increasing consolidation and industrialization of large volume, internationally traded commodities such as seafood and hence preference for specific AqGR.
- There will be increased emphasis on food safety and traceability, which will present challenges for smaller operators and may limit their options for production systems and the

AqGR they employ.

- There will be continuous exploration of new AqGR species to satisfy the demand for new commodities and to fill niche markets.
- Demand for ornamental species will increase, driving the development of farmed types as well as demands on wild relatives.

Changing human food preferences and ethical considerations

- With changing demographics, consumer attitudes towards fish are also changing, affecting acceptability and demand for different AqGR.
- Fish consumption is increasingly recognized as part of a healthy and balanced diet, and increasing urbanization will drive demand for seafood, which will act as an incentive for increasing supply from aquaculture and, to some extent, fisheries.
- Concern remains over the development and use of genetically modified organisms in some markets, generating consumer resistance. This may also include resistance to other farmed types (e.g. hybrids, triploids).
- There is increasing awareness regarding the unsustainable exploitation of wild relatives, driving demand for farmed types.

Effect of habitat loss and degradation on ecosystems

- Changes in the use of land, water, coastal areas, wetlands and watersheds all have impacts on the quantity and quality of habitat for AqGR.
- Changes to watersheds are among the principal factors that affect aquatic systems. Aspects that affect AqGR include, among others, damming of rivers, drainage systems, flood control and flood protection, hydropower development, irrigation, partitioning of wetlands and road construction.
- The establishment of invasive species can have direct, and typically negative, impacts on AqGR through competition or predation, as well as indirect impacts on food webs and ecosystems that support wild relatives.
- Water pollution has strong negative impacts, particularly in freshwater, and affects both wild relatives and farmed AqGR.

Direct and indirect effects of climate change

- Climate change will have impacts on freshwater availability and implies changing ambient temperatures, which will have both direct and indirect impacts on farmed and wild AqGR.
- Climate change will have a disproportionate impact in tropical regions.
- There are possible positive effects on some farmed types, such as managed or natural selection for climate tolerant characteristics.
- Climate change will make it possible to farm some species beyond their current natural and cultured range.
- Though potential impacts on wild relatives are difficult to determine, many are likely to be negative.

3.1 Direct impacts on farmed types and wild relatives

Numerous drivers will affect aquatic genetic resources (AqGR) and the people who depend on them. It is expected that the most significant drivers in the coming decades will be human population growth, competition for resources, ability to achieve good governance, increased wealth and demand for fish and fish products, consumer attitudes (i.e. food preference and ethical considerations), habitat management and climate change (FAO, 2014a). The growth of the aquaculture sector itself will depend on many of these drivers and will have a significant influence on food production (see Outlook section in FAO, 2014a).

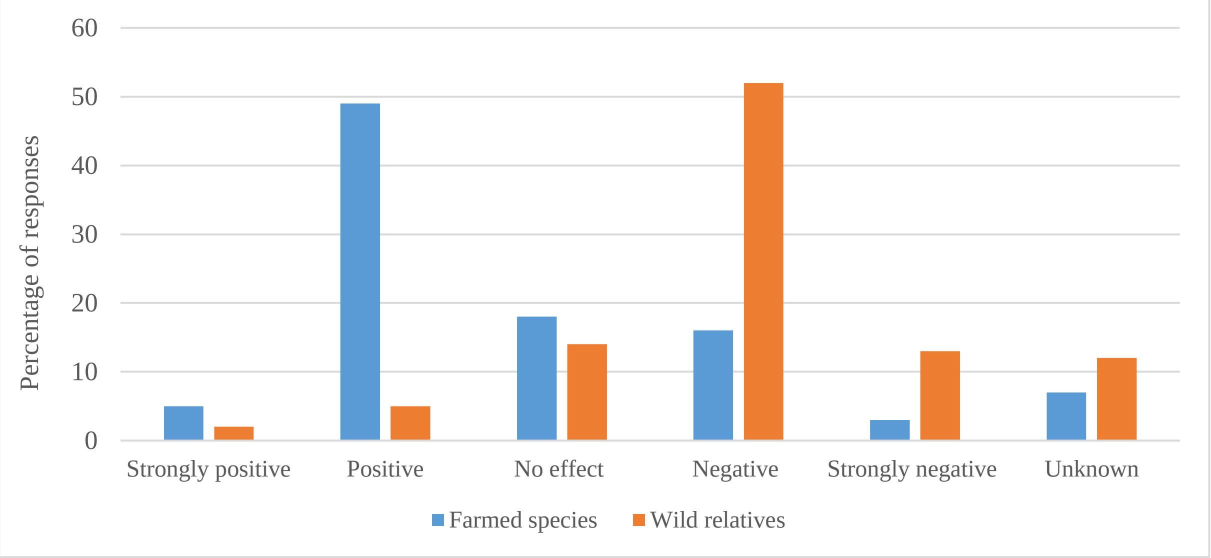
3.1.1 Human population increase

Linked to population growth models, projections of food consumption patterns and preferences forecast significantly increased demand for seafood products in the future. While total fish supply will likely be equally split between capture and aquaculture by 2030, projections indicate that 62 percent of food fish will be produced by aquaculture by 2030. Beyond 2030, aquaculture will likely dominate global fish supply, with global aquaculture production of food fish (excluding aquatic plants) expected to reach 93.6 million tonnes by 2030 (World Bank, 2013).

Over the past three decades, growth in global aquaculture production has outpaced population growth, resulting in increased per capita aquaculture production in most regions. Asia has led other regions in this regard, but substantial variation occurs even within Asia (FAO, 2018). The overall growth in global aquaculture (including aquatic plants), while slowing slightly, has averaged around 6 percent per year over the past 15 years (FAO, 2018).

More than half (54%) of country responses regarding the effects of population growth on AqGR indicate that the impact is likely to be positive for farmed type genetic resources (Figure 49). This appears to be linked to the consequent increase in demand for aquaculture products that will occur as population increases. Notably, since some developed countries did not expect their population to rise significantly, a strong increase in demand for seafood would not occur. It is expected that diversity of farmed type genetic resources will increase, including the development of improved farmed types (tolerance to high-density production; increased disease resistance; improved quality traits such as colour, shape, dress-out weight, head-tail ratio; phycocolloid gel properties, etc.), and the search for new species to culture, also known as diversification.

Figure 49
Country responses on the impacts of population growth on aquatic genetic resources of farmed species and their wild relatives



Nineteen percent of respondent countries viewed population growth as likely to negatively or strongly negatively impact farmed genetic resources; this was largely linked to pressures on resources. Pressures on water resources limit extensive aquaculture systems and the associated species that are used. Intensification and industrialization/rationalization may narrow the range of species that are cultured as commodities. This is a similar trend seen in the livestock sector, as high-performing breeds displace locally adapted breeds (FAO, 2007). While the increasing intensification and globalization of movement of aquatic species will increase the risk of spread of diseases, the impact of this on AqGR is unknown.

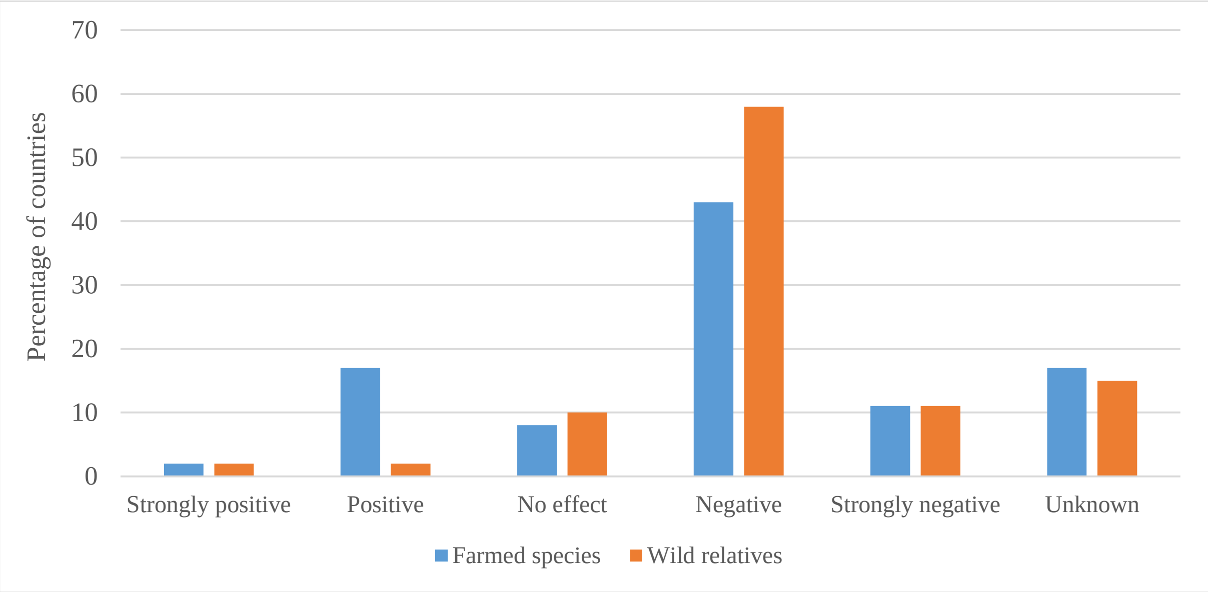
The impact of population growth on wild relatives is foreseen as generally negative (65%), with only 7 percent of respondents considering there would be positive effects. Respondents considered that increasing population and consequent demand for fish would drive overfishing of wild relatives, as well as negatively impact freshwater ecosystems that support wild relatives. In the absence of effective management, this would particularly affect the most vulnerable species. Vulnerable species have life history traits such as late sexual maturation, low fecundity and/or complex breeding or migratory characteristics. Part of this complexity also means that these species are challenging or prohibitively expensive to domesticate and breed in captivity (e.g. bluefin tuna, eel, lobster). This places an additional pressure on wild relatives, as the sourcing of seed for aquaculture typically takes place through the capture of wild juveniles.

Fishing pressure and gear selectivity may also have an effect on wild relatives by driving selection in wild stocks, though the scale is unquantified (Hard *et al.*, 2008).

3.1.2 Competition for resources

Overall, more than half of the country responses (54%) considered that competition for resources would have a negative effect on farmed AqGR, as opposed to 19 percent considering the effects would be positive (Figure 50). These responses were overwhelmingly concerned with the availability of freshwater and competition for it from other sectors, such as agriculture, irrigation, recreational uses and drinking water supply. There were no regional or economic differences between the responses.

Figure 50
Effect of competition for resources on aquatic genetic resources of farmed species and their wild relatives



Changing priorities regarding the use of water force aquaculture to produce more with less. A general trend exists towards rehabilitation of inland waters in many countries and restoration of habitat and conservation of biodiversity. This in turn may limit the prospects for aquaculture expansion because the amenity value and increased demand for conservation and rehabilitation of the aquatic environment will limit available sites for aquaculture and increasingly impose restrictions on water abstractions and effluent discharges.

In many countries, it will be necessary to increase aquaculture production through intensification approaches that utilize feed, water and space more efficiently than at present. This has strong implications for domestication and breeding of existing aquaculture species, as well as interest in

developing aquaculture systems for species that are not currently cultured. Several country respondents noted that competition for resources would have a positive effect on the development of more efficient production systems that had reduced nutrient discharge footprints.

When considering drivers affecting AqGR as a whole, it is useful to first examine trends in aquaculture production. It is recognized that some differences exist between these data collected through the Food and Agriculture Organization of the United Nations (FAO) statistics updated biennially and those reported through the Country Reports; a discussion of the causes and implications of these differences is included in Chapter 2 of this publication. In this chapter, the FAO aquaculture statistics are used to illustrate general trends related to taxonomic groupings, habitat and feeding level; such trends do not vary significantly between biennial reports.

Based on 2016 aquaculture production data (FAO, 2018), a total of 554 aquatic species and species items were farmed (Table 7), with approximately 56 percent being marine, 36 percent freshwater and 8 percent diadromous.

Despite the smaller number of species, freshwater aquaculture currently dominates finfish production (47.5 million tonnes versus 6.5 million tonnes in marine and brackish waters), especially in Asia (Table 10). Increased expansion in this subsector will inevitably lead to competition for freshwater and land resources. An opportunity remains for aquaculture expansion (and thus expansion of AqGR of farmed types) in the development of systems and species in brackish-water and saltwater systems.

The higher number of species being farmed in marine and brackish-water environments is an indicator of the diversity of these systems. An advantage worth noting is that saline environments are one of the few areas that does not directly compete with livestock and agriculture production for space and water, meaning that there is considerable potential for increased cultured food production from these environments in the future.

The rising price of key feed ingredients for aquaculture (especially fishmeal and fish oil) is already driving the aquaculture sector to explore lower cost alternatives. Development of innovative feeds is one outcome, but the selection of species for improved performance (growth, feed conversion ratio) on these feeds is a parallel development. Considerable improvements in performance have been achieved through selective breeding for a number of species (e.g. salmon, channel catfish, Nile tilapia).

Although availability of aquaculture feed is an important concern regarding the future of aquaculture development, 50 percent of the world's aquaculture production is cultured in systems that do not require the addition of feed. This is achieved mainly through the production of seaweed and microalgae (27%), filter-feeding finfish (8%) and filter-feeding molluscan species (15%) (FAO, 2014b). The production of unfed aquatic animal species was 23 million tonnes in 2014, representing 23 percent of the world production of all farmed fish species (FAO, 2016). This trend has been reasonably consistent over the past decade. While the trend in production of carnivorous species has risen slightly (from 8% to 9%) over the past decade, it is greatly outweighed by the production of non-carnivorous species (Table 29).

The most important unfed aquatic animal species include:

- two freshwater finfish species, silver carp and bighead carp (tilapia in extensive systems are also able to filter feed but are not included here);
- bivalve molluscs (clams, oysters and mussels, etc.); and
- other filter-feeding animals (such as sea squirts) in marine and coastal areas.

While many of these pressures could have a positive impact on farmed AqGR, the limitations imposed on water and land, as well as the trend to rationalize systems, may tend to reduce the diversity of farmed aquatic animals in some regions.

Table 29
Comparison of production (tonnes) of fed and unfed aquaculture (2004–2014)

	Species	2004	2009	2014	% of 2014 total
Unfed	Algae	10 382 167	14 823 908	26 839 288	27
	Bivalve molluscs	10 622 252	12 214 046	14 516 676	15
	Filter-feeding carp	5 381 150	6 568 469	8 220 882	8
	Other filter-feeding species	87 702	171 392	275 568	0
Fed	Herbivorous species	3 980 855	5 138 466	6 722 240	7
	Omnivorous species	17 991 921	26 541 037	33 347 307	34
	Carnivorous species	4 754 449	6 597 555	8 942 613	9
Unknown	Other species unknown	4 992 202	5 258 884	4 897 668	5
Totals	Total unfed	26 473 271	33 777 815	49 852 414	50
	Total fed	26 727 225	38 277 058	49 012 160	50
	Total unfed animals	16 091 104	18 953 907	23 013 126	23
	Total all species	58 192 698	77 313 757	103 762 242	
Percentage of annual total	Unfed	50	47	50	
	Fed	50	53	50	

For wild relatives, the picture of competition for resources is clearer. Competition for resources was considered to be overall negative for 69 percent of respondent countries versus only 4 percent considering there would be positive effects.

The negative impacts on wild relatives include reduction in availability of freshwater, loss of habitat, and competition over land and maritime space (in countries with mariculture). Changes to watersheds are among the principal factors that affect aquatic systems, including activities such as damming of rivers, drainage systems, flood control and flood protection, hydropower development, irrigation, partitioning of wetlands and road construction. Environmental impacts on water that can affect wild relatives include land use changes and soil degradation impacting water quality, as well as agricultural runoff and unregulated urban and industrial discharges into waterbodies.

There is an additional specific impact created by the demand for aquaculture feeds derived from capture fisheries, although the species targeted for aquaculture feeds (e.g. fishmeal, low value/trash fish) are not typically wild relatives of aquaculture species (Table 30).

Table 30
Summary of impacts on wild relatives created by competition for resources

Typical impacts of habitat loss and degradation	Loss of wild habitat and water flows resulting from changes in rivers, wetlands and other waterbodies, caused by changing land use, watershed development and drainage of freshwater wetlands. This reduces the available habitat to sustain populations and affects the function of habitats during critical seasons (e.g. overwintering, dry-season refuges).
	Physical obstruction and changing water-flow regimes affecting upstream and downstream migration and reproduction of riverine species. This is caused by damming of rivers and loss of connectivity in waterways (e.g. low water control structures, weirs, irrigation structures).
	Changing ecosystem quality (driven by land management, watershed management) leading to increased soil erosion and sediment loads in waterbodies. This directly affects species sensitive to poor water quality and can affect quality of spawning grounds or nurseries.
Impacts of pollution on waters	Direct effect of toxins and heavy metals from untreated industrial discharges.
	Indirect effect of effluents from urbanization leading to eutrophication and changed water quality and food chains.
	Direct impact on fish through feminization effects (oestrogen-analogues in effluents).
	Nutrients from agriculture runoff leading to eutrophication of waterbodies.
	Pesticide runoff from agriculture directly affecting fish, or indirectly through ecosystem level impact on prey and/or food chains.
Impact of demand for seed or broodstock	Some aquaculture systems still rely on wild relatives as the source of seed for stocking. This may be completely benign, as in the form of capturing natural spatfall as in the case of molluscs (e.g. clams, oysters, mussels, cockles).

	The active fishing for seed for stocking may have greater impact if that activity takes place after there has already been significant mortality during recruitment. In this case, there can be direct impacts on the wild population (e.g. collection of juvenile lobster or grouper for ongrowing). In other systems, the collection of juveniles for stocking appears to have little or no impact on the wild population, e.g. yellowtail, *Seriola*, seed collection in Japan.
Impact of demand for feeds	Capture fisheries that are specifically managed for production of fish for fishmeal are not typically comprised of wild relatives of aquaculture species. The use of trawl bycatch for fishmeal is more complex, as the species targeted may be highly diverse. There are ecosystem effects in these fisheries, affecting the stock composition, although the effect on wild relatives of aquaculture species is not quantified.

3.1.3 Governance

Governance factors were overwhelmingly perceived as having a positive effect on farmed AqGR (76%). There were no obvious regional or economic differences in the country responses. In general, country responses indicated that a combination of more effective regulation of the sector, coupled with increased organization and empowerment of aquaculture producers, was a desirable goal. Where indicated, countries reported that effective governance was a positive factor contributing to the management of AqGR. The development of specific regulations to manage importation of species, regulation of AqGR at the farm level, and controls on the feed sector were identified as principal factors. Government investment in breeding programmes and the development of aquaculture development programmes (and agencies to promote this) were positive outcomes identified in the Country Reports. This had enabled more effective dialogue between producers and regulators and improved understanding of the issues relating to aquaculture production. This was extended to engagement with civil society, civil society organizations and environmental groups in some reports.

Noted as important were the need to encourage better dialogue concerning aquaculture and its use of AqGR and potential impacts or threats to wild relatives. The prospects of governance for positively impacting farmed genetic resource were considered to be as follows:

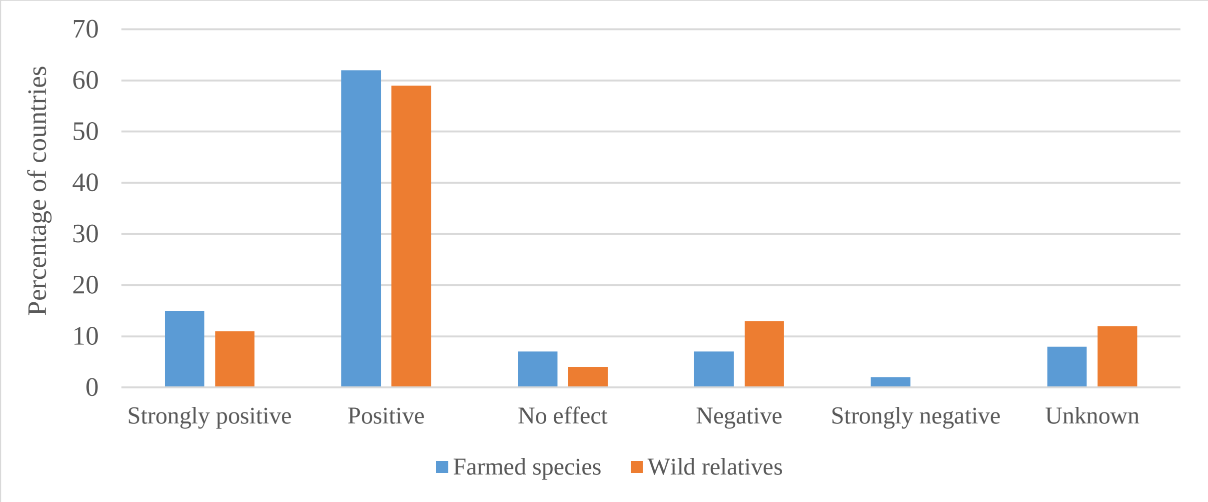
- increased regulation and management of farmed types, including licensing of hatcheries, can contribute to more systematic and effective controls over farmed AqGR;
- effective biosecurity systems to assess and manage risks of translocations, introductions of both farmed and wild species as well as pathogens and parasites;
- professionalization of the sector, including greater understanding and appreciation of good-quality genetic strains;
- development of specific pathogen resistance in farmed types; and
- development of effective measures to enable exchange of material between countries (this is currently increasingly constrained by national legislation on genetic resources and biosecurity; see Chapter 6).

Only 9 percent of respondent countries considered that governance would have any negative effect on AqGR. These responses were concerned with poor regulatory environments and limited research. Some concern was voiced that the lack of government leadership on AqGR left too much influence in the hands of the private sector, with implications for unregulated imports and movements.

A similar figure for positive impacts of governance (70%) was expressed for wild relatives, with responses (where provided) focusing on the importance of effective fishery management to protect wild relatives. No obvious regional or economic differences appeared in the country responses. The existence of effective fishery assessment programmes was identified as an important element. Some specific examples highlighted the protection of specific habitats and development of protected areas and sanctuaries to preserve wild stocks (Bangladesh, Benin). For marine stocks, marine fishery management measures, including seasonal closures of the fishery, were mentioned. Rehabilitation of freshwater resources (including habitat) was also noted in some countries. Some reports indicated the importance of effective relationships between government regulatory bodies and fishers, as well as fish farm

operators, in order to achieve positive environmental outcomes (Figure 51).

Figure 51
Effect of governance factors on aquatic genetic resources of farmed species and their wild relatives



While not strictly a governance issue, some mismanagement problems of AqGR of farmed types arise from the governance structures and degree of regulatory control, research and communication. Concerns remain over the impact on wild relatives from escapees of farmed types, especially any genetically modified organisms (GMOs), thus identifying the need for more stringent measures to prevent or reduce possible harm in the future. Preventing harmful impact is linked to effective sector regulation and management, which is therefore related to the degree of effectiveness of governance of the sector. These management issues are summarized in Table 31.

Table 31
Aquaculture sector governance and management issues that impact aquatic genetic resources

Limited genetic diversity in founder populations	Limited numbers of broodstock fish are used in research centres as the techniques for breeding are established. Successful mass production sees this stock disseminated to other hatcheries for upscaling, without accessing large numbers of new broodstock. This may be a particular issue where the broodstock are non-native.
Small private hatcheries with limited numbers of broodstock	In many developing countries, small-scale private or state operated hatcheries may have exceptionally small numbers of broodstock. The replenishment of broodstock may not occur for many years; and, in some cases, broodstock is never replenished. This results in inbreeding and decreased performance. This problem can be corrected by national initiatives on broodstock management and dissemination.
Species disseminated worldwide from a relatively limited number of sources	Specific farmed types may be held in reference centres and access to these farmed types may be limited by legal or financial constraints. Improved access may require cooperation or sharing agreements, and greater national financial support.
Limitations on refreshing genetic stocks from the wild	Replenishment of broodstock from wild relatives may be constrained in a number of ways. One of the greatest threats is weak governance on the management of the habitats and stocks of wild relatives, which can lead to their decline in the wild and loss as a potential source of broodstock for the future.
Non-compliance with regulations by the private sector	It was noted in some country responses that the private sector had the ability to bypass government controls on importation and movements of aquatic animals.
Poor controls on accidental or deliberate release of cultured fish to the wild	Accidental or deliberate (in the case of stocking of open waters) release of domesticated species, hatchery bred and GMO material may impact wild relatives.

Improved governance also benefits wild relatives by strengthening controls over biosecurity and limiting farm escapees, both of which have potential impacts, including genetic pollution. The improvement of management of the environment and biodiversity may be an additional positive effect, contributing to more effective conservation of wild relatives. Some measures include:

- the establishment of well-managed conservation hatcheries to increase/maintain genetic diversity of wild relatives;
- reduction of risks of transmission of parasites and pathogens to wild relatives through effective biosecurity, especially in relation to introductions;
- prevention of the establishment of invasive species; and
- reduction of the risk of interactions between farmed and wild fish.

Few negative responses were received in relation to the impact of governance on AqGR – 9 percent in the case of farmed types and 13 percent for wild relatives. In some responses, delegation of implementation to the private sector and reliance on voluntary compliance were perceived as weaknesses. An area that is quite commonly found in developing countries is a lack of effective assessment of risks concerning the introduction and movement of aquatic species, which can directly conflict with biodiversity and conservation policies or simply undermine both existing production systems and policies on economic development, livelihoods and food security. Neglecting to conduct risk assessment contrasts with those policies that are in place to promote aquaculture development; pursuing development without adequate regulatory measures may result in unintended negative consequences in the future.

Some country responses indicated that a general negative aspect of weak governance was policy fragmentation or weak institutional coordination on water and the environment. This is common in many countries where the roles and jurisdictions of water management and development are spread across multiple agencies and the private sector, typically including irrigation, drinking supply, hydropower, biodiversity and environmental management, fisheries and aquaculture, coastal zone management, protected areas, and conservation. In the water sector, the impacts can range from inability to coordinate on the multipurpose management and use of water and waterbodies (e.g. for aquaculture, fisheries, recreation, conservation, drinking supply, irrigation) to direct policy conflicts (e.g. power generation versus biodiversity conservation and food/livelihood security).

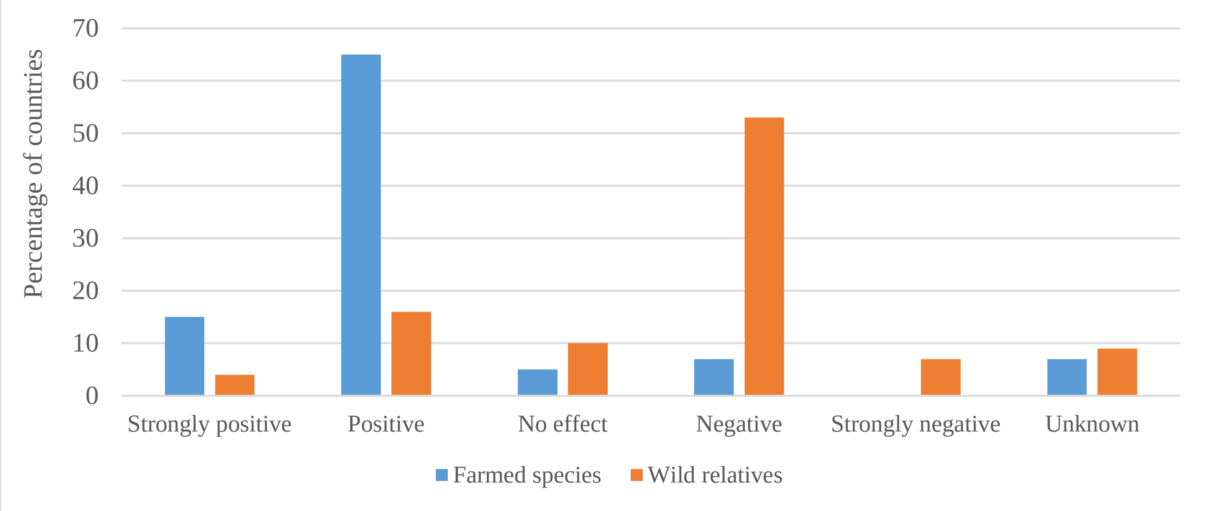
Modernization of legal frameworks and institutional reforms can assist in rectifying these negative impacts, especially in the area of water management, aquaculture zoning and biosecurity (see Chapter 7).

3.1.4 Increased wealth and demand for fish

Eighty percent of respondent countries considered that increased wealth would positively affect farmed AqGR (Figure 52).

Expanding economies and increasing wealth drive demand for seafood products, and aquaculture products form part of this demand. There is some evidence that increasing urbanization leads to a slight decrease in the relative amount of fish consumed (relative to other meats), but overall total consumption increases as economies develop due to increased purchasing power (Delgado *et al.*, 2003). Long-term projections indicate a general decline in global per capita fish consumption, but this would be more than compensated for by greater overall demand due to population increase (World Bank, 2013; Delgado *et al.*, 2003). The Country Reports indicated that positive impacts of increased wealth and national economic development are seen as driving the demand for fish, which is often a more expensive food in many countries. An example of this phenomenon is demonstrated in the urban populations of countries, as diverse as China and the Democratic Republic of the Congo, experiencing increasing wealth.

Figure 52
Effect of increased wealth on aquatic genetic resources of farmed species and their wild relatives



Increasing wealth and greater interest in healthy eating were considered by several country respondents to be driving the increased demand for seafood. These also promoted increased demand for fish as a healthy food, particularly in middle-income families. Several countries noted that low incomes and poor economic conditions were a limiting factor in the ability of their population to access fish.

The lowering of fish prices through aquaculture was also seen as a positive effect on affordability of fish. The growth in demand was seen as a positive commercial incentive for aquaculture development. One outcome was the introduction or development of aquaculture for commercial, exotic and native species to meet new market demands.

There were limited examples of negative impacts, with only 7 percent of countries reporting this outcome. Increased urbanization and standardization of aquaculture products may also have some negative impacts on the range of species being cultured. This occurs as urban consumers purchase increased amounts of processed fish commodities (e.g. frozen white fish and salmon fillets, shrimp, surimi products) or convenience food (e.g. fish sticks), and hence there is less demand for a broad diversity of species, which may require more elaborate preparation. The change in preference from traditional freshwater species (e.g. cyprinids) to imported marine seafood is another aspect of preference enabled by increased wealth and improved international value chains.

Some countries (e.g. Morocco) identified an increased demand for better quality fish. Increasing urbanization and economic development also see the emergence of longer value chains, supermarkets, and increased processing and standardization of products. Aquaculture is well placed to meet the specific demands of supermarkets, which include consistent quality, reliable supply, standard product form and dependable food safety.

Also manifesting was increasing interest in indigenous species, especially as wild relatives become harder to obtain or more expensive. Growing affluence creates demand for luxury products, and aquaculture responds to this demand. The rise of salmon, trout, shrimp and sturgeon (for caviar) aquaculture is a classic example of how aquaculture has been able to bring previously inaccessible and expensive foods into globally available commodity chains.

Over the past two decades (1995–2015), there has been a substantial increase in trade in many aquaculture products based on both low- and high-value species. New markets have emerged in developed, transitioning and developing countries. Aquaculture is now a significant contributor to the international trade in fishery commodities. These markets are dominated by high-value species such as salmon, seabass, seabream, shrimp and prawns, bivalves and other molluscs, but also include lower-

value species such as tilapia, catfish (including *Pangasius*) and carps. These low-value species are traded in large quantities within and between countries in two main regions (Asia and Latin America and the Caribbean) and are increasingly finding markets in other regions (e.g. *Pangasius*, tilapia) (FAO, 2014a).

Increased wealth is also linked to increased interest in high-value ornamental fish, where markets are largely found in cities and economically developed contexts. Trade in live fish includes ornamental fish, which are high in terms of economic value but almost negligible in terms of quantity traded (FAO, 2014a). Though it is probable that more than 870 freshwater and marine species are cultured for the ornamental trade,[19] in most cases they are not officially reported at national and FAO levels.

Due to the impact of increased wealth on AqGR of farmed organisms, greater attention is paid to improving strains, diversification and experimentation with new species to address demands from niche markets.

Country responses were mixed with regard to the impacts of increased wealth on wild relatives. Sixty percent considered there would be overall negative impacts. The country responses described that increased demand would drive fishing effort with negative consequences for capture fisheries.

Increased wealth may drive demand for wild relatives of some species for food (e.g. bluefin tuna, sturgeon caviar, live reef fish, sea cucumber) and for ornamental fish keeping (e.g. Arowana species, marine aquarium species). It was also considered that this demand would drive illegal, unreported and unregulated fishing for some species, particularly those that are threatened or protected.

Twenty percent of respondents considered that the effects of increased wealth were likely to be positive. The respondents' explanation was that increased wealth would boost consumption of fish from capture fisheries, but that consumers' increasing wealth would result in greater awareness concerning responsible and sustainable exploitation. There was some consideration that aquaculture was in a position to provide fish that were equivalent to the species currently obtained from wild stocks that were under pressure.

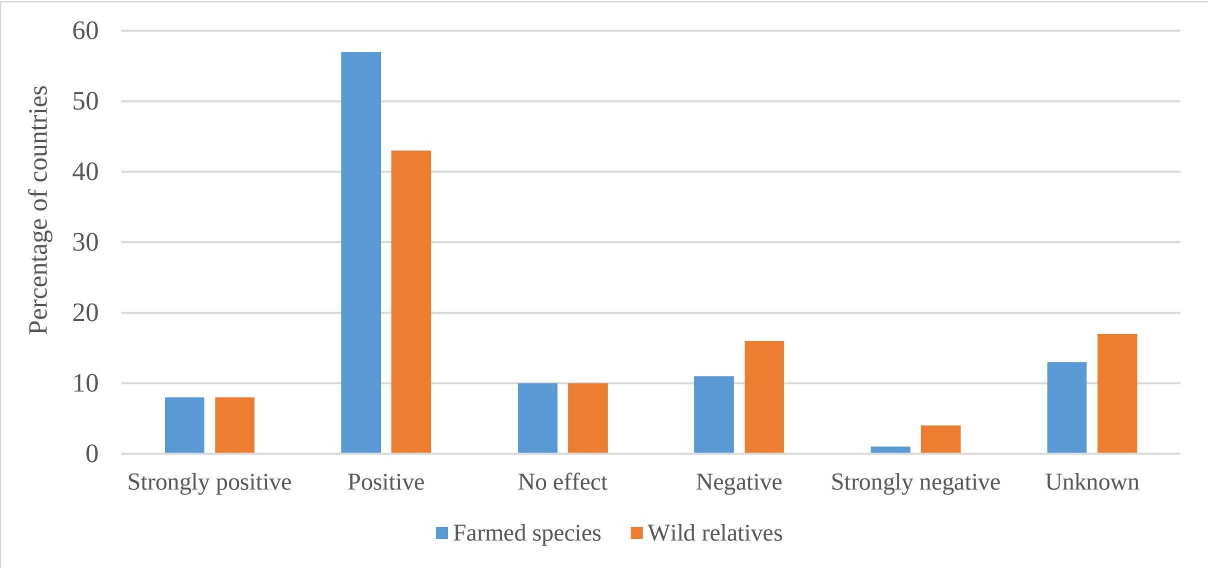
[19] Based on an assumption that 95 percent of freshwater species (> 850 species) and 5 percent of marine species (~1 400 species) are cultured.

3.1.5 Consumer food preferences and ethical considerations

Sixty-five percent of responding countries considered that consumer preferences and ethical considerations would have a positive impact on farmed type AqGR (Figure 53).

Figure 53

Effect of consumer preferences and ethical considerations on aquatic genetic resources of farmed species and their wild relatives



Developing interest in fish as a healthy food drives an increasing demand for fish as a staple of the diet. When linked to population increase, this becomes a significant driver in the global demand for fish. Consumer preferences and ethics will have an additional impact on which species and farmed types are purchased, and which of their characteristics become the highest priority in the market. These consumer preferences will be quite diverse according to a range of socio-cultural factors, and will affect the demand for particular farmed types, including the preferences listed in Table 32.

Table 32
Features affecting consumer preferences and their relevance to genetic characteristics of farmed type aquatic genetic resources

Preference	Feature	Genetic and/or culture characteristics
Appearance and taste	External colouration	Preference for red strains of tilapia over darker natural colouration. A strong (fundamental) feature in the ornamental trade.
	Flesh colour	Preference for white fish and avoidance of yellow/grey flesh (note that this feature can be affected by the diet administered). Different levels of red colouration in salmonids.
	Body shape	This is typically to maximize the fillet or dress-out weight (or head-to-tail ratio in shrimp). In some cases, there is a preference for a larger head (bighead carp). Body shape is a major factor in selection of fish in the ornamental trade.
	Taste and texture	Dependent upon the species (flesh qualities). Osmotic tolerance – salinity can influence the saltiness of the fish; in the case of shrimp, lower salinities can make the flesh taste sweeter, as amino acids that are used to maintain osmotic balance also affect flavour. Culture methods and feeds used can influence the fat levels in the flesh.
	Processing	Increased interest in raw, smoked and dried forms of particular farmed types.
Cost	High value	Farmed types of high-value wild relatives (tuna, grouper, halibut, lobster, shrimp, salmon, etc.). These may be cheaper than wild relatives.
	Low value	Lower-value species that are affordable and that can be produced in systems with low production costs per unit (e.g. tilapia, *Pangasius* and other catfish, common carp, Indian and Chinese major carps).
Fish welfare	Domestication	Manner of production, suitability for higher intensity of production.
		Perceptions of stress to the animal.
		Reduced stress in the case of domesticated farmed types.
Other environmental concerns	Indigenous versus exotic	A preference for indigenous species to avoid threat of introduced/exotic species.
		Organic certified production may require use of indigenous species.
Genetic manipulation	Transgenic methods	General preference to avoid GMOs is expressed in a number of Country Reports.
	Monosex/sex reversed	Preference for genetically manipulated monosex/sterile animals versus concern over use of hormones.

The price of fish is a strong driver concerning consumer choice between wild and farmed fish, as well as particular species. Since the eventual price to consumers is dependent upon the cost of production, it can be strongly influenced by genetic characteristics of the farmed type being produced.

Twelve percent of the respondents considered that human preferences and ethical considerations would have negative effects on farmed fish. There are some consumer concerns regarding welfare of cultured fish. This has been accompanied by some regulation (e.g. European Union) and the development of health standards by the World Organisation for Animal Health (OIE) for welfare, slaughtering and transportation.[20] The successive breeding of captured stock does result in a domestication process, whereby fish become more tolerant than their wild relatives of water quality conditions, stocking density and other stressors that may arise in culture systems.

A major challenge in developing improved aquaculture strains will be consumer perceptions and ethical concerns regarding the sustainability and ethical basis for modern aquaculture. This links to fish welfare, perceived environmental impacts, and possibilities of escapees and their impacts on wild populations. Another emerging concern is the use of GMO and transgenic organisms. It is still unclear how

[20] The OIE Aquatic Animal Health Code (the Aquatic Code) sets out standards for the improvement of aquatic animal health and welfare of farmed fish worldwide, and for safe international trade in aquatic animals (amphibians, crustaceans, fish and molluscs) and their products. See www.oie.int/en/standard-setting/aquatic-code/access-online.

significantly consumer perceptions will influence developments in this situation. There is currently only one GMO/transgenic farmed type (Chinook salmon) being commercially farmed; consumer concerns were a major driver in the approval process for this fish.

Though there is general concern over the use of GMO and transgenic techniques in aquaculture, to date only a few examples of transgenic organisms are being studied in research facilities. Limited examples are modification to increase growth rates and performance in cold temperatures (examples: Atlantic salmon, chinook salmon, rainbow trout, cutthroat trout, tilapia, striped bass, mud loach, channel catfish, common carp, Indian major carp, goldfish, Japanese medaka, northern pike, red and silver seabream, walleye, seaweed, sea urchin and *Artemia*) (Rasmussen and Morrissey, 2007; Beardmore and Porter, 2003). Transgenic fish have been produced for the aquarium trade (altering fluorescence or colouration).

Positive impacts on wild relatives (51% of respondents) are linked to increasing consumer concern over unsustainable extraction of species from the wild and increasing calls for sustainable management and sourcing policies. Changing attitudes were seen as leading to increased efforts to preserve or sustain stocks of wild relatives, which are linked in turn to the improved governance and impact on fishery management. Changing attitudes are also associated with the rise of ecolabelling and certification of capture fisheries.

Twenty percent of respondents perceived negative impacts of consumer concerns on the AqGR of wild relatives. This was seen as the negative effect of demand or preference for wild stocks and unregulated poaching and fishing for food.

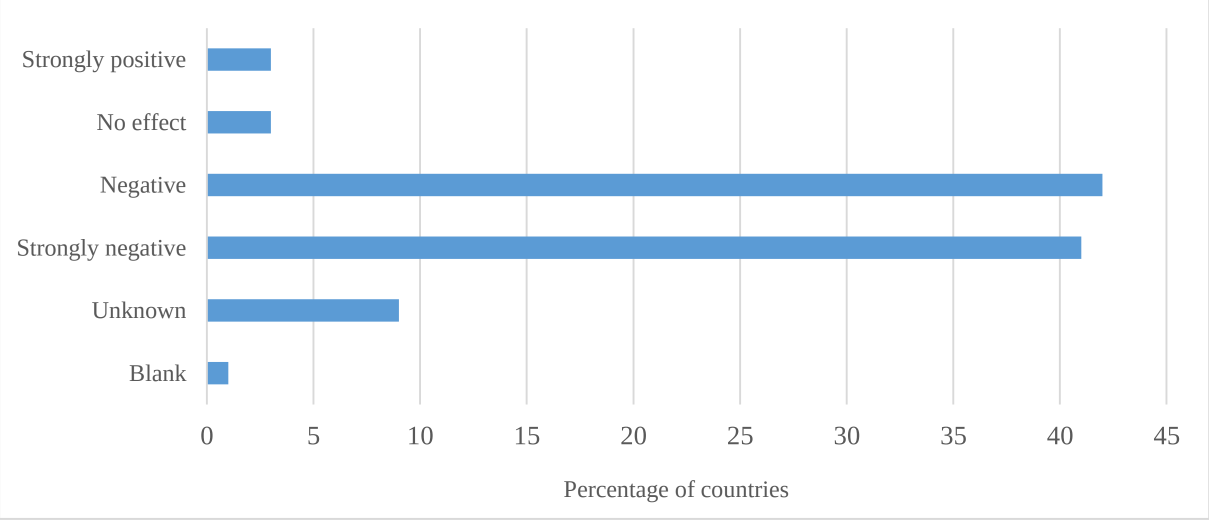
A number of countries identified the retention of catch of wild relatives from recreational fisheries as negative, but it was believed that changing attitudes would eventually resolve this in a positive way in the form of catch-and-release recreational fishing.

3.2 Drivers that are changing aquatic ecosystems

3.2.1 Habitat loss and degradation

Habitat loss and degradation was almost universally considered to have a negative impact by respondent countries (84%). The limited responses that considered habitat loss in a positive way described how their country was actively addressing its impact. In this regard, all countries appeared to view habitat loss as having a negative impact (Figure 54).

Figure 54
Effect of habitat loss and degradation on aquatic ecosystems that support aquatic genetic resources of wild relatives of farmed aquatic species



The types of habitat loss were variable between countries and generally related to the impact on the natural environment and wild relatives rather than to the impacts on farmed types. This is presumably because the aquaculture environment is actively managed to avoid or mitigate these impacts.

Countries identified the need to address hydromorphological degradation of the watercourses that occurs as a result of various interventions, such as dyke construction as protection against flooding, obstructing features to regulate flow-off, water damming, and energy generation measures. This is mainly due to the impact of water management (irrigation, damming, flood control, hydroelectric power generation). To ensure water connectivity and maintenance of (near-) natural water flows, the need was recognized to promote the development of regulatory measures to ensure near-natural conditions and improved passability of the waterbodies (e.g. European Union Water Framework Directive 2000/60/EC).

Improving the management of water in large waterbodies, including reservoirs, to ensure fish migrations was also noted. This is a particular mitigation of the impact of large dams on water flow and connectivity. Adjustment of the water level in reservoirs during spawning and supporting longitudinal permeability by functional fish ladders were noted as good management strategies.

Mitigating the impact of lost habitat connectivity in floodplains, rivers and other aquatic systems was identified as a priority action in the Country Reports. These impacts typically arise from water management (such as irrigation), but also can occur through land use change, development of floodplains, and urban and industrial development. Agriculture changes may also have a strong impact on floodplains and water connectivity. The development of improved connectivity between isolated areas and habitats through engineering of hydrology and provision of fish ways and other courses for movement of aquatic animals were recommended as remediation measures.

Several strategies were identified for the mitigation of the loss of natural habitats through environmental degradation, water management and land use change. These include the need to:

- develop conservation and protection programmes focusing on critical breeding and nursery habitats;
- delineate and protect breeding areas in lakes and rivers and develop networks of spawning areas along larger rivers;
- establish fish sanctuaries and dry season refuges in floodplains;
- restore habitat in freshwaters and seek to restore environmental quality and habitat of spawning and juvenile grounds; and

- protect riparian vegetation, upland forests and other terrestrial habitats that affect watersheds.

Country Reports highlighted that mitigation of impacts from overfishing should focus on recruitment and protection of broodstock, particularly through the establishment of protected areas/closed areas and implementing closed fishing seasons to protect nurseries and broodstock.

Countries commonly referred to stocking of degraded systems as an activity which can increase the potential production from degraded aquatic and marine systems. However, stocking needs to be undertaken responsibly to avoid further degradation or negative impacts. This includes responsible choice of species and stocking strategies, which require effective planning and appropriate monitoring and evaluation. Stocking programmes are often poorly monitored and their outcomes are sometimes questionable (Cowx, Funge-Smith and Lymer, 2015).

Reduction of erosion, pollution and other impacts from land-based sources (especially agriculture and forestry) are important for the health of freshwater, estuarine and delta systems. This can be achieved by improved agriculture practices to reduce soil erosion (e.g. terracing, reforestation, conservation agriculture). Active promotion of agricultural practices that reduce soil erosion and the consequent improvement in the quality of water in streams and rivers can have a major impact on the health of aquatic ecosystems. This is also enhanced if there is limitation of wastewater and land management to reduce external nutrient and solid substance load to waters.

Addressing pollution from all sources will have positive impacts on aquatic ecosystems and habitats, in particular those from urban and industrial sources. The reduction of pesticide and nutrient runoff from agriculture is also an important outcome that can be promoted by improved regulation and relevant economic incentives.

Conservation of habitats in estuarine systems includes delta and mangrove systems. In marine areas, this principally focuses on the establishment of marine protected areas and protection of coral reefs and seagrass habitats. Protection of critical habitats and breeding grounds outside of these environments (e.g. marine fishery spawning grounds and nursery areas) is also vital. Development of artificial reefs to restore habitat may protect habitats from further degradation from human disturbances (e.g. from active fishing gears).

Strengthened regulatory systems must be established in order to achieve these outcomes. Steps include:

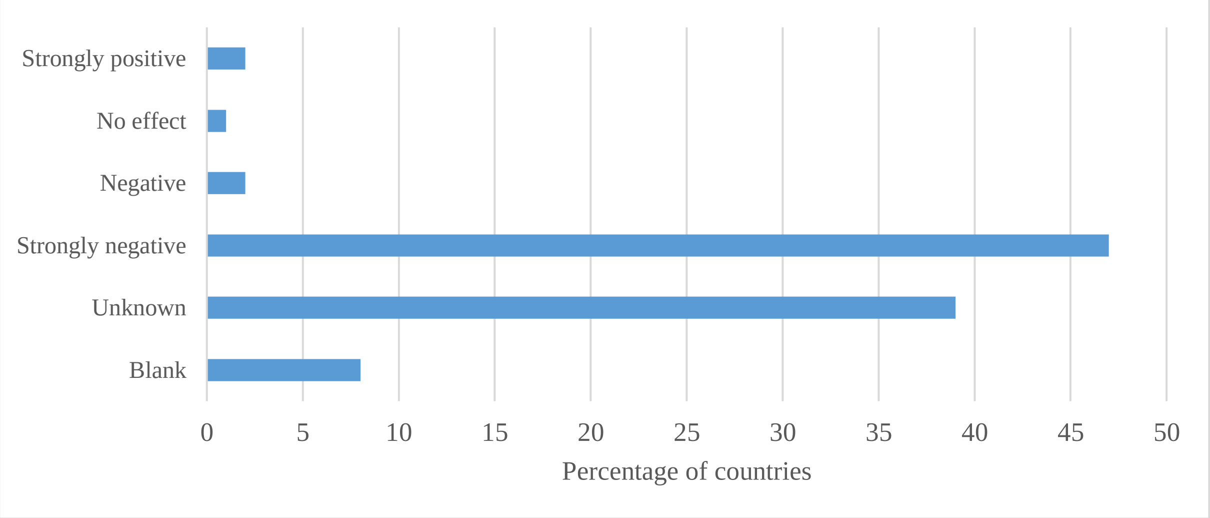
- effective environmental impact assessment in place for all major infrastructure projects that may impact aquatic ecosystems;
- effective legal support for conservation of genetic resources in the planning of hydropower projects;
- establishment of protected areas;
- regulation on the prevention of escapees;
- general measures aimed at habitat conservation and restoration, as well as at establishing protected areas for AqGR;
- implementation of community-based management;
- spatial planning and zoning of aquaculture; and
- more effective water management to balance the needs for agriculture, drinking water and sustained aquatic ecosystems.

Recreational fishing might have both positive and negative impacts on AqGR. There are drivers for improving the conservation of wild relatives by conserving both their habitats and their populations. In terms of reducing the fishing impact on wild relatives, most recreational fisheries have regulations aimed at conservation of the stock.

3.2.2 Pollution of waters

Forty-nine percent of respondent countries recognized the negative impacts of pollution on ecosystems and the consequent effect on AqGR. A further 39 percent recorded that this was unknown (Figure 55). Human population increase and increased urban development and industrialization will increase the pollution threats to aquatic ecosystems. Both freshwater and coastal waters are impacted, to varying degrees, by pollution, which can directly impact on reproductive performance through acute toxicity or chronic sublethal effects that cause mutations, deformities and bioaccumulation.

Figure 55
Effect of pollution on aquatic ecosystems that support aquatic genetic resources of wild relatives of farmed aquatic species



Identified sources of pollution entering open waters were the following:

- urban sewage discharges;
- industrial discharges, including both routine and accidental spillages, as well as airborne contamination, leading to toxins entering the water cycle (e.g. heavy metals, organic halogen compounds);
- freshwater runoff from agriculture, logging and land development, causing soil erosion, sedimentation, turbidity and reduced water quality;
- runoff from agriculture, leading to eutrophication and pesticide contamination; and
- radiation contamination in the case of leakage from nuclear power station accidents (e.g. Chernobyl, Fukushima).

There were comparatively few examples from the marine environment.

The impacts are more severe on wild relatives, but there can be indirect impacts on farmed types through contamination of water and sediments. Only 3 percent of the countries identified this driver as positive on aquatic ecosystems of relevance for wild relatives of farmed aquatic species, and less than 2 percent of the countries reported no effect.

Typically, aquaculture operations would not be sited where there is a risk of toxic levels of pollution that could cause the loss of stock. However, aquaculture is vulnerable to accidental release of pollutants (e.g. spillage/discharges in water), as well as to sublethal or chronic pollution (e.g. heavy metals or other organic pollutants) in sediments and water that may not have been monitored or detected. This issue is common in countries where comprehensive environmental monitoring is not well established or implemented.

The specific negative impacts on AqGR vary according to the form of pollution, the sensitivity of the ecosystem fauna and flora, and the degree to which the pollution is present (e.g. acutely or chronic/sublethal concentration). The risks of pollution are direct to fish in terms of poisoning or water-quality impacts to aquaculture operations and wild relatives in watercourses. Consumers are also at risk from long-term consumption of contaminated fish. Table 33 indicates the various type of impacts where pollutants directly affect AqGR (farmed type or wild relatives).

Table 33
Types of pollution and their potential impact on aquatic genetic resources (AqGR)

Source of pollution	**Typical pollutants**	**Impacts on AqGR**
Untreated or inadequately treated domestic sewage	Organic and inorganic, nitrogen and phosphates	Eutrophication and loss of water quality in waterbodies (ecosystem impact on wild relatives)
		Harmful algal blooms
	Some heavy metals and organic compounds	Sublethal effects on performance
		Oestrogen analogues causing feminization and disrupting reproduction
	High organic and bacterial loadings from untreated domestic sewage, including potential fish and human pathogens	This may directly infect AqGR or indirectly stress AqGR through impact on water quality. AqGR harvested from these waters may pose a threat to human health
Improperly stored solid waste	Leachates from landfill	A wide range of pollutants from urban and domestic garbage directly toxic to aquatic life
Industrial organic and inorganic wastes	Mining wastes (heavy metals and suspended solids)	Direct toxicity; Sublethal effects on performance
		Clogging of gills, impacts on water quality, fouling of spawning areas
	Heavy metals, organic compounds in industrial wastewater discharges and accumulation in sediments	Direct toxicity in acute cases; Heavy metal accumulation (possible impacts on breeding performance in wild relatives (Pyle, Rajotte and Couture, 2005); Indirect toxicity through accumulation in prey organisms
Agricultural runoff and wastes	Nutrient runoff from agricultural fertilizers	Eutrophication and loss of water quality in rivers and waterbodies (ecosystem shifts), loss of habitat impacts wild relatives
		Harmful algal blooms
	Pesticide runoff	Direct toxicity on wild relatives; Indirect impacts on prey organisms
Soil erosion and sedimentation	Suspended solids/sediments	Clogging of gills, impacts on water quality, fouling of spawning areas
	Acidity	Direct acidification impacts
Oil/gas exploration	Oil and oil dispersant; heavy metals and organic compounds in drilling muds and cuttings	Direct toxicity on wild relatives; Indirect impact through toxicity to prey organisms (especially in the marine environment)
Power generation	Waste heat (from industry and power generation)	Establishment of warm-water invasive species; Displacement of wild relatives
Aerosol and atmospheric pollution	Acid rain, acidified land and water runoff mobilizes heavy metals	Direct toxicity of mobilized metals and acidity
	Dioxins from industry/waste incineration	Accumulation in food chains with impacts on reproduction and performance of wild relatives; Accumulation in fish used for fishmeal
Radioactive waste	Radionuclide release from reprocessing or irresponsible disposal. Typically a point source impact, but may promulgate through the food chain in the case of extended or large-scale release	Accumulation of radionuclides in wild relatives; Accumulation of radionuclides in prey organisms

In all cases where countries indicated a solution, the response was the establishment of effective regulatory regimes to address pollution and its environmental impacts. These range from legislation to the establishment of water monitoring systems and environmental regulatory bodies. Water purification (of urban and industrial discharges) was noted as an important step and the use of bioremediation was also noted by some countries.

3.2.3 Direct and indirect climate change impacts

3.2.3.1 Direct impacts of climate change

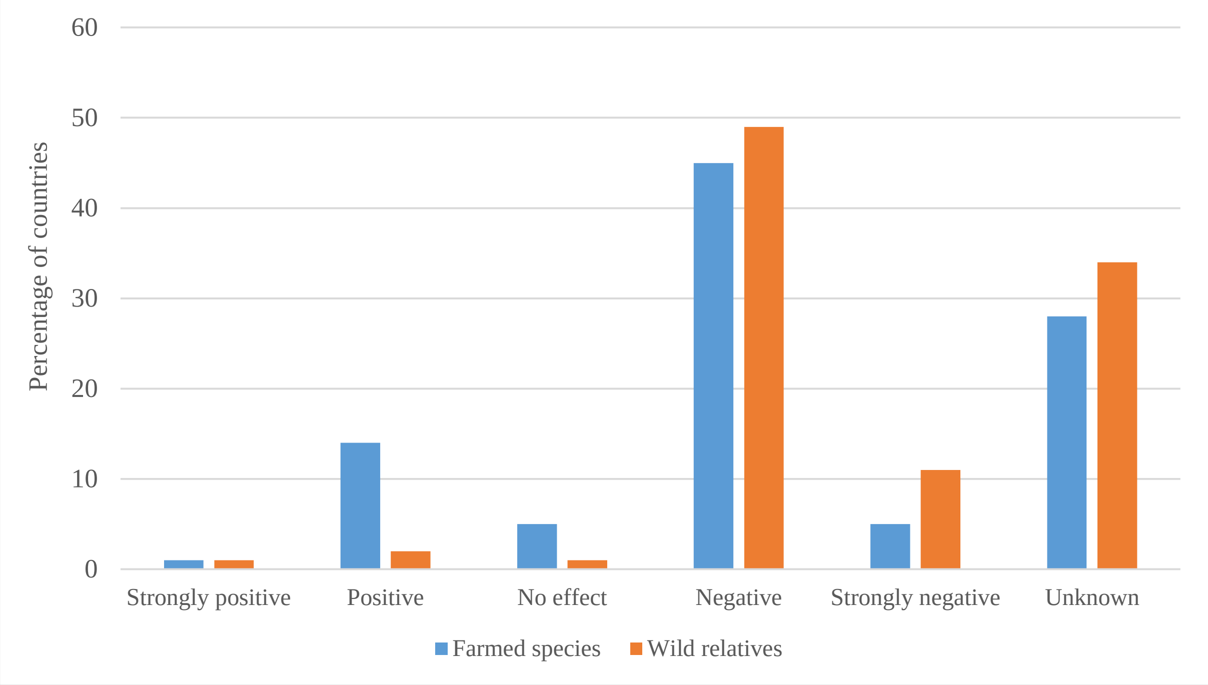
Climate change has implications for aquaculture, especially in the warm tropics where species may be already cultured at the upper end of their temperature tolerance range.

Fifty percent of respondent countries indicated that climate change would have a negative or strongly negative impact on farmed type genetic resources; most of these countries believed this was likely to be a strongly negative impact (Figure 56). Potential impacts included:

- increased sea temperatures affecting grow-out (e.g. Finland; bivalves in Australia and Chile);
- increased incidence of stress and disease mainly as a result of temperature rise, but also changes in water availability and water quality (Bangladesh, Canada, Guatemala, Honduras, Malaysia, Morocco, the Philippines);
- water shortages drying out ponds or reservoirs impacting production or choice of broodstock for the next crop (Colombia, Malawi, Nigeria, Sri Lanka, Uganda, Zambia);
- water levels in reservoirs reduced to the anoxic "dead zone" with water quality issues and temperature rises (Cuba, Ghana);
- delayed rains and seasonal shifts affect grow-out season, deteriorate water quality and increase disease outbreaks (Venezuela, Bolivarian Republic of);
- combination of high temperature and increased salinity impacting brackish-water culture (Costa Rica);
- temperature and seasonal impacts on reproductive capacity with impacts on hatchery production (Benin, Lao People's Democratic Republic);
- establishment of invasive species in areas that were previously too cold (e.g. grass carp and common carp in Sweden; *Hypostomus plecostomus* in Guatemala);
- extreme weather events impacting aquaculture facilities (Viet Nam);
- increased flooding events affecting water quality (Belize, Benin, Sri Lanka) or impacting production facilities (United Republic of Tanzania); and
- abandonment of aquaculture due to low productivity (Senegal).

There was also a reasonably high degree of uncertainty regarding the impacts of climate change on farmed types (28%). The country responses indicated that this was largely due to lack of scientific information and consequent uncertainty over how changes in climate driven factors (particularly temperature rise) would affect aquaculture species.

Figure 56
Direct effects of climate change on aquatic genetic resources of farmed species and their wild relatives



In terms of positive effects, only 15 percent of respondents believed that there would be a positive or strongly positive effect on farmed types. In Hungary, positive climate impacts were related to slightly elevated temperatures giving better growth rates in temperate water aquaculture. In Iran (Islamic Republic of), it was considered that increased salinity opens opportunities for cultivation of marine species in lagoons and coastal areas.

There may be other opportunities for expansion of warm water systems into areas which were hitherto slightly too cold for some species. The development of cold tolerant, warm-water species is already established (e.g. tilapia hybrids), and selection for salinity tolerance (e.g. where there are threats of saline intrusion) and transgenic approaches have greatly increased growth rates in some cold-water species (transgenic salmon). In terms of wild relatives, higher water temperatures may extend the range of native species within large continental rivers and along coasts.

Many respondents (60%) considered there would be negative effects on wild relatives (Figure 56), generally driven by the ecosystem impacts, such as:

- higher sea temperatures impacting ecosystems and reefs (Australia) (e.g. Box 9);
- shifting species distribution because of temperature or salinity changes, or inability to shift because of geographical features (e.g. bays, lagoons, gulfs), results in loss of stocks (China, Costa Rica, Dominican Republic); similar impacts on distributions because of temperature are observed in freshwaters (Germany);
- physiological impacts on reproductive capacity (Mexico);
- loss of species (Burkina Faso, Cabo Verde, Cameroon, Togo);
- effects caused by changing environmental cues for migration, breeding and spawning (Brazil, Colombia, Malawi);
- increased stress leading to disease problems (Zambia);

- acidification impacts on estuarine and marine shellfish (Canada, Honduras, the United States of America); and
- drying of dry season refuges and breeding areas (Malawi, Nigeria, Uganda).

Thirty-four percent of responding countries reported that the impacts were unknown. This was related to an inadequate understanding of how climate change would impact the complex interactions between ecosystems, wild relatives and their predators/prey, as well as reproduction and other physiological mechanisms. This level of uncertainty suggests a need for improved understanding of climate driven impacts on wild relatives.

Box 9
The potential effect of climate change on wild relatives: the case of Australian abalone

In February/March 2011, a catastrophic "marine heatwave" event occurred off the southwestern coast of Western Australia. During that time, sea surface temperatures rose more than 3 °C above long-term monthly averages, with these averages exceeded by 5 °C in some locations at its peak. This heatwave coincided with a strong La Niña event and a record strength of local currents. This was regarded by experts as a major temperature anomaly superimposed over a trend of long-term ocean warming. Such events may become more common as global warming progresses (Pearce *et al.*, 2011). During this event, significant changes in population numbers were recorded for a number of important seafood species (Caputi *et al.*, 2015), but perhaps the most dramatic was that for Roe's abalone (*Haliotis roei*) for which there are important commercial and recreational fisheries (120–150 tonnes per annum). This species suffered mortality rates of up to 99.8 percent in the northern part of the fishery, which represents the northern limit of the distribution of the species.

As a result of the heatwave, the fisheries for the hardest hit species in Western Australia were closed, and it was debatable whether the species could ever recover in these locations (Hart, 2015). Plans were made to promote recovery through translocation of surviving stock, but prior to initiating such events, it was necessary to characterize and understand the genetic structure of stocks. Next generation sequencing was used to develop over 30 000 single nucleotide polymorphism (SNP) markers for the species (Sandoval-Castillo *et al.*, 2015). This resource can be used for a range of applications, including association studies to identify traits underpinning performance in aquaculture and restocking, adaptation of populations to temperature changes, and to determine how both natural selection and domestication selection influence the ability of populations to maintain genetic diversity and to respond to changing conditions. The screening of variation in samples collected from the wild show that "neutral" SNPs (i.e. DNA markers that are not under the influence of natural selection) support the existence of a single, highly connected population across the range sampled. However, when SNP markers under natural selection (i.e. non-neutral markers) were sampled, three genetically distinct groups of populations were identified. Analysis of levels of genetic variation in the remnant populations did not reveal significant loss of genetic variation yet, but this would seem likely in the longer term due to the severe genetic bottlenecks (Sandoval-Castillo *et al.*, 2015).

In the most severely impacted parts of the fishery, the remnant populations are either unlikely to recover or may recover slowly. Information from the genetic studies can inform the likely genetic implications of translocation or restocking (i.e. from hatchery-produced stock) and help identify appropriate source populations. The markers could also potentially be used to identify genotypes that may be more resistant to future heatwave events. Without such intervention, the most likely future scenario is a shifting of production of this species eastward (Hart, 2015).

The only positive considerations of climate change on wild relatives concerned the pressure to develop aquaculture stocks of those species that were disappearing from wild catches. In one case, climate change was perceived as an opportunity to expand the range of brackish-water species in delta areas or for expansion of species that prefer warmer waters.

3.2.3.2 Indirect impacts of climate change through effects on ecosystems

The indirect effects of climate change are those that arise from changes to aquatic ecosystems that have consequent impacts on AqGR. These drivers are the increased frequency of extreme climatic events and long-term climate change. Sixty percent of respondents considered that the indirect effects of climate

change through its impacts on ecosystems would be negative (Figure 57). There was a relatively high level of uncertainty regarding impacts (33%). Notably, there is a need to assess anthropogenic and environmental factors affecting aquatic ecosystems. The implications of climate change for fisheries and aquaculture should strongly emphasize the ecological and economic resilience of fisheries and aquaculture operations for developing an effective and flexible fisheries management system in an ecosystem context.

Many of the identified impacts concerned terrestrial and freshwater ecosystems and coastal environments, with correspondingly less concern regarding marine systems. The impacts were typically related to the effects on wild relatives, but also included culture systems (farmed types) in some instances. General ecosystem-level changes affect water availability, hydrological regimes and habitat. This has a variety of knock-on effects to AqGR (Bangladesh, Benin, Brazil, Chile, the Democratic Republic of the Congo, Ecuador, Egypt, Honduras, Kazakhstan, Kenya, Panama), particularly to wild relatives. Impacts on ecosystems such as forests and grazing lands contribute to erosion, soil degradation and consequent impacts on water (Chad).

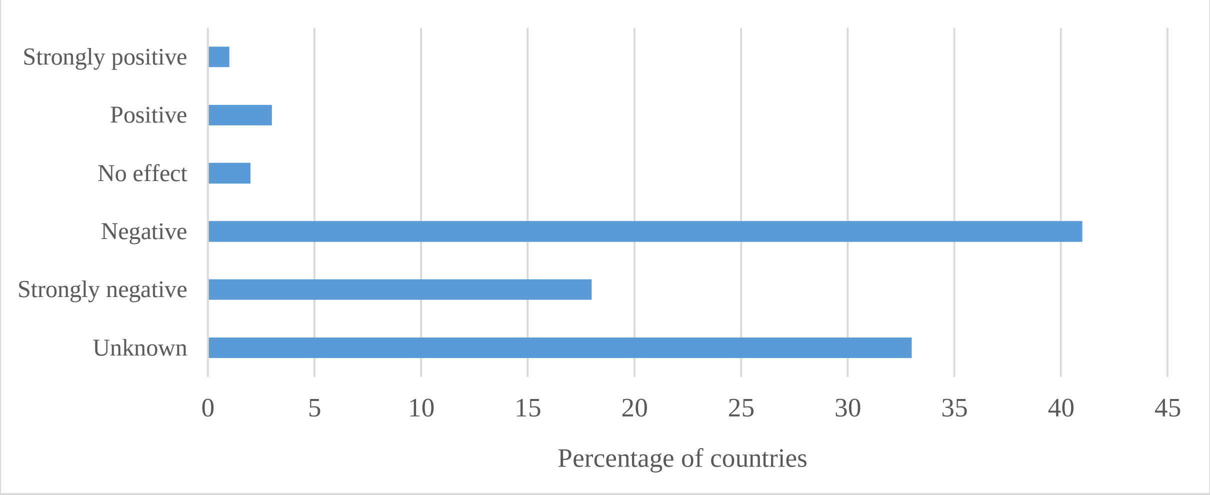
The most commonly identified threat was related to unseasonal or extreme weather conditions. Heavy rainfall leading to flash flooding was an identified threat. This can cause farmed type stocks to be washed out into the wild and increases the risk of escapes. Adaptation measures identified by respondents related to improving the biosecurity of flood-prone aquaculture (pond and cage) as an important regulatory and management measure to be introduced. Unseasonal rainfall and flooding (Cuba, Nigeria, Sri Lanka, the United Republic of Tanzania) can lead to flash flooding. This damages infrastructure but also impacts water quality. Several countries indicated that the restoration of forests and riparian vegetation was an important strategy to reduce flash flooding and erosion.

The converse of flooding is extended drought periods and unseasonal drying out of waterbodies. Reduced water availability in rivers (Belize, Costa Rica, Dominican Republic, Hungary, Kenya) affects wild relatives and the availability of water for aquaculture. This loss of water area and/or habitat can have serious consequences on wild relatives, as well as on aquaculture operations that are based in waterbodies or dependent upon river flows for water. An extreme or unpredictable environment would drive aquaculture operations to be more self-contained, (e.g. recirculating, oxygenated and fed systems) with minimal contact with the environment.

Together with temperature-adapted species, the adjustment of stocking and harvesting cycles was proposed as a way to work around problems related to changing and less reliable seasonal weather. More efficient production systems that conserved freshwater were another measure for adaptation. Stocking programmes to mitigate loss of recruitment are another adaptation measure being considered for some large waterbodies.

Sea level rise and reduced freshwater flows in rivers result in seawater intrusion in delta areas (e.g. Mekong Delta in Viet Nam). Despite this being seen as a negative impact, it will drive interest for developing salt-tolerant farmed types. It will also extend the range of brackish-water species in delta areas. In the coastal zone, mangrove reforestation was indicated as a strategy, presumably to improve coastal protection, but also to restore coastal habitats.

Figure 57
Indirect effects of climate change on aquatic genetic resources through impacts on aquatic ecosystems



Water temperature rise will enable species to extend their ranges in temperate areas and encourage the establishment of invasive species. Warming temperatures also increase the range of some non-native species and support their establishment. For example, the common carp and Chinese grass carp have become established in the wild in Sweden. This could be viewed as a negative impact on indigenous ecosystems. Warming can also lead to competition between indigenous species, as in the case of brown trout being displaced by common carp in Hungary.

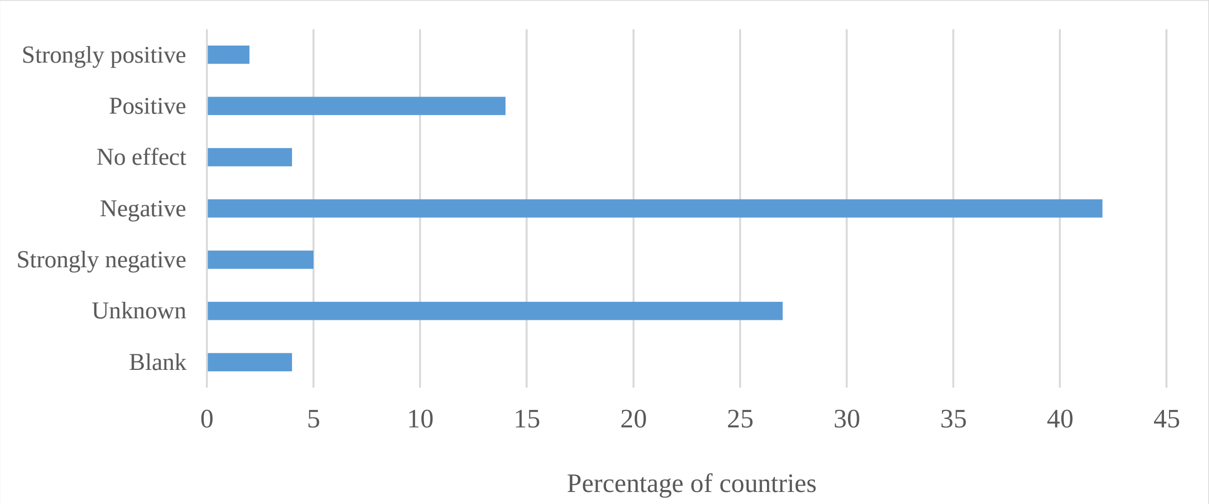
A major indirect impact of climate change is the modification or loss of habitat (the Republic of Korea), particularly in floodplain and wetland systems (Burkina Faso, Cameroon, Chad, Romania) and mangroves and mudflats (Ghana, Senegal), which can affect wild relatives. This occurs in both freshwater and brackish-water ecosystems, with declining water coverage in waterbodies or drying out of wetlands.

Climate change can affect both temperate and tropical marine environments. Such impacts include coral bleaching, mass mortalities and shifts in the distribution of species. Temperature changes can also increase the potential for the establishment of invasive species (from shipping ballast water for example).

3.2.4 Impacts of purposeful stocking and escapees from aquaculture

Just under half of country responses (47%) indicated negative impacts on wild relatives due to ecosystem impacts from purposeful stocking and escapees from aquaculture (Figure 58). These responses were mostly related to the genetic issues of poorly managed stocking programmes and negative interactions of aquaculture stock with wild relatives. These negative interactions are both genetic (e.g. interbreeding of escaped farmed types with wild relatives) and ecosystem-type impacts (e.g. predation, competition for resources and space, transmission of disease), as described in the section below on invasive species.

Figure 58
Impacts of purposeful stocking and escapees from aquaculture on aquatic genetic resources of wild relatives of farmed aquatic species



Twenty-seven percent of countries responded that there were unknown effects regarding the impact of this driver on aquatic ecosystems of relevance for wild relatives of farmed aquatic species. This highlights the existing knowledge gap regarding the scientific assessment of negative and/or positive effects (pathogen-related, socio-economic, environmental, ecological and genetic effects) of purposeful stocking and escapees from aquaculture in natural aquatic environments. Further research is important, given that the stocking of open waters is considered a mitigation of impacts on fisheries or a fishery enhancement strategy in a number of countries.

Sixteen percent of countries considered there were positive impacts of purposeful stocking and escapees on wild relatives; these responses were largely based on the perceived positive impacts of culture-based fisheries and stocking to establish capture fisheries and species recovery programmes. Stocking programmes are rarely objectively evaluated (Cowx, Funge-Smith and Lymer, 2015). Few countries (4%) considered there to be no impacts.

The variability in the country responses is partly due to the combination of purposeful introduction and aquaculture escapees (which are typically an accidental event). This inevitably results in a range of responses from countries, which consider culture-based fishery and fishery enhancements as largely positive (or having no overall impacts), versus those countries which had experiences of aquaculture escapees which they consider to be a negative impact. It is not possible to disaggregate clearly between these two issues. Future questionnaires will need to treat these two issues separately.

The extent of the movement of aquatic species between countries and regions is not well documented. FAO has developed a Database on Introductions of Aquatic Species (DIAS), which is now in need of updating to support a strengthened understanding of the extent and impacts of introduced species on AqGR (Box 10).

Box 10

The useful information contained in the FAO Database on Introductions of Aquatic Species (DIAS)

The FAO Database on Introductions of Aquatic Species (DIAS) was initiated in the early 1980s. Initially, it considered primarily freshwater species and formed the basis for a FAO Fisheries Technical Paper (Welcomme, 1988). Today, DIAS has been expanded to include additional taxa, such as molluscs and crustaceans, and marine species. In the mid-1990s, a questionnaire was sent to national experts to gather additional information on introductions and transfers of aquatic species in their countries.

While including records of species introduced or transferred from one country to another, DIAS does not consider movements of species inside the same country. The database contains more than 5 500 records of aquatic species introductions, which include information such as the common and scientific name of the introduced species and the countries of origin and destination. Additional information, such as the date of introduction, the introducer, reasons for introduction, and detailed introduction features (status of the introduced species in the wild, establishment strategy, aquaculture use, reproduction features, ecological and socio-economic effects, etc.) are also available for a certain number of records.

DIAS can be used to investigate the various purposes for introduction and their subsequent outcomes. Comparisons can be made between beneficial and adverse impacts of introductions. This can be further broken down into the purpose of the introduction (including accidental introductions) and the pathway of that introduction. There is also information on the donor and recipient countries.

This database is now in need of considerable updating, as the extent of movements has accelerated with the boom in aquaculture around the world and the increasing diversity of species farmed. Though this is perhaps most notable in Asia, transcontinental movements have also been increasing.

3.2.4.1 Impacts of purposeful stocking

Formal stocking programmes are generally recognized as an important tool to compensate for declines in fishery production due to reduced recruitment and loss of fish species diversity. While stocking programmes are widely implemented in many countries across a variety of aquatic habitats, they are predominantly seen in inland waters. The major exceptions are salmon stocking and ranching (e.g. Japan).

In developing countries, the objective of stocking is typically related to improved food security and to increase the supply of protein for human consumption. Since most inland water systems have now reached their maximum potential natural production, rising demand for fisheries products is now pushing fisheries managers to increase yields through stock enhancement. In many countries, this process is advanced and the infrastructure has been developed to provide the required amount of fingerlings for stocking.

Developed countries may place less emphasis on stocking programmes for fish for human consumption; instead, stocking is often implemented (either through private or government funding) to sustain recreational fisheries or as part of conservation initiatives (Table 34).

Table 34
Differing use and management strategies for inland water fisheries between developed temperate and developing tropical countries

	Developed temperate countries	Developing tropical countries
Objectives	Conservation Recreation	Provision of food Income/livelihoods
Management approaches	Recreational fisheries Habitat restoration Environmentally sound stocking Intensive, discrete, industrialized aquaculture	Food fisheries Habitat modification Enhancement through intensive stocking and management of ecosystem Extensive, integrated, rural aquaculture
Economic	Net consumer Capital intensive Profit	Net producer Labour intensive Production

Source: After Welcomme and Bartley, 1998a, 1998b.

There are five types of fishery enhancement systems that utilize AqGR (Lorenzen, Beveridge and Mangel, 2012). These are either aquaculture-related activities using farmed type or hatchery-produced individuals for release, or pursuing conservation or capture fishery objectives. In the latter case, these will be targeting stocks or wild relatives. Each of these systems has a different primary purpose and involves different management practices (Table 35).

Table 35
The five types of fishery enhancement system that involve stocking

Enhancement type	Primary purpose(s)
Culture-based fisheries and ranching	Increased fish production
	Creation of recreational fisheries
	Bio-manipulation
Stock enhancement	Sustaining and improving fisheries in the face of intensive exploitation
	Sustaining and improving fisheries in the face of habitat degradation
Restocking	Rebuilding depleted populations
Supplementation	Reducing extinction risk
	Conserving genetic diversity
Re-introduction	Re-establishing a locally extinct population

Source: From Lorenzen, Beveridge and Mangel, 2012.

If conditions are conducive and the enhancement measures are well designed, these enhancements can be effective in increasing fisheries yields for food or income, or as opportunities for recreational fishing and wider socio-economic benefits. In practice, many enhancements have been either ineffective or have caused demonstrable ecological damage (FAO, 2015).

In most cases, the need for introductions arises because of human activities. Many newly constructed reservoirs lack native species capable of fully colonizing lentic waters and there is interest in developing commercial fisheries through species introduction, for example:

- *Limnothrissa miodon* (Tanganyika sardine) introduced in Lake Kariba;
- *Neosalanx taihuensis* (Chinese icefish) introduced to many Chinese reservoirs;
- *Cyprinus carpio* (common carp) in Lake Naivasha and Tana River hydroelectric dams (Kenya);
- economic impact of the establishment of *Lates niloticus* (Nile perch) fishery in Lake Victoria (Uganda/Kenya); and
- *Oreochromis niloticus* and *O. mossambicus* (tilapia) in Sri Lankan freshwater irrigation tanks and reservoirs.

Much of the stocking that takes place in Asia can be more narrowly classified as culture-based fisheries. Culture-based fisheries and ranching systems are used to maintain stocks that do not recruit naturally, (i.e. they are not self-reproducing), and typically, the seed for stocking is derived from aquaculture hatcheries. Some of these culture-based systems are relatively closed, take place in human-made waterbodies or highly modified waterbodies, and thus can be considered an extensive form of aquaculture.

Recently, there have been increasing concerns about the potential risks associated with the stocking and introduction of fish, particularly with respect to ecosystem functioning, changes in community structure, and contamination of genetic structure of populations and stocks. Although the stocking and introduction of species may have had obvious benefits, they are not without cost, and the issue of introducing fish species is highly controversial.

Many stocking activities, both deliberate and accidental, have had negative effects on indigenous fish communities and other fauna through predation, competition, introduction of pathogens and change in ecosystem dynamics. The effects of hybridization, genetic contamination and reduction in biodiversity should be considered.

Of particular concern are shifts in food-web structure and trophic status that may occur, and the impacts that these could have on indigenous flora and fauna. In addition, stocking or introductions may lead to competition with, or predation on, indigenous biota (Hickley and Chare, 2004; van Zyll de Jong, Gibson and Cowx, 2004; Lorenzen, 2014). This can have serious implications for waterbodies that are part of designated conservation sites or support protected plant or animal species. These impacts are summarized in Table 36.

Table 36
Potential detrimental impacts associated with stocking activities in a hierarchy from species-specific to ecosystem-wide outcomes

Impact	Cause
Increased intraspecific competition	Increased abundance of the species by the addition of hatchery-reared fishes
Shifts in prey abundance	Change in the abundance of prey species due to increases in fish predator abundance as a result of stocking
Prey-switching by wild predators	Changes in the targeted prey of wild predatory species, usually to focus on hatchery reared (naïve) fishes due to large numbers released
Starvation/food limitation	Overstocking
Exceeding the carrying capacity of an ecosystem (swamping)	Continued stocking after recovery of a stock
Interspecific competition	Competition between hatchery-reared fish and other species with similar ecological requirements. May lead to a reduction in abundance of competing species and prey species.
Displacement of wild stock	Displacement by hatchery-reared conspecifics, although there are no well-documented examples
Introduction of diseases and parasites	Poor hatchery management and husbandry of fish to be stocked
Changes in or loss of genetic structure	Lack of knowledge on, or lack of attention to, the genetic structure of wild populations when stocking can result in changes to the genetic structure of populations and even the breakdown of population structure, which can impact the adaptive fitness of these stocks.
Loss of genetic diversity and fitness	Lack of genetic management of broodstock within the production system of the fish to be stocked is common. In poorly designed stocking programmes certain alleles of wild fish may become rare or lost due to the release of hatchery-reared fish with a low genetic diversity. This is of higher risk where the wild stock is reduced to low levels prior to stocking. This can result in genetic bottleneck effects and loss of adaptive fitness.
Extinctions	The loss of species due to increase in the abundance of released fish and ecosystem shifts
Ecosystem shifts	Shifts in the distribution of biomasses or other species, possibly resulting in the loss of other ecosystem values

Source: Adapted from FAO, 2015.

A major weakness of many stocking programmes is the failure to evaluate fully the outcomes of the activity or limiting the evaluation of their effectiveness, in terms of benefits as well as adverse impacts (FAO, 2015). An example of good practice in this regard is presented in Box 11.

Box 11

Case example of the value of effectively assessing national aquatic genetic resources to inform stocking initiatives

It is important to have adequate knowledge of specific genetic features and characteristics in order to protect genetically independent populations from the harmful effects of stocking and resettlement measures. In this regard, the Federal Ministry of Food and Agriculture of Germany (BMEL) is currently engaged in a pilot project for the molecular genetic documentation of genetic management units of crayfish, brown trout, lake trout, sea trout, barbel, burbot, grayling and tench. The knowledge gained during this project is to be incorporated into practical recommendations for the stock management of these species. The triple aim is to respect the genetic diversity across the entire distribution area of a species at the population level, to preserve such species as "evolutionary entities" with their regional genetic and phenotypical characteristics, and to secure their stocks in the long term. This not only serves the purpose of species protection, but also promotes fish stocks that are regionally well adapted to prevailing conditions. This information will also be made available in the Aquatic Genetic Resources Deutschland (AGRDEU) database for those active in the fish-related management of bodies of water.

3.2.4.2 Purposeful stocking in recreational fisheries

Recreational fishing has traditionally been a developed country activity, but it is becoming more popular in developing countries. Recreational fisheries are also engaged in the stocking of open waters and rivers to enhance recreational fisheries (e.g. for trout, salmon) using material from aquaculture hatcheries. This may have some impact on interactions between wild relatives and the cultured farmed type. Some recreational fisheries introduce and translocate species. In some cases, non-native species are introduced for recreational fishing. Examples include:

- Latin American species such as pacu (*Colossoma macropomum*), *Arapaima* and red-tail catfish (*Phractocephalus hemioliopterus*) have been introduced to Asia;
- North American species such as rainbow trout (*Oncorhynchus mykiss*) and black bass (*Micropterus* sp.) introduced to Europe; and
- the movement of the European (Wels) catfish (*Silurus glanis*) has resulted in its subsequent establishment beyond its natural range within Europe.

3.2.4.3 Impact of escapees from aquaculture

Escapees from aquaculture have a range of potential impacts on AqGR, particularly with respect to wild relatives, although there are also threats to farmed types. Farmed types can escape from aquaculture operations in a number of ways, which influences the number of escapees and their consequent impact in the wild. Pathways for escapees are as follows:

- flooding of aquaculture ponds releasing fish into nearby waterways (this can result in massive releases, e.g. flooding of coastal shrimp farms);
- escape of farmed types during harvesting operations (usually relatively small numbers as farms take precautions not to lose stock);
- loss of larger numbers during emergency harvest or "dumping" of diseased stock;
- storm/cyclone damage to cages in the sea or freshwater bodies (can be considerable where cages are artisanal, poorly constructed and present in large densities);
- net damage in cages;
- deliberate dumping of fish (aquarium species) into waterways; and
- movement by predatory birds and travel across land can occur, but is limited to small numbers. It is a factor in horizontal disease transmission between farms.

Aquaculture species that escape and become established can reduce and disturb the natural biodiversity

and native AqGR (Diana, 2009; Krishnakumar *et al*., 2011; Nunes *et al*., 2015), which can affect ecosystem functions and integrity. The range of threats that these escapees present is summarized in Table 37.

Table 37
The range of threats presented by aquaculture escapees on aquatic genetic resources of wild relatives and farmed types

Affected	Nature of impact
Wild relatives	Genetic introgression because of genetically changed farmed types breeding with wild relatives. Note that this has been shown in the case of large-scale purposeful stocking, e.g. wild Thai silver barb (*Puntius gonionotus*) in Thailand (Kamonrat, 1996), and arguably in the case of escaped Atlantic salmon (*Salmo salar*), but there are few other clearly demonstrated examples of this resulting from farm escapees.
	Transmission of disease/parasites to wild relatives.
	Establishment in the wild (invasion). Establishment of escaped farmed types can compete with indigenous fauna.
	Maladapted farmed types breed with wild relatives. Typical maladaptations in farmed types include selection for precocious breeding or out-of-season breeding (selection for early spawning or later migration). Less obvious maladaptation for the wild may include less aggressive behaviour. Some of these maladaptations may limit the success of the escapee from successful breeding with wild relatives.
Farmed types	Transmission of disease or parasites between aquaculture farms.
	Establishment of naturalized fisheries that compete with farmed types in the market.

3.2.4.4 Escapees from the aquarium trade

While escapees from the aquarium trade are often limited to individuals and thus the risks of their becoming established are relatively low, the widespread movement of AqGR for the aquarium trade means that species are moved well beyond their natural range. Significant threats are often associated with escapees from breeding and holding operations. This emphasizes the importance of effective regulation and monitoring of such operations and ensuring that they have adequate biosecurity controls in place. Urban-based breeding facilities are relatively lower risk, but open pond-based systems or riparian operations in peri-urban or rural areas may be vulnerable to flooding or other risks of escape; it is from this type of operation that escapees are more likely to become established in open waters.

One example of a significant impact from an escape from the aquarium trade is the establishment of lion fish *Pterois volitans* and *Pterois miles* that have become established throughout the Western Atlantic and the Caribbean seas. These species are believed to have escaped from aquarium or related facilities during late 1980 to 1990s, and to be responsible for declines of native fish in the region (Ballew *et al*., 2016; Green *et al*., 2012).

3.2.5 Establishment of invasive species

There are numerous examples of non-native species that have become established accidentally or deliberately beyond their natural range. Some of these introductions have resulted in adverse environment and economic impacts, i.e. the introduced species became invasive or introduced pathogens. Well-known cases which illustrate the potential negative impacts of invasive species include Nile perch (*Lates niloticus*) in Lake Victoria, Africa (Ogutu-Ohwayo, 2001), salmonids in Chile (Consuegra *et al*., 2011), Nile tilapia (*Oreochromis niloticus*) in the Mississippi River in the United States of America (Peterson, Slack and Woodley, 2005), and common carp in the Murray River in Australia (Koehn, 2004).

Despite these invasions with established negative impacts, the majority of introductions recorded in DIAS had many more positive social and economic impacts than negative environmental impacts

(Bartley and Casal, 1998).

The FAO Database on Introduced Aquatic Species provides lists of known introductions according to purpose:

- accidental introduction
- aquaculture
- ornamental
- angling/recreational fishing
- biological control

Not all introductions result in the establishment of the species. The Global Invasive Species Database (GISD, 2016) recognizes 129 invasive species of freshwater, marine and brackish-water ecosystems (Table 38).

Table 38
Global Invasive Species Database list of invasive species of freshwater, brackish water and marine ecosystems

Taxon	Number of species	Taxon	Number of species
Finfish species	51	Ctenophora	3
Aquatic plants	17	Brachiopods	2
Bivalve molluscs	17	Echinoderms	2
Gastropod molluscs	12	Calanoids	1
Decapod crustaceans	6	Amphibians	1
Ascidians	6	Sponges	1
Ectoprocta	4	Myxosporea (*Myxobolus cerebralis*)	1
Polychaete worms	3	Fungi (*Aphanomyces astaci*)	1
Cnidarians	3		

Source: GISD, 2016.

An example of an assessment of the number of species that have been introduced or moved beyond their natural range within a country are the lists of 759 fish species in the United States of America, maintained by the United States Geological Survey (USGS, 2016).

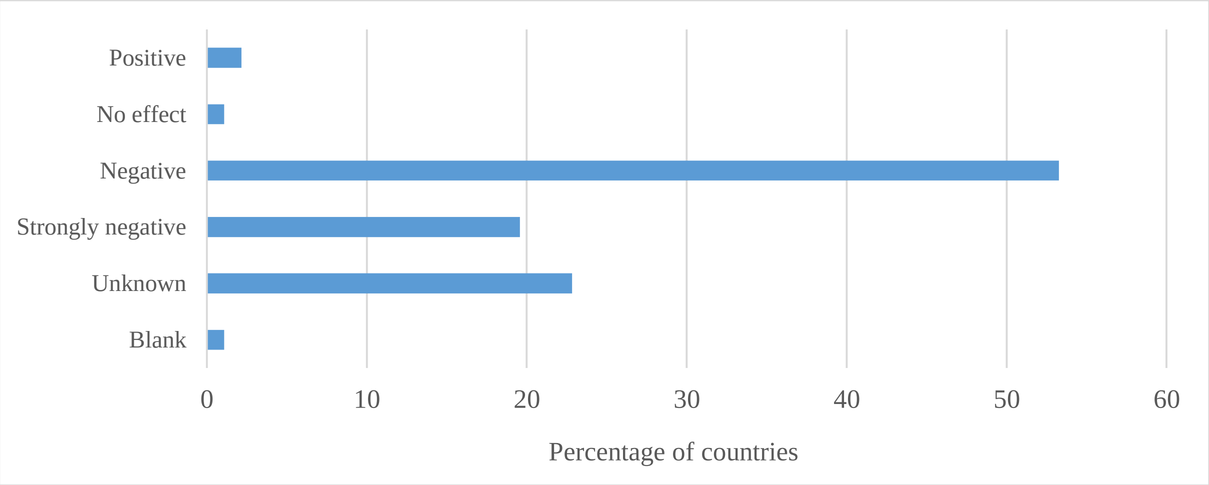
The impact of non-native species on an ecosystem may range from undetectable to major. Major impacts include ecosystem changes such as effects on their prey or changes to food chain linkages. Sometimes, the impact is not directly apparent, and the species is simply regarded as an unwanted species, less preferred than other similar native species. Examples of the types of impacts are presented in Table 39.

Table 39
Examples of impacts of non-native species on ecosystems and aquatic genetic resources of wild relatives and farmed types

Introduction of disease	• Introductions can host pathogens/parasites which impact native or non-native species
Effect on food webs	• Direct predation on native species • Predation of eggs of native species • Transmission of parasites/disease to both wild and farmed types • Predation on prey species (e.g. insects, zooplankton) of native fish
Competition	• Higher fecundity than native species • Greater tolerance for adverse environmental conditions • Exclude native species from breeding areas or disruption of breeding areas • Compete for matings
Engineer ecosystems, undesirable behaviour or characteristics	• Burrowing behaviour into river banks, affecting stability, etc. • Increase turbidity • Removal of vegetation • Crowding out of native species • Clogging of aquatic habitats impacting flow – e.g. water hyacinth (*Eichhornia crassipes*) or benthic habitat (zebra mussel, *Dreissena polymorpha*)

Seventy-three percent of countries considered that the establishment of invasive species had a negative impact on AqGR, with only 2 percent reporting positive effects (Figure 59). This echoes the finding, as reported by 47 percent of countries, that purposeful stocking and escapees from aquaculture (as source of invasive species) was a negative impact, with only 16 percent reporting a positive impact (Figure 58). The establishment of invasive species in the wild is clearly viewed in the same way. In many developing countries, there is a low level of awareness regarding the threat to aquaculture and wild AqGR from invasive species and transfer of aquatic pathogens through movements and introductions.

Figure 59
Effect of establishment of invasive species on the aquatic genetic resources of wild relatives of farmed aquatic species



As it is extremely difficult, if not impossible, to eradicate introduced species that become invasive, the best protection is prevention. Prevention may include more effective biosecurity measures and regulation on translocations (Box 12). There is also a need to limit or prevent further movement within a country once a species has become established. This is a clear area where there is a strong justification for more effective and comprehensive monitoring of AqGR in general and invasive species in particular (Germany, the Republic of Korea).

Box 12

Impact of invasive mussels on local genetic diversity

Marine mussels are among some of the more successful invasive marine species, and there are numerous records of non-native species successfully colonizing coastal areas, even across continents. There are a number of studies that have assessed the impacts of these invasions on genetic diversity of both the invasive and endemic species.

One of the impacts of the invasive species can be introgression with local species, as has been documented in California. Here the Mediterranean mussel (*Mytilus galloprovincialis*) was introduced through anthropogenic influences and has been present at least several decades, establishing extensive populations in the wild. In some locations, these have displaced the native *Mytilus trossulus*. There are incomplete reproductive barriers between *Mytilus* species. Saarman and Pogson (2015) studied the introgression of the two species across several hybrid zones, where both species occurred, using next generation DNA sequencing (ddRADseq). They identified that, despite the known reproductive barriers, introgression was occurring between the species in these hybrid zones. Heterogeneous patterns of introgression across the zones were consistent with the colonization history of *M. galloprovincialis*. Relatively few early and advanced backcrossed individuals were observed across the hybrid zone, confirming the presence of strong barriers to interbreeding. The authors concluded that the threat posed by invasive *M. galloprovincialis* is more ecological than genetic considering the displacement of the native *M. trossulus* from much of central and southern California.

Genetic technologies can be used to inform and understand the nature and extent of invasions. South Africa has a number of invasive species of mussels, although *M. galloprovincialis* is the only invader to have extensively colonized parts of the South African coast. Micklem *et al.* (2016) used mitochondrial DNA (mtDNA) analysis to identify a single population of the invasive Asian green mussel (*Perna viridis*) in Durban Harbour, with the phylogenetic technique capable of distinguishing it from the phenotypically similar indigenous *P. perna*. Zeeman (2016) used the same technique to analyse the origins of invasive mussels on the West Coast of South Africa, confirming the presence of *Semimytilus algosus* and suggesting that the indirect origin of the introduction was from Chile by way of a natural spread from the introduction to Namibia.

Countries also indicated the impacts of non-fish species, which affect ecosystems or directly predate fish. Examples include invasive bird species that predate fish and have impacts on wild AqGR (e.g. cormorant, *Phalacrocorax carbo sinensis*, in Czechia). Mitigation would involve elimination of these invasive fish predators. Water hyacinth (*Eichhornia crassipes*) is a major pest species of waterways and waterbodies (Ghana).

In several Country Reports, there was a consistent theme regarding the need to develop national guidelines for transfers and introductions of AqGR, and establishment of more effective import risk analysis (risk assessment, risk management and risk communication strategies) for potential invasive species and health threats (Kenya, Thailand, Viet Nam). International guidelines and reports of risk assessment on the use of non-native species do exist, indicating a lack of awareness in countries. For example, the ICES code of practice (ICES, 2008) on introductions has been adopted in principle by FAO's inland regional fisheries bodies (see Bartley and Halwart, 2006).

An example where regulations already exist is the European Union regulation (REG (EC) No. 708/2007) concerning the use of alien and locally absent species in aquaculture. This contains relatively strict provisions for the avoidance of risks associated with the use of alien species in aquaculture (e.g. fauna falsification and the introduction of diseases and parasites).

There have been various efforts to develop economic uses for established introduced species. This is partly to provide an economic incentive for their collection/removal from the wild. Examples include:

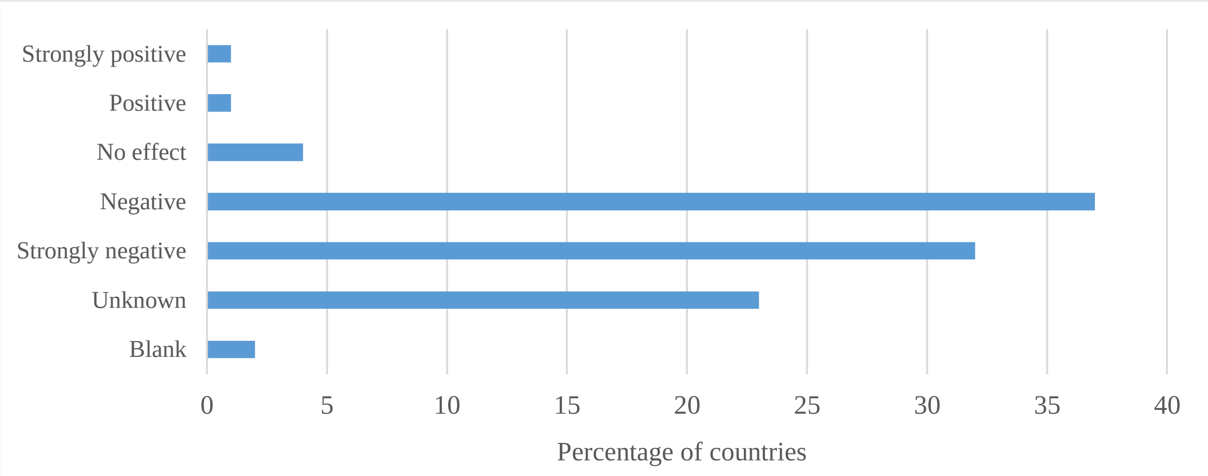
- harvest of introduced species for reduction into fishmeal: e.g. silver carp (*Hypophthalmichthys molitrix*) in the United States of America and knifefish (*Chitala* sp.) in the Philippines; and
- harvest and direct use as fish or livestock feeds: e.g. golden apple snail (*Pomacea canaliculata*) in the Philippines and Bangladesh.

3.2.6 Introductions of parasites and pathogens

A majority (69%) of the surveyed countries reported a negative or strongly negative effect of introductions of pathogens and parasites in aquatic ecosystems of relevance for wild relatives of farmed aquatic species. Twenty-three percent indicated an unknown effect for this driver, indicating that a knowledge gap persists regarding the impacts of pathogens and parasite introductions.

Accidental or purposeful introductions and transfers of aquatic species have been the main sources of pathogen and parasite introductions, together with other minor reasons such as ballast water and migrations. Only 2 percent of countries believed the impacts were positive (Figure 60).

Figure 60
Effect of introduction of parasites and pathogens on the aquatic genetic resources of wild relatives of farmed aquatic species



Species transferred between regions for aquaculture purposes have also resulted in the introduction of diseases, which have severely affected aquaculture production or stocks of wild relatives. Examples include:

- The noble crayfish (*Astacus astacus*), which was decimated in the wild due to crayfish plague (*Aphanomyces astaci*), spread via introduction of the signal crayfish (*Pacifastacus leniusculus*) (Alderman, 1996; Söderhäll and Cerenius, 1999; Edgerton *et al*., 2002).
- The spread of *Bonamia* parasites through European oyster stocks caused by the movement of non-native oysters in Europe, which were resistant to the disease (Corbeil and Berthe, 2009).
- The spread of penaeid shrimp diseases, which has resulted in massive losses of production periodically since the start of shrimp culture. This has largely occurred through the large-scale translocations of post-larvae or new species for aquaculture. These include the following diseases: Taura syndrome virus; white spot syndrome virus; infectious hypodermal and hematopoietic necrosis virus; yellow-head virus disease; and acute hepatopancreatic necrosis syndrome (Lightner, 1999; Tran *et al.*, 2013).
- *Streptococcus* in tilapia, and possibly a recently discovered virus in tilapia (Amal and Zamri-Saad, 2011; Surachetpong *et al*., 2017).
- The swim bladder worm (*Anguillicola crassus*) in eels introduced in the 1980s, which constitutes a serious threat to indigenous stocks of eel in Europe. Asian eels are tolerant to the disease, but Dutch analyses show that problems with the spawning migration of the European eel can occur if the infestation is serious enough (Székely *et al*., 2009; Lefebvre *et al*., 2012).
- Various carp viruses, which have been transferred through movements of fish for aquaculture as well as for the aquarium trade (e.g. koi herpes virus, carp edema virus) (Adamek *et al*., 2018; OIE, 2018).
- Transmission of various parasites and diseases, which have affected the cultured salmon industry and wild relatives, in some cases due to interactions (bidirectional) between the two:

infectious salmon anaemia and pancreas disease, furunculosis, *Gyrodactylus salaris* (Bakke and Harris, 1998; Olivier, 2002; Pettersen *et al*., 2015).

- Viral hemorrhagic septicemia, infectious haematopoietic necrosis and whirling disease in salmonids (Warren, 1983; Bartholomew and Reno, 2002; Dixon *et al*., 2016).
- The introduction of epizootic ulcerative syndrome to a number of countries has affected indigenous fish species (e.g. *Puntius* spp., *Channa* spp., *Clarias* spp., *Mastacembelus* spp.) (Kamilya and Baruah, 2014).

Management and controls to prevent or minimize impacts of spread of aquatic pathogens are similar to those which would be applied to introductions and movements of aquatic species. This is because the spread of invasive species and introduction of aquatic pathogens require similar procedures of monitoring, risk analysis and border controls.

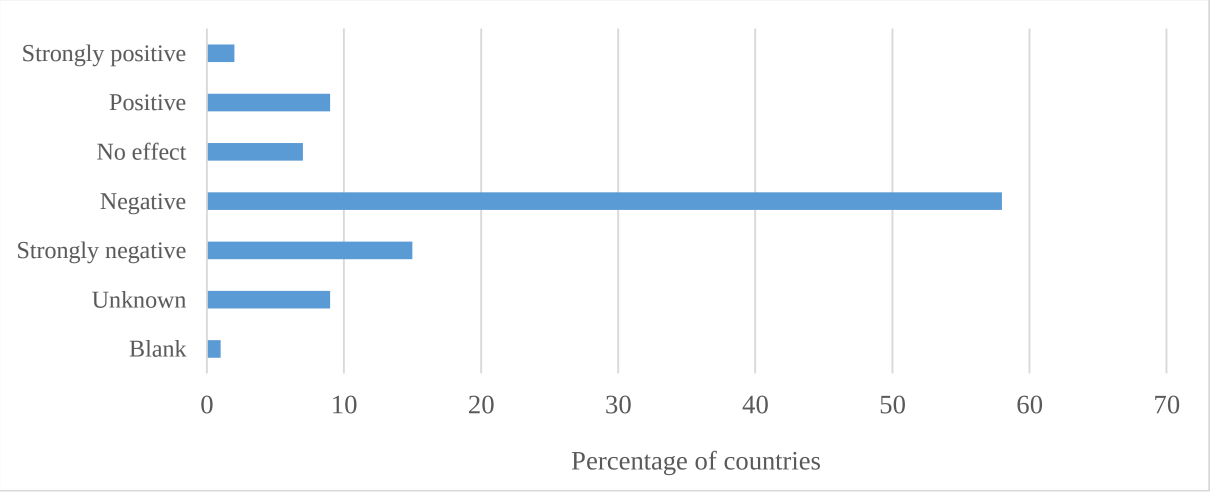
A second level of biosecurity, which is equally important, is the extent to which a country is able to control movements and transfers within its boundaries. Once a disease or invasive species has entered a country, it can still be prevented from spreading between waterbodies, watersheds or river basins.

On the other hand, there are examples of deliberate introduction of diseases. For instance, the cyprinid herpesvirus 3 (CyHV-3) is being considered as a biological control agent to reduce or eradicate populations of common carp from the Murray-Darling River (Australia).

3.2.7 Impacts of capture fisheries on ecosystems and wild relatives

Capture fishery impacts on AqGR are most directly linked to impacts on wild relatives where they are directly targeted; these are generally negative (Figure 61). Seventy-three percent of country responses considered these impacts to be negative or strongly negative.

Figure 61
Effect of capture fisheries on the aquatic genetic resources of wild relatives of farmed aquatic species



The threats to AqGR via ecosystem impacts are linked to the level of fishing pressure, the extent to which the fishery is effectively managed, and whether the fishery targets vulnerable or critical life stages. In the latter case, this includes fisheries which target juveniles (as in the case of glass eel fisheries) or breeding adults (gravid sturgeon for caviar, grouper spawning aggregations) (Lovatelli and Holthus, 2008). Fisheries based around spawning migrations may have a disproportionate impact on the populations of wild relatives. This fishing activity may be for the purpose of food or for capture of juveniles for fattening in aquaculture systems (e.g. eel, bluefin tuna, yellowtail, grouper, marbled sand goby). Two examples of the relationship between aquaculture and wild relatives as a source of seed for this are discussed in Box 13.

Box 13

Link between wild relatives and aquaculture that depend on wild seed

Spain has a thriving aquaculture sector for the Mediterranean mussel (*Mytilus galloprovincialis*) producing over 200 000 tonnes per year, making it one of the largest mussel producers in the world. The majority of this production occurs on ropes hanging from rafts, with the bulk of production in Galicia in the northwest of the country. This production is exclusively based on wild caught seed, which is either collected directly from mussel beds on rocky shores or via natural spatfall on collectors hung from the rafts (Camacho, Gonzalez and Fuentes, 1991). The success of this aquaculture sector is fully dependent on the health and viability of the natural populations, which have remained strong in these regions.

Another example of the interdependency of aquaculture and fisheries is the case of yellowtail or amberjack culture in Japan (Ottolenghi *et al.*, 2004). The Japanese have traditionally fished and cultured three *Seriola* species (*S. quinqueradiata, S. dumerili* and *S. lalandii*) with the greater emphasis on *S. quinqueradiata*, known in Japan as the Japanese amberjack. In the decade from 1990 to 1999, aquaculture production of *S. quinqueradiata* ranged from 140 000 to 160 000 tonnes compared to wild catch production of 34 000 to 75 000 tonnes (Nakada, 2000). Aquaculture of *Seriola* in Japan has traditionally relied upon wild caught seed, and still does today, despite the global expansion of *Seriola* culture in other countries such as Australia, where the system is based primarily on hatchery-reared seed. The main reasons for this are thought to be the reliability of supply and superior quality of wild caught seed and the relative cost of wild caught versus hatchery-reared seed. The Japanese Government regulates the number of juvenile *Seriola* captured in order to conserve and manage the resource, which while having the effect of limiting the scale of aquaculture production, also contributes to a relatively stable balance of production between aquaculture and wild catch.

More general fishing impacts on AqGR relate to unsustainable levels of exploitation, which threaten the viability of wild populations and thus their potential as a source of genetic material. Some fisheries may also affect AqGR that are not the target species. These may be “bycatch” issues or habitat impacts (because of gear interactions with habitat and consequent impacts on a non-target species). An example of this sort of bycatch issue would be the capture of juvenile wild relatives in trawl and push net fisheries (FAO, 2014c).

Country comments on how to mitigate or prevent these impacts proposed the adoption of ecosystem approaches to fishery management that take into account broader ecosystem impacts of the fishing activity beyond the target stocks, and which incorporate habitat and environmental considerations. It was also emphasized that more effective measures be applied to prevent the impact of fisheries on critical life stages and habitats.

Eleven percent of countries considered that capture fisheries had a positive impact on the ecosystem and consequently AqGR (Figure 61). This response was difficult to interpret, although based on country responses it appeared that effective fishery management measures were being put in place to address potential impacts on AqGR.

Belize reports that fishing pressure on invasive tilapia has been keeping the species under control. Bulgaria has implemented a sturgeon fishing ban that has driven aquaculture-related sturgeon production. In the case of freshwater fisheries in Germany, there is an obligation of fishery management to achieve diversity of fish species adapted to that waterbody/fishery.

Responsibly managed fisheries, e.g. using an ecosystem approach, can be considered as *in situ* conservation (see Chapter 4). This also necessitates that the fisheries sector would be committed to the protection of aquatic habitats and the protection of aquatic species in addition to the species being targeted by the fishery. Another general consideration is that fishing pressure alone rarely results in the extinction of any fish species; however, it can have long-term implications for genetic diversity of species and population causing bottlenecks and genetic drift. Extinctions (including local extinctions) are typically more influenced by ecosystem-type impacts, particularly loss of habitat and changing water quality and flow (in the case of freshwater). Nine percent of the countries assessed the impact of capture fisheries as unknown.

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Global Invasive Species Database (www.iucngisd.org/gisd)
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CHAPTER 4

IN SITU CONSERVATION OF FARMED AQUATIC SPECIES AND THEIR WILD RELATIVES WITHIN NATIONAL JURISDICTION

PURPOSE: The purpose of this chapter is to review the current status and future prospects for the *in situ* conservation of genetic resources of farmed aquatic species and their wild relatives.

KEY MESSAGES:

- *In situ* conservation is the preferred method of conserving aquatic genetic resources (AqGR) according to international agencies such as the Convention on Biological Diversity because it maintains the link between the resource and the environment regardless of whether that environment is in nature or on-farm.
- "Preservation of aquatic genetic diversity" and "Maintain good strains for aquaculture production" were the main priorities reported from *in situ* protected areas, although there were slight regional differences.
- "To help adapt to impacts of climate change" and "Meet consumer and market demands" were reported to have the lowest priorities for aquatic protected areas.
- Countries reported on over 2 300 protected areas, with over 2 100 reported as being very or somewhat effective; however, these results are heavily influenced by a few countries reporting large numbers of effective aquatic protected areas.
- Policies exist that explicitly state conservation as an objective in about 50 percent of the responses for aquaculture facilities and fishery management.
- Fisheries and aquaculture were seen to be effective mechanisms for *in situ* conservation in about 90 percent of the responses.
- The collection of broodstock and early life history stages from the wild was seen as a component of *in situ* conservation and as justification for maintaining habitats, at least to some extent, in 50–100 percent of the responses.
- On-farm *in situ* conservation in aquaculture is rare and difficult to distinguish from *ex situ* conservation, due to the relatively recent development of aquaculture and the recent domestication of aquatic species.

4.1 Introduction

In situ conservation, as defined by the Convention on Biological Diversity (CBD), includes areas both on farm and in nature:

> *In situ* conservation means the conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings and, in the case of domesticated or cultivated species, in the surroundings where they have developed their distinctive properties.[1]

All wild relatives of farmed aquatic species still exist in nature and the farming and fishing of wild types (or near wild types) play an important role in food production (see section 2.5.3). Therefore, maintenance of the aquatic habitats supporting wild relatives is essential for their *in situ* conservation.

Habitat rehabilitation has been undertaken in efforts to improve fishery production and conserve aquatic biodiversity; there are a variety of strategies that can improve aquatic ecosystems (Roni *et al.*, 2005). However, the efficacy of many habitat rehabilitation programmes for fish production has not been

[1] https://www.cbd.int/convention/articles/default.shtml?a=cbd-02. [cited 10 May 2018].

adequately evaluated on a global scale (Roni *et al.*, 2005).

The CBD states that *in situ* is the preferred method for conserving biological diversity (CBD, 1992). Preservation or maintenance of habitat, whether on farm or in nature, is crucial because it allows organisms to continue to be connected to their environment in order to adapt to *in situ* conditions.

In situ conditions could be a fish farm, pristine aquatic ecosystems, or those ecosystems impacted by development (e.g. damming of rivers or coastal erosion). It has often been said that to conserve something, humans must use it. Therefore, this part of the Report evaluates the extent to which the use of aquatic genetic resources (AqGR) through aquaculture and fisheries contributes to its conservation.

There are numerous examples of *in situ* conservation of AqGR. The most widely cited are marine protected areas (MPAs), freshwater protected areas (FPAs), Ramsar[2] sites, and the International Union for Conservation of Nature (IUCN)[3] categories of protected areas. In addition to geographically defined protected areas, certain types of fishery management would also qualify as *in situ* conservation. This chapter reviews the current status and future prospects for *in situ* conservation of farmed AqGR and their wild relatives and includes both on-farm and in nature conservation areas, as well as fisheries management.

4.2 *In situ* conservation of wild relatives of farmed aquatic species

Aquatic protected areas, both MPAs and FPAs, have been strongly promoted as a method for conserving biological diversity. The Aichi Biodiversity Targets of the CBD have called for countries to establish protected areas in 17 percent of their terrestrial and inland waters and 10 percent of their marine areas by 2020. Recognizing that there are various levels of "protection", the IUCN defined six categories of protected areas (Box 14).

These categories reflect different objectives of a protected area or of *in situ* conservation.

The Country Reports also expressed differing objectives for *in situ* conservation, with "Preservation of aquatic genetic diversity" and "Maintain good strains for aquaculture production" being the highest priority objectives reported; overall, the lowest priorities were "To help adapt to impacts of climate change" and "Meet consumer and market demands" (Table 40).

These priorities for *in situ* conservation vary somewhat among economic classes, but in all cases "Preservation of aquatic genetic diversity" had the highest priority. Surprisingly, "Meet consumer and market demands" scored low, even in developing and least developed countries. Perhaps countries either do not comprehend the role that the conservation of genetic diversity *in situ* has in meeting consumer demands and preferences in the market, or consider other methods to be easier and less costly.

Analysis by region revealed a similar trend. All regions, with the exception of North America, listed "Maintain good strains for aquaculture production" and "Future strain improvement in aquaculture" as the highest priorities (Table 41).

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[2] Ramsar Wetlands Convention: www.ramsar.org/sites-countries/the-ramsar-sites.

[3] IUCN categories of protected areas: www.iucn.org/about/work/programmes/gpap_home/gpap_quality/gpap_pacategories.

Box 14

IUCN Protected Area Categories System

IUCN categories classify protected areas according to their management objectives. The categories are recognized as the global standard for defining and recording protected areas by international bodies, such as the United Nations, and by many national governments. As such, they are increasingly incorporated into government legislation.

Strict Nature Reserve:
Category Ia are strictly protected areas set aside to protect biodiversity and also possibly geological/geomorphological features, where human visitation, use and impacts are strictly controlled and limited to ensure protection of the conservation values. Such protected areas can serve as indispensable reference areas for scientific research and monitoring.

Wilderness Area:
Category Ib protected areas are usually large unmodified or slightly modified areas, retaining their natural character without permanent or significant human habitation, which are protected and managed so as to preserve their natural condition.

National Park:
Category II protected areas are large natural or near natural areas set aside to protect large-scale ecological processes, along with the complement of species and ecosystems characteristic of the area, which also provide a foundation for environmentally and culturally compatible, spiritual, scientific, educational, recreational, and visitor opportunities.

Natural Monument or Feature:
Category III protected areas are set aside to protect a specific natural monument, which can be a landform, sea mount, submarine cavern, geological feature such as a cave or even a living feature such as an ancient grove. They are generally quite small protected areas and often have high visitor value.

Habitat/Species Management Area:
Category IV protected areas aim to protect particular species or habitats, and management reflects this priority. Many Category IV protected areas will need regular, active interventions to address the requirements of particular species or to maintain habitats, but this is not a requirement of the category.

Protected Landscape/Seascape:
Category V protected areas are where the interaction of people and nature over time has produced an area of distinct character with significant, ecological, biological, cultural and scenic value; where safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation and other values.

Protected Area with Sustainable Use of Natural Resources:
Category VI protected areas conserve ecosystems and habitats together with associated cultural values and traditional natural resource management systems. They are generally large, with most of the area in a natural condition, where a proportion is under sustainable natural resource management.

Table 40
Ranking of objectives for *in situ* conservation of aquatic genetic resources by economic classification of countries (1 = highest priority; 10 = lowest priority)

Objective	Rank*			
	Overall	Developed Countries	Other Developing Countries	Least Developed Countries
Preservation of aquatic genetic diversity	1.9	2.3	1.8	1.9
Maintain good strains for aquaculture production	2.9	3.3	2.8	2.7
Meet consumer and market demands	4	4.7	3.8	3.7
To help adapt to impacts of climate change	4	4.7	3.8	3.7
Future strain improvement in aquaculture	3.2	3.7	3.1	3

* Ranks were determined by averaging the rankings provided in the Country Reports.

Table 41
Ranking of objectives for *in situ* conservation of aquatic genetic resources by region (1 = highest priority; 10 = lowest priority)

Objective	Rank					
	Africa	Asia	Europe	Latin America & the Caribbean	North America	Oceania
Preservation of aquatic genetic diversity	2.1	1.4	2.5	1.7	3	1.3
Maintain good strains for aquaculture production	2.7	2.8	3.5	2.8	2.5	2.9
Meet consumer and market demands	3.4	3.8	5.4	3.6	3.5	4.9
To help adapt to impacts of climate change	3.4	3.7	5.6	3.4	3	5.4
Future strain improvement in aquaculture	2.9	2.8	4.1	3.1	2.5	4.3

Other high-priority objectives reported by individual countries were:

- conservation of endemic species;
- maintain national heritage species;
- promote sustainable wild populations of aquatic organisms;
- maintain and recover resources for commercial and recreational fishing; and
- conserve and restore wild stocks of genetic resources, especially those that are listed on endangered species lists.

The responses for major and minor producing countries were extremely similar and followed the same general trend above (data not shown).

The Ramsar Convention in 1996, at its Sixth Meeting of the Conference of the Contracting Parties, adopted criteria based on characteristics of aquatic biodiversity and important traditional use of fisheries for identifying wetlands of international importance, thus allowing wetlands that support traditional fisheries and fishing communities to be included in the listing of wetlands of international significance. The Ramsar List is the world's largest network of protected areas, which includes over 2 200 wetlands of international importance; these sites provide an excellent means of *in situ* conservation of AqGR.

Formally designated protected areas have been shown in popular and scientific literature to be effective at conserving biological diversity. Country Reports confirmed this general statement (Figure 62 and Table 42). Overall, countries reported on 2 344 protected areas, with over 2 100 reported as being very or somewhat effective (Table 42 and Box 15). The trend was consistent regardless of economic class or if a country was a major or minor aquaculture producing country. There was no important difference between the responses from major or minor producing countries (Table 42). Because of the large difference in the numbers of major and minor producing countries, the percentage of responses is reported in Table 42. The results are heavily influenced by the reports from Canada, Colombia, the Philippines and the United Republic of Tanzania, where a large number of protected areas were reported as being extremely effective.

Figure 62
Effectiveness of *in situ* protected areas for conservation of aquatic genetic resources (total number of protected areas per group)

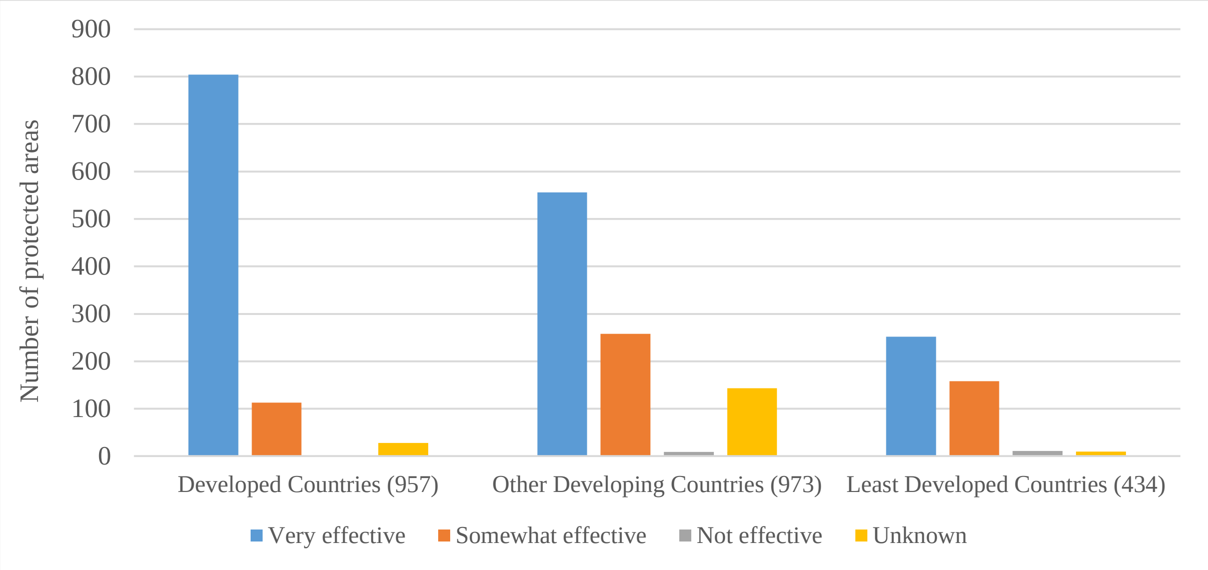


Table 42
Effectiveness of aquatic protected areas by region (number of responses) and by level of aquaculture production (percent of responses)

Effectiveness	Africa	Asia	Europe	Latin America & the Caribbean	North America	Oceania	Total by effectiveness	Major producing countries (%)	Minor producing countries (%)
Very effective	104	296	7	394	797	14	1 612	53	70
Somewhat effective	217	156	85	70		1	529	33	21
Not effective	11		2	8		1	22	0	1
Unknown	11	37	16	115		2	181	13	7
Total by region	343	489	110	587	797	18	Total number of protected areas 2 344		

Box 15

In situ conservation examples: Australia, Bulgaria and China

Australia

One example of an ongoing activity for *in situ* conservation is that of the National Recovery Plan for Murray cod (*Maccullochella peelii peelii*). The federal government and all state governments with jurisdiction over the Murray-Darling River Basin to which the fish is endemic support this plan. The Murray cod was an important species in this large river basin, supporting both commercial and recreational fishing. The objectives of this plan include:

- determining the distribution, structure and dynamics of Murray cod populations across the Murray-Darling River Basin;
- managing river flows to enhance recruitment to Murray cod populations;
- undertaking risk assessments of threats and evaluating benefits of recovery actions on Murray cod populations for each spatial management unit;
- determining the habitat requirements of Murray Cod life stages and populations;
- managing the recreational fishery for Murray cod in a sustainable manner while recognizing the social, economic and recreational value of the fishery;
- encouraging community ownership for Murray cod conservation; and
- managing the Recovery Plan implementation.

This plan includes a review of knowledge of population genetics and current and future gene flow and identification of any particular genetic units that need additional attention.

Bulgaria

According to the Habitats Directive from the government, a number of water areas of Bulgaria are set as special Areas of Conservation due to their fish species of community importance, as described in Annex 2 of the Directive. The effective management of protected areas with fishes from Annex 2 requires the creation and implementation of monitoring programmes to ensure adequate assessment, both in terms of their conservation status and in terms of their spatial distribution.

Protected areas under Natura 2000 in Bulgaria cover 35 percent of the country’s area. In connection with the implementation of the commitments of Bulgaria, in accordance with Article 8 of Directive 92/43/EEC of the European Union on the conservation of natural habitats and of wild fauna and flora, a national framework for priority action (NFPA) under Natura 2000 for 2014–2020 was developed. The purpose of NFPA is to better define priorities for Natura 2000 at the national and regional level and determine financing needs. This framework will facilitate the integration of the above-mentioned needs into future programmes financed by the European Union.

China

Endemic to the Lake Qinghai basin in China, the population of the cyprinid *Gymnocypris przewalskii* has decreased significantly since the 1970s. Most of these fish are below 25 cm, and the mature individual size has become shorter. The species has been recognized as “endangered” in the Red List of Species in China, and the Chinese Government has implemented conservation and management measures. After the fish was declared a high priority for protection, fisheries were closed during the breeding season and a catch limit was established. The main protection measures were to:

- manage the water level of the lake by controlling input and output;
- protect the spawning grounds of *Gymnocypris przewalskii*;
- rebuild vegetation in the lake area;
- implement stock enhancement through seed production;
- close the fishery during the breeding season; and
- adopt regular procedures for managing living beings in the lake, including environment inspection.

After a number of years following these measures, *Gymnocypris przewalskii* populations showed some recovery.

In addition, the Rescue Centre for *Gymnocypris przewalskii* was established. The centre contains a laboratory to study the species, a broodstock facility and a seed production station for stock enhancement. The centre has studied the reproduction biology of the species and continues to survey Lake Qinghai and its critical habitat. The centre also conducts monitoring and evaluation of the effectiveness of the stock enhancement programme.

Fishery management can be considered *in situ* conservation under certain conditions. For example, if the objective of the fishery management plan is to maintain natural populations and the ecosystem that supports them, then this would qualify as *in situ* conservation (Box 16).

The Ecosystem Approach to Fisheries (EAF) (FAO, 2003) encompasses this broad view of fishery management; fishery managers around the world are adopting the EAF and similar approaches. However, policies and fishery management plans should explicitly state conservation as an objective. The objectives of a fishery management plan or an aquatic protected area should be clearly stated and should indicate whether they would be considered as *in situ* conservation. Fishery management plans that call for the introduction of non-native species (e.g. the introduction of non-native rainbow trout into high mountain lakes where they could prey on local fauna) or that support the selective removal of certain species (e.g. the removal of sea stars to enhance scallop growth) may increase the financial value of a fishery but would not be a conservation measure.

Countries reported that, in general, policies exist that explicitly include conservation as a goal for aquaculture facilities or for fishery management (Figure 63, Figure 64 and Figure 65). This was also evident when countries were analysed by economic, regional and level of aquaculture production classifications (data not shown).

Figure 63
Countries reporting conservation as an objective of aquaculture and/or fisheries policies (total for all countries)

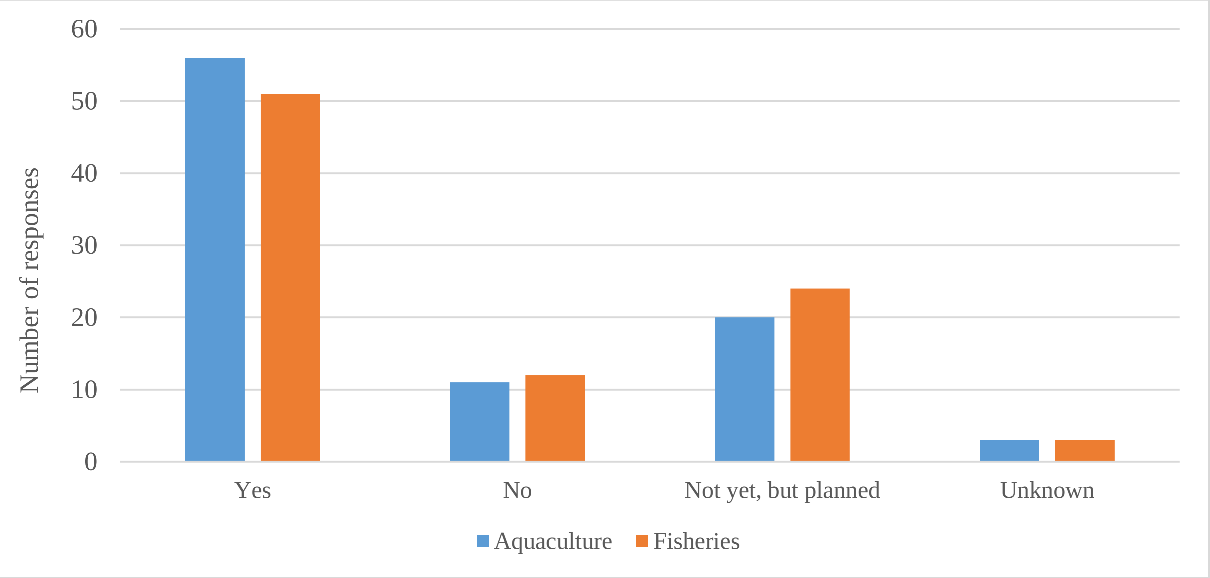


Figure 64
Countries reporting conservation as an objective of aquaculture policies (by region)

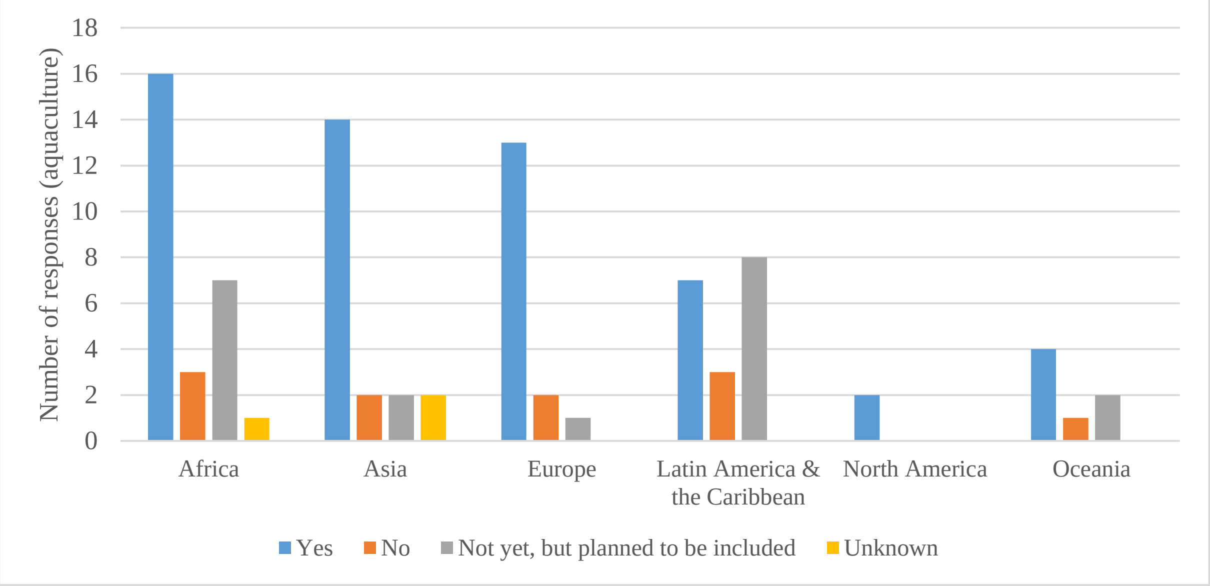
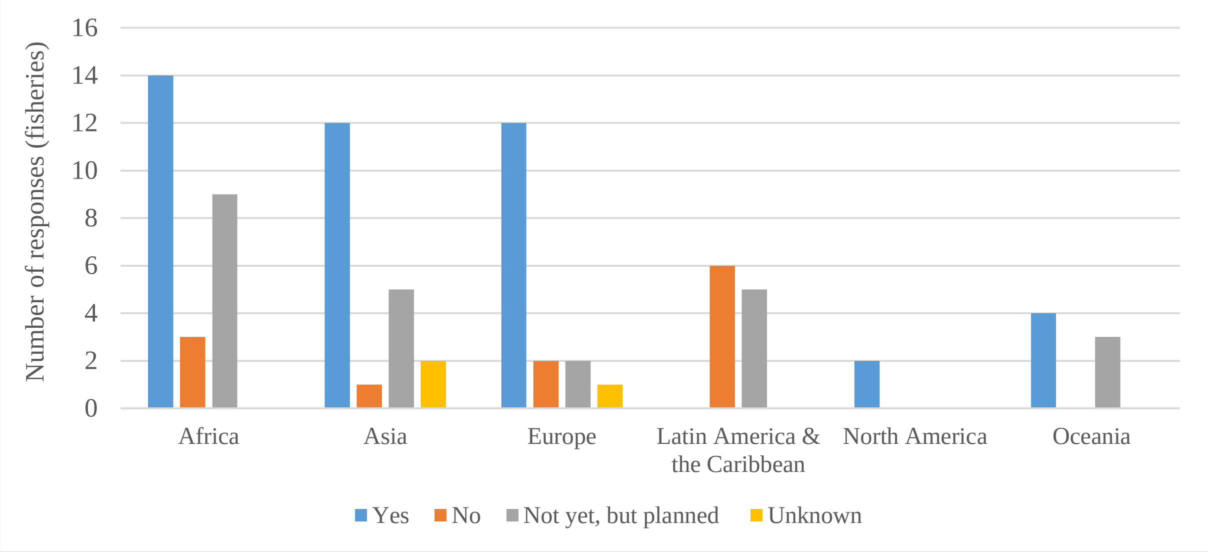
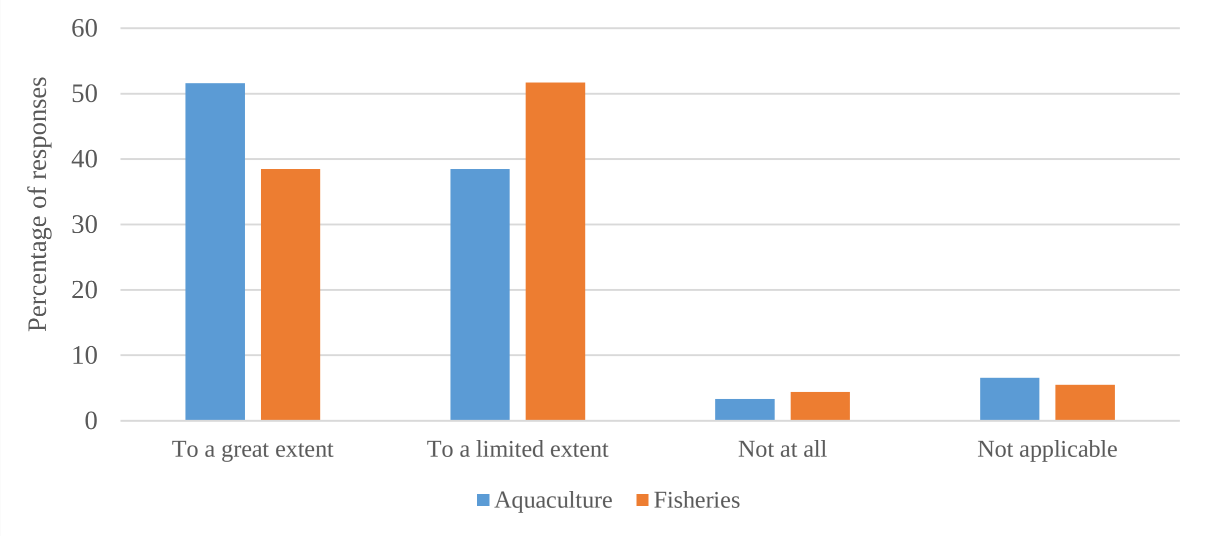


Figure 65
Countries reporting conservation as an objective of fisheries policies (by region)



Countries reported generally positive messages with regard to whether they considered aquaculture and fisheries management to provide effective *in situ* conservation (Figure 66). This trend was present in the analysis of countries grouped by region, economic class and level of aquaculture production (data not shown). It is noteworthy that both aquaculture and fisheries were seen as contributing to the conservation of AqGR to about the same extent.

Figure 66
Extent of effectiveness of fisheries and aquaculture in providing *in situ* conservation of farmed aquatic species and their wild relatives



The practice of collection of broodstock and/or early life history stages from the wild was also seen as providing *in situ* conservation and contributing to maintaining habitats, at least to some extent in most areas (Figure 67 and Figure 68).

The "not applicable" reported in some areas, primarily with regard to collection of AqGR from the wild, could indicate a lack of awareness of the role that fisheries and aquaculture can play in the conservation of AqGR and aquatic habitats (Figure 66, Figure 67 and Figure 68). Thus, it is important that objectives of *in situ* conservation should be explicitly stated in aquaculture and fisheries management policies and operating plans and communicated to resource managers, fishers and aquaculturists.

Figure 67
Contribution of collectors of wild broodstock and seed towards *in situ* conservation and maintenance of aquatic habitats by economic groupings

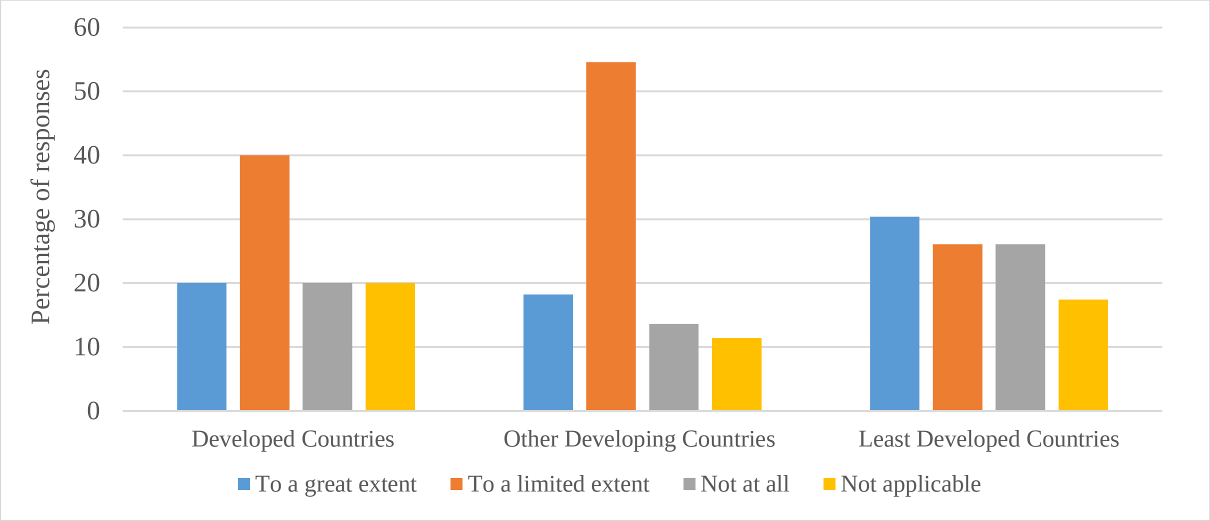
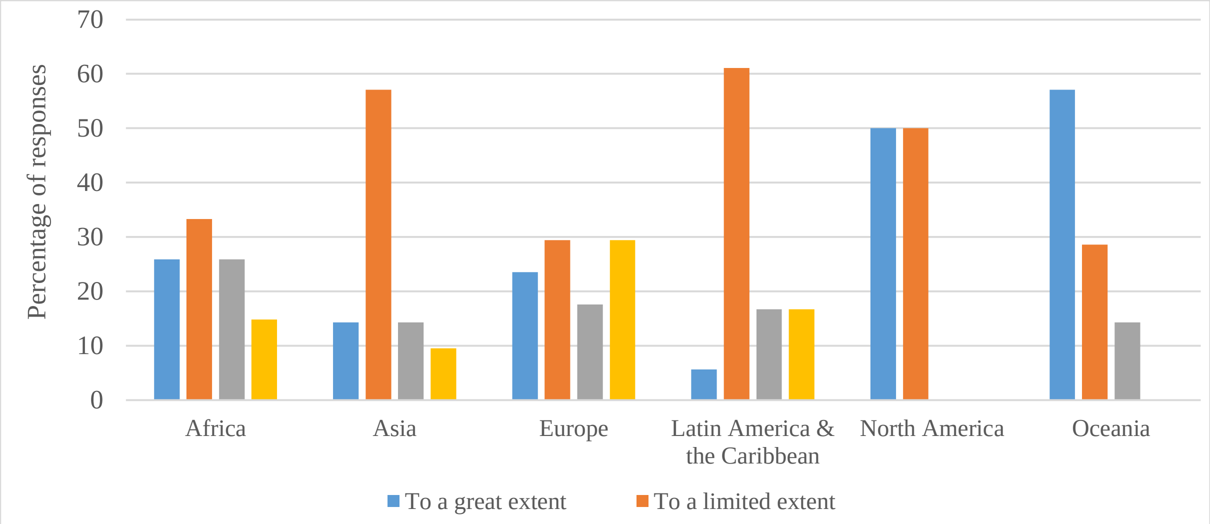


Figure 68
Contribution of collectors of wild broodstock and seed towards *in situ* conservation and maintenance of aquatic habitats by regional groupings



MPAs have been promoted as a fishery management tool to maintain or rebuild capture fisheries. This provides a clear example of where fishery management and conservation merge. This merge has not been without controversy, however, as the efficacy of MPAs as a tool for fishery management and increased fish production has been questioned (Adams *et al.*, 2004; Weigel *et al.*, 2014). There is often tension between those seeking more conservation from a protected area and those seeking more livelihood benefits.

Rice fields are an example of a modified ecosystem that can serve as *in situ* conservation of biological diversity if properly managed. Rice fields in Asia have been shown to contain over 100 species, including fish, insects, crustaceans, molluscs, amphibians and reptiles (Halwart and Bartley, 2005). Integrated pest management in rice fields is a traditional practice in much of Asia that eliminates or reduces the amount of pesticides used and relies on natural enemies of pests and on beneficial species to facilitate production of rice. Country Reports did not specifically mention rice fields as sources of *in situ* conservation, perhaps indicating a lack of appreciation of the role that modified ecosystems can play in conservation.

4.3 *In situ* conservation of farmed aquatic species

In situ conservation of farmed aquatic species essentially means "on-farm" conservation. This type of *in situ* conservation is less common in aquaculture than in agriculture due to the relatively recent domestication of most farmed aquatic species in relation to the long history of domestication in terrestrial agriculture.

Living on-farm gene banks of some species do exist that would qualify as on-farm *in situ* conservation. However, on-farm *in situ* and on-farm *ex situ* conservation are often difficult to distinguish. For the former, the farm must necessarily maintain:

- a production environment;
- the desired species; and
- no further genetic alteration or manipulation.

Thus, the desired species would adapt to the production environment over time.

Box 16

On-farm *in situ* and *ex situ* conservation of aquatic genetic resources

"On-farm *in situ* conservation" of terrestrial genetic resources for food and agriculture is well established. Useful varieties and breeds of crops, fruit trees, livestock and poultry have been developed, used and conserved by small-scale farmers over hundreds of generations. Modern and larger-scale agriculture is improving many of those varieties and breeds; the source of breeding material is often small farms in rural areas which represent and can be identified as "on-farm *in situ*" gene banks. However, the situation with aquatic genetic resources (AqGR) is much different.

Because of the relatively recent domestication of aquatic species, there has been little differentiation of species into different strains (see Chapter 2). The differentiation occurring has usually been the result of breeding programmes, not by small-scale farmers in a local area but by larger companies or institutions, and in areas often distant from the natural distribution of the species (see Box 21 in Chapter 9). In the aquatic sector, where strains of useful species do exist, farmers do not want to conserve the resource, but rather to continue to improve the properties of the strain to make it more profitable to farm. Living gene banks, such as are found for example for carps, sturgeon and salmonids, are generally considered to be *ex situ* conservation. Perhaps in the future, small-scale farmers will develop useful strains of aquatic species and maintain them on-farm without further genetic improvement.

Another complication of applying these definitions in the aquatic sector is the practice of using hatcheries to produce early life history stages of aquatic species for release back into the wild. This practice of "stocking" fish into the wild can be to rebuild populations of threatened or endangered species, and/or for rebuilding or enhancing fisheries. If the hatchery can be considered a "farm", and the breeding programme at the hatchery is intended to conserve a species or stock that would be the same or similar to the species or stock in the wild, then the hatchery could be considered to be applying "on-farm *in situ* conservation". Such hatcheries are often called "conservation hatcheries" in North America and try to minimize artificial or inadvertent selection within the hatchery environment; the goal of conservation hatcheries is to produce an organism that will reproduce in the wild and that is as similar as possible to the wild stock. Hatcheries that produce fast-growing fish that are easily captured by fishers and are not expected to reproduce (often called "culture-based fisheries" or "ranching" operations) would not be considered either *in situ* or *ex situ* conservation.

It is thus apparent that examples of "on-farm *in situ* conservation" are relatively rare for AqGR. Whether a conservation programme is labelled *in situ* or *ex situ* and/or "on-farm" is of less importance than is a clear statement outlining the objectives of the programme.

On-farm *ex situ* conservation would require the farm to maintain the desired species where no selection or genetic change would take place. Thus, the desired species would not change over time because it was not in a production environment.

Therefore, it is difficult to establish the distinction between *in situ* and *ex situ* conservation of farmed aquatic species (Box 16). In fact, the Fish Culture Research Institute in Szarvas, Hungary, maintains numerous strains of common carp under farm-like conditions. Although this appears to be *in situ* conservation, the researchers at the institute call it *ex situ* conservation (personal communication, Z. Jeney, Retired Director Fish Culture Research Institute, Szarvas). Given the fact that aquaculture is rapidly growing and there will be strong motivation to increase productivity through continuously improving AqGR, it may be difficult to find actual cases of on-farm *in situ* conservation.

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Online resources

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CHAPTER 5

EX SITU CONSERVATION OF AQUATIC GENETIC RESOURCES OF FARMED AQUATIC SPECIES AND THEIR WILD RELATIVES WITHIN NATIONAL JURISDICTION

PURPOSE: The purpose of this chapter is to review the current status and future prospects for the *ex situ* conservation of aquatic genetic resources of farmed aquatic species and their wild relatives. Specifically, this chapter reviews:

- existing *ex situ* conservation of aquatic genetic resources (AqGR) of farmed species and their wild relatives in aquaculture facilities, culture collections and gene banks, research facilities, zoos and aquaria (both *in vivo* and *in vitro* collections); and
- needs and priorities for the future development of *ex situ* conservation of AqGR of farmed aquatic species and their wild relatives, including any that are threatened or endangered.

KEY MESSAGES:

- *Ex situ* collections, both *in vivo* and *in vitro*, are common mechanisms for the conservation of AqGR. Approximately 75 percent of the responding countries have current *ex situ in vivo* conservation programmes, and 38 percent of the responding countries have current *ex situ in vitro* conservation programmes.
- More than 690 cases of aquatic *ex situ in vivo* conservation programmes of approximately 290 different species were reported for live breeding organisms in various types of facilities.
- The major producing countries reported more *ex situ in vivo* conservation programmes than the minor producing countries.
- Almost 200 endangered aquatic species are being maintained in *ex situ in vivo* collections.
- Finfish are the group most often conserved in *ex situ* collections; about 90 percent of the AqGR conserved in *ex situ in vivo* collections were finfish, and about 10 percent were microorganisms such as rotifers and algae.
- The most important objective for *ex situ* conservation at the global level (both *in vivo* and *in vitro*) was the preservation of aquatic genetic diversity, followed by future strain improvement in aquaculture and for the maintenance of good strains for future aquaculture production. This ranking was similar when countries were grouped by region, economic level and level of aquaculture production.
- The least important objective for *ex situ* conservation programmes was for adaptation to climate change.
- Multiple uses of species in *ex situ in vivo* conservation collections were reported, including for direct human consumption, as live feed organisms, for future domestication or use in aquaculture; for conservation of aquatic biodiversity, as ornamental species, for pharmaceutical uses, for spat monitoring, for restocking and stock enhancement purposes, for recreational fisheries; and for research.
- Direct human consumption was the most often cited use for *ex situ in vivo* conservation. Nile tilapia was the species most conserved *in vivo*, and its primary use was for direct human consumption.
- Two hundred ninety-five *ex situ in vitro* conservation collections were reported, including more than 133 aquatic species in various types of facilities.
- Asia maintains the highest number of *in vitro* collections, whereas Latin America and the Caribbean reported the highest number of *in vitro* collections per country.
- Common carp (*Cyprinus carpio*) and rainbow trout (*Oncorhynchus mykiss)* were the two species most often conserved *in vitro*.
- Gametes were the type of AqGR most often conserved *in vitro* (almost exclusively male gametes).
- "Research facilities" were the type of facility most often used for *in vitro* conservation.

5.1 Background

Because of the short history of domestication of aquatic organisms, the relatively recent initiation of breeding programmes and the limited knowledge of our cultured aquatic genetic resources (AqGR) and their wild relatives, farmable aquatic species have high importance as genetic resources. Many of these free-living populations of AqGR, especially in freshwater, are among the world's most seriously threatened biodiversity (NSW DPI, 2018; Carrizo, Smith and Darwall, 2013).

In order to help mitigate the threats and better inform development and conservation planning processes, knowledge is required in terms of where species occur, how important they are for human livelihoods and ecosystem functioning, and how threatened their status is. Moreover, in aquaculture, as in agriculture, most private sector seed producers and farmers maintain only the most profitable farmed types. Their use in aquaculture production and related research of alien species and of genetically altered farmed types (e.g. distinct strains, hybrids, polyploids, transgenes, whether developed from introduced or indigenous species) is important (see Chapter 2).

These circumstances suggest an urgent need for better management, including the use and conservation, of AqGR relevant for aquaculture. These conservation strategies can include:

- *in situ in vivo*, e.g. free-living, wild and feral populations;
- on-farm *in situ*, e.g. captive populations on-farm in which conservation is the objective (see Box 16);
- *ex situ in vitro*, e.g. collections of cryopreserved sperm, embryos and other tissues/DNA; and
- *ex situ in vivo*, e.g. aquarium and research populations.

In situ conservation programmes are considered in Chapter 4, but considering the complementarity of the two approaches, some reference is made in this chapter.

Ex situ conservation programmes are especially relevant for certain threatened and endangered aquatic species, and even more so when natural habitats have disappeared or are threatened. However, establishing and maintaining *ex situ* conservation programmes is expensive and may require public and private sector investment and partnerships.

5.2 Complementarity of *in situ* and *ex situ* programmes

Conservation programmes can be broadly grouped into two complementary strategies: *in situ* and *ex situ*. In *ex situ* conservation, the AqGR is maintained outside of its natural habit, which is to say, not where the genetic resource has evolved or been developed. The goal of *ex situ* conservation is to maintain the same genetic diversity and genetic structure as the source of the material; collections should, as far as possible, maintain the same allelic and genotypic frequencies as the original population. Outside their natural habitat, a species does not experience the same selection pressures as would a wild population. As a result of different selection pressures, it may undergo artificial selection (whether deliberate or accidental) if maintained *ex situ* for multiple generations (Engels *et al.*, 2001). On the other hand, *in situ* is a dynamic system, and the genetic resource will continue to evolve over time as a result of natural and anthropogenic selection processes within the environment.

According to the Convention on Biological Diversity, *in situ* conservation is the preferable mode of conservation. *In situ* measures are the primary conservation approach because they provide a more holistic strategy for conservation by allowing easier conservation of a greater number of ecological and evolutionary processes.

However, the use of *ex situ* conservation is recommended if *in situ* conservation is not available or not functional for the near-term survival of a species. Furthermore, *ex situ* strategies can be used as a supplemental or redundant strategy to insure against catastrophic loss of the wild population. Although *ex situ* and *in situ* conservation were historically treated as distinct conservation strategies, both methods can be implemented cooperatively within regional conservation plans in order to reach biodiversity conservation goals more effectively.

5.3 *Ex situ* conservation overview

Ex situ conservation is a mechanism to conserve AqGR outside its natural habitats, targeting all levels of biodiversity including the ecosystem level, species level and subspecies level (Kasso and Balakrishnan, 2013). Broadly, *ex situ* conservation includes a variety of activities, from managing captive populations, education and raising awareness, supporting research initiatives to collaborating with *in situ* efforts.

The main objectives of *ex situ* conservation programmes are maintaining the original levels of genetic diversity through avoiding allelic shifts, which can be caused by inbreeding, genetic drift and selection for captive conditions (including artificial feeding and mating systems). Thus, genetic resources are available for later use, usually as propagation for (re)stocking or selective breeding programmes. Note that selective breeding programmes deliberately shift allelic frequency, selecting for favourable traits, and are at odds with *ex situ* conservation programmes.

Populations of living organisms kept in captivity can deteriorate for many reasons, among them the loss of genetic diversity, inbreeding leading to inbreeding depression, genetic adaptations to captivity and accumulation of deleterious genes. These factors could seriously put at risk the success of *ex situ in vivo* conservation programmes. Additionally, it is recognized that *ex situ* conservation has many constraints in terms of personnel, costs and reliance on electric power sources (especially in many developing countries where electricity supply can be unreliable). *Ex situ* conservation requires facilities and financial investment. Also, it cannot conserve all of the thousands of plant and animal species that make up complex ecosystems. Furthermore, the capture of individuals from the wild for captive breeding or translocation sometimes can have detrimental effects on the survival prospects of the species as a whole through mining of viable organisms from the wild (Kasso and Balakrishnan, 2013).

The most important challenges of applying *ex situ* conservation include identifying the precise role of the conservation efforts within the overall conservation action plan and setting realistic targets in terms of required time span, population size, founder numbers, resources, assurance of sound management and cooperation (Leus, 1988; Kasso and Balakrishnan, 2013). In addition, care must be employed in the management of small samples to avoid inbreeding and other changes in genetic structure. New tools and technical methods, especially related to cryopreservation and subsequent reanimation, need to be developed. Ownership rights and access and benefit-sharing protocols must also be considered.

5.3.1 Mechanisms for *ex situ* conservation

There are several mechanisms commonly used for *ex situ* conservation. These include aquaria and zoos, botanical gardens and gene banks (which can be subdivided into *in vivo* captive breeding programmes and *in vitro* collections).

One mechanism for conservation, arguably the simplest, is observable in aquaria, zoos and botanical gardens. These can serve as reservoirs of genetic diversity, often distributed far from the natural range of the organisms. These places are often run by universities or other scientific research organizations and often have associated research programmes. These facilities can serve multiple roles: maintaining collections while also conducting scientific research and conservation, as well as organizing exhibits and providing education. However, maintenance of genetic diversity (avoiding inbreeding, etc.) is often of secondary importance and may not be considered at all. These various facilities are often supported through memberships or entrance fees, which may be subsidized by government programmes. Botanical gardens are especially relevant for freshwater aquatic macrophytes (e.g. lotus, water lily), which have uses as food and fodder, as well as representing cultural value.

Gene banks (also known as genome banks) are the most common type of *ex situ* conservation programmes. Different types of gene banks have been established for the storage of AqGR, depending on the type of materials conserved. These include both *in vivo* gene banks (captive breeding) and *in vitro* gene banks (cryopreservation of gametes or tissues) (Kasso and Balakrishnan, 2013).

In vivo gene banks rely on captive breeding and can be an essential element in overall conservation action plan for a species. However, as previously discussed, the measure is rarely enough on its own to guarantee successful species preservation. Captive breeding is an intensive practice, most relevant for threatened genetic resources or species endemic to a threatened environment. Small populations, even if under a strong *in situ* conservation programme with strong environmental protection, still face the risk of extinction (at least of certain alleles) resulting from random events and catastrophes. It is important to manage captive populations so that the individuals being conserved will resemble original species, stock, strain or farmed type as closely as possible, as this will increase the chances of successful later use (e.g. reintroduction into the wild or initiation of selective breeding programmes in captivity). Captive populations under *ex situ* conditions are subject to problems such as accumulation of inbreeding, loss of genetic diversity and domestication selection, a form of selection whereby the species is selected for adaptation to the captive environment (Kleiman, Katerina and Baer, 2010).

Using the Hardy Weinberg principles as a guide, a captive breeding programme should aim to maintain genetic diversity by eliminating selection (artificial or natural), genetic drift (by ensuring a large enough population size) and gene flow (introductions or escapes). Eliminating selection can be difficult in captive breeding populations. Often, more aggressive animals will have higher feeding success when feeding on artificial feed in a competitive environment and are thus more likely to be successful in breeding which can significantly change traits over a few generations. Other traits may also be favoured or selected against in the captive environment, such as colouration and tolerance of specific conditions. To avoid this, it is often recommended to ensure random mating (where individuals are tagged and randomly assigned partners), if possible, which has an additional benefit of eliminating mate selection effects and can also reduce accumulation of inbreeding. To prevent genetic drift (random loss or fixation of a certain allele), the target effective population size must be carefully managed. In general, the target effective population size indicates the number of individuals that are required to maintain appropriate levels of genetic diversity, which is generally considered to be 90 percent of the current genetic diversity, for a period of 100 years (Frankham, Ballou and Briscoe, 2011). The number of individuals required to meet this goal varies based on potential growth rate, effective population size, current genetic diversity and generation time (Kleiman, Katerina and Baer, 2010). Once the target effective population size is achieved, the focus shifts to maintaining the population and avoiding genetic issues such as selection within the captive population. Finally, eliminating unwanted gene flow into (or out of) the population through application of effective biosecurity measures should be practised (consider the effects if a few individuals carrying a rare allele escape, or an individual with foreign alleles is added).

Another subgroup of gene banks is *in vitro* collections. In *vitro* has been defined, for the purpose of this study, as specimens maintained in a tissue culture laboratory rather than as living organisms. *In vitro* conservation, such as freezing of microorganisms, cells, DNA, gametes or molecules, is conducted using components of an organism that have been isolated from their usual biological surroundings. Specimens are either maintained permanently in their original form (cryopreservation) or propagated clonally; therefore, the strain genetics remain constant even when small populations are maintained. This is quite different from captive breeding, where genetic drift and small population size must be a constant consideration when maintaining genetic diversity over generations (Kasso and Balakrishnan, 2013). However, while sperm cryopreservation can be effectively applied in many species, the eggs and embryos of most aquatic species are difficult to store and reanimate after freezing, and therefore this technique has limited application for AqGR except for DNA, some tissues and sperm.

The following are some of the advantages of *in vitro* conservation programmes and studies.

- **Simplicity:** *in vitro* work simplifies the system under study, so the investigator can focus on a small number of components (Price and Nairn, 2009; Vignais and Vignais, 2010).

- **Species specificity:** with *in vitro* methods, cells can be studied without "extrapolation" from an experimental animal's cellular response (Price and Nairn, 2009).

- **Convenience, automation:** *in vitro* methods can be miniaturized and automated, yielding high-throughput screening methods for testing molecules in pharmacology or toxicology. Relatedly, it is relatively convenient to conduct research on frozen genetic material, which can be easily exchanged, transferred or purchased by laboratories and scientists for experimentation.

- **Cost:** "*ex situ in vitro*" conservation is a relatively low-cost method when it involves cryogenic freezing of genetic materials of animals. Collecting, cryogenically freezing and storing specimens generally requires little space and staff maintenance is minimal. Long-term storage is economical.
- **Genetic drift:** samples do not suffer from genetic drift while frozen.
- **Long-term security:** with *in vitro*, there is relatively low risk that human error, environmental change, disaster or political changes will affect a small cryo-laboratory, whereas *ex situ* programmes need to plan for these contingencies.

By contrast, the primary disadvantage of *in vitro* conservation is that it may be challenging to extrapolate from the results of *in vitro* work back to the biology of the intact organism. Investigators doing *in vitro* work must be careful to avoid over-interpretation of their results, which can lead to erroneous conclusions about organismal and systems biology (Rothman, 2002). Another risk around cryogenic storage of genetic material, particularly in developing countries, is the reliability of the supply of liquid nitrogen. It only takes the material to thaw out once over many years to render it useless.

5.4 *In vivo* collections identified in Country Reports

Countries were asked to provide a detailed list of their country's existing collections of live breeding aquatic organisms that could be considered as contributing to the *ex situ* conservation of AqGR, including not only collections of aquatic species farmed directly for human use, but also collections of aquatic live feed organisms and collections of aquatic organisms devoted to other uses. The term *in vivo* has been used to signify *ex situ* conservation of live organisms.

5.4.1 Overview

Regarding the existing collection of live breeding organisms of AqGR, a total of 69 countries (75 percent of the 92 Country Reports) have current *ex situ* conservation activities and programmes being implemented at the national level. A total of 690 cases exist where aquatic species are being conserved in *ex situ* conservation programmes (Table 43). The countries with the largest number of *ex situ* conservation cases were Colombia, Peru, China, Bangladesh, Viet Nam and Mexico.

The precise number of species maintained *in vivo* is difficult to determine. In the case of Brazil, the Government estimates around 55 species (marine and freshwater) are being maintained in "real" *ex situ* conservation programmes, although the information is incomplete at this stage because of many private stakeholders (fish breeders) maintaining their own *ex situ* conservation facilities.

Although the questionnaire did not specifically inquire as to who was funding *ex situ* conservation, Sweden stated that most *ex situ* conservation actions of live aquatic organisms are being conducted by private fish farmers and fish breeders, as well as by private fishing (recreational fisheries) associations. Therefore, the Government does not possess accurate information regarding these efforts.

Table 43

Countries reporting *ex situ in vivo* conservation programmes

Country	Number of programmes	Country	Number of programmes	Country	Number of programmes
Colombia	78	Norway	9	Cameroon	3
Peru	64	Senegal	9	Ghana	3
China	51	Turkey	9	Niger	3
Bangladesh	43	United States of America	9	Palau	3
Viet Nam	26	Germany	8	Chad	2
Mexico	23	Croatia	7	Czechia	2
Romania	23	Estonia	7	Dominican Republic	2
Argentina	22	Finland	7	Fiji	2
Japan	22	Ukraine	7	Guatemala	2
Philippines	20	Thailand	6	Republic of Korea	2
Sweden	20	Tunisia	6	Madagascar	2
Bulgaria	16	Benin	5	Sierra Leone	2
Algeria	15	Georgia	5	Togo	2
India	15	Indonesia	5	Venezuela (Bolivarian Republic of)	2
Sri Lanka	14	Malawi	5	Armenia	1
Uganda	14	Cambodia	4	Belize	1
Costa Rica	12	El Salvador	4	Bhutan	1
Malaysia	12	Nigeria	4	Canada	1
Egypt	10	Poland	4	Denmark	1
Iran (Islamic Republic of)	10	United Republic of Tanzania	4	Nicaragua	1
Zambia	10	Belgium	3	Vanuatu	1
Hungary	9	Burkina Faso	3	Australia	n.s.
Kenya	9	Burundi	3		

Notes: n.s. – not specified. Australia reports *ex situ in vivo* gene banks of several hundred species of marine algae, including multiple strains of many species.

Asia was the region reporting the most *ex situ in vivo* conservation programmes followed by Latin America and the Caribbean (Figure 69). More *ex situ in vivo* conservation programmes are established in other developing countries than in the countries classified as lower development status; the major producing countries reported more *ex situ* conservation programmes per country than the minor producing countries (Figure 70 and Figure 71).

Figure 69
Distribution of *ex situ in vivo* conservation programmes by region

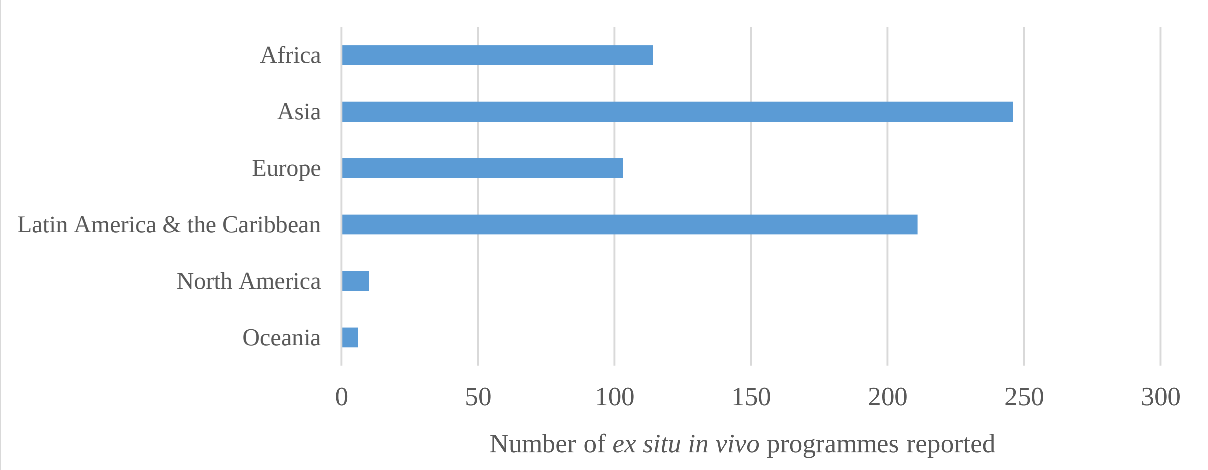


Figure 70
Distribution of *ex situ in vivo* conservation programmes by economic classification

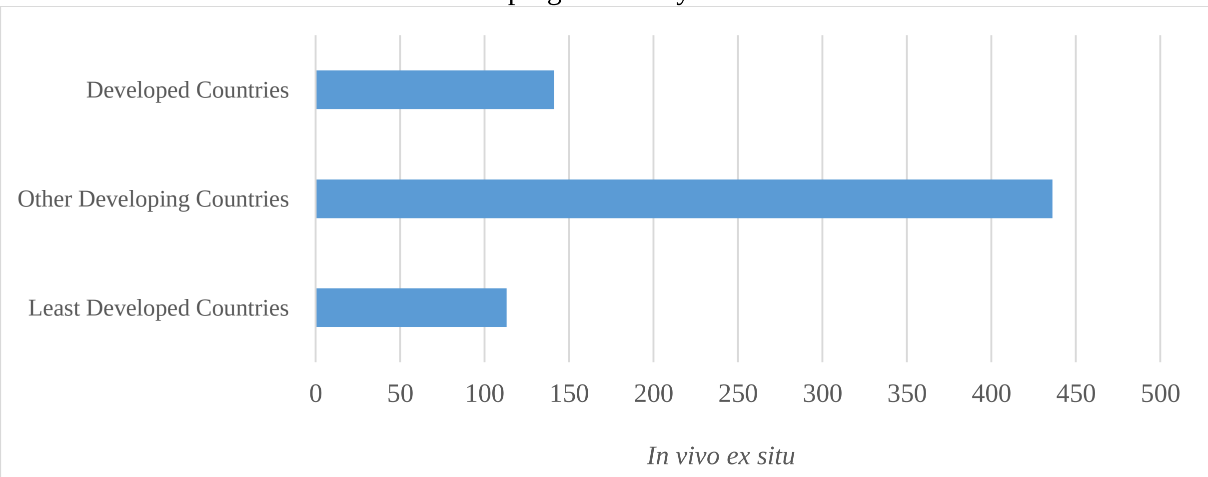
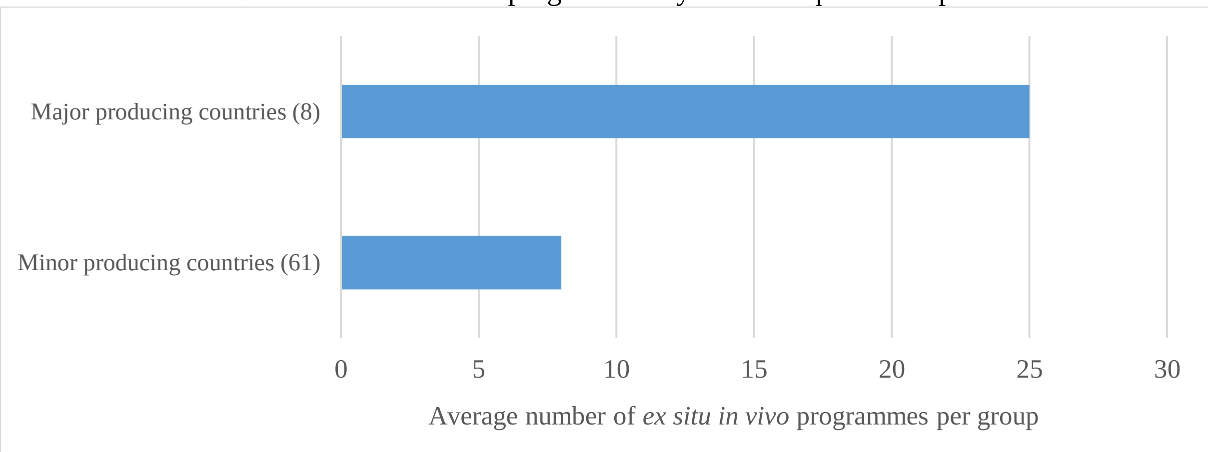


Figure 71
Distribution of *ex situ in vivo* conservation programmes by level of aquaculture production



5.4.2 Endangered species

Countries were also asked to include whether the species being maintained in *ex situ* conservation facilities are threatened or considered as endangered at national and/or international levels. Thirty-four countries (49 percent of the 69 countries reporting on this issue) indicated the maintenance of threatened/endangered AqGR in their *ex situ* conservation.

A total of 197 examples of endangered aquatic species are being conserved under *ex situ in vivo* conservation programmes (Table 44). Colombia reported the highest absolute number of endangered species undergoing *ex situ in vivo* conservation, while several countries reported that all of their *ex situ in vivo* conservation programmes targeted endangered species. An example of a successful regional collaboration is described in Box 17.

Table 44
Endangered aquatic species maintained in *ex situ in vivo* conservation programmes

Country	Number of endangered species in a conservation programme	Total number of *ex situ in vivo* conservation programmes	Proportion of conserved species that are endangered (percent)
Colombia	49	78	63
Bangladesh	22	43	51
Viet Nam	15	26	58
India	10	15	67
Hungary	8	9	89
Romania	8	23	35
Philippines	7	20	35
Bulgaria	6	16	38
China	5	51	10
Finland	5	7	71
Georgia	5	5	100
Germany	5	8	63
Iran (Islamic Republic of)	5	10	50
Thailand	5	6	83
Turkey	5	9	56
Ukraine	5	7	71
Argentina	3	22	14
Burundi	3	3	100
Cambodia	3	4	75
Palau	3	3	100
Sri Lanka	3	14	21
Czechia	2	2	100
Guatemala	2	2	100
Japan	2	22	9
Norway	2	9	22
Armenia	1	1	100
Bhutan	1	1	100
Costa Rica	1	12	8
Croatia	1	7	14
Denmark	1	1	100
Malaysia	1	12	8
Mexico	1	23	4
Poland	1	4	25
Uganda	1	14	7

Box 17

Sturgeon 2020 – a coordinated approach to conservation of endangered and critical genetic resources in the Danube River Basin

Sturgeon fisheries in the Danube River have long represented a major income source for communities along the river, particularly in the Middle and Lower Danube and the Delta. Sturgeons are part of the natural heritage of the Danube River Basin. However, populations have declined rapidly and drastically in recent decades. Of the six species of sturgeon native to the Danube, one has already gone extinct in the basin and a further four are classed as critically endangered, with one of these on the verge of extinction. Even the most common species, the sterlet (*Acipenser ruthenus*), is classed as vulnerable. The decline of these populations is due to multiple factors, including overfishing, illegal fishing, anthropogenic disruptions to spawning migration, and habitat loss attributed to river engineering.

As a flagship species, conservation of sturgeon has been recognized by the Danube countries and the European Commission as a basin-wide issue of great importance.

The European Union adopted the EU Strategy for the Danube Region (EUSDR) in June 2011 with the objective of harmonizing sectoral policies under an integrated approach, providing a framework for balancing environmental protection with regional social and economic requirements. As a result of the EUSDR, scientists and governmental and non-governmental organizations came together to form the Danube Sturgeon Task Force in January 2012 to support the target of the EUSDR "to ensure viable populations of sturgeon and other indigenous fish species by 2020". The Sturgeon 2020 programme (Sandu, Reinartz and Bloesch, 2013) was conceived as a living structure dependent on the long-term commitment of the Danube and Black Sea countries, requiring cooperation between various stakeholders, including governments, policy-makers, local communities, scientists and non-governmental organizations. The various measures proposed were grouped under six key topics:

- acquiring political support for sturgeon conservation;
- capacity building and law enforcement;
- *in situ* sturgeon conservation;
- *ex situ* sturgeon conservation;
- socio-economic measures to support sturgeon conservation; and
- raising public awareness.

Of specific interest in the context of this Report was the integrated approach to *in situ* and *ex situ* conservation.

The focus of *in situ* conservation is the characterization of sturgeon populations, including genetic characterization using modern molecular tools, and the identification of sturgeon life cycles. This will inform the development of applied *in situ* conservation measures, such as monitoring of the sturgeon life cycles, the conservation and restoration of life cycle requirements, harmonization of the respective measures, methods and fishing regulations within the Danube River Basin, and research on the possibility to develop and introduce sturgeon friendly fishing techniques. The plan has also identified and prioritized species and region specific requirements.

The focus of *ex situ* conservation is the establishment of captive broodstock of all species within a joint regional network, preferably in non-commercial facilities. *Ex situ* hatcheries will develop breeding and release protocols in line with World Sturgeon Conservation Society-FAO guidelines (Chebanov *et al*., 2011) to support targeted stocking and reintroduction programmes, which will follow IUCN guidelines (IUCN, 1998).

Neither *in situ* (see Chapter 4) or *ex situ* conservation methods are intended to stand alone; instead

they will be integrated to support and best ensure the viability of the natural life cycle, including in the implementation of species and region specific requirements. Research on the characterization of sturgeon populations and life cycles will underpin coordinated strategies for both *in situ* and *ex situ* conservation. Active monitoring programmes will be applied to both *in situ* and *ex situ* conservation and the impacts of restocking will be fully evaluated.

Sturgeon 2020 represents a holistic approach to conservation of flagship aquatic genetic resources, involving strong international cooperation and incorporating strong integration of both *ex situ* and *in situ* conservation.

5.4.3 Main species being conserved

The ten species most often reported as being maintained in *ex situ in vivo* conservation programmes were either finfish or microorganisms (Table 45). Approximately 90 percent of AqGR conserved are finfish species and 10 percent are aquatic microorganisms, such as rotifers and microalgae.

Table 45
The most common species and species items in *ex situ in vivo* conservation programmes

Species	Number of programmes	Species	Number of programmes
Oreochromis niloticus	16	Microalgae	4
Oncorhynchus mykiss	10	Tilapia	4
Brachionus plicatilis	9	*Probarbus jullieni*	3
Clarias gariepinus	9	*Salmo trutta*	3
Cyprinus carpio	9	*Skeletonema costatum*	3
Isochrysis galbana	9	*Spirulina* sp.	3
Acipenser gueldenstaedtii	7	*Tor putitora*	3
Huso huso	7	*Undaria pinnatifida*	3
Acipenser stellatus	6	*Artemia salina*	3
Chlorella sp.	6	*Brachionus rotundiformis*	3
Salmo salar	6	Copepoda	3
Sander lucioperca	6	*Crassostrea gigas*	3
Acipenser ruthenus	5	*Dicentrarchus labrax*	3
Nannochloropsis oculata	5	*Esox lucius*	3
Tetraselmis sp.	5	*Hypophthalmichthys molitrix*	3
Acipenser baerii	4	*Lutjanus guttatus*	3
Artemia sp.	4	*Macrobrachium rosenbergii*	3
Chaetoceros sp.	4	*Moina* sp.	3
Penaeus monodon	4	*Nannochloropsis* sp.	3
Penaeus vannamei	4	*Microcyclops* sp.	1
Brachionus sp.	4	Rotifers	3

5.4.4 Main uses of conserved species

Countries were asked to provide the main destination or use of each conserved aquatic species in *ex situ* conservation programmes or actions, including those used as live feed, for direct human consumption, and for other purposes. Finfish are maintained both for direct human consumption and as live feed for aquaculture, while microorganisms are used as live feed for aquaculture in most cases.

From the 690 reported *ex situ in vivo* conservation programmes, 398 cases, including 290 species, were reported to be used for direct human consumption; 127 species were conserved for use as live feed in aquaculture or other primary industries; and 212 aquatic species were conserved for "other uses" (Figure 72), such as future domestication or potential use in aquaculture, conservation of aquatic

biodiversity, potential use as ornamental species, pharmaceutical uses, spat monitoring, restocking and stock enhancement purposes, recreational fisheries, and research (Table 46).

Certain species are being conserved for several uses. For example, Nile tilapia is used both for direct human consumption and as live feed for aquaculture in certain countries where carnivorous species are fed Nile tilapia juveniles. Rotifers (e.g. *Brachionus* spp.) were the most important group of AqGR used for live feed (Table 46 and Table 47). Main aquatic species used as live feed organisms for aquaculture activities and number of reported programmes are listed in Table 47. Notably, many of the species typically conserved in *ex situ in vivo* gene banks are among the most commonly farmed species (see Table 20).

Figure 72
Uses of *ex situ* conserved aquatic species (number of reported species programmes)

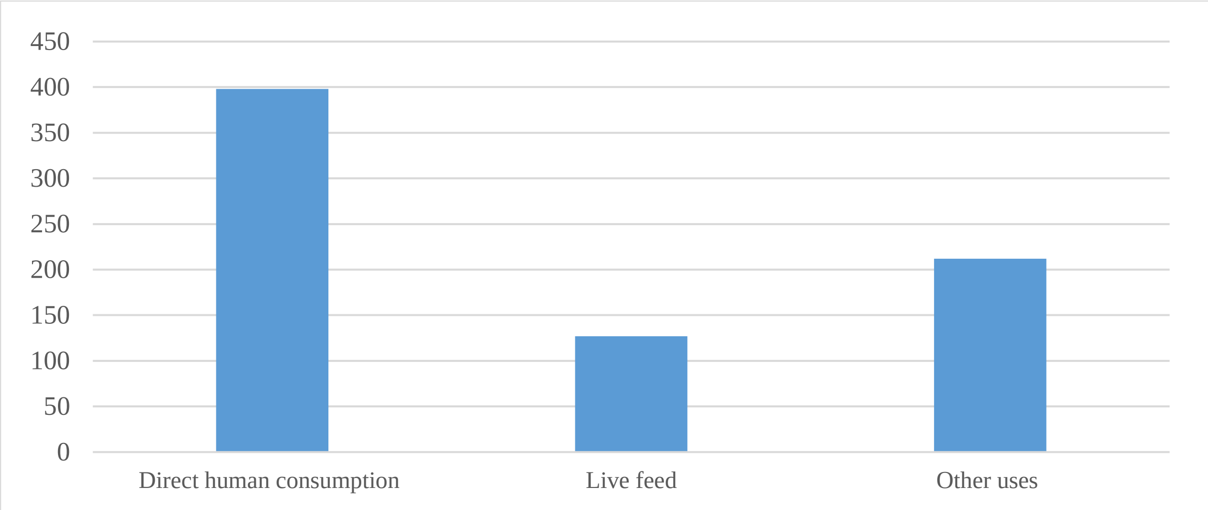


Table 46
The most important species or species items reported in *ex situ in vivo* conservation and their uses

Species	Number of countries reporting	Type of use	Species	Number of countries reporting	Type of use
Oreochromis niloticus	16	DHU	*Macrobrachium rosenbergii*	3	DHU
Clarias gariepinus	9	DHU	*Probarbus jullieni*	3	DHU
Cyprinus carpio	9	DHU	*Salmo trutta*	3	DHU
Oncorhynchus mykiss	9	DHU	Other tilapia	3	DHU
Huso huso	6	DHU	*Brachionus plicatilis*	8	LF
Acipenser gueldenstaedtii	5	DHU	*Isochrysis galbana*	8	LF
Acipenser ruthenus	5	DHU	*Chlorella* sp.	5	LF
Acipenser stellatus	5	DHU	*Artemia* sp.	4	LF
Acipenser baerii	4	DHU	*Brachionus* sp.	4	LF
Penaeus monodon	4	DHU	*Chaetoceros* sp.	4	LF
Penaeus vannamei	4	DHU	Microalgae	4	LF
Sander lucioperca	4	DHU	*Nannochloropsis oculata*	4	LF
Crassostrea gigas	3	DHU	Rotifers	3	LF
Lutjanus guttatus	3	DHU	*Spirulina* sp.	3	LF

Notes: DHU = direct human use; LF = live feed organism.

Table 47
Main aquatic species used as live feed organisms for aquaculture activities and number of reported programmes

Category	**Species**	**Number of programmes**
Rotifers	*Brachionus plicatilis*	11
	Brachionus rotundiformis	3
	Brachionus sp.	4
Artemia*	*Artemia salina*	4
	Artemia franciscana	1
	Artemia urmiana	1
Copepods	*Thermocyclops* sp.	1
Cladocerans	Cladocerans	1
	Daphnia moina	1
	Daphnia pulex	1
Microalgae	*Isochrysis galbana*	8
	Tetraselmis tetrahele	6
	Dunaliela tertiolecta	6
	Nannochloropsis oculata	6
	Chaetoceros gracilis	6
	Skeletonema costatum	6
	Nitzschia alba	6
	Chlorella vulgaris	6
	Chaetoceros lorenziano	1
	Chaetoceros compressus	1
	Chaetoceros debilis	1
	Chaetoceros socialis	1
	Chlorella sp.	5
	Dendrocephalus affinis	1
	Diaphanosoma sp.	1
Cyanobacteria	*Spirulina* sp.	3
Live fish	*Clarias anguillaris*	1
	Clarias gariepinus	1
	Oreochromis niloticus	2

*Lavans and Sorgeloos (1996) report uncertainty over the taxonomy of Artemia. They report the culture of additional species, including *Artemia parthenogenetica, A. tibetiana* and *A. sinica,* which were not reported in Country Reports and may have been included as *A. salina*. Issues on the culture of Artemia are dealt with in detail in the draft Thematic Background Study by Russel Hill, 2016: *Genetic resources of microorganisms of current and potential use in aquaculture*. Available at www.fao.org/3/a-bt491e.pdf.

5.5 *In vitro* collections identified in Country Reports

5.5.1 Overview

This section provides a global review of existing activities in *ex situ* conservation of AqGR of farmed species and their wild relatives *in vitro*.

Countries were asked to provide a detailed list of *in vitro* collections and gene banks of gametes, embryos, tissues, spores and other quiescent forms of farmed aquatic species and their wild relatives, using cryopreservation or other methods of long-term storage.

Countries were also requested to describe major examples, identifying the facilities in which the collections are held, and including examples of any such genetic material from the country that is being kept in *in vitro* collections outside the country on behalf of beneficiaries in country.

A total of 35 countries reported *in vitro* collections of aquatic genetic resources of both farmed and wild relatives. Countries reported 295 cases of aquatic species involving about 133 separate species being maintained in *in vitro* collections (Table 48).

However, this figure may be an underestimate, as it is not possible to determine the exact number of *in vitro* collections from the answers given by surveyed countries; several institutions and agencies are involved in maintaining these collections without specific monitoring from the government. The number and complexity of the *in vitro* conservation programmes often makes it difficult to list all the species being conserved. For example, in Norway, there are more than 1 000 isolates of marine bacteria being conserved *in vitro* in various institutes. The diversity of freshwater conservation programmes can also be too high to list all conserved species in the Country Report; in addition, Malaysia reported 73 aquatic species being conserved for future aquaculture uses, biodiversity conservation and other uses.

The country with the largest number of species being maintained *in vitro* collections is Malaysia, followed by India and Mexico.

Table 48
Countries and number of species maintained in *in vitro* collections

Country	Species	Country	Species
Malaysia	73	Bangladesh	4
India	34	Thailand	3
Mexico	30	Tunisia	3
Finland	29	Indonesia	2
Germany	14	Kiribati	2
United States of America	13	Republic of Korea	2
Uganda	11	Philippines	2
Argentina	10	Poland	2
Czechia	9	Tonga	2
Colombia	8	Ukraine	2
Turkey	7	Armenia	1
Egypt	6	Hungary	1
Senegal	6	Iran (Islamic Republic of)	1
Sri Lanka	6	Kenya	1
Netherlands	5	Nigeria	1
Palau	5		

Table 49 and Table 50 provide the absolute number and average numbers of species maintained per country by region and by economic class. Differences are observed between regions, with Asia maintaining the most *in vitro* collections and Latin America and the Caribbean maintaining the highest number of collections per country. The least developed countries had the lowest average number of *in vitro* collections, but the differences among the economic groupings were not large (Table 50). There were only small differences found in the average number of *in vitro* collections when countries were analysed by level of aquaculture production (data not shown).

Table 49
In vitro collections by region – total number of species maintained and average number of species maintained per country

Region	Species	Number of countries	Average species/country
Africa	28	6	4.7
Asia	135	10	13.5
Europe	63	7	9.0
Latin America & the Caribbean	56	3	18.7
North America	13	1	13.0
Oceania	10	4	2.5

Table 50
In vitro collections by economic class – total number of species maintained and average number of species maintained per country

Economic class	Species	Country	Average species/country
Developed Countries	78	10	7.8
Other Developing Countries	131	17	7.7
Least Developed Countries	23	4	5.75

5.5.2 Main species being conserved

Table 51 provides a summary of the 133 species being conserved in *in vitro* conservation programmes. Common carp (*Cyprinus carpio*) and rainbow trout (*Oncorhynchus mykiss*) were reported to be the species most often conserved *in vitro*. The assessment of these species shows that their principal use is for direct human consumption (data not shown).

Detailed information on the main objectives of the *ex situ* conservation programmes at global, subregional and by economic class levels is provided in section 5.6.

Table 51
Summary of species conserved in *in vitro* collections

Species name	N	Species name	N	Species name	N
Cyprinus carpio	6	*Clarias* catfish hybrid *(Clarias longifilis × C. gariepinus)*	1	*Ompok pabda*	1
Oncorhynchus mykiss	5	*Clarias batrachus*	1	*Oncorhynchus* sp.	1
Oreochromis niloticus	5	*Clarias gariepinus*	1	*Oncorhynchus tshawytscha*	1
***Artemia* sp.**	4	*Colossoma macropomum*	1	*Oreochromis* sp.	1
Isochrysis galbana	4	*Coregonus lavaretus*	1	*Pagrus pagrus*	1
Anguilla anguilla	3	*Coregonus maraena*	1	*Pangasianodon gigas*	1
Brachionus plicatilis	3	*Coregonus peled*	1	*Paralichthys californicus*	1
Catla catla	3	*Crassostrea gasar*	1	*Penaeus monodon*	1
Chaetoceros muelleri	3	*Crassostrea virginica*	1	*Penaeus vannamei*	1
Labeo rohita		*Ctenopharyngodon idellus*	1	*Perca flavescens*	1
Salmo salar	3	*Dicentrarchus labrax*	1	*Piaractus brachypomus*	1
Acipenseridae	2	*Eucheuma cottonii*	1	*Piaractus mesopotamicus*	1
Artemia salina	2	*Eucheuma striatus*	1	*Pleuronectes platessa*	1
Cirrhinus mrigala	2	*Epinephelus coioides*	1	*Polyprion americanus*	1
Crassostrea gigas	2	*Epinephelus malabaricus*	1	*Porphyra tenera*	1
Gadus morhua	2	*Etroplus suratensis*	1	*Prochilodus lineatus*	1
Huso huso	2	*Garra surendranathanii*	1	*Prochilodus* sp.	1
Pangasius pangasius	2	*Haliotis rufescens*	1	*Pseudoplatystoma corruscans*	1
Psetta maxima	2	*Heteropneustes fossilis*	1	*Pseudoplatystoma* sp.	1
Rachycentron canadum	2	*Horabagrus brachysoma*	1	*Rhamdia quelen*	1
Salmo trutta	2	*Hypophthalmichthys molitrix*	1	*Rhinomugil corsula*	1
Silurus glanis	2	*Hypophthalmichthys nobilis*	1	*Sahyadria chalakkudiensis*	1
Acipenser baerii	1	*Hypselobarbus curmuca*	1	*Salminus brasiliensis*	1
Acipenser fulvescens	1	*Ictalurus furcatus*	1	*Salmo ischchan*	1
Acipenser gueldenstaedtii	1	*Ictalurus punctatus*	1	*Sarotherodon melanotheron*	1
Acipenser oxyrhynchus	1	*Kappaphycus alvarezii*	1	*Schizothorax richardsonii*	1
Acipenser ruthenus	1	*Labeo calbasu*	1	*Sciaenops ocellatus*	1
Acipenser sturio	1	*Labeo dero*	1	*Seriola lalandi*	1
Acipenser stellatus	1	*Labeo dussumieri*	1	*Silonia silondia*	1
Anabas testudineus	1	*Labeo dyocheilus*	1	*Sorubim cuspicaudus*	1
Anoplopoma fimbria	1	*Labeo fimbriatus*	1	*Spirulina*	1
Bagrus docmak	1	*Labeo victorianus*	1	*Tenualosa ilisha*	1

Barbodes carnaticus	1	*Lates calcarifer*	1	*Tetraselmis* sp.	1
Barbus altianalis	1	*Lates niloticus*	1	*Tilapia guiniensis*	1
Brachionus	1	*Leiarius marmoratus*	1	Tilapia	1
Brycon moorei	1	*Leporinus obtusidens*	1	*Tinca tinca*	1
***Brycon* sp.**	1	Microalga	1	*Tor khudree*	1
Channa marulius	1	*Moina belli*	1	*Tor putitora*	1
Channa striata	1	*Morone chrysops*	1	*Totoaba macdonaldi*	1
Chelidonichthys cuculus	1	*Morone saxatilis*	1	*Undaria pinnatifida*	1
Chirostoma humboldtianum	1	*Mugil cephalus*	1	*Wallago attu*	1
Chitala chitala	1	*Mytilus edulis*	1		
***Chlorella* sp.**	1	*Nannochloropsis sp.*	1		
Chlorella vulgaris	1	*Odontesthes bonariensis*	1		
Cirrhinus cirrhosus	1	*Ompok malabaricus*	1		

Note: N = number of countries maintaining *in vitro* collections of the species.

5.5.3 *In vitro* conservation mechanisms

Countries were asked to provide information on the *in vitro* conservation mechanisms and strategies used for each species. Options given in the report for "type of *ex situ* conservation collection *in vitro*" were:

- *in vitro* collection of gametes;
- *in vitro* collection of embryos;
- *in vitro* collection of tissues;
- spores; and
- others.

As a result of this assessment, it was observed that (Table 52):

- gametes (almost exclusively male gametes) are the type most often conserved *in vitro*, with about 46 percent of species maintained in the form of gametes (mostly in the case of finfish species);
- twenty-five percent of the species are conserved as embryos (with a wide range of genera and species, including finfish, molluscs and crustaceans, e.g. *Artemia*, oysters and mullets);
- twenty-four percent of the species are conserved as tissues (mostly freshwater finfish species);
- only four percent are conserved in the form of spores (this methodology is mostly being applied in the case of microalgae used as live feed for aquaculture or conserved for research purposes); and
- fifteen percent of aquatic species are conserved in undefined other ways.

Table 52
Summary of the number of species being maintained by each mechanism, including the percentage out of 248 total *in vitro* collections reported

Mechanism	Number of collections	Proportion of all collections (percent)
In vitro collection of gametes	115	46
In vitro collection of embryos	25	10
In vitro collection of tissues	60	24
Others	37	15
Spores	11	4

5.5.4 *In vitro* conservation facilities

Countries were also asked to identify the type of facilities where AqGR are being conserved in *in vitro* conservation programmes.

The report provided the following options to surveyed countries:

- aquaculture facilities;
- research facilities;
- universities and academia;
- zoos and aquaria; and
- others.

Among the 133 aquatic species being conserved in 269 cases of *in vitro* conservation programmes, 56 are conserved in aquaculture facilities, 146 are conserved in research facilities, 59 are conserved in universities and academia, 2 are conserved in zoos and aquaria, and 6 are conserved in other types of facilities (Table 53).

Table 53
Summary of the number of species being maintained by each type of facility, including the percentage out of 269 total collections reported by countries

Type of facility	Number of collections	Proportion of total number of facilities (percent)
Aquaculture facilities	56	21
Research facilities	146	54
Universities and academia	59	22
Zoos and aquaria	2	1
Others	6	2

5.6 Global assessment of objectives of *ex situ* conservation programmes

Countries were requested to assess the level of importance of several objectives of *ex situ* conservation programmes (both *in vivo* and *in vitro)* in their respective countries (Table 54):

Objectives were ranked from one to ten, with one being a very important objective of the overall national *ex situ* conservation programmes and ten an unimportant objective. The most important objective for *ex situ* conservation at the global level was the “Preservation of aquatic genetic diversity” (Table 54), followed by the use of these resources to “Maintain good strains for aquaculture production” and for “Future strain improvement in aquaculture”. A less important objective of national *ex situ* conservation programmes at the global level was the need to maintain these resources “To help adapt to impacts of climate change”.

Analysis by region (Figure 73) revealed similar results with five of the six regions citing preservation of AqGR as the highest priority and four of the six citing adaptation to climate change as the least important objective. Meeting consumer demands was also listed as a relatively less important objective of *ex situ* conservation. Analysis by economic and production level (Figure 74 and Figure 75) revealed similar results.

Surprisingly, “Meet consumer and market demands” was reported to have a lower priority in countries that have the highest level of aquaculture production (Figure 75). However, this is a similar result to that reported for the priority objectives for *in situ* conservation (see Chapter 4). The low ranking of adapting to impacts of climate change was also seen in the rankings of objectives for *in situ* conservation.

Table 54
Ranking of objectives of *ex situ* conservation programmes

	1	2	3	4	5	6	7	8	9	10	Average rank
1. Preservation of aquatic genetic diversity	51	10	10	5	8				1	2	2.18
2. Maintain good strains for aquaculture production	45	10	12	6	4	1		1	4	4	2.70
3. Future strain improvement in aquaculture	33	19	13	7	5	2		4	2	2	2.82
4. To help adapt to impacts of climate change	20	10	9	9	15	5	4	4	7	4	4.26
5. Meet consumer and market demands	13	11	16	11	12	6	5	7	1	5	4.29
6. Other											2.33

Note: Column numbers are ranks with 1 = highest priority and 10 the lowest.

Figure 73
Priority rankings of objectives for *ex situ* conservation of aquatic genetic resources by region (see text for full explanation of objectives)

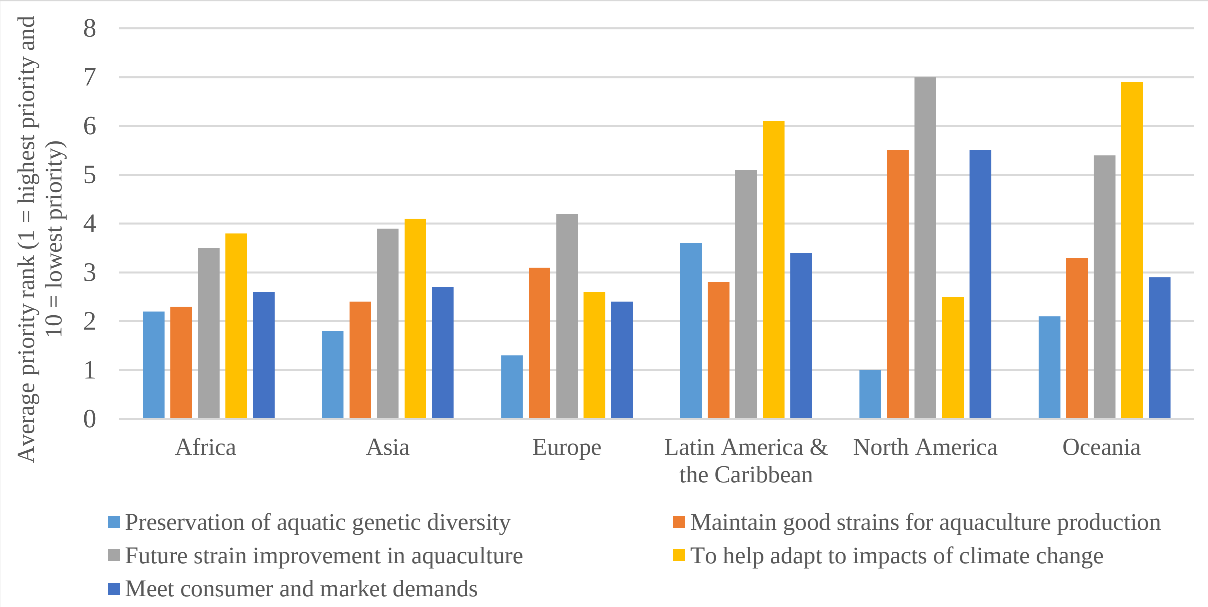


Figure 74
Priority rankings of objectives for *ex situ* conservation of aquatic genetic resources by economic classification (see text for full explanation of objectives)

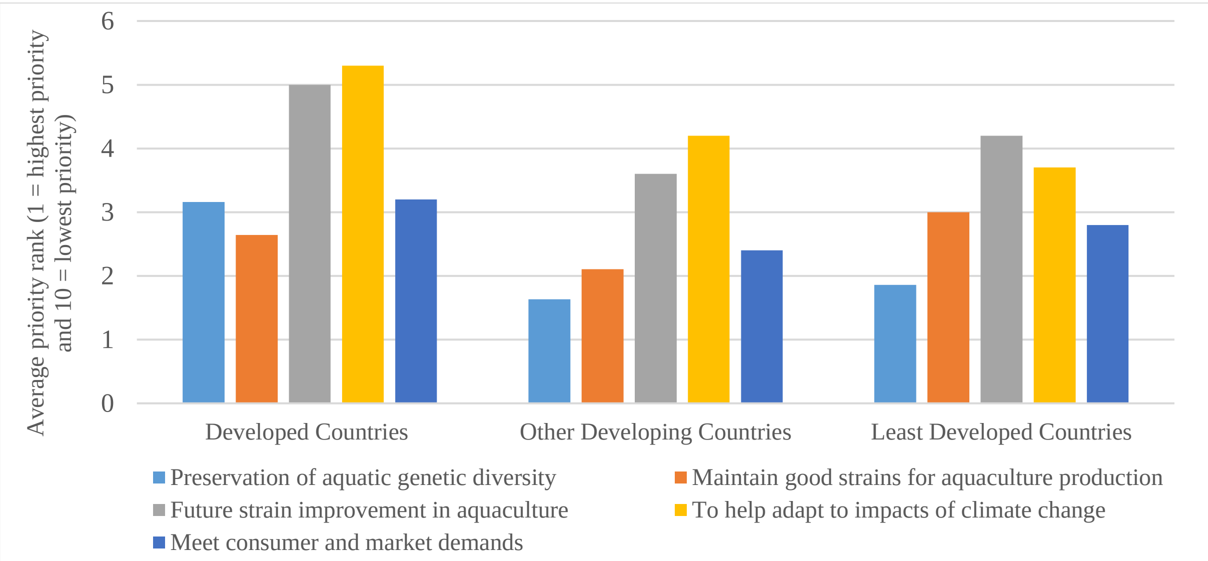
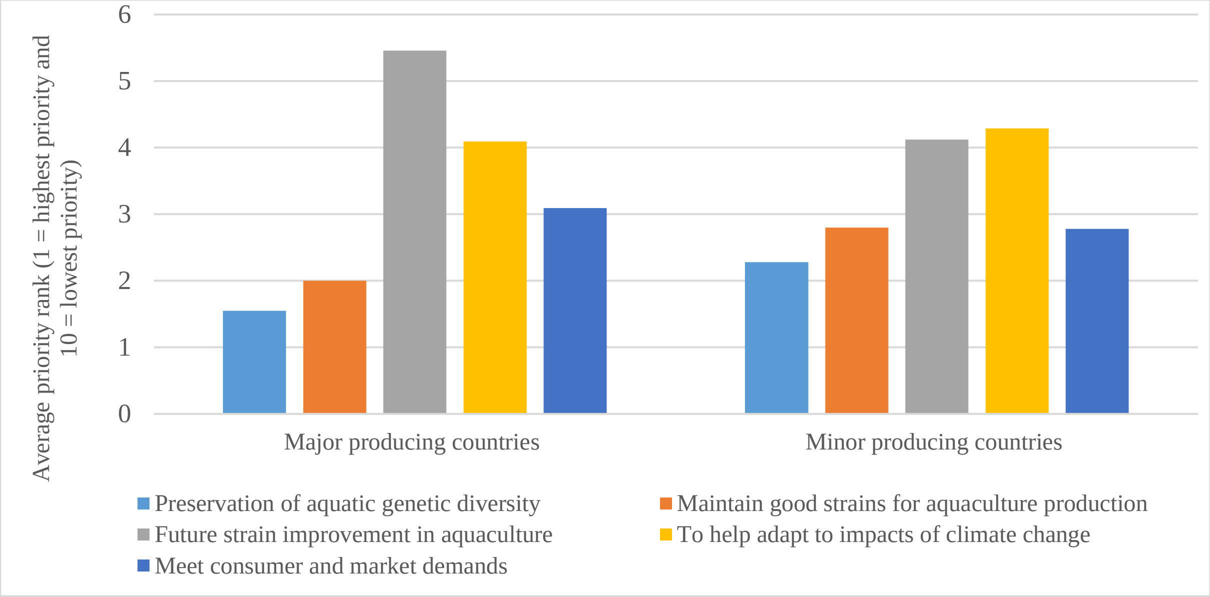


Figure 75
Priority rankings of objectives for *ex situ* conservation of aquatic genetic resources by level of aquaculture production (see text for full explanation of objectives)



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CHAPTER 6

STAKEHOLDERS WITH INTERESTS IN AQUATIC GENETIC RESOURCES OF FARMED AQUATIC SPECIES AND THEIR WILD RELATIVES WITHIN NATIONAL JURISDICTIONS

PURPOSE: Chapter 6 provides an overview of the perspectives and needs of the principal stakeholders with interests in aquatic genetic resources (AqGR) of farmed aquatic species and their wild relatives for food and agriculture within national jurisdictions. Specific objectives are to:

- identify the different principal stakeholder groups with interests in AqGR of farmed aquatic species and their wild relatives;
- identify the type(s) of AqGR of farmed aquatic species and their wild relatives in which each stakeholder group has interests and why;
- describe the roles of stakeholder groups and the actions they are taking for the sustainable management, development, conservation and use of the AqGR in which they have interests; and
- describe the actions that stakeholder groups would like to see taken for the sustainable management, development, conservation and use of the AqGR in which they have interest.

KEY MESSAGES:

- Through participatory regional workshops, 12 key stakeholder groups and 10 categories of activity were identified.
- Some differences were observed among regions in terms of how they viewed stakeholder participation in the conservation, management and use of AqGR of farmed species and their wild relatives.
- Numerous groups are considered as stakeholders in the sustainable management, development, conservation and use of AqGR. Government resource managers, fishing and aquaculture associations, and donors played the greatest roles in the conservation, management and use of AqGR, while consumers, people involved in marketing and fishers played lesser roles.
- Activities related to conservation, production and advocacy were the most common roles played by the 12 stakeholder groups.
- Stakeholder interests in conservation, management and use of AqGR were consistently greatest at the species level, followed by strain. There was relatively low interest in AqGR at the genome level.
- The importance of indigenous communities in conservation and protection of aquatic biodiversity and aquatic ecosystems of relevance for wild relatives of farmed aquatic genetic resources is recognized by nearly all countries.
- Women are important in the aquaculture sector in all countries, although the qualitative information provided suggests that they may play a wider range of roles in developed countries.
- Little information was provided on what stakeholder groups would like to see take place with respect to the conservation, management and use of AqGR.
- Continued work towards further clarifying the identification and roles of the many stakeholders in the conservation, management and use of AqGR will be important.

6.1 Background

Many stakeholders have an interest in the conservation, management, use and development of aquatic genetic resources (AqGR) of farmed aquatic species and their wild relatives, either because it comes within the ambit of their jobs or for livelihood and income-generating purposes. Yet, in specific terms little knowledge exists concerning where, specifically, these interests lie or what they entail. This section addresses the findings and knowledge gaps from analyses of a total of 91 national responses to the question "Please indicate the principal stakeholder groups with interests in AqGR".

6.2 Identification of stakeholders

Stakeholder groups were identified on the basis of institutional knowledge, as well as from sectoral and subsectoral consultations conducted during the country reporting process and, where necessary, from expert opinion. Gender issues pertaining to the conservation, management, use and development of AqGR of farmed aquatic species and their wild relatives are considered, as well as the perspectives and needs of indigenous peoples and local communities.

Multistakeholder workshops or meetings were convened in some countries to assess the involvement of different stakeholder groups in key areas associated with AqGR conservation, management, use and development. Most countries followed a participatory and inclusive strategy, involving a wide range of stakeholders with interests in AqGR, either through a national consultative process such as workshops or seminars or through the establishment of national committees or task forces composed of key players.

Some countries, such as Germany or Mexico, provided details on the consultative and participatory processes followed in the stakeholder assessment exercise, involving the aquaculture industry, hatchery managers, policy-makers and research/academia, among others.

6.3 Global level analysis of stakeholder roles

6.3.1 Introduction

Through the process of national consultation, supported by regional capacity-building workshops and advice, countries identified 12 stakeholder groups with interests in the conservation, management and use of AqGR of farmed species and their wild relatives (Table 55).

Table 55
Brief description of stakeholders in conservation, management and use of aquatic genetic resources, developed by the Secretariat from discussions at national consultations and at stakeholder workshops

Stakeholder	Description
Aquatic protected area managers	Persons responsible for controlling or administering protected areas of seas, oceans, rivers or lakes; these areas usually restrict human activity for a conservation purpose, typically to protect natural or cultural resources.
Consumers	A person who purchases goods and services (in this case related to aquatic genetic resources) for personal use.
Donors	Any individuals, organizations or institutions that make a gift.
Fish farmers	Professionals involved in raising aquatic organisms commercially by controlling the entire or parts of the aquatic organism's life cycle.
Fish hatchery people	Professionals involved in running and/or management of a place for breeding aquatic organisms, including hatching and rearing through their early life stages, with special emphasis on finfish and shellfish in particular.
Fishers	People who capture fish and other aquatic animals from a body of water.
Fisheries and aquaculture associations	Professional societies of fish farmers, fishers, or both, which are registered and legally recognized at national, regional or international levels.
Government resource managers	Managers working in the public sector who are responsible for management of natural resources.
IGOs	Intergovernmental organizations or international governmental organizations (IGOs) are composed primarily of sovereign states (referred to as member states) or of other IGOs.
NGOs	Non-governmental organizations (NGOs) include any non-profit, voluntary citizens' groups that are organized at local, national or international levels.
People involved in marketing	Professionals involved in the action or business of promoting and selling products or services related to aquatic genetic resources, including market research and advertising.
Policy-makers	People responsible for formulating policies and other types of regulatory frameworks and instruments.

For the purposes of the present exercise, ten roles (including "other") associated with the conservation, management and use of AqGR were also identified through the process of national consultation, supported by regional capacity-building workshops (Table 56).

Table 56
Brief description of roles in conservation, management, and use of aquatic genetic resources, developed by the Secretariat from discussions at national consultations and stakeholder workshops

Role	Definition
Advocacy	Individual or group activity that aims to influence decisions within political, economic and social systems and institutions
Breeding	Mating and reproduction of offspring by animals
Conservation	Preserving, guarding or protecting wise use
Feed manufacture	Production of aquaculture feeds from plant and animal-based feedstuffs
Marketing	Management process responsible for identifying, anticipating and satisfying customer requirements profitably[1]
Outreach/extension	Application of scientific research and new knowledge to aquaculture practices through farmer extension
Processing	Processes associated with aquatic animals and aquatic animal products between the time when they are caught or harvested and the time the final product is delivered to customers
Production	Elaboration of aquatic animal biomass in aquaculture systems through maintenance of good growing conditions and the provision of food
Research	Systematic investigation of scientific theories and hypotheses
Other	None of the above; largely undefined by countries in their responses

Source: www.CIM.co.uk.

[1]Definition from the Chartered Institute of Marketing.

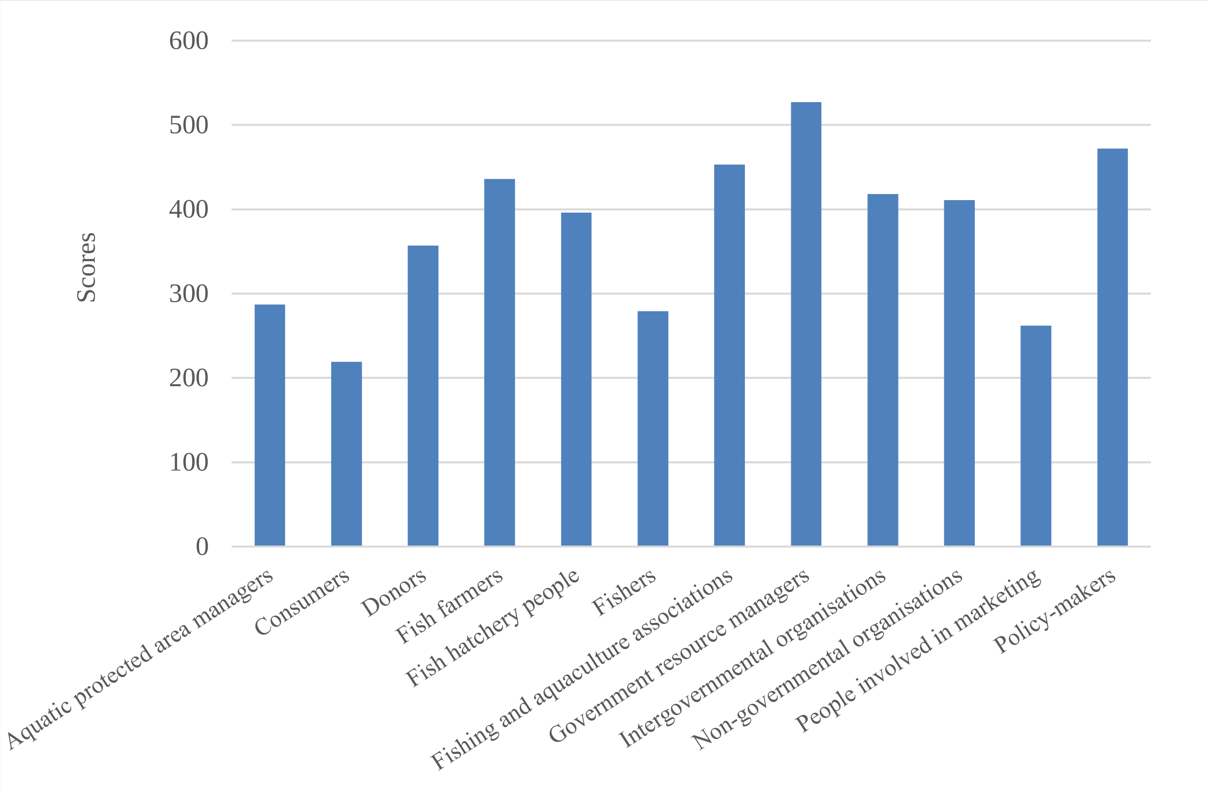
6.3.2 Roles of different stakeholder groups in the sustainable management, development, conservation and use of AqGR

In order to provide a simple global-level indicator of stakeholder activity in the conservation, management and use of AqGR, data were summed from the number of countries that found various stakeholder groups to be involved in each of the ten categories. Out of a possible maximum score of 1 092 (i.e. all 91 responding countries reported that all 12 stakeholder types are involved in a particular category of AqGR conservation, management or use), highest scores were found for conservation (681, equivalent to 62% of the maximum score), production (653, or 60%), and marketing (537, or 49%); lowest scores were found for processing (355, or 33%), feed manufacturing (262, or 24%), and other (65, or 6%) (Table 57).

An overview revealing the importance of the roles of each stakeholder group was developed by summing all scores submitted by all reporting countries for each of the ten categories associated with the conservation, management and use of AqGR. The highest score possibly attained by any stakeholder group would result if all countries (91) agreed that a particular stakeholder group was involved in all ten roles associated with the conservation, management and use of AqGR conservation, i.e. $91 \times 10 = 910$. The results show that government resource managers (527), fishing and aquaculture associations (453) and fish farmers (436) played the greatest roles, while consumers (219), people involved in marketing (262) and fishers (279), with approximately half the average scores of those that topped the rankings, were located at the bottom (see Figure 76 and Table 57).

In terms of the categories in which the majority of countries agreed the stakeholder played a role (i.e. > 50%), the highest score, at six out of ten categories, was accorded to fisheries and aquaculture organizations and government resource managers. There followed a cluster of three stakeholder groups – IGOs, non-governmental organizations (NGOs), policy-makers – whom the majority of countries reported played a role in half (i.e. five out of ten) of the different categories of AqGR conservation, management and use. The lowest scoring groups of stakeholders were people involved in marketing and consumers, whom the majority of countries assessed as playing a role in only one of the categories (Table 57). Examining the top- and bottom-scoring countries in Table 57 in more detail, it is apparent that both fisheries and aquaculture organizations and government resource managers were regarded as active in similar categories of AqGR; perhaps unsurprisingly, consumers were seen as only being active in marketing, as were people involved in marketing.

Figure 76
Total scores (number of responding countries × number of categories in the conservation, management and use of aquatic genetic resources of farmed species and their wild relatives) for each identified stakeholder group (see text)



Source: Data derived from Table 57.

If the results are ranked in terms of the top three stakeholders by category of AqGR conservation, management and use (Table 58), then fish farmers and fisheries and aquaculture organizations were assessed as playing the greatest number of roles (five out of ten categories), followed by policy-makers and people involved in marketing (four out of ten categories). Only consumers were not ranked in the top three of any category of AqGR conservation, management and use. Fishers also scored low.

Table 57
Roles of different stakeholder groups in the conservation, management and use of aquatic genetic resources of farmed species and their wild relatives, as determined by the global numbers (percentage) of all respondent countries that agreed on the particular role of a stakeholder

	Roles									
	Advocacy	**Breeding**	**Conservation**	**Feed manufacturing**	**Marketing**	**Outreach/ extension**	**Processing**	**Production**	**Research**	**Other**
Aquatic protected area managers	64 (70)	16 (18)	87 (96)	2 (2)	4 (4)	46 (50)	1 (1)	12 (13)	52 (57)	3 (3)
Consumers	30 (33)	5 (5)	21 (23)	3 (3)	51 (56)	16 (18)	38 (42)	37 (41)	4 (4)	14 (15)
Donors	47 (52)	34 (37)	59 (65)	18 (20)	27 (30)	43 (47)	22 (24)	41 (45)	54 (59)	12 (13)
Fish farmers	21 (23)	76 (84)	37 (41)	42 (46)	72 (79)	27 (30)	47 (52)	87 (96)	25 (27)	2 (2)
Fish hatchery operators	22 (24)	85 (93)	53 (58)	23 (25)	43 (47)	35 (38)	7 (8)	77 (85)	49 (54)	2 (2)
Fishers	23 (25)	7 (8)	48 (53)	5 (5)	57 (63)	17 (19)	42 (46)	64 (70)	11 (12)	5 (5)
Fisheries and aquaculture organizations	49 (54)	48 (53)	49 (54)	43 (47)	61 (67)	53 (58)	43 (47)	76 (84)	27 (30)	4 (4)
Government resource managers	67 (74)	58 (64)	85 (93)	32 (35)	37 (41)	70 (77)	30 (33)	69 (76)	76 (84)	3 (3)
IGOs	57 (63)	35 (38)	72 (79)	17 (19)	33 (38)	55 (60)	23 (25)	53 (58)	67 (74)	6 (7)
NGOs	64 (70)	34 (37)	77 (85)	20 (22)	31 (34)	59 (65)	21 (23)	51 (56)	51 (56)	3 (3)
People involved in marketing	23 (25)	16 (18)	9 (10)	20 (22)	78 (86)	29 (32)	42 (46)	30 (33)	13 (14)	2 (2)
Policy-makers	56 (62)	42 (46)	84 (92)	37 (41)	43 (47)	54 (59)	39 (43)	56 (62)	52 (57)	9 (10)
Total	523	456	681	262	537	504	355	653	481	65

Table 58
The three stakeholder groups with the greatest involvement in each category of conservation, management and use of aquatic genetic resources (AqGR), as judged from Country Reports (number of countries in parenthesis)

Roles in AqGR conservation	Top three stakeholders (number of countries reporting that the stakeholder plays a role)[1]	Total scores[2]
Advocacy	Government resource managers (67) Aquatic protected area managers (64) NGOs (64)	523
Breeding	Fish hatchery operators (85) Fish farmers (76) Government resource managers (58)	456
Conservation	Aquatic protected area managers (87) Government resource managers (85) Policy-makers (84)	681
Feed manufacturing	Fisheries and aquaculture organizations (43) Fish farmers (42) Policy-makers (37)	262
Marketing of AqGR	People involved in marketing (78) Fish farmers (72) Fisheries and aquaculture organizations (61)	537
Outreach/extension	Government resource managers (70) NGOs (59) IGOs (55)	504
Processing	Fish farmers (47) Fisheries and aquaculture organizations (43) Fishers (42) People involved in marketing (42)	355
Production	Fish farmers (87) Fish hatchery operators (77) Fishing and aquaculture organizations (76)	653
Research	Government resource managers (76) IGOs (67) Donors (54)	481
Other	Consumers (14) Donors (12) Policy-makers (9)	65

[1]Unless two categories of stakeholders have the same score.
[2]Sum of all countries that determined a stakeholder played a role in a particular aspect of AqGR conservation, management and use. Maximum score for each type of role = 91 (i.e. number of respondent countries) × 12 (number of stakeholder types) = 1 092; see text and Table 57.

6.4 Analysis of stakeholder roles by geographic region, economic class and level of aquaculture production

6.4.1 Introduction

Almost half of all countries in the world responded to the questionnaire, with between 40 percent and 100 percent of countries answering on a regional basis. The top 11 aquaculture-producing countries, responsible for approximately 96 percent of global production, responded to and are included in the analysis. The number of countries per economic class that responded was judged sufficient for the present analysis.

6.4.2 Stakeholder interest in aquatic genetic resources by geographic region

Few consistent inter-regional differences were found in terms of stakeholder interest in AqGR (Table 59). Interest in North America and Africa was somewhat higher than in the rest of the world.

Table 59
Interest of stakeholders (percentage of respondent countries that identified the category of stakeholder) in aquatic genetic resources by geographic region

	Africa	Asia	Europe	Latin America & the Caribbean	North America	Oceania
Aquatic protected area managers	37	35	27	26	40	23
Consumers	32	22	22	24	10	9
Donors	45	34	23	44	25	63
Fish farmers	57	39	49	42	75	44
Fish hatchery operators	46	34	42	52	40	43
Fishers	39	24	30	23	45	36
Fisheries and aquaculture organizations	62	46	54	38	50	33
Government resource managers	63	53	56	60	75	47
IGOs	54	42	36	42	30	64
NGOs	53	43	45	39	30	43
People involved in marketing	33	26	24	31	75	16
Policy-makers	60	47	70	35	75	29

6.4.3 Interest of stakeholders in types of aquatic genetic resources by economic class and by level of aquaculture production

Stakeholder interest in the conservation, management and use of AqGR of farmed and wild relatives was consistently high (69–88% of respondent countries) at the species level, the interest being greatest among fisheries and aquaculture associations (88%), closely followed by aquatic protected area managers, fishers, government resource managers and NGOs, all of whom attracted 87 percent of country responses (Table 60). At the strain level, respondent countries recorded lower and more variable interest among stakeholders (27–77%), with the greatest interest at this level being among fish hatchery operators (77%), fish farmers (75%) and government resource managers (74%). Interest among stakeholders in AqGR at the genome (DNA) level was lowest: 0–33 percent of respondent countries that acknowledged stakeholder interest, unsurprisingly, were lowest among consumers and fishers (Table 60).

In summary, interest in AqGR among stakeholders is greatest at the species level, lower at the level of the strain, stock or variety, and lowest at the genome level.

Table 60
Summary of type of aquatic genetic resources of interest to different stakeholders by number of respondent countries (maximum = 91) and percentage of total respondent countries (in parenthesis)

Stakeholder	Genetic resources of interest			
	Species	Strain, stock, variety	Genome	Other
Aquatic protected area managers	79 (87)	52 (57)	14 (15)	3 (3)
Consumers	76 (84)	25 (27)	1 (1)	4 (4)
Donors	63 (69)	45 (49)	19 (21)	12 (13)
Fish farmers	78 (86)	68 (75)	3 (3)	6 (7)
Fish hatchery operators	78 (86)	70 (77)	19 (21)	6 (7)
Fishers	79 (87)	35 (38)	0	1 (1)
Fisheries and aquaculture associations	80 (88)	55 (60)	6 (7)	5 (5)
Government resource managers	79 (87)	67 (74)	30 (33)	13 (14)
IGOs	72 (79)	52 (57)	19 (21)	7 (8)
NGOs	79 (87)	53 (58)	18 (20)	6 (7)
People involved in marketing	75 (82)	31 (34)	2 (2)	8 (9)
Policy-makers	78 (86)	56 (62	25 (27)	10 (11)
Total	916	609	156	81

The above pattern of interest in AqGR remained similar irrespective of economic class of country (Table 61) or status as an aquaculture-producing country (Table 62).

Table 61
Interest of different economic classes of country in aquatic genetic resources (AqGR), as determined across all stakeholder groups

Economic class of country	Countries that reported stakeholder interest (%)	AqGR of interest
Developed Countries	85	Species
	56	Strain, stock, variety
	17	Genome
Other Developing Countries	81	Species
	54	Strain, stock, variety
	12	Genome
Least Developed Countries	88	Species
	59	Strain, stock, variety
	17	Genome

Table 62
Interest in aquatic genetic resources (AqGR) of countries grouped by level of aquaculture production, as determined across all stakeholder groups

Level of aquaculture production	Countries that reported stakeholder interest (%)	AqGR of interest
Major producing countries	89	Species
	71	Strain, stock, variety
	30	Genome
Minor producing countries	83	Species
	54	Strain, stock, variety
	12	Genome

6.5 Indigenous and local communities

Individuals from indigenous and local communities in many parts of the world are employed by aquaculture businesses – hatcheries, fish farms, and as traders – as well as by the public sector and NGOs engaged in aquaculture or conservation of AqGR. In countries such as Indonesia or the Philippines, for example, small-scale hatcheries and aquaculture production is common among indigenous and local communities. The Tanzania Country Report reported on the involvement of communities not only in fingerling production, but also in aquaculture producer associations, in the marketing of fingerlings, and in the collection of wild relatives of farmed fish as broodstock.

With regard to the indigenous and local communities and their roles in the conservation, management and use of AqGR, of the 83 respondent countries, 70 provided details of their involvement in response to an open-ended question on the role of indigenous and local communities. A number of countries reported that while indigenous and local communities were involved in the conservation, management and use of AqGR, their specific roles were unknown (e.g. Argentina). Migrations occurring for reasons such as war can have an impact on coastal zones and associated AqGR (e.g. in El Salvador through increased fishing activity and access rights). However, from those countries providing details, it is apparent that indigenous and local communities in many countries are involved in a wide range of conservation and management activities. Some countries, such as Cambodia, indicate the importance of indigenous knowledge in the formulation of policies that protect AqGR. Others point to specific activities, such as helping enforce protection of marine protected areas and implementation of fishing regulations with respect to gear and fishing seasons (e.g. Sri Lanka). Other conservation and management activities include support of aquaculture-based fisheries (i.e. release into the wild of hatchery-reared juveniles in support of depleted fisheries, such as in South Africa). In countries such as Australia and the United States of America indigenous peoples have rights by law to the sustainable exploitation of AqGR.

No consistent differences in roles of communities are readily apparent between economic classes of country or geographic regions.

One example of the important role of indigenous communities in the conservation of genetic resources for food and agriculture at a national level is Brazil, which reported that:

> ⋯ indigenous and local communities' knowledge usually enables them to make sustainable use of natural resources. The relationships between such people and the environment pass on through generations and are an important source of information on the distinct uses of biodiversity. Fish and other aquatic organisms are not different. Long-term conservation of genetic resources rely mainly on aquatic environment preservation.

6.6 Gender

The Country Reports include responses to an open-ended question about the most important role of women with regard to AqGR. Only 8 percent of reporting countries omitted to mention gender; these omissions were unrelated to geography or country economic status (Table 63). While often pointing out that women make up a relatively small part of the agricultural labour force (e.g. Brazil, 13%; Bulgaria, 10%), the majority of the least developed and other developing countries mention the important role of women in the use of AqGR – in hatcheries, through harvesting, post-harvest, processing and marketing activities – directly related to the aquaculture and fisheries sectors. While many such countries omitted mention of the specific role of women in the conservation and management of AqGR, some did not (e.g. Bangladesh, Benin, Bhutan, the Philippines).

By contrast, the majority of developed countries indicated that, as in other economic activities, women are fully integrated in the aquaculture sector and play a crucial role at all levels and in all stages of the production chain, including broodstock management, seed production, grow-out, harvest, processing, research, academia and policy-making action. Specific mention was sometimes made of gender equality in law.

Some respondent countries pointed to their lack of knowledge of the role of women in conservation, management and use of AqGR. The Philippines, for example, has noted that:

> The participation of women before and after fish harvest in the aquaculture industry has been given little importance, leading to the near invisibility of women as contributors to this sector. However, these pre- and post-production activities are significant in terms of their economic and social value. These include: net mending, sorting fish upon landing, fish vending, trading and market retailing (handling the small-scale marketing that involves inexpensive fish varieties), processing and preservation (salting or drying) which are considered tasks for women.

Table 63
Reports of the roles of women in the conservation, management and use of aquatic genetic resources

Role	Country
No information provided	Algeria, Burkina Faso, Canada, Japan, Palau, Togo, Ukraine
All categories that men are involved in	Argentina, Australia,[1] Bulgaria,[3] Chile, China, Croatia, Cuba, Czechia, Dominican Republic, Ecuador, Estonia, Finland, Germany,[4] Guatemala, Kiribati, Republic of Korea, Latvia, Norway,[3] the Philippines, Romania,[3] Samoa, Slovenia, South Africa, Tonga, United States of America
Little (no other details)	Belize, Vanuatu[6]
Finance	Niger
Breeding and hatchery work	Armenia, Bangladesh, Chad, Georgia, Hungary, Indonesia, Senegal, Sri Lanka, United Republic of Tanzania
Farming	Bangladesh, Bhutan, El Salvador, India, Iran (Islamic Republic of), Kenya, Madagascar,[5] Mozambique, Paraguay, Senegal, Sri Lanka, United Republic of Tanzania
Post-harvest processing	Brazil,[3] Burundi, Cabo Verde, Cameroon, Democratic Republic of the Congo, Costa Rica, Cyprus, El Salvador, Georgia, Hungary, India, Kenya, Lao People's Democratic Republic, Malawi, Mexico, Morocco, Niger, Paraguay, Sierra Leone, Sri Lanka, Sudan, Uganda
Trading and marketing	Benin,[2] Bhutan, Burundi, Cabo Verde, Cameroon, Democratic Republic of the Congo, Cyprus, Egypt, El Salvador, Fiji, Georgia, Ghana, Honduras, Hungary, India, Indonesia, Kenya, Lao People's Democratic Republic, Malawi, Mexico, Morocco, Nicaragua, Niger, Paraguay, Peru, Sierra Leone, Sri Lanka, United Republic of Tanzania, Thailand, Uganda, Venezuela (Bolivarian Republic of), Zambia
Food preparation and consumption	Bangladesh, Cambodia
Shellfish collecting	Benin,[2] Morocco, Tunisia
Fishing	Cabo Verde
Fisheries management	Cabo Verde
Consultancy	Netherlands[3]
Professional organizations	Dominican Republic, Georgia, Morocco
Conservation	Burundi, Cabo Verde, Cameroon, Fiji, Honduras, Peru
Advocacy	Bhutan, Fiji
Non-governmental organizations	Georgia, Netherlands,[3] Panama
Education and extension	Honduras, Indonesia, Peru, Viet Nam
Policy-making	Honduras, Hungary, Mexico, Netherlands,[3] Panama, Peru
Research	Armenia, Fiji, Georgia, Honduras, Iran (Islamic Republic of), Malaysia, Mexico, Mozambique, Netherlands,[3] Panama, Peru, Venezuela (Bolivarian Republic of)

Note: Stakeholder roles were identified by the countries themselves and thus differ somewhat from those used elsewhere in the text.
[1] Women are involved especially in marketing and research; [2] women dominate in trading and marketing; [3] women play only a minor role in the sector; [4] women play a minor role in production; [5] women are involved especially in seaweed and sea cucumber production; [6] women's involvement needs to be improved.

6.7 Discussion and conclusions

6.7.1 Introduction

Analysis of the Country Reports in this chapter has identified some responses and recognized inter-country and regional differences that are sometimes difficult to explain. This warrants a closer consideration of the process of producing the first report on the *State of the World's Aquatic Genetic Resources for Food and Agriculture*, e.g. the design of the questionnaire, the terminology used and the overall process. With regard to collecting the data, it is thus worth reviewing what was done and how.

6.7.2 Terminology

The list of stakeholders assembled for the purposes of the present study is not exhaustive, but nonetheless is fairly comprehensive. Prior to implementation of the study, a regional stakeholder consultation workshop was held in Thailand, at which it was decided to merge some stakeholder types and to discard others. Arguably, the final list should have included scientists, regional fisheries management bodies and aquaculture networks – and indeed future consideration may wish to be given to the list of stakeholders used – although it remains debatable as to whether their roles are important or would change the overall picture.

Twelve stakeholder types were ultimately chosen. Some are relatively unambiguous; others, however, may be open to a degree of interpretation. For example, the regional stakeholder workshop in Thailand initially found it difficult to determine how the role of a "government resource manager" differed from that of a "policy-maker". Similarly open to interpretation are the various possible roles of stakeholders in the conservation, management and use of AqGR of farmed species and their wild relatives. Post hoc definitions are provided in Table 55 and Table 56; future studies may wish to include clear definitions of stakeholders.

All individuals consulted or directly involved in completing a country questionnaire belonged to at least two stakeholder groups. Everyone, for example, is a consumer; some fish farmers also own and operate their own hatcheries or processing facilities, while some fishers may also be aquaculturists. This should have helped foster an understanding of stakeholder roles and types of conservation, management and use of AqGR among respondents.

Excluding "other", nine types of AqGR conservation, management and use were distinguished for the purpose of this first attempt to capture stakeholder roles. Most are self-obvious (e.g. advocacy, breeding, conservation, marketing, outreach/extension, production, research), while two are not: feed manufacture and processing. In the absence of any other guidance, it is concluded here that the former refers to the use of wild fish in the form of fishmeal and fish oil; the fisheries that form the basis of these products are not always being sustainably managed. Similarly, processors of farmed aquatic species by definition use AqGR. Nevertheless, these two categories recorded the lowest scores, suggesting a degree of uncertainty among respondents.

The category "other", which was included both for AqGR conservation, management and use and for AqGR of interest to stakeholders, is something of a catch-all, with minimal purpose besides signaling that stakeholders had roles and interests in areas other than those included in the study.

However, little attention was paid to defining roles beyond the categories developed for the purposes of the present questionnaire, leaving exactly what stakeholders did in fulfillment of these roles being left open to interpretation. Take the issue of conservation of AqGR, for example. Almost 90 percent of responding countries believed policy-makers were involved in conservation of AqGR, although, as elsewhere, no supporting evidence is provided. It may simply have been assumed that policy-makers develop policies that conserve AqGR; but is this true, and are the assumptions supported by evidence? Are the conservation policies being implemented, and are they effective? The responses in Chapter 7 on national policies indicate that policies exist for AqGR at the species level; however, significant challenges exist in implementing and enforcing them. Several populations of wild relatives of farmed aquatic species are decreasing, indicating that in fact conservation policies are not working in many instances (see Chapter 2).

Fish farmers often also claim to be managing *ex situ* AqGR, but it is unclear if they are sufficiently knowledgeable to manage the resources in such a way that creates more productive farmed strains while effectively avoiding inbreeding. Various studies point to mismanagement of *ex situ* AqGR for aquaculture purposes as being the norm. Brummett, Agnoni and Pouomogne (2004), for example, demonstrated that the growth performance of African catfish (*Clarias gariepinus*) sourced from commercial hatcheries, where they had been derived from third or fourth generation fish taken from the wild, was inferior to that of fry obtained directly from wild broodstock, indicating poor hatchery

management of broodstock. Chapters 4 and 5 point out some of the problems with on-farm conservation of AqGR. In fact, the main goal of farmers is to produce a profitable farmed type; only a few farmers have the objective to "conserve" AqGR.

6.7.3 Country and regional responses

Ideally, all countries in all regions would have completed the questionnaire for this first analysis. This did not prove to be the case. However, more than 40 percent of countries in all regions did respond, with a response rate ranging from 41 percent (Oceania) to 100 percent (North America). Additionally, the proportion of countries within economic class at around 45 percent was reasonable and balanced. The top 11 aquaculture producing countries, accounting for approximately 96 percent of global production, also responded.

6.7.4 The roles of stakeholders in aquatic genetic resources conservation, management and use

At a global level, the results from the questionnaire show clear differences among stakeholders in terms of their roles – actual and perceived – in conservation, management and use of AqGR of farmed aquatic species and their wild relatives. According to the roles accorded by the responding countries, one-third of all stakeholders are seen as being involved in all of the roles associated with AqGR conservation, management and use.

The majority of responding countries concurred that fish farmers play roles in conservation, research, production, advocacy and extension. This result was also reported in Chapter 5 on *in situ* conservation. Leaving aside the issue of how exactly they implement these roles and whether or not they are effective, the results are not surprising. Some critics of aquaculture, for example in countries with wild stocks of Atlantic salmon (*Salmo salar*), might point to the conflicting roles of salmon farmers in both developing *ex situ* genetically improved strains, and, through the inadvertent introduction of feral farmed fish to the environment, increasing the risk of introgression of alien aquatic genetic material, with consequent effects on fitness (McGinnity *et al*., 2003). Similar points have been made elsewhere (Youngson *et al*., 2001; Lind, Brummett and Ponzoni, 2012; Lorenzen, Beveridge and Mangel, 2012).

6.7.5 Genetic resources of interest

The results here contained few surprises regarding the role of stakeholders in different types of conservation, management and use of AqGR of farmed species and their wild relatives. The most striking result is that interest among stakeholders still resides primarily at the species level. And yet the results from the questionnaires also provide some interesting insights. Fish farmers and hatchery operators, for example, are seen as being especially interested in AqGR at the strain level. However, only a few aquaculture subsectors – most notably salmon and tilapia farmers – currently have access to such varieties (Olesen *et al*., 2007); many fish farmers remain unaware of the impact of genetically improved strains on production, growth and profitability. Similarly, few stakeholders are yet interested in AqGR at the genome level. Interest at this level can be expected to increase as the importance of marker-assisted selection and of the importance of conserving genetic diversity of AqGR at the population level in the wild becomes more apparent.

6.7.6 Indigenous and local communities and gender

The reports from respondent countries indicated some confusion as to what information was being sought in these open-ended questions in the questionnaire. Others may have thought this section of the

questionnaire irrelevant, as they had no indigenous communities (e.g. five of the developed European countries), failing to notice that information on local communities was also sought. Some respondents limited details to the employment of individuals from such communities in hatcheries and fish farms. Answers were also often vague, explicitly or implicitly indicating that while the respondents were sure that indigenous and local communities played a role in the conservation, management and use of AqGR, they were not entirely sure what that role was (e.g. the communities " ... conserved genetic resources in bodies of water adjacent to [their] community;" or were engaged in "conservation activities"). Nevertheless, it was also apparent that indigenous and local communities were actively engaged in enforcing regulations on destructive fishing gear and maintenance of marine protected areas.

Women seem to have been comprehensively engaged in all activities related to the conservation, management and use of AqGR. The developed countries mentioned a wider range of activities than developing countries; other developing countries may reflect the real situation or may not have fully addressed the questions asked.

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CHAPTER 7

NATIONAL POLICIES AND LEGISLATION FOR AQUATIC GENETIC RESOURCES OF FARMED AQUATIC SPECIES AND THEIR WILD RELATIVES WITHIN NATIONAL JURISDICTION

PURPOSE: The purpose of Chapter 7 is to review the status and adequacy of national policies and legislation, including access and benefit sharing, concerning aquatic genetic resources (AqGR) of farmed aquatic species and their wild relatives. The specific objectives are:

- to describe the existing national policy and legal framework for the conservation, sustainable use and development of AqGR of farmed aquatic species and their wild relatives;
- to review current national policies and instruments for access to AqGR of farmed aquatic species and their wild relatives and the fair and equitable sharing of benefits arising from their utilization; and
- to identify any significant gaps in policies and legislation concerning AqGR of farmed aquatic species and their wild relatives.

KEY MESSAGES:

- There is a large range of policies relevant to AqGR for food and agriculture because their management encompasses farming, fishing, breeding and conserving aquatic species.
- Lack of awareness of national policies and lack of technical capacity and insufficient resources were identified as key gaps in effective policy implementation; other gaps in policy concerned transboundary watercourses, import and export of AqGR, long-term aquaculture development, breeding and genetic manipulation, climate change, objective evaluation of policy efficacy, financial subsidies to implement policies, and ownership and harmonization of policies.
- Numerous national policies exist, but there are gaps in national policies with reference to how they impact on genetic resources when these are considered below the level of species.
- Policies also include fisheries management, fishing closures, and restrictions on import/export of a variety of types of AqGR.
- Monitoring and enforcement of national policies are often constrained by lack of human and financial resources.
- Access and benefit-sharing regimes will be different for AqGR than for genetic resources of other sectors of agriculture.
- Genetic improvement of farmed aquatic species is often done by large companies or international institutions with modern breeding facilities, and in areas outside of the centre of origin for many species, rather than by rural farmers. Thus, some aspects of “farmers’ rights” meant to recognize and reward rural farmers for their past, present and future contributions to the development and conservation of genetic resources are less relevant to aquaculture than to other sectors of agriculture.
- Countries have taken steps to facilitate access to AqGR that address primarily access to living specimens.
- Countries have encountered obstacles in accessing or importing AqGR, primarily resulting from their own restrictive national legislation.

7.1 Introduction

The Code of Conduct for Responsible Fisheries (CCRF) of the Food and Agriculture Organization of the United Nations (FAO) lays out a series of guiding principles and recommendations on which to base national legislation and policy (FAO, 1995). The CCRF was adopted by the FAO Council in 1995 and includes sections on fishery management, fishing operations, coastal area management, aquaculture

development, post-harvest and trade, international cooperation and research; there are articles on the special needs of developing countries. Whereas each biennium Country Reports to the FAO Committee on Fisheries (COFI) regarding its progress on implementation of the CCRF, rarely have countries specifically reported on AqGR below the species level.

The Thirty-first Session of COFI established the Advisory Working Group on Aquatic Genetic Resources and Technologies (COFI AWG AqGR/T) in order to advise FAO and increase international cooperation on AqGR. The COFI AWG AqGR/T developed a framework (FAO, 2016) to assist countries in managing their AqGR, noting that often it is the lack of specific guidance on a range of issues that constrains effective use and conservation of AqGR (Box 18).

Box 18

Framework of minimum requirements for sustainable management, development, conservation and use of aquatic genetic resources[1]

The Framework contains five main components: (i) information and databases; (ii) governance, policy and planning; (iii) infrastructure and equipment; (iv) capacity building and training; and (v) enabling the private sector.

The information and databases component calls for:

(i) Information on aquatic genetic resources (AqGR):
  a. directory of species, including non-native species, farmed in-country with standard names and terminology
  b. inventory or directory of native and non-native AqGR and their distribution
  c. list and map of significant native AqGR to be protected

(ii) Information on genetic technologies:
  a. directory of acceptable technologies and any restrictions on their use

(iii) Information on the impacts AqGR have on society and the environment:
  a. monitoring programme on which farms (and how many) are using a specific farm type
  b. monitoring programme on impact of farm type on human well-being
  c. monitoring programme on impact of farm type on the environment

(iv) General information:
  a. directory of laboratories, institutions and centres of excellence working on AqGR
  b. communication plan for dissemination of information to stakeholders and the public
  c. single easily accessible database or information system on AqGR, including the above elements
  d. authoritative glossary of technologies and concepts

The governance, policy and planning component calls for:

(i) Designation of competent authority to manage and oversee AqGR
(ii) Authoritative national policy instrument
(iii) Inclusion of AqGR in national aquaculture strategy and/or development plan
(iv) Inclusion of AqGR in aquaculture management policy
(v) Comprehensive guidelines on AqGR development and management, including zoning for aquaculture and AqGR use
(vi) Enforcement strategies
(vii) Human well-being:
  a. adoption of international instruments on governance, tenure and human rights into national legislation
  b. a national agency for oversight of food safety and quality
(viii) Facilitation of permitting and reporting system for private industry and research sector (academic and government)
(ix) Link to regional and international countries and/or entities for harmonization of policies and practices and for improved management of shared AqGR
(x) Effective and transparent engagement between government departments, private industry and other stakeholders for, among other things, exchange of policy and technical information

The infrastructure and equipment component calls for:

(i) A plan for the development, use and maintenance of all infrastructure, taking into account partnerships and economies of scale
(ii) Access to broodstock development and management facilities[2]
(iii) Access to biosecure facility(ies) for genetic management and/or genetic improvement of aquacultured species, including effective marking/tagging/identification
(iv) Access to multiplication and dissemination centres for genetically improved strains
(v) Access to genetic characterization and diagnostic laboratories
(vi) Quarantine and veterinary facilities
(vii) Research, extension and training centres

The component on enabling the private sector calls for:

(i) Putting in place policies and practices that create an enabling environment for the aquaculture industry
(ii) Having an aquaculture development plan that provides clear guidance for the industry
(iii) Establishing an effective extension service from government or academic extension agencies, or from international agencies in the absence of national services
(iv) Establishing a forum for industry to be involved in government decision and policy-making

Capacity building is needed on all of the above components and would be facilitated by effective extension services.

[1]The Framework was developed by FAO and further revised through the workshop SADC-WORLDFISH-FAO Platform for Genetics in Aquaculture and Validation of the FAO "Framework on Sustainable Use, Management and Conservation of Aquatic Genetic Resources for Aquaculture", 25–29 September 2017, in Lusaka, Zambia, and by the COFI Advisory Working Group on Aquatic Genetic Resources and Technologies at their Second Session in Rome. In addition to the members of the COFI Advisory Working Group, the following people contributed to this final version of the Framework: D.M. Bartley, M. Halwart, Z. Jeney, K.K. Lal, D. Lucente and A. Stankus. The Government of Germany support for the development of the Framework is greatly appreciated.

[2]In consideration of partnerships with facilities in other countries and taking advantage of economies of scale, it may not be necessary to have all infrastructure developed in a country as long as the country has "access to" the infrastructure. Where AqGR are being imported from another country, quarantine and biosecure facilities will be necessary in-country.

Because AqGR encompass farming, breeding, fishing and conserving aquatic species, the range of policies relevant to its management is extremely vast. National legislation governing AqGR is generally lacking at the genetic level in most parts of the world (Pullin, Bartley and Kooiman, 1999). Policies are better developed at the species level in capture fisheries and aquaculture, such as for setting catch limits and seasons for capture fisheries (FAO, 2003), or for allowing the import/export of certain species considered to be invasive (Bartley and Halwart, 2006).

Often, ministries and policies promoting fishery and aquaculture development, e.g. the use and exchange of AqGR, are in conflict with those promoting conservation (see Chapter 3); the use of non-native species is one example. The terrestrial agriculture sector is largely based on non-native species that were domesticated thousands of years ago and moved around the world with little regard for environmental risks. The relatively recent development of aquaculture and the domestication of aquatic species are occurring within a background of environmental awareness and an existing food production sector (Bartley *et al.*, 2007). Therefore, a much more restrictive policy environment exists today for development and use of AqGR than existed during the development and transfer of terrestrial genetic resources.

The precautionary approach (FAO, 1996), including environmental impact assessments and risk analyses, provides a means to balance the risk/benefit of proposed development actions (Arthur *et al.*, 2009). These approaches are sometimes incorporated into national policy and allow the

development of aquaculture and AqGR with due regard for the environment and biodiversity.

Recommendations have been made stating that policies and legislation should be decentralized to the extent possible to take into consideration the needs and capacities of local communities. However, local practices may often be inconsistent with international treaties or instruments (Chapter 8; Barlow, 2016). For example, local trade of species listed on the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)[1] appendices would be legal within a country, but would require special permits if the species were to be traded internationally.

This chapter reviews the status and adequacy of national policies and legislation on AqGR. Access to and the sharing of benefits derived from the use of AqGR are also presented.

7.2 Overview of national policies and legislation

The majority of Country Reports were submitted by signatories to the Convention on Biological Diversity (CBD). Under that convention, countries are required to develop National Biodiversity Strategic Action Plans (NBSAP).[2] The emphasis of the NBSAP is primarily on the species level for aquatic organisms. Other national legislation contains opportunities for protecting genetically distinct segments of a species that are of special evolutionary importance (Box 19).

Box 19
Conservation of aquatic genetic resources below the species level

Whereas national legislation on conservation is usually directed at the species, in the United States of America, the Endangered Species Act (ESA) recognized genetically important stocks of Pacific salmon as a "species" and therefore eligible for protection under the act. Under the ESA, a species, subspecies or a distinct population segment (DPS) may be listed as threatened or endangered. Numerous stocks of Pacific salmon and steelhead (*Oncorhynchus* sp.) on the west coast of North America have substantially declined and are at a fraction of their historical abundance. Reasons for these declines include excess fishing effort, loss of critical habitat, hydropower facilities, ocean conditions, and fish hatchery practices. As a result, the National Marine Fisheries Service (NMFS) listed 28 stocks of salmon and steelhead in California, Idaho, Oregon and Washington as "endangered species" under the ESA.

According to United States federal policy guidance: "populations of salmon substantially reproductively isolated from other conspecific populations and representing an important component in the evolutionary legacy of the biological species are considered to be an ESU [evolutionarily significant unit]." Some Pacific salmon populations under the ESA would be treated as an ESU and a DPS, and hence a "species" eligible for protection.

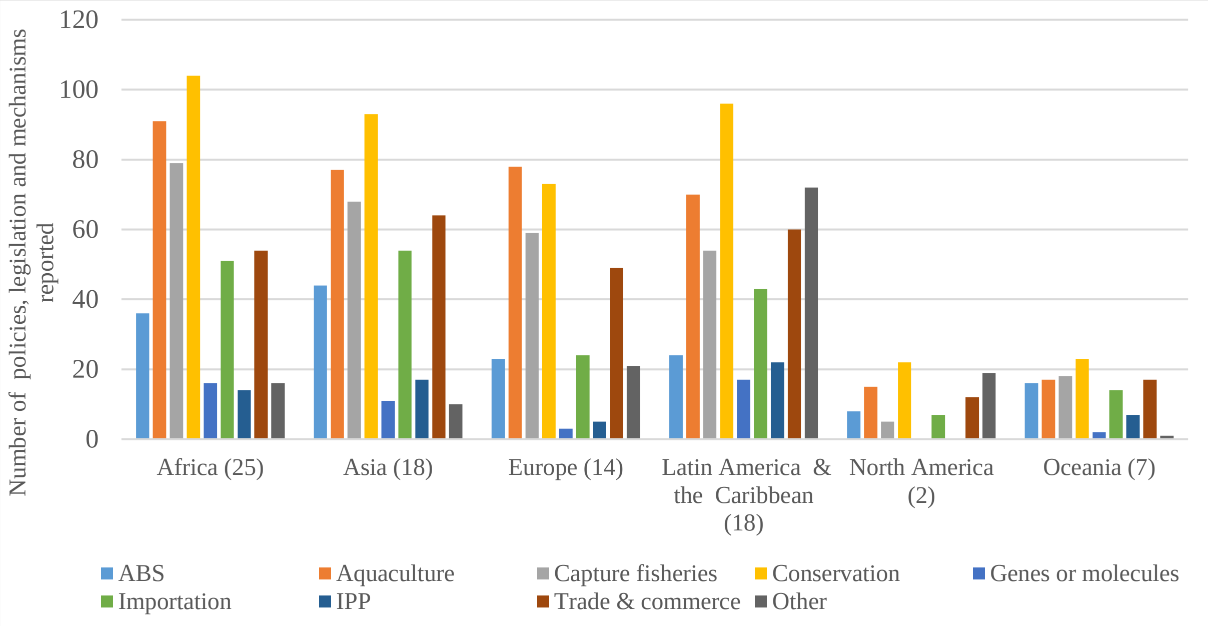
Source: www.nmfs.noaa.gov/pr/pdfs/species/sacramentoriver_winterrunchinook_5yearreview.pdf.

Countries reported a total of 619 policies and legislation that address AqGR for food and agriculture (Figure 77). Many countries have fishery management plans that regulate the time and quantity of fishing activities. The Philippines, for example, lists several national policies regulating the use of amphibians, fish and shellfish. Globally, most policies are primarily aimed at the species level; however, there are examples of policies directed below the species level (see example from the United States of America in Box 19).

[1] See www.cites.org.
[2] National Biodiversity Strategic Action Plans: www.cbd.int.

Figure 77

Scope of national policies (number of countries in region)



Note: ABS = access and benefit sharing; IPP = intellectual property protection.

Several countries reported that lack of awareness of national policies, lack of technical capacity and insufficient resources are key gaps in effective policy implementation. A fundamental challenge is that often the majority of legislation does not specifically refer to AqGR, but rather to biodiversity at the habitat and species level. Conservation of aquatic resources *per se* is implied in legislation and its implementation, but is rarely explicit, even in legislation for conservation and marine protected areas. As a result, there is little if any monitoring of AqGR below the species level other than on specific research and development projects (e.g. as reported for Australia and Morocco).

Other policy gaps were identified, including:

- transboundary watercourses (Bangladesh, Thailand);
- policies on import and export of AqGR (Uganda);
- lack of long-term aquaculture development policies (Colombia);
- lack of policies on breeding and genetic manipulation (Bulgaria);
- out-of-date policies that do not address modern genetics (Mozambique, Panama);
- lack of policies dealing with climate change (Egypt);
- lack of objective evaluation mechanisms of institutional programmes implemented (Mexico);
- lack of financial subsidies to help develop the sector (Romania);
- unclear ownership of genetic resources (Senegal); and
- lack of mechanism to harmonize legislation (Zambia).

Additionally, countries reported that significant problems in monitoring and enforcing national polices arose from lack of human resources and finances. In countries with extensive wetlands and coastal areas (e.g. Brazil, Indonesia), "monitoring of environmental laws to protect genetic resources is a difficult task" (Brazil).

7.3 Access and benefit-sharing policies

The international community has adopted the Nagoya Protocol a 2010 supplementary agreement to the 1992 Convention on Biological Diversity (CBD).[3] The Protocol's objective is the fair and equitable sharing of benefits arising from the utilization of genetic resources, and thereby contributing to the conservation and sustainable use of biodiversity. The concept of "farmers' rights" also addressed benefit sharing. Farmers' rights refer to the rights arising from past, present and future contributions of farmers in conserving, improving and making available plant genetic resources, particularly those in the centres of origin/diversity. These rights are recognized internationally, based upon the understanding that farmers have the right to be rewarded for their contribution to conservation and further development of plant genetic resources.[4]

Access to AqGR and the sharing of benefits derived from their use present special considerations in aquaculture and fisheries. Unlike plant breeding where domestication and stewardship of improved varieties often resulted from farmers using and improving genetic resources over millennia, the domestication and genetic improvement of many commercial aquatic species did not take place in centres of origin, or as the result of the efforts of local aquaculturists (Bartley *et al.*, 2009). Often genetic improvement of AqGR was the result of large-scale private industry with advanced breeding programmes.

For example, the establishment of the strain of Specific Pathogen Resistant shrimp took place in a biosecure part of the Hawaiian Islands (United States of America); genetic improvement of the Pacific oyster, native to Japan, took place in North America, Australia and New Zealand; the genetic improvement of a tilapia native to Africa took place in the Philippines (Bartley *et al.*, 2009). Thus, some aspects of farmers' rights that refer to rural people maintaining and developing local genetic resources over hundreds of generations in centres of origin (Andersen and Winge, 2003) are less relevant to aquaculture than to other sectors of agriculture.

7.3.1 Principles guiding access to aquatic genetic resources

Principles have been established in some areas to guide access to native genetic resources. Key principles regarding access include prior informed consent and clearly defined benefit arrangements. Though not specifically addressing AqGR, a well-known example of a bilateral access and benefit-sharing (ABS) agreement concerns Costa Rica and the international pharmaceutical company Merck. Guiding principles to promote access to native biodiversity in Costa Rica included:

- genetic resources access permits;
- registration of interested parties;
- access request; and
- formulation and management of their prior informed consent agreement between providers and stakeholders (Coughlin, 1993).

The arrangement between Costa Rica and Merck may not be reproducible in many areas; it relies on a strong financial partner (Merck). Many groups wishing to access AqGR are not as wealthy as Merck. After the Merck/Costa Rica case, the international community has adopted the Nagoya Protocol (see Chapter 9) to help promote the fair and equitable sharing of benefits arising from the utilization of genetic resources. This protocol contributes to the conservation and sustainable use of biodiversity,

[3] www.cbd.int/abs.
[4] www.fao.org/plant-treaty/areas-of-work/farmers-rights/en.

establishing more predictable conditions for access to genetic resources and helping to ensure benefit sharing when genetic resources leave the contracting Party that provides the genetic resources.

Material Transfer Agreements (MTA) have also been established on a case-by-case basis that outline the general conditions and obligations associated with accessing genetic resources. The WorldFish Center of the CGIAR (formerly the Consultative Group for International Agricultural Research) required MTAs before distributing their genetically improved farmed tilapia (Box 20). These principles and obligations have been promoted by FAO (Bartley *et al.*, 2008) and would apply regardless of whether the entity seeking the genetic resource was national or foreign.[5]

Box 20: Indicative elements of Material Transfer Agreements for accessing aquatic genetic resources

A country planning to import new or exotic species has to sign a Material Transfer Agreement (MTA), which states that the recipient agrees to:

- abide by the provisions of the Convention on Biological Diversity and the FAO Code of Conduct for Responsible Fisheries;
- preclude further distribution of germplasm to locations at which it could have adverse environmental impact;
- not claim ownership over the material received, nor seek intellectual property rights over the germplasm or related information;
- ensure that any subsequent person or institution to whom they make samples of germplasm available is bound by the same provision;
- comply with the country's biosafety and import regulations and any of the recipient country's rules governing the release of genetic materials;
- follow quarantine protocols; and
- abide by international guidelines in case germplasm is transferred beyond the boundaries of the country[1] (see Chapter 8).

Source: WorldFish Center: www.worldfishcenter.org; Bartley *et al.*, 2008.
[1]www.fao.org/nr/cgrfa/cgrfa-global/cgrfa-codes/en.

7.3.2 Facilitating and restricting access to aquatic genetic resources

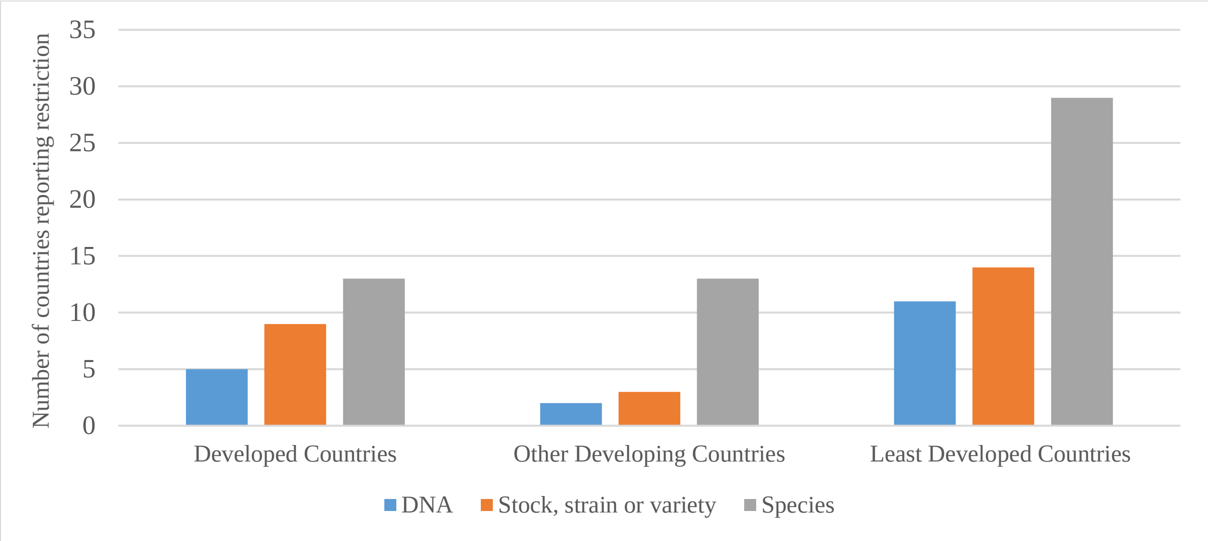
Countries have sovereign rights to determine access to AqGR. At the genome, stock/strain and species levels, there was a complete range in level of restrictions reported, from no restriction to severe restriction. For example, in Germany, there is no legislation restricting access to genetic resources in line with CBD Article 15 or the Nagoya Protocol.[6] Whereas for Malawi, there is highly restricted access unless national approval is obtained.

Certain countries identified individual species where access was restricted, e.g. Thailand restricts access to *Botia sidthimunki*, *Probarbus jullieni*, *Catlocarpio siamensis*, *Scleropages formosus*, *Pangasianodon gigas*, and *Datnioides microlepis* (several of these species are on CITES Appendix 1 and international trade would be restricted as well).

Species was the most often cited level of AqGR for which restrictions were put in place (Figure 78). This trend was also seen when countries were grouped by region and by level of aquaculture production. There was no important difference seen among country groupings, e.g. major producing countries did not restrict access any more than minor producing countries.

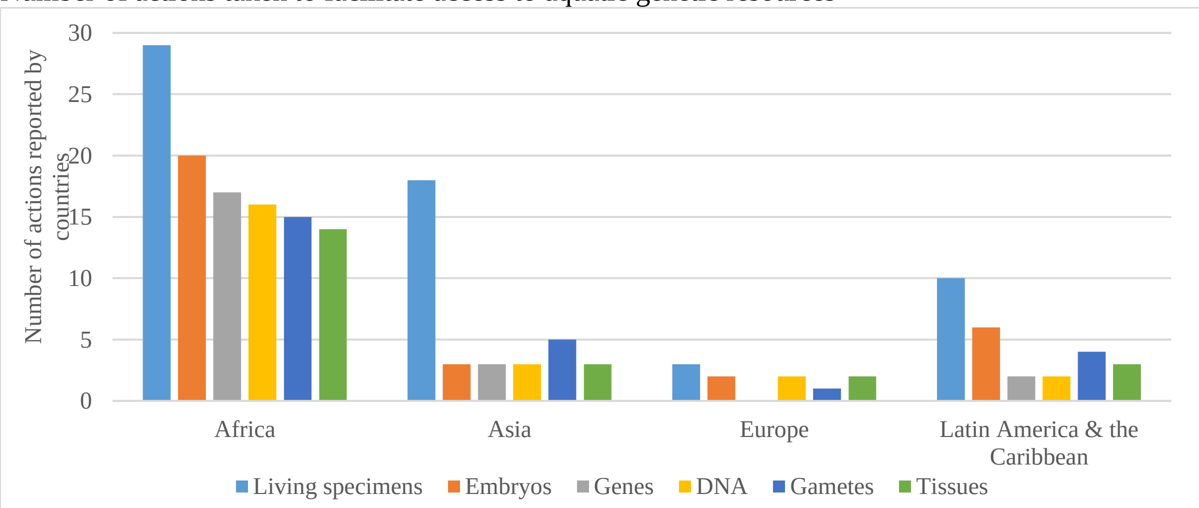
[5] https://www.cbd.int/abs/doc/protocol/nagoya-protocol-en.pdf.
[6] Nagoya Protocol: www.cbd.int/abs.

Figure 78
Types of aquatic genetic resources for which countries have restricted access



Whereas access to AqGR has been restricted in some instances, countries do report actions taken to facilitate their access to AqGR from other countries (Figure 79). Overall, living specimens were the group of organisms reported where access was most often facilitated. This trend was similar when countries were grouped by region, economic class and level of aquaculture production (data not shown). However, in Asia there was more facilitation of access to embryos (Figure 79).

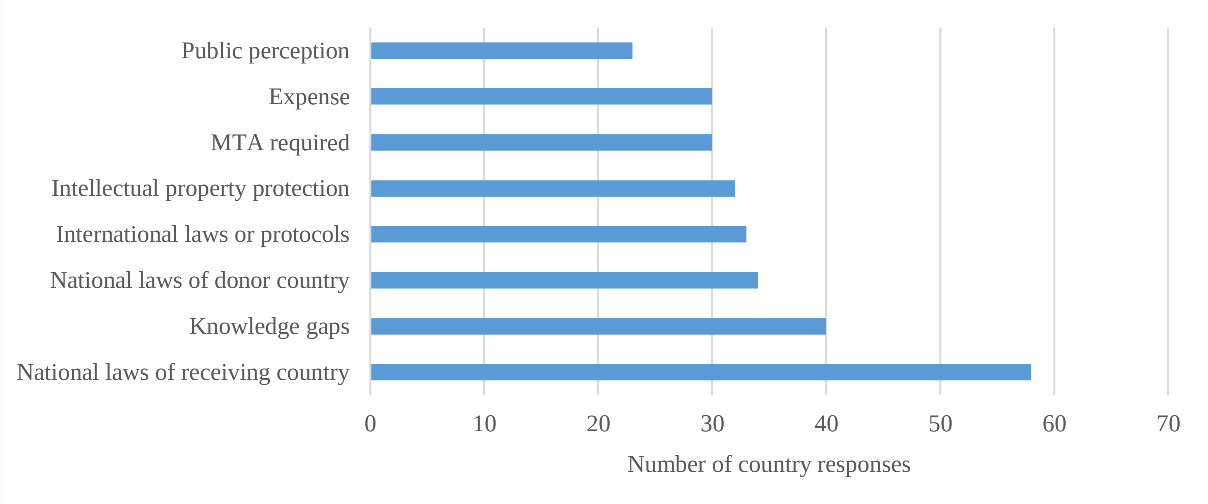
Figure 79
Number of actions taken to facilitate access to aquatic genetic resources



7.3.3 Obstacles to accessing aquatic genetic resources

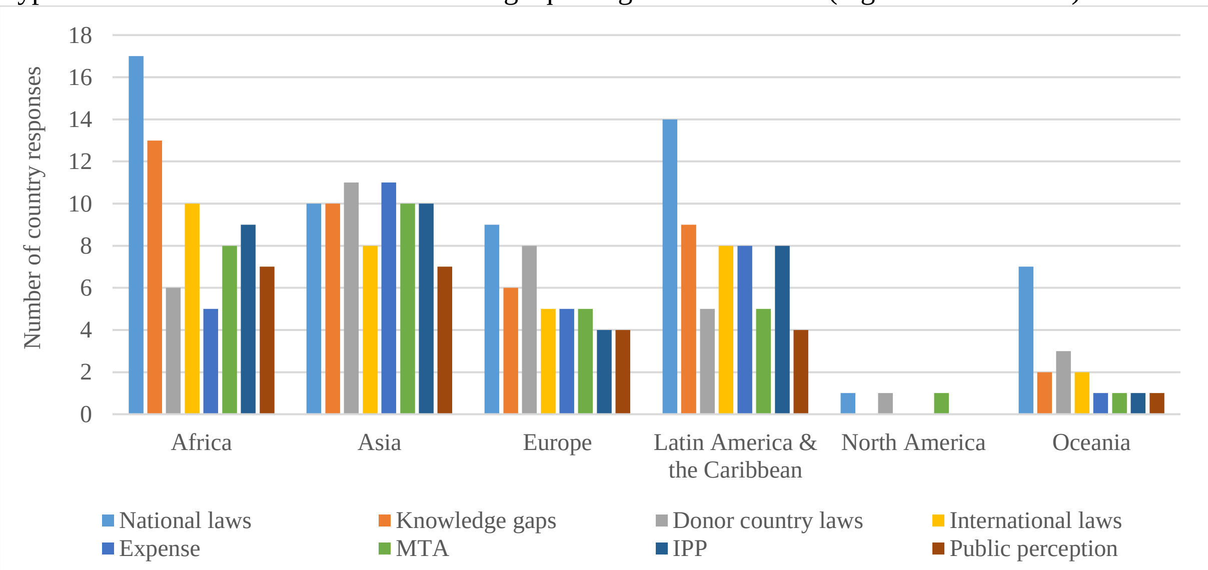
Countries seeking to access AqGR have also encountered obstacles. The most widely reported obstacle was national legislation in the receiving country; however, legislation in exporting country was also seen as an obstacle (Figure 80). National legislation can include, *inter alia*, access and benefit-sharing, but the questionnaire does not allow further resolution of the specific type of legislation. Lack of knowledge was identified as another overall important obstacle. Analysis by regional groups revealed a similar pattern, except that Asia reported that donor country laws and expense were the major obstacles to accessing AqGR (Figure 81).

Figure 80
Types of obstacles encountered in accessing aquatic genetic resources (global assessment)



Note: MTA = Material Transfer Agreements.

Figure 81
Types of obstacles encountered in accessing aquatic genetic resources (regional assessment)

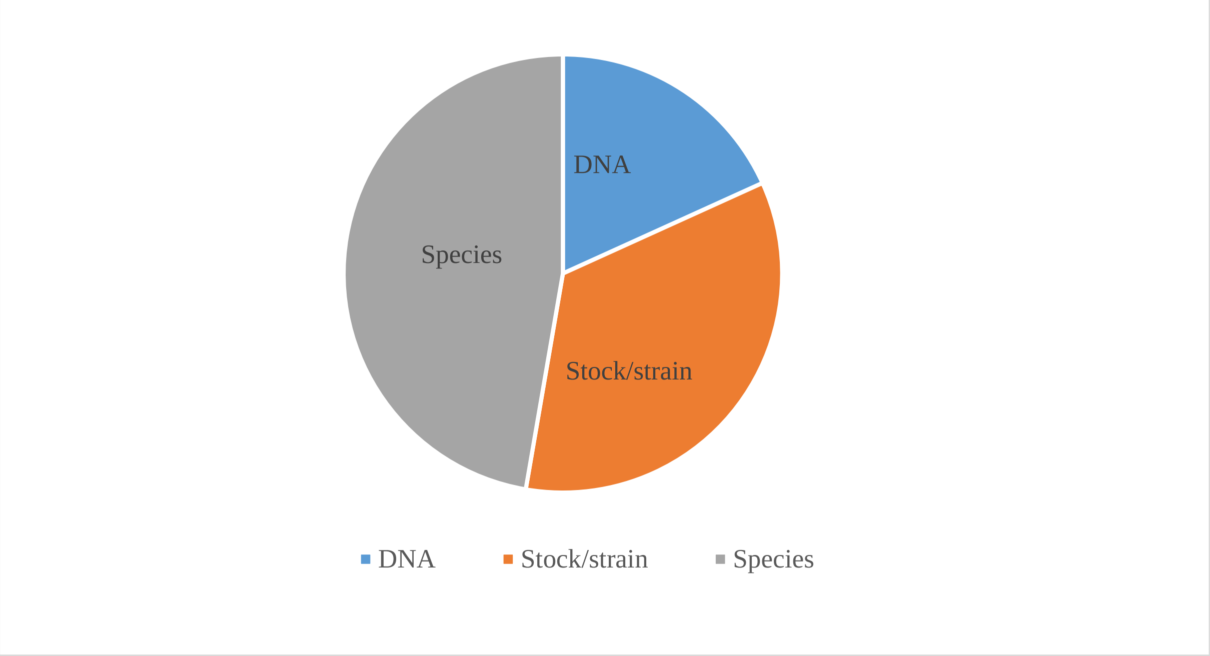


Note: IPP = intellectual property protection; MTA = Material Transfer Agreements.

Species was the type of AqGR where most (47 percent) obstacles to access were encountered (Figure 82), but obstacles in accessing strains were also encountered in about one-third of the responses; countries reported having problems accessing DNA in 18 percent of the responses.

Figure 82

Types of aquatic genetic resources where obstacles to access were encountered (number of responses)



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CHAPTER 8

RESEARCH, EDUCATION, TRAINING AND EXTENSION ON AQUATIC GENETIC RESOURCES WITHIN NATIONAL JURISDICTION: COORDINATION, NETWORKING AND INFORMATION

PURPOSE: The purpose of Chapter 8 is to review the status and adequacy of national research, education, training and extension, coordination and networking arrangements, and information systems that support the conservation, sustainable use and development of aquatic genetic resources (AqGR) of farmed aquatic species and their wild relatives for food and agriculture, specifically to:

- describe the current status, future plans, gaps, needs and priorities for research, training, extension and education on the conservation, sustainable use and development of AqGR of farmed aquatic species and their wild relatives;
- describe existing or planned national networks for the conservation, sustainable use and development of AqGR of farmed aquatic species and their wild relatives; and
- describe existing or planned information systems for the conservation, sustainable use and development of AqGR of farmed aquatic species and their wild relatives.

KEY MESSAGES:

- Ninety-seven percent of countries have at least one research institution dealing with use, conservation and management of AqGR.
- Eighty percent of countries noted that research on AqGR (conservation, use and/or management) is covered under their national research programmes, with Mexico, China, the Philippines and India each reporting more than 20 cases where AqGR is covered in national research programmes.
- “Basic knowledge on AqGR” was the most often reported research topic.
- Countries prioritized the need for increased capacities for “Characterization and monitoring of AqGR” and for conducting “Genetic improvement of AqGR”.
- Four hundred eighty-three research centres were identified from 89 countries. Seventy-nine percent of these centres are focused on basic knowledge on AqGR; 33 percent are focused on economic valuation as one of their research areas.
- Three hundred ninety-eight training and education centres dealing with use, conservation and/or management of AqGR were identified from 83 countries. The main areas of training at the global level are “Genetic resource management” and “Characterization and monitoring of AqGR”. The least covered area was “Economic valuation of AqGR”.
- One hundred ninety-nine intersectoral collaboration mechanisms were listed by 67 countries. Asia reported the highest average number of mechanisms per country.
- “Increase technical capacities of institutes” was reported to be the most important capacity need to strengthen intersectoral collaboration, followed closely by “Improve awareness and improve information sharing”.
- Two hundred fifty-three national networks were listed from 67 countries (73% of the total). The most important objective of these networks at the global level was to “Improve communication on aquatic genetic resources”; however, on a per country basis, to “Improve capacities for characterization and monitoring of aquatic genetic resources” was the main objective.
- One hundred seventy-one information systems on AqGR were listed from 64 countries. The region with the highest number of information systems per country was Latin America and the Caribbean.
- Main users of national information systems on AqGR are universities and academia, and government resource managers.
- Major aquaculture producing countries reported a higher number of information systems per country than did the minor producing countries.

- The type of information stored in these information systems was mostly species names, followed by distribution and production. Few information systems are focused on genomic data, farmed types or stocks of AqGR.

8.1 Introduction

Appropriate capacities, knowledge and skills related to sustainable use, conservation, management and development of aquatic genetic resources (AqGR) are key requirements to better characterize, use and develop the resources of importance for food and agriculture, and therefore for livelihoods and national economies. Pertinent knowledge and skills, including at country, subregion and regional levels, will help ensure sustainable use and development of these resources for future generations.

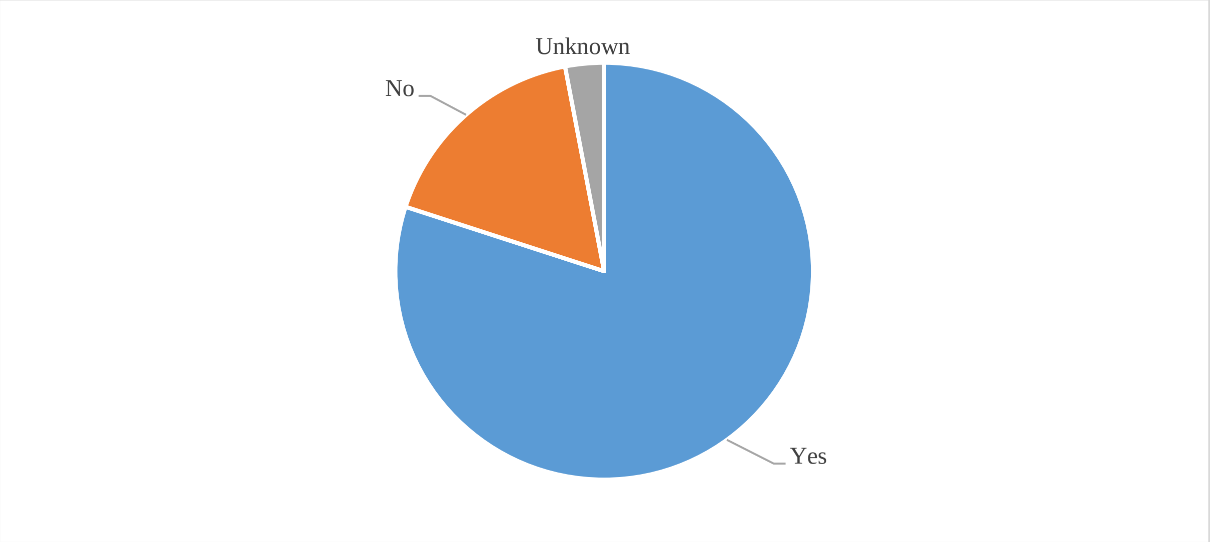
Applied scientific research in aquaculture, and its publication and extension, are key for long-term sustainable development of the sector, and should aim to boost the value, competitiveness and sustainability of global aquaculture. Research should improve and increase food production from aquaculture through integrated studies of a range of disciplines, including genetics, physiology, health, nutrition, environment and food science. Furthermore, education, training and capacity building are cross-cutting themes for sustainable development in the aquaculture sector. Training and extension material, guidelines and participatory approaches to knowledge creation could be developed, promoted and applied around the world; ongoing research is relevant for all countries, regardless of their level of development or current level of aquaculture production.

This chapter aims to examine the education and training situation regarding AqGR, and to report on actions that can enhance knowledge on the use and conservation of AqGR. The Country Reports also identified specific needs, gaps, limitations and constraints, which should be addressed by countries and development partners to identify suitable and feasible entry points with regard to education, research and training for aquaculture improvement.

8.2 Research on aquatic genetic resources

Countries were asked if their current national research programmes support the conservation, sustainable use and development of AqGR of farmed aquatic species and their wild relatives. Out of the 92 responding countries, 80 percent reported that AqGR were included in national research programmes (Figure 83).

Figure 83
Percentage of respondent countries where aquatic genetic resources are included in national research programmes



Regarding geographical distribution of answers, the various countries within regions reported good coverage of AqGR within their research national programmes (Table 64). Analysis of countries based on economic level did not reveal substantial differences (Table 65). Mexico was the country that reported the most research facilities covering AqGR, followed by China and the Philippines (Table 66).

This question also has a section devoted to additional information from surveyed countries regarding existing and/or planned research programmes on AqGR. Many countries inserted detailed information about their existing and/or planned programmes and actions, which are mostly being implemented by public institutions and in close collaboration with universities and academia.

Developed countries noted that the participation of the private sector in research is certainly increasing, mostly applied to characterization of potential farmable species, breeding and economic valuation of AqGR, while public institutions are more focused on conservation and characterization of AqGR that provide ecosystem services (data not shown).

Least developed countries and developing countries reported that there are no private initiatives in research on AqGR, and that public institutions, universities and academia, funded by external projects and foreign donors for a short duration of time, are implementing most of the activities.

The poor continuity of funding support makes it difficult to maintain research activities at the national level in many developing countries, which affects not only the long-term sustainability of the aquaculture sector, but also the level of ongoing engagement of national researchers and trainers.

Table 64

Regional coverage regarding national research programmes supporting conservation, sustainable use and development of aquatic genetic resources

Region	Yes	No	Unknown
Africa	19	7	1
Asia	18	1	1
Europe	13	2	1
Latin America & the Caribbean	13	5	
North America	2		
Oceania	7		

Note: Yes = number of countries with aquatic genetic resources research programmes; no = number of countries without aquatic genetic resources research programmes.

Table 65

Coverage of national research programmes supporting the conservation, sustainable use and development of aquatic genetic resources by economic class of country

Economic class	Yes	No	Unknown
Developed Countries	20	2	2
Other Developing Countries	36	7	
Least Developed Countries	16	6	1

Note: Yes = number of countries with aquatic genetic resources research programmes; no = number of countries without aquatic genetic resources research programmes.

Table 66
The countries with 10 or more research facilities covering aquatic genetic resources and number of facilities

Country	Number of facilities
Mexico	32
China	23
Philippines	21
India	20
Iran (Islamic Republic of)	15
Argentina	12
Nigeria	11
Australia	10
Bangladesh	10
Romania	10
Zambia	10

8.2.1 Research institutions

Countries were asked to list main institutions, organizations, corporations and other entities in their respective countries that are engaged in various types of field and/or laboratory research related to the conservation, sustainable use and development of AqGR of farmed aquatic species and their wild relatives. Eighty-nine countries out of 92 (97%) affirmed the existence of such institutions.

A total of 483 institutions were identified by these 89 countries as main research centres at the national level (about 5.4 institutions per country). The two regions with the higher number of institutions per country are North America and Asia (Table 67).

Table 67
Regional distribution of research centres on aquatic genetic resources

Region	Number of institutions	Number of countries reporting	Average institutions/ country
Africa	101	25	4.0
Asia	141	20	7.0
Europe	86	17	5.0
Latin America & the Caribbean	109	18	6.0
North America	17	2	8.5
Oceania	29	7	4.1
Total	483	89	5.4

“Other developing countries” was the economic class with the highest number of research centres per country, while “Least developed countries” had the lowest number (Table 68).

Table 68
Distribution of research centres on aquatic genetic resources by economic level

Economic class	Number of institutions	Number of countries reporting	Average institutions/ country
Developed Countries	124	25	5.0
Other Developing Countries	277	43	6.4
Least Developed Countries	82	21	3.9
Total	483	89	5.4

8.2.2 Major areas of research

The main areas of research of the 483 listed research centres were provided by countries. Most institutions (79%) were focused on "Basic knowledge on aquatic genetic resources", while other areas of research were not well covered by research centres (Table 69).

Table 69
Main areas of research of institutions focused on aquatic genetic resources

Area of research of institutions	Number of institutions devoted to each area of research (total = 483)	Percentage
Basic knowledge on aquatic genetic resources	381	79
Conservation of aquatic genetic resources	295	61
Characterization and monitoring of aquatic genetic resources	292	60
Communication on aquatic genetic resources	267	55
Genetic resource management	236	49
Genetic improvement	226	47
Access and distribution of aquatic genetic resources	193	40
Economic valuation of aquatic genetic resources	158	33

"Basic knowledge on aquatic genetic resources" was the most often reported focus of research in all classifications, without regional or economic distinctions (Table 70). The least covered area of research was reported to be the "Economic valuation of aquatic genetic resources".

Certain differences are observed between regions and economic classes, as demonstrated in Table 70 and Table 71 through Table 78; for example, "Conservation of AqGR" is as important as "Basic knowledge on AqGR" in developed countries, while it is not as well covered in least developed and other developing countries.

Table 70
Main areas of research by economic class of country

Description	Response count	Area of research	Average number of institutions per country[1]
Developed Countries	103	Basic knowledge on aquatic genetic resources	4.3
	90	Conservation of aquatic genetic resources	4.3
	94	Characterization and monitoring of aquatic genetic resources	3.5
	79	Genetic resource management	3.4
	73	Communication on aquatic genetic resources	3.3
	53	Access and distribution of aquatic genetic resources	2.8
	56	Genetic improvement	2.8
	51	Economic valuation of aquatic genetic resources	3.1
Other Developing Countries	211	Basic knowledge on aquatic genetic resources	5.1
	154	Characterization and monitoring of aquatic genetic resources	4.5
	153	Conservation of aquatic genetic resources	4.1
	115	Genetic resource management	3.5
	140	Communication on aquatic genetic resources	4.5
	107	Access and distribution of aquatic genetic resources	3.3
	134	Genetic improvement	3.8
	82	Economic valuation of aquatic genetic resources	2.9
Least Developed Countries	67	Basic knowledge on aquatic genetic resources	4.1
	54	Communication on aquatic genetic resources	3.9
	52	Conservation of aquatic genetic resources	3.7
	44	Characterization and monitoring of aquatic genetic resources	3.4
	42	Genetic resource management	2.8
	33	Access and distribution of aquatic genetic resources	2.1
	36	Genetic improvement	2.6
	25	Economic valuation of aquatic genetic resources	2.5

[1]Based on the number of institutions reporting activities in each research area per country.

Table 71
Geographical and economic distribution of institutions focused on various aspects of research on aquatic genetic resources

Geographic region	Number of institutions	Number of countries	Average
Africa	47	17	2.8
Asia	68	17	4.0
Europe	51	16	3.2
Latin America & the Caribbean	38	13	2.9
North America	13	2	6.5
Oceania	19	6	3.2
Total	236	71	
Economic class	**Number of institutions**	**Number of countries**	**Average**
Developed Countries	79	23	3.4
Other Developing Countries	115	33	3.5
Least Developed Countries	42	15	2.8
Total	236	71	

Table 72
Geographical and economic distribution of institutions focused on basic knowledge of aquatic genetic resources

Geographic region	Number of institutions	Number of countries	Average
Africa	81	22	3.7
Asia	101	19	5.3
Europe	70	16	4.4
Latin America & the Caribbean	90	17	5.3
North America	17	2	8.5
Oceania	22	7	3.1
Total	381	83	
Economic class	**Number of institutions**	**Number of countries**	**Average**
Developed Countries	103	24	4.3
Other Developing Countries	211	42	5.0
Least Developed Countries	67	17	3.9
Total	381	83	

Table 73
Geographical and economic distribution of institutions focused on characterization and monitoring of aquatic genetic resources

Geographic region	Number of institutions	Number of countries	Average
Africa	57	22	2.6
Asia	95	17	5.6
Europe	62	16	3.9
Latin America & the Caribbean	41	10	4.1
North America	15	2	7.5
Oceania	22	7	3.1
Total	292	74	
Economic class	**Number of institutions**	**Number of countries**	**Average**
Developed Countries	94	27	3.5
Other Developing Countries	154	34	4.5
Least Developed Countries	44	13	3.4
Total	292	74	

Table 74
Geographical and economic distribution of institutions focused on genetic improvement of aquatic genetic resources

Geographic region	Number of institutions	Number of countries	Average
Africa	46	20	2.3
Asia	88	14	6.3
Europe	36	14	2.6
Latin America & the Caribbean	34	13	2.6
North America	8	2	4.0
Oceania	14	6	2.3
Total	226	69	
Economic class	**Number of institutions**	**Number of countries**	**Average**
Developed Countries	56	20	2.8
Other Developing Countries	134	35	3.8
Least Developed Countries	36	14	2.6
Total	226	69	

Table 75
Geographical and economic distribution of institutions focused on economic valuation of aquatic genetic resources

Geographic region	Number of institutions	Number of countries	Average
Africa	35	11	3.2
Asia	49	14	3.5
Europe	37	12	3.1
Latin America & the Caribbean	19	10	1.9
North America	5	2	2.5
Oceania	13	6	2.2
Total	158	55	
Economic class	**Number of institutions**	**Number of countries**	**Average**
Developed Countries	51	17	3.0
Other Developing Countries	82	28	2.9
Least Developed Countries	25	10	2.5
Total	158	55	

Table 76
Geographical and economic distribution of institutions focused on conservation of aquatic genetic resources

Geographic region	Number of institutions	Number of countries	Average
Africa	54	17	3.2
Asia	91	15	6.1
Europe	65	16	4.1
Latin America & the Caribbean	46	16	2.9
North America	13	2	6.5
Oceania	26	7	3.7
Total	295	73	
Economic class	**Number of institutions**	**Number of countries**	**Average**
Developed Countries	90	21	4.3
Other Developing Countries	153	38	4.0
Least Developed Countries	52	14	3.7
Total	295	73	

Table 77
Geographical and economic distribution of institutions focused on communication on aquatic genetic resources

Geographic region	Number of institutions	Number of countries	Average
Africa	64	18	3.6
Asia	89	14	6.4
Europe	52	16	3.2
Latin America & the Caribbean	38	11	3.4
North America	9	2	4.5
Oceania	15	6	2.5
Total	267	67	
Economic class	**Number of institutions**	**Number of countries**	**Average**
Developed Countries	73	22	3.3
Other Developing Countries	140	31	4.5
Least Developed Countries	54	14	3.9
Total	267	67	

Table 78
Geographical and economic distribution of institutions focused on access and distribution of aquatic genetic resources

Geographic region	Number of institutions	Number of countries	Average
Africa	43	18	2.4
Asia	68	16	4.2
Europe	34	14	2.4
Latin America & the Caribbean	29	11	2.6
North America	9	2	4.5
Oceania	10	6	1.7
Total	193	67	
Economic class	**Number of institutions**	**Number of countries**	**Average**
Developed Countries	53	19	2.8
Other Developing Countries	107	32	3.3
Least Developed Countries	33	16	2.1
Total	193	67	

8.2.3 Capacity needs

Countries reported on the main capacity strengthening needs in order to improve national research in support of the conservation, sustainable use and development of aquatic genetic resources of farmed aquatic species and their wild relatives.

The following capacities were assessed by countries, and were ranked from very important (1) to not important at all (10), as shown in Table 79.

Table 79
Ranking of capacity needs on research applied to aquatic genetic resources at the global level

Capacity need	Ranking
Improve access to and distribution of aquatic genetic resources	3.5
Improve communication on aquatic genetic resources	3.4
Improve capacities for economic valuation of aquatic genetic resources	3.1
Improve capacities for genetic resource management	2.4
Improve capacities for conservation of aquatic genetic resources	2.4
Improve basic knowledge on aquatic genetic resources	2.1
Improve capacities for genetic improvement	2.0
Improve capacities for characterization and monitoring of aquatic genetic resources	1.9

Note: Highest priority = 1; lowest priority = 10.

At the global level, the capacities ranked the highest were “Improve capacities for characterization and monitoring of aquatic genetic resources” and “Improve capacities for genetic improvement” (Table 79). The capacity needs ranked the lowest were “Improve access to and distribution of aquatic genetic resources” and “Improve communication on aquatic genetic resources”.

At the regional level, “Improve capacities for genetic improvement” and “Improve capacities for characterization and monitoring of aquatic genetic resources” were often the highest ranked research needs (Table 80).

Table 80
Top two research capacity needs identified by regions

Region	Highest ranked research capacity need	Second highest ranked research capacity need
Africa	Improve capacities for genetic improvement	Improve capacities for characterization and monitoring of aquatic genetic resources
Asia	Improve capacities for basic knowledge on aquatic genetic resources	Improve capacities for characterization and monitoring of aquatic genetic resources
Europe	Improve capacities for genetic improvement	Improve capacities for characterization and monitoring of aquatic genetic resources
Latin America & the Caribbean	Improve capacities for basic knowledge on aquatic genetic resources	Improve capacities for characterization and monitoring of aquatic genetic resources
North America	Improve capacities for characterization and monitoring of aquatic genetic resources	Improve capacities for genetic resource management
Oceania	Improve capacities for characterization and monitoring of aquatic genetic resources	Improve capacities for genetic improvement

8.3 Education, training and extension on aquatic genetic resources

8.3.1 Institutions, areas of work and type of courses

Countries reported the extent that education, training and extension covers the conservation, sustainable use and development of AqGR of farmed aquatic species and their wild relatives, listing the main institutions involved and the types of courses offered by these institutions.

A total of 83 countries (90% of the total responding countries) indicated that there are specific institutions involved in education, training and/or extension on AqGR. A total of 398 training institutions were identified by the 83 countries, yielding an average of around 4.8 training centres per country.

Table 81 provides a summary of training centres on AqGR per region, including the average number of training centres per country for each region. The regions with the higher number of education and training centres on AqGR per country are Asia, followed by Europe.

Table 81
Total number and average number per country of training centres on aquatic genetic resources by geographical region

Geographical region	Number of institutions	Number of countries	Average
Africa	120	26	4.6
Asia	109	16	6.8
Europe	80	16	5.0
Latin America & the Caribbean	67	16	4.2
North America	9	2	4.5
Oceania	13	7	1.9
Total	398	83	4.8

Table 82 provides a summary of training centres on AqGR by economic class, including the average number of training centres per country for each economic class. There is no significant difference among the three economic classes.

Table 82
Number of training centres on aquatic genetic resources by economic class and average number of training centres per country

Economic class	Number of institutions	Number of countries	Average
Developed Countries	103	22	4.68
Other Developing Countries	185	39	4.74
Least Developed Countries	110	22	5.00
Total	398	83	4.80

Table 83 lists the countries that reported 10 or more training institutions that cover AqGR, with Germany reporting the most institutions.

Table 83
Total number of training institutions for countries reporting 10 or more training institutions

Country	Number of institutions	Country	Number of institutions
Germany	22	Mexico	13
Bangladesh	18	Senegal	12
India	18	Benin	11
Madagascar	14	Niger	11
Turkey	14	Thailand	10

Countries reported on the education level offered by these training centres. The level of course with the lowest average number of courses is “Extension”; this was especially true in the thematic areas of “Characterization and monitoring of aquatic genetic resources” and “Economic valuation of aquatic genetic resources” (Table 84). The highest average number of courses per country was at the “Undergraduate” level, with a major emphasis on “Genetic resource management”.

Table 84
Average number of courses per country covering different key thematic areas related to aquatic genetic resources by academic/technical level

Thematic area	Average number of courses per level per country			
	Undergraduate	Post-graduate	Training	Extension
Genetic resource management	7.0	3.3	3.1	2.9
Characterization and monitoring of aquatic genetic resources	2.9	3.4	3.2	2.5
Genetic improvement	2.8	3.3	3.2	3.0
Economic valuation of aquatic genetic resources	2.5	2.7	3.0	2.4
Conservation of aquatic genetic resources	2.9	3.3	3.3	2.9
Mean number of courses per level	3.6	3.2	3.2	2.7

There are more courses available for “Genetic resource management”, “Characterization and monitoring of AqGR” and “Conservation of AqGR” than the other thematic areas; the fewest courses available are for “Economic valuation of AqGR” (Table 85).

Table 85
Courses available for each thematic area

Thematic area	Undergraduate	Post-graduate	Training	Extension	Total number of courses
Genetic resource management	173	168	175	110	221
Characterization and monitoring of aquatic genetic resources	163	200	158	81	215
Genetic improvement	150	170	146	89	193
Economic valuation of aquatic genetic resources	104	108	107	52	151
Conservation of aquatic genetic resources	175	180	188	111	219

Note: Courses may address more than one level of education and training.

8.4 Coordination and networking on aquatic genetic resources

8.4.1 Networking mechanisms

Countries reported mechanisms within their respective countries that are responsible for coordinating the aquaculture, culture-based fisheries and capture fisheries subsectors with other sectors that use the same watersheds and coastal ecosystems (e.g. agriculture, forestry, mining, tourism, waste management and water resources), and that have impacts on AqGR of wild relatives of farmed aquatic species. Examples of such mechanisms include the cooperation of two ministries in the management of aquatic resources of the Sundarbans in Bangladesh, and the cooperation of four agencies in the issuance of aquaculture establishments in Ghana.

A total of 199 different mechanisms of intersectoral and intrasectoral coordination were identified by 67 countries (Table 86). Therefore, 70 percent of the responding countries (92 countries in total) responded positively to the presence of coordination mechanisms between different subsectors, including the aquaculture and fisheries sectors.

Countries that did not include the existence of any intersectoral coordinating mechanisms are Armenia, Belize, Burundi, Cabo Verde, Canada, Chad, China, the Democratic Republic of the Congo, Czechia, Finland, Georgia, Honduras, Iraq, Kazakhstan, Kenya, Kiribati, Latvia, Poland, Samoa, the Sudan, Togo, Tonga, Vanuatu, Viet Nam and Zambia.

Table 86
Total number of coordinating mechanisms detailed by 67 countries with positive responses

Country	Number of mechanisms	Country	Number of mechanisms
Algeria	2	Japan	3
Argentina	6	Republic of Korea	1
Australia	1	Lao People's Democratic Republic	2
Bangladesh	6	Madagascar	12
Belgium	6	Malawi	2
Benin	5	Malaysia	5
Bhutan	1	Mexico	6
Brazil	2	Morocco	2
Bulgaria	5	Mozambique	1
Burkina Faso	1	Netherlands	5
Cambodia	1	Nicaragua	1
Cameroon	2	Niger	1
Chile	1	Nigeria	4
Colombia	4	Norway	7
Costa Rica	1	Palau	1
Croatia	1	Panama	4
Cuba	1	Paraguay	1
Cyprus	2	Peru	2
Denmark	1	Philippines	20
Djibouti	1	Romania	1
Dominican Republic	2	Senegal	3
Ecuador	2	Sierra Leone	2
Egypt	1	Slovenia	1
El Salvador	2	South Africa	1
Estonia	1	Sri Lanka	6
Fiji	2	Sweden	5
Germany	5	United Republic of Tanzania	1
Ghana	1	Thailand	7
Guatemala	1	Tunisia	1
Hungary	1	Turkey	1
India	2	Uganda	5
Indonesia	3	Ukraine	1
Iran (Islamic Republic of)	3	United States of America	2
		Venezuela (Bolivarian Republic of)	6
		Total	199

The regions with the highest average number of intersectoral mechanisms per country are Asia and Europe. The regions with the lowest level of intersectoral mechanisms are Oceania and North America (Table 87).

Table 87
Number of intersectoral coordination mechanisms on aquatic genetic resources by region and the average number of mechanisms per country in that region

Geographical region	Number of mechanisms	Number of countries	Average
Africa	48	19	2.5
Asia	63	15	4.2
Europe	40	13	3.1
Latin America & the Caribbean	42	16	2.6
North America	2	1	2.0
Oceania	4	3	1.3
Total	199	67	3.0

Other developing countries and least developed countries are the economic classes with the highest number of intersectoral mechanisms per country (Table 88).

Table 88
Number and average number of per country intersectoral coordination mechanisms on aquatic genetic resources by economic class

Economic class	Number of mechanisms	Number of countries	Average
Developed Countries	47	17	2.76
Other Developing Countries	108	35	3.09
Least Developed Countries	44	15	2.93
Total	199	67	2.97

8.4.2 Capacity needs

Countries were requested to rank how capacity strengthening could be improved in intersectoral coordination in support of the conservation, sustainable use and development of AqGR. Three different capacities were ranked by countries, from 1 (very important) to 10 (no importance). “Increase technical capacities of institutions” was identified by countries as the most important, followed by “Increase awareness in institutions” and “Increase information sharing between institutions” (Table 89).

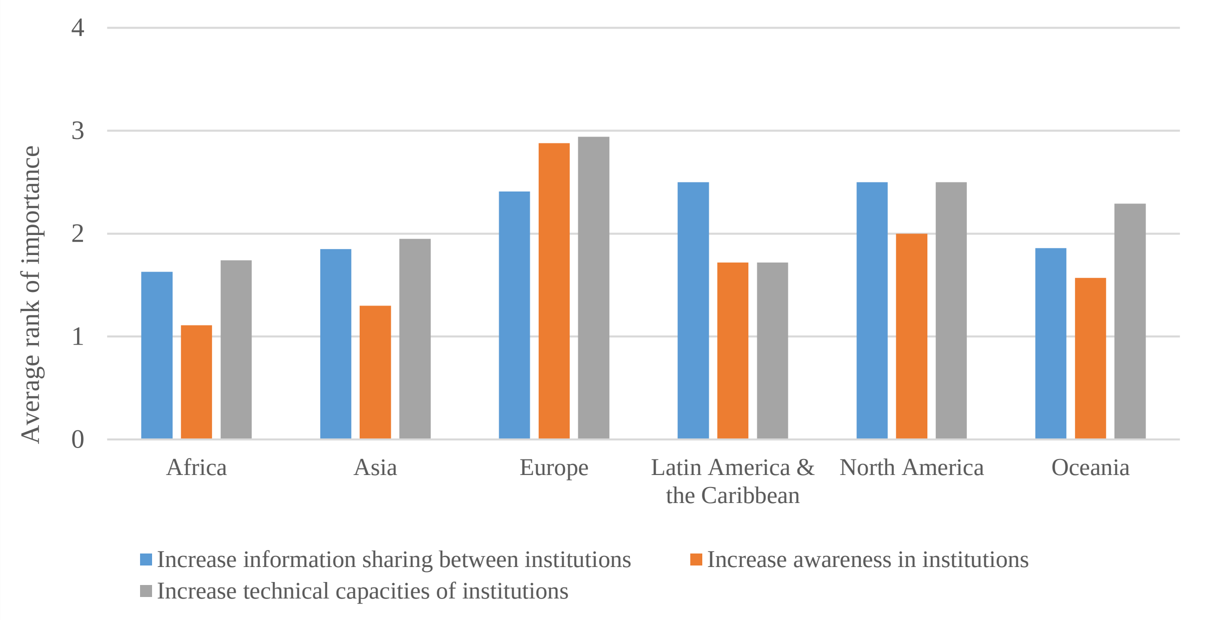
Table 89
Average rank of capacity strengthening to be improved in intersectoral coordination in support of conservation, sustainable use and development of aquatic genetic resources

Capacities to be improved	Average rank
Increase information sharing between institutions	2.1
Increase awareness in institutions	2.0
Increase technical capacities of institutions	1.7

Note: 1 = very important; 10 = no importance.

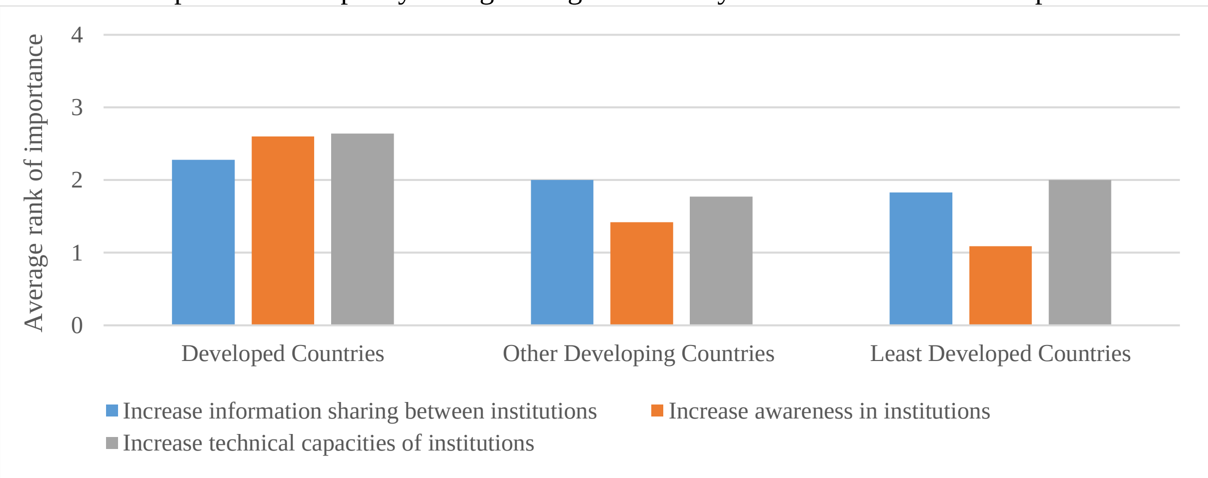
The three capacity-strengthening activities were generally ranked similarly in level of importance; however, “Increase technical capacities of institutions” ranked most important in five of the six regions (Figure 84). “Increase technical capacities of institutions” was generally ranked more important when countries were grouped by level of economic development (Figure 85). However, in developed countries, “Increase awareness in institutions” was ranked most important.

Figure 84
Rank of the importance of capacity-strengthening activities by region



Note: 1 = very important; 10 = no importance.

Figure 85
Rank of the importance of capacity-strengthening activities by level of economic development



Note: 1 = very important; 10 = no importance.

8.4.3 National networking on aquatic genetic resources

Countries reported the number of national networks in their respective countries, as well as all international networks to which their country belongs, that support the conservation, sustainable use and development of AqGR.

Sixty-seven countries have national networks related to use, conservation and/or management of AqGR. A total of 253 national networks were identified by these 67 countries, which gives an average value of 3.8 networks per country. Peru was the country with the most national networks; several countries listed only one national network (Table 90).

Table 90
Number of national networks related to aquatic genetic resources

Country	Number of networks	Country	Number of networks	Country	Number of networks
Peru	25	Indonesia	4	Sudan	2
Germany	11	Iran (Islamic Republic of)	4	United Republic of Tanzania	2
Bangladesh	10	Slovenia	4	Thailand	2
China	10	Argentina	3	Viet Nam	2
Philippines	10	Bulgaria	3	Zambia	2
Cambodia	9	Dominican Republic	3	Algeria	1
Uganda	8	Hungary	3	Belize	1
Canada	7	Republic of Korea	3	Benin	1
Romania	7	Norway	3	Burundi	1
El Salvador	6	Palau	3	Chad	1
Ghana	6	Tunisia	3	Colombia	1
India	6	Turkey	3	Costa Rica	1
Mexico	6	Belgium	2	Czechia	1
Nigeria	6	Brazil	2	Egypt	1
Senegal	6	Cabo Verde	2	Fiji	1
Croatia	5	Cuba	2	Mozambique	1
Malawi	5	Democratic Republic of the Congo	2	Niger	1
Malaysia	5	Guatemala	2	Panama	1
Netherlands	5	Japan	2	Paraguay	1
Sweden	5	Madagascar	2	Poland	1
Australia	4	Sierra Leone	2	Togo	1
Cameroon	4	Sri Lanka	2	Ukraine	1
				United States of America	1

The region with the highest number of national networks, as well as the most networks per country, is Asia (Table 91).

The economic class with the highest number of national networks related to AqGR is other developing countries, followed by developed countries and least developed countries (Table 92).

Table 91
Total number and average number of national networks related to aquatic genetic resources by region

Geographic region	Number of networks	Number of countries	Average
Africa	60	22	2.7
Asia	72	14	5.1
Europe	51	13	3.9
Latin America & the Caribbean	54	13	4.2
North America	8	2	4.0
Oceania	8	3	2.7
Total	253	67	3.8

Table 92
Total number and average number of national networks related to aquatic genetic resources by economic level of development

Economic class	Number of networks	Number of countries	Average
Developed Countries	65	17	3.8
Other Developing Countries	132	33	4.0
Least Developed Countries	56	17	3.3
Total	253	67	3.8

Countries reported the various objectives of national networks on AqGR (Table 93). On a global level, the main objective of most national networks was to “Improve communication on AqGR”; however, on a per country basis, the main objective was to “Improve capacities for characterization and monitoring of AqGR”. There are several networks with various objectives in most countries.

However, analysis by regional and level of economic development revealed a diversity of a number of networks for the various objectives (Figure 86 and Figure 87). The major producing countries consistently had more networks for a given objective than the minor producing countries (Figure 88).

Table 93
Total number of networks for each of the objectives and the average number of networks per country reporting this objective

Objectives of the network	Number of networks	Average networks per country
Improve capacities for characterization and monitoring of aquatic genetic resources	157	3.6
Improve capacities for conservation of aquatic genetic resources	181	3.5
Improve communication on aquatic genetic resources	188	3.5
Improve basic knowledge on aquatic genetic resources	175	3.4
Improve capacities for economic valuation of aquatic genetic resources	119	3.0
Improve access to and distribution of aquatic genetic resources	115	2.9
Improve capacities for genetic improvement	112	2.8

Figure 86
Average number of networks per country with a given objective by region

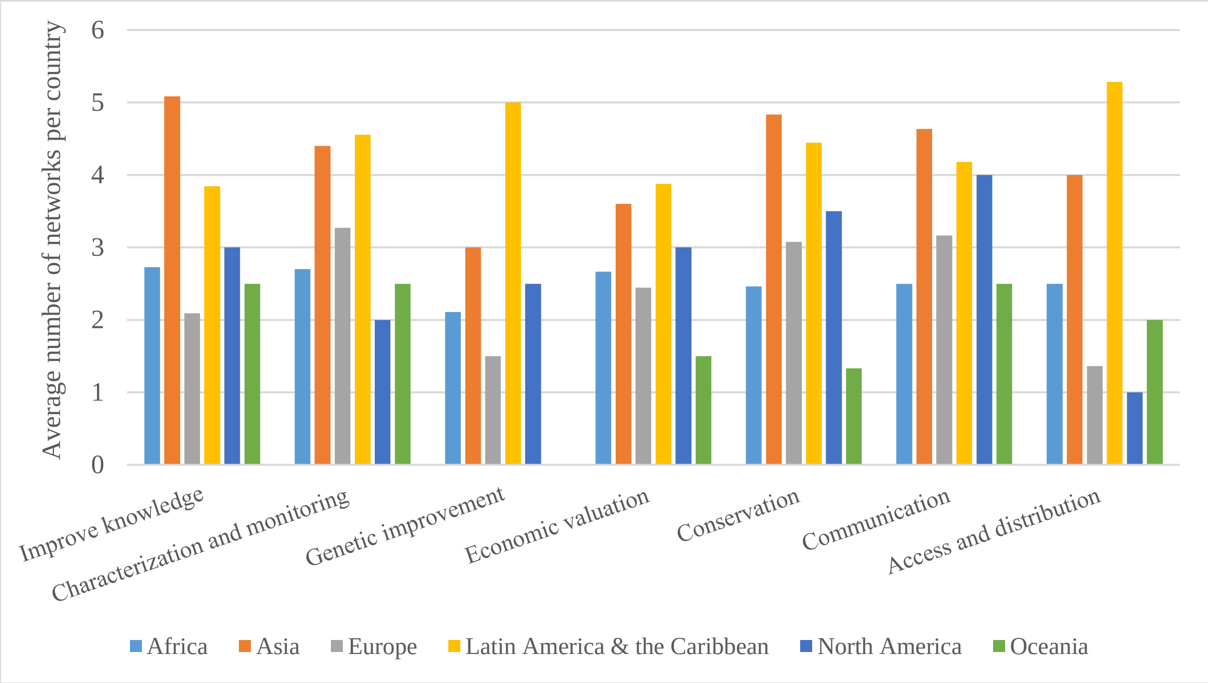


Figure 87
Average number of networks per country with a given objective by economic level

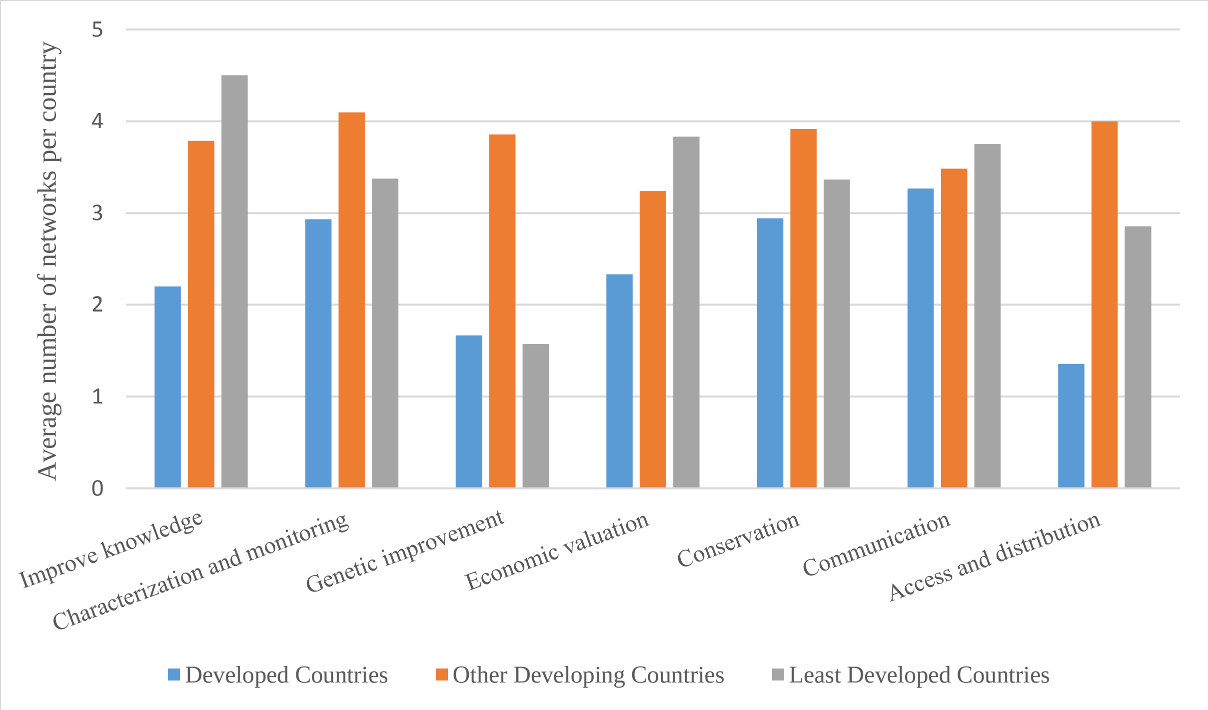
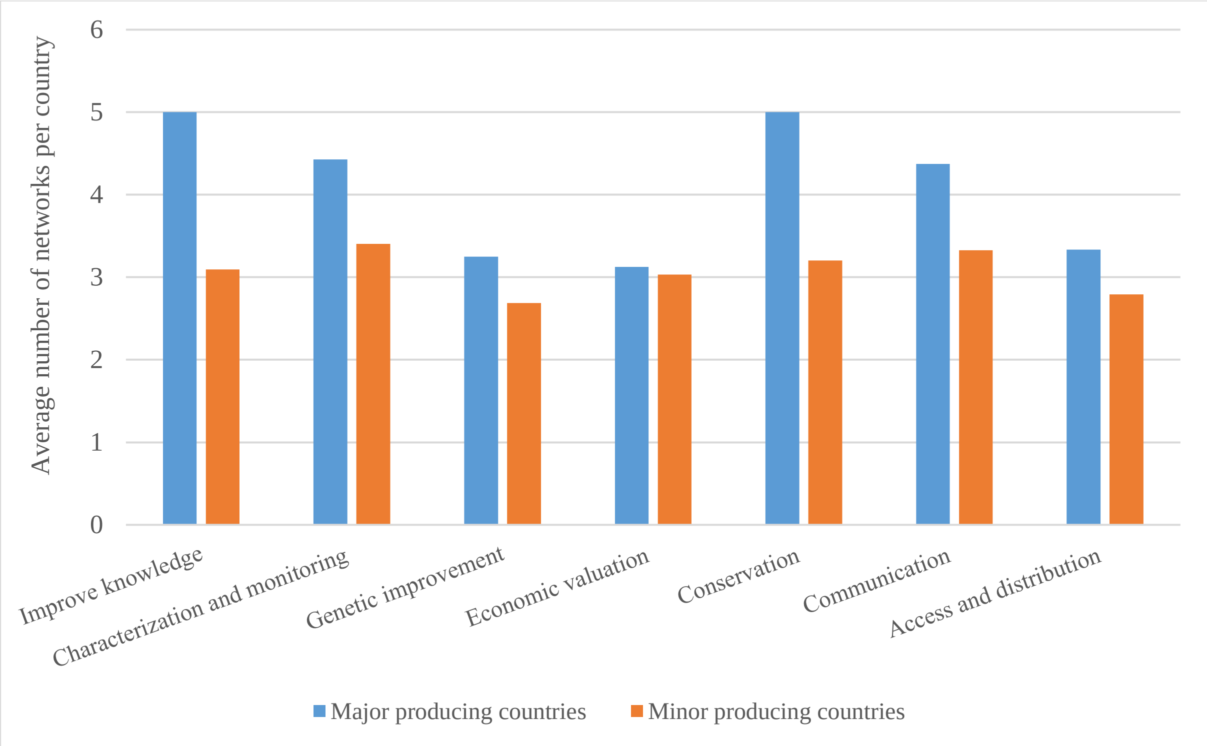


Figure 88
Average number of networks per country with a given objective by level of aquaculture production



8.5 Information systems on aquatic genetic resources

Countries reported on the information systems related to receiving, managing and communicating information about the conservation, sustainable use and development of AqGR of farmed aquatic species and their wild relatives. A total of 171 information systems related to AqGR were listed by 64 countries (70% of responding countries), which gives an average of 2.6 information systems on AqGR per country. Mexico reported the most information systems on AqGR (18), followed by India (9), and the Philippines (9) (Table 94).

Table 94
Number of information systems on aquatic genetic resources

Country	Number of information systems	Country	Number of information systems
Algeria	4	Japan	3
Argentina	2	Republic of Korea	1
Bangladesh	2	Madagascar	7
Belgium	1	Malawi	5
Benin	4	Malaysia	4
Bhutan	2	Mexico	18
Brazil	1	Morocco	7
Bulgaria	1	Mozambique	1
Cabo Verde	1	Netherlands	6
Cambodia	1	Niger	1
Cameroon	1	Nigeria	6
Chile	1	Norway	4
China	1	Palau	1
Colombia	5	Panama	1
Costa Rica	2	Philippines	9
Croatia	3	Poland	2
Cuba	2	Romania	3
Cyprus	1	Samoa	1
Czechia	2	Senegal	2
Democratic Republic of the Congo	1	Sierra Leone	1
Denmark	2	Slovenia	1
Dominican Republic	2	South Africa	1
Egypt	1	Sri Lanka	3
El Salvador	1	Sweden	1
Finland	2	United Republic of Tanzania	1
Germany	5	Thailand	3
Ghana	1	Tunisia	2
Guatemala	1	Uganda	3
Honduras	1	Ukraine	1
Hungary	2	United States of America	1
India	9	Viet Nam	1
Iran (Islamic Republic of)	3	Zambia	2
		Total	171

The region with the highest absolute number of information systems on AqGR is Africa; the region with the highest average number of information systems per country related to AqGR is Latin America and the Caribbean, followed closely by Asia (Table 95).

Table 95
Number and average number per country of information systems on aquatic genetic resources by region

Geographic region	Number of information systems	Number of countries	Average
Africa	52	20	2.6
Asia	43	14	3.1
Europe	36	15	2.4
Latin America & the Caribbean	37	12	3.1
North America	1	1	1.0
Oceania	2	2	1.0
Total	171	64	2.7

Other developing countries have an average of 3.0 information systems on AqGR per country, while developed countries have listed an average of 2.3 information systems per country. The major producing countries had on average more information systems on AqGR than the minor producing countries (Table 96 and Table 97).

Table 96
Number and average number per country of information systems on aquatic genetic resources by region

Economic class	Number of information systems	Number of countries	Average
Developed Countries	41	18	2.3
Other Developing Countries	97	32	3.0
Least Developed Countries	33	14	2.4
Total	171	64	2.7

Table 97
Number and average number per country of information systems on aquatic genetic resources related to level of aquaculture production

Level of production	Number of information systems	Number of countries	Average
Major producing countries	32	10	3.2
Minor producing countries	139	54	2.6
Total	171	64	

8.5.1 Main users of information systems

Countries reported on the main user base and the extent of use of the information systems on AqGR that are available at the national level. Main users identified by countries and the extent of use of the aforementioned 171 information systems are provided in Table 98.

The main users of information systems identified by responding countries are "Universities and academia" and "Government resource managers". Stakeholders, i.e. users, with limited use of these information systems, are consumers, politicians, donors and people involved in marketing. Aquaculture producers (hatcheries, farmers), fishers in capture fisheries and people involved in marketing of aquatic genetic resources also have a medium level of use of information systems (Table 98).

Table 98
Main users of information systems on aquatic genetic resources and number of information systems

Main users	Number of information systems
Government resource managers	134
University and academia	134
Non-governmental organizations	107
Fisheries and aquaculture associations	104
Policy-makers	99
Fish farmers	98
Intergovernmental organizations	91
Fishers in capture fisheries	84
Aquatic protected area managers	84
Fish hatchery people	79
People involved in marketing	64
Donors	62
Politicians	52
Consumers	50

8.5.2 Type of information stored in information systems on aquatic genetic resources

The type of information stored in national information systems on AqGR was assessed by countries, as shown in Figure 89.

Most of the information systems available at national levels are focused on species names, distribution of AqGR and production data; few information systems contain information on DNA sequences, genes and genomics, or strains and stocks (Figure 89 and Table 99). This pattern was observed regardless of how countries were grouped. Major producing countries had on average more information systems on a particular class of information except for production figures (Figure 90).

Figure 89
Types of information stored in information systems on aquatic genetic resources

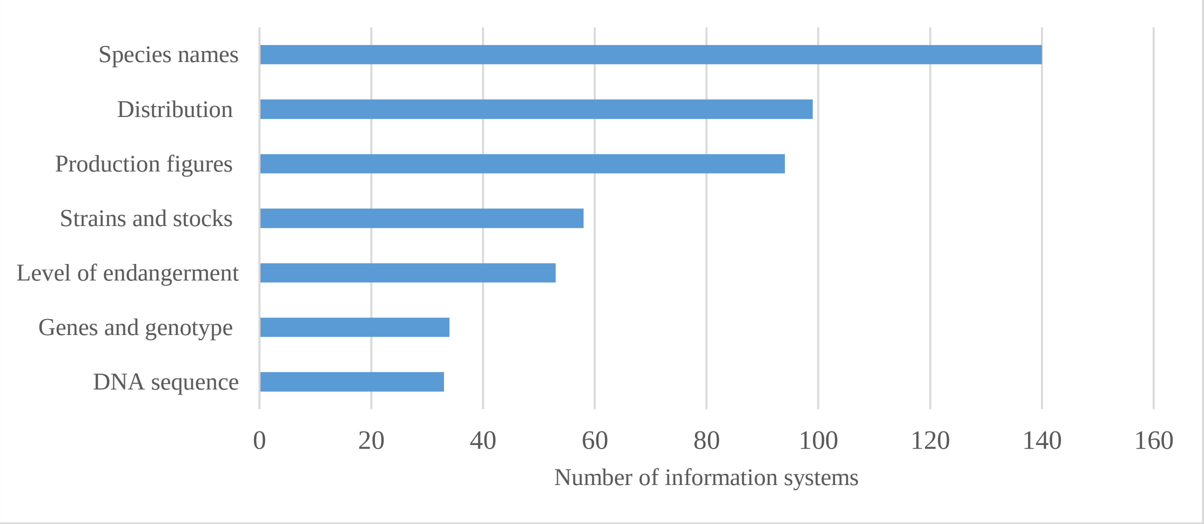
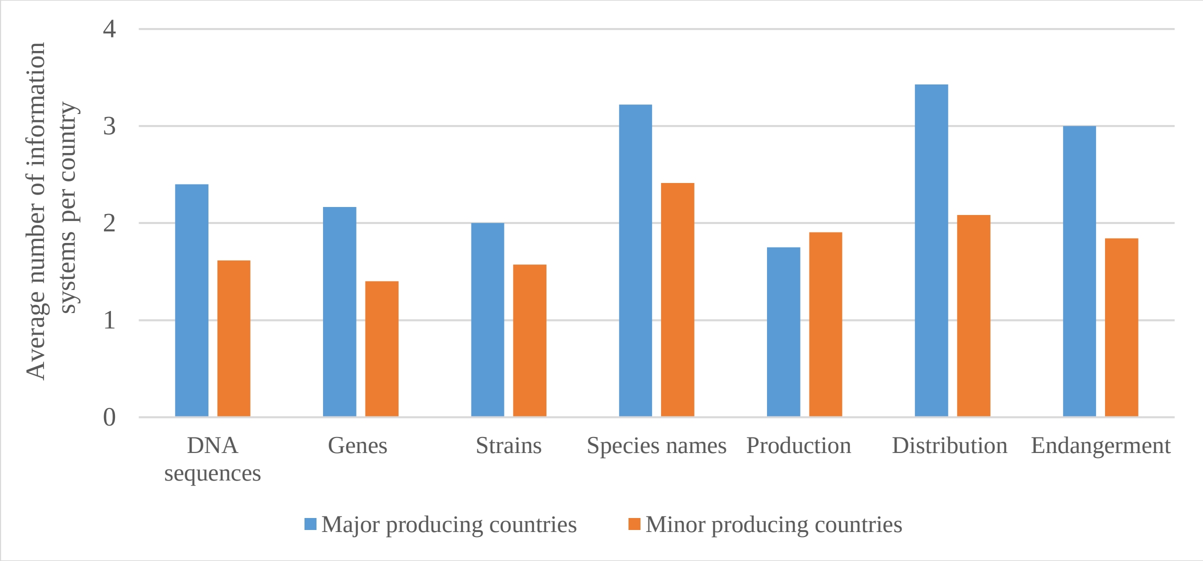


Table 99
Type of information stored and number of information systems in national information systems by economic class

Economic class	DNA sequences	Genes	Strains	Species names	Production	Distribution	Endangerment
Developed Countries	7	10	19	36	25	30	12
Other Developing Countries	22	20	21	76	50	55	32
Least Developed Countries	4	4	18	28	19	14	9
Total	33	34	58	140	94	99	53

Figure 90
Average number of information systems addressing specific types of aquatic genetic resources per country by level of production



References and key documents

Key documents and information sources that have been consulted include:

- Commission on Genetic Resources for Food and Agriculture (CGRFA) reports;
- CGRFA working documents, information documents and background study papers;
- FAO Fisheries Glossary;
- www.cbd.int (Convention on Biological Diversity).

CHAPTER 9

INTERNATIONAL COLLABORATION ON AQUATIC GENETIC RESOURCES OF FARMED AQUATIC SPECIES AND THEIR WILD RELATIVES

PURPOSE: The purpose of this chapter is to review the mechanisms and instruments through which a country participates in international collaboration on aquatic genetic resources (AqGR) of farmed aquatic species and their wild relatives. The specific objectives are to:

- identify a country's current participation in bilateral, subregional, regional and global collaboration on AqGR. Countries were requested to list their national memberships or status as a party to agreements, as well as other forms of affiliation in agreements, conventions, treaties, international organizations, international networks and international programmes;
- identify any other forms of international collaboration on AqGR;
- review the benefits from existing international collaboration on AqGR; and
- identify needs and priorities for future international collaboration on AqGR.

KEY MESSAGES:

- Countries participate through a wide range of mechanisms and instruments relating to international collaboration on AqGR of farmed aquatic species and their wild relatives.
- The number of international agreements of relevance to AqGR use, conservation and management varies from 1 to 24 per country, with a total of 169 unique agreements of international collaboration reported.
- The impact of international agreements on sustainable use, conservation and management of AqGR has been assessed from positive to strongly positive for 85 percent of the agreements.
- All eight identified areas of collaboration were ranked as being fairly important, scoring between 2 and 3 on a scale of 1 (highest importance) to 10 (no importance). The highest priority was for improved communication and improved capacities for the conservation and economic valuation of AqGR, followed by improved basic knowledge, improved capacities for characterization and monitoring, improved access and distribution of AqGR, and improved information technology and database management.
- The extent to which assessed needs are not/only partially met is rather high (all equal or above 74 percent). This highlights the need for an international network.
- Regional and international collaboration can be a key driver for successful conservation, use, management and development of AqGR, as nicely demonstrated by the global and regional case studies on tilapias, common carp, Atlantic salmon, and the summary of reports from international organizations documented in this chapter.

9.1 Introduction

Countries participate through a wide range of mechanisms and instruments relating to international collaboration on aquatic genetic resources (AqGR) of farmed aquatic species and their wild relatives. This introductory section lists several key international instruments that have been considered by countries as being of relevance to aquatic genetic resources use, conservation and management.

9.1.1 Convention on Biological Diversity

Opened for signature at the Earth Summit in Rio de Janeiro in 1992, and entering into force in December 1993, the Convention on Biological Diversity (CBD) is an international treaty for the conservation of biodiversity, the sustainable use of the components of biodiversity, and the equitable sharing of the benefits derived from the use of genetic resources. With 196 Parties (as of March 2018),[21] the CBD has near universal participation among countries. The CBD seeks to address all threats to biodiversity and ecosystem services, including those resulting from climate change. Threats are addressed through

[21] www.cbd.int/information/parties.shtml. [Cited 8 March 2018].

scientific assessments, the development of tools, incentives and processes, the transfer of technologies and good practices, and the full and active involvement of relevant stakeholders, including indigenous and local communities, youth, women, non-governmental organizations and the business community. The Cartagena Protocol on Biosafety and the Nagoya Protocol on Access and Benefit-sharing are supplementary agreements to the CBD. The Cartagena Protocol, which entered into force on 11 September 2003, seeks to protect biological diversity from the potential risks posed by living modified organisms resulting from modern biotechnology. To date (March 2018), 171 Parties[22] have ratified the Cartagena Protocol. The Nagoya Protocol aims at sharing the benefits arising from the utilization of genetic resources in a fair and equitable way, including by appropriate access to genetic resources and by appropriate transfer of relevant technologies thereby contributing to the conservation and sustainable use of biodiversity. It entered into force on 12 October 2014, and as of March 2018 has been ratified by 105 Parties.[23]

9.1.2 FAO's Code of Conduct for Responsible Fisheries

The Food and Agriculture Organization of the United Nations (FAO) Committee on Fisheries (COFI), in 1991, called for the development of new concepts that would lead to responsible and sustained fisheries and aquaculture. Following significant developments in international fishing – such as, *inter alia*, the International Conference on Responsible Fishing, in Cancun, Mexico (1992), the United Nations Conference on Environment and Development, in Rio de Janeiro, Brazil (1992), and the United Nations Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks, in New York, United States of America – the FAO Governing Bodies recommended the formation of a global Code of Conduct for Responsible Fisheries which would be consistent with these instruments. FAO's Code of Conduct for Responsible Fisheries (CCRF), in a non-mandatory manner, established principles and international standards of behaviour for responsible practices with a view to ensuring the effective conservation, management and development of living aquatic resources, with due respect for the ecosystem and biodiversity. The CCRF was unanimously adopted on 31 October 1995 by the FAO Conference and now functions as the cornerstone for the work of the FAO Fisheries and Aquaculture Department. Although the CCRF is non-mandatory, countries, as Members of FAO, are committed to its implementation to the extent possible. Certain parts of the CCRF are based on relevant rules of international law, including those reflected in the United Nations Convention on the Law of the Sea. The CCRF also contains provisions that may be or have already been given binding effect by means of other obligatory legal instruments among the parties (Bartley, Marttin and Halwart, 2005).

9.1.3 Convention on International Trade in Endangered Species of Wild Fauna and Flora

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) is an international agreement between governments with the aim of ensuring that international trade in specimens of wild animals and plants does not threaten their survival.

9.1.4 Ramsar Convention

The Convention on Wetlands of International Importance especially as Waterfowl Habitat, called the Ramsar Convention, is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. It currently (February 2018) has 169 Contracting Parties, and there are 2 299 Ramsar Sites, which are distributed across the globe, with a total surface area for the designated sites of 225 517 367 hectares (Ramsar, 2018).

[22] http://bch.cbd.int/protocol. [Cited 8 March 2018].
[23] www.cbd.int/abs/nagoya-protocol/signatories/default.shtml. [Cited 8 March 2018].

9.1.5 United Nations Framework Convention on Climate Change

The United Nations Framework Convention on Climate Change (UNFCCC) has 197 Members and is the parent treaty of the 1997 Kyoto Protocol. The Kyoto Protocol has been ratified by 192 of the UNFCCC Parties (UNFCCC, 2018). The ultimate objective of both treaties is to stabilize greenhouse gas concentrations in the atmosphere at a level that will prevent dangerous human interference with the climate system.

9.1.6 United Nations Convention on the Law of the Sea

The United Nations Convention on the Law of the Sea (UNCLOS) of 10 December 1982 is the international agreement that resulted from the third United Nations Conference on the Law of the Sea (UNCLOS III), which occurred between 1973 and 1982. The Law of the Sea Convention defines the rights and responsibilities of nations with respect to their use of the world's oceans, establishing guidelines for businesses, the environment, and the management of marine natural resources. UNCLOS came into force in 1994 and has been ratified by 168 Parties.[24]

9.2 International agreements and their impacts on aquatic genetic resources and on stakeholders: overview by region, subregion and economic class

This section deals with the impacts of international agreements on AqGR of both farmed aquatic species and their wild relatives, as well as on stakeholders. Countries were asked to summarize the most important international agreements to which they subscribe that cover aquatic genetic resources of farmed species and their wild relatives. Countries were also asked to assess the impact of those agreements on AqGR and stakeholders, such as for example on:

- establishment and management of shared or networked aquatic protected areas;
- aquaculture and culture-based fisheries in transboundary or shared waterbodies;
- sharing aquatic genetic material and related information;
- fishing rights, seasons and quotas;
- conservation and sustainable use of shared waterbodies and watercourses; and
- quarantine procedures for aquatic organisms and for control and notification of aquatic diseases.

[24] www.un.org/Depts/los/reference_files/chronological_lists_of_ratifications.htm. [Cited 8 March 2018].

9.2.1 Participation in international forums of relevance for aquatic genetic resources

Reporting countries listed between 1 and 24 agreements relevant to AqGR in which they participate (Table 100).

Table 100
Number of international agreements relevant for aquatic genetic resources (by country)

Country	Number of international agreements	Country	Number of international agreements	Country	Number of international agreements
Algeria	8	El Salvador	8	Norway	24
Argentina	8	Estonia	1	Palau	7
Armenia	5	Fiji	1	Panama	16
Australia	11	Finland	11	Paraguay	1
Bangladesh	8	Georgia	4	Peru	8
Belgium	3	Germany	21	Philippines	12
Belize	1	Ghana	2	Romania	17
Benin	6	Guatemala	3	Samoa	2
Bhutan	4	Honduras	6	Senegal	4
Brazil	8	Hungary	3	Sierra Leone	4
Bulgaria	5	India	5	South Africa	2
Burkina Faso	7	Indonesia	6	Sri Lanka	4
Burundi	1	Iran (Islamic Republic of)	8	Sudan	6
Cabo Verde	8	Japan	3	Sweden	13
Cambodia	5	Kiribati	2	United Republic of Tanzania	6
Cameroon	3	Republic of Korea	3	Thailand	4
Canada	2	Lao People's Democratic Republic	2	Togo	6
Chad	7	Madagascar	5	Tonga	2
Colombia	10	Malawi	6	Tunisia	13
Democratic Republic of the Congo	5	Malaysia	6	Turkey	9
Costa Rica	8	Mexico	7	Uganda	11
Croatia	9	Morocco	8	Ukraine	3
Cuba	6	Mozambique	3	United States of America	11
Czechia	4	Netherlands	5	Vanuatu	2
Djibouti	1	Nicaragua	4	Venezuela (Bolivarian Republic of)	3
Dominican Republic	11	Niger	3	Viet Nam	5
Ecuador	8	Nigeria	10	Zambia	11
Egypt	1				

Countries reported 169 different international agreements. These agreements are at various levels and with different scope, ranging from bilateral or subregional agreements on certain aquatic taxa to full-fledged conventions, protocols and treaties covering all genetic resources including fish.

Table 101 lists the most important international agreements that were reported by countries. The CBD and CITES were most often cited, followed by the Nagoya Protocol, the Cartagena Protocol, the Ramsar

Convention, UNCLOS, CCRF and UNFCCC. The Barcelona Convention and the Convention on the Conservation of Migratory Species of Wild Animals (CMS) were cited by less than 10 percent of reporting countries.

In the aggregate for all countries, a total of 515 agreements were reported. It should be noted that many countries are reporting the same agreements (e.g. 60 countries reported on CBD); these agreements are considered independently throughout the remaining discussion.

Seventy-eight percent of the countries reported only one international agreement of relevance to AqGR, indicating that this subject is still accorded relatively low priority despite the growing global importance of farmed aquatic production.

Table 101
The top ten important international agreements dealing with use, conservation and management of aquatic genetic resources (by region)

International agreements	Total countries	Asia	Africa	Europe	Latin America & the Caribbean	North America	Oceania
CBD	60	12	17	12	13	1	5
CITES	60	15	18	10	12		5
Nagoya Protocol	46	10	10	11	13		2
Cartagena Protocol	40	11	9	7	12		1
Ramsar Convention	35	8	13	4	9		1
UNCLOS	25	7	7	8	2		1
CCRF	21	5	8	4	2		2
UNFCCC	15	2	9	1	3		
Barcelona Convention	6	1	4	1			
CMS	6		4	2			

The number of international agreements by region ranges from 13 in North America to 147 in Africa (Table 102), and by economic class from 115 in the least developed countries to 243 in other developing countries (Table 103). The number of international agreements by minor and major producing countries is 448 and 67, respectively (Table 104).

Table 102
Number of international agreements reported by region

Geographical regions	Number of international agreements reported	Total number of responding countries	Average number of agreements per country
Asia	93	17	5.6
Africa	147	26	5.7
Europe	119	13	9.1
Latin America & the Caribbean	116	17	6.8
North America	13	2	6.5
Oceania	27	7	3.9

Table 103
Number of international agreements reported by economic class

Economic class	Number of international agreements reported	Total number of responding countries	Average number of agreements per country
Developed Countries	157	20	7.9
Other Developing Countries	243	39	6.2
Least Developed Countries	115	23	5.0

Table 104
Number of international agreements reported by minor and major producing countries

Economic class	Number of international agreements reported	Total number of responding countries	Average agreements per country
Major producing countries	67	9	7.4
Minor producing countries	448	73	6.1

The impact of international agreements on AqGR was reported for 469 out of the total 515 agreements (recalling that agreements are considered by country, i.e. there are only 169 unique agreements, but each country considers the impacts independently).

The impact has generally been assessed from positive to strongly positive for a total of 399 agreements, 67 agreements have been considered as having no effect, while 3 agreements have been reported as having a negative impact (Table 105).

Table 105
Impact of international agreements on aquatic genetic resources, presented as number of responses per country

Impact on aquatic genetic resources	Number of agreements	Country (number of agreements having impact)
Strongly positive	87	Argentina (1); Benin (6); Burkina Faso (5); Cambodia (2); Costa Rica (7); Cuba (1); Czechia (1); Djibouti (1); Dominican Republic (2); Guatemala (3); India (1); Japan (3); Republic of Korea (1); Lao People's Democratic Republic (1); Malawi (1); Malaysia (3); Mexico (7); Nicaragua (1); Niger (1); Paraguay (1); Peru (6); Philippines (12); Senegal (1); Sierra Leone (2); Sweden (2); United Republic of Tanzania (4); Togo (1); Tunisia (3); Turkey (1); Uganda (5); Viet Nam (1)
Positive	312	Algeria (6); Argentina (7); Australia (3); Bangladesh (7); Belgium (3); Bulgaria (3); Burkina Faso (2); Burundi (1); Cabo Verde (1); Cambodia (3); Cameroon (1); Canada (2); Chad (7); Colombia (10); Democratic Republic of the Congo (5); Costa Rica (1); Croatia (4); Cuba (5); Czechia (2); Dominican Republic (8); Ecuador (8); Egypt (1); El Salvador (8); Finland (9); Germany (18); Ghana (2); Honduras (6); India (4); Indonesia (6); Iran (Islamic Republic of) (6); Kiribati (2); Republic of Korea (2); Lao People's Democratic Republic (1); Madagascar (3); Malawi (5); Malaysia (3); Morocco (8); Mozambique (3); Netherlands (5); Nicaragua (2); Niger (2); Nigeria (5); Norway (22); Palau (7); Panama (15); Peru (2); Romania (6); Samoa (2); Senegal (3); Sierra Leone (2); South Africa (2); Sri Lanka (4); Sudan (6); Sweden (1); United Republic of Tanzania (2); Thailand (4); Togo (3); Tonga (2); Tunisia (8); Uganda (6); Ukraine (3); United States of America (7); Vanuatu (2); Viet Nam (4); Zambia (9)
No effect	67	Armenia (1); Australia (8); Bhutan (4); Brazil (8); Bulgaria (2); Croatia (1); Czechia (1); Dominican Republic (1); Estonia (1); Fiji (1); Finland (2); Georgia (4); Germany (2); Hungary (3); Iran (Islamic Republic of) (1); Madagascar (1); Nicaragua (1); Norway (2); Romania (11); Togo (2); Tunisia (2); United States of America (4); Venezuela (Bolivarian Republic of) (2); Zambia (2)
Negative	3	Bangladesh (1); Cameroon (2)

The impact of international agreements on stakeholders was reported for 465 out of the total 515 agreements (recalling that agreements are considered by country, i.e. there are only 169 unique agreements, but each country considers the impacts independently).

The results are similar for the impact of international agreements on stakeholders, which has been assessed from positive to strongly positive, for a total of 387 agreements; 66 agreements have been considered as having no effect, and 12 agreements have been reported as having a negative impact (Table 106).

Table 106
Impact of international agreements on stakeholders, presented as number of responses per country

Impact on stakeholders	Number of agreements reported	Country (number of agreements having impact)
Strongly positive	62	Argentina (1); Benin (6); Burkina Faso (4); Costa Rica (7); Cuba (1); Czechia (1); Djibouti (1); Dominican Republic (2); Guatemala (3); Japan (3); Malaysia (3); Mexico (7); Nicaragua (1); Paraguay (1); Peru (6); Sierra Leone (2); United Republic of Tanzania (4); Tunisia (3); Turkey (1); Uganda (4); Ukraine (1)
Positive	325	Algeria (6); Argentina (7); Australia (3); Bangladesh (7); Belgium (1); Brazil (6); Bulgaria (3); Burkina Faso (3); Burundi (1); Cameroon (2); Canada (2); Chad (7); Colombia (10); Democratic Republic of the Congo (5); Costa Rica (1); Cuba (5); Czechia (2); Dominican Republic (8); Ecuador (8); Egypt (1); El Salvador (8); Finland (8); Germany (17); Ghana (1); Honduras (6); India (5); Indonesia (6); Iran (Islamic Republic of) (5); Kiribati (2); Republic of Korea (3); Lao People's Democratic Republic (2); Madagascar (3); Malawi (6); Malaysia (3); Morocco (8); Mozambique (3); Netherlands (4); Nicaragua (2); Niger (3); Nigeria (5); Norway (21); Palau (6); Panama (15); Peru (2); Philippines (12); Romania (6); Samoa (2); Senegal (4); Sierra Leone (2); South Africa (2); Sri Lanka (4); Sudan (6); Sweden (3); United Republic of Tanzania (2); Thailand (4); Togo (4); Tonga (2); Tunisia (8); Uganda (7); Ukraine (2); United States of America (7); Vanuatu [illegible]; Viet Nam [illegible]; Zambia [illegible]
No effect	66	Armenia (2); Australia (8); Bhutan (4); Brazil (2); Bulgaria (1); Cambodia (3); Croatia (3); Czechia (1); Dominican Republic (1); Estonia (1); Fiji (1); Finland (2); Georgia (4); Germany (1); Ghana (1); Hungary (3); Iran (Islamic Republic of) (2); Madagascar (1); Nicaragua (1); Norway (2); Romania (11); Togo (2); Tunisia (2); United States of America (4); Venezuela (Bolivarian Republic of) (2); Zambia (1)
Negative	12	Bangladesh（1); Belgium (2); Cambodia (2); Cameroon (1); Finland (1); Germany (2); Netherlands (1); Norway (1); Zambia (1)

A presentation by geographical region confirms that in all regions the impact of international agreements on AqGR has been considered to be either positive or strongly positive. Europe, followed by Latin America and the Caribbean, Asia and then Africa, has the highest number of international agreements where "no effect" predominates (Table 107). Three international agreements were considered to have a negative impact.

Table 107
Impact of international agreements on aquatic genetic resources by geographical region (number of responses)

Geographical region	Impact on aquatic genetic resources			
	Strongly positive	Positive	No effect	Negative
Asia	25	44	10	1
Africa	30	93	7	2
Europe	3	76	25	0
Latin America & the Caribbean	29	72	12	0
North America	0	9	4	0
Oceania	0	18	9	0
Total	87	312	67	3

9.2.2 International collaboration – needs assessment: overview by region, subregion and economic class

This section focuses on the need for international collaboration as assessed by reporting countries. All areas of collaboration were ranked as being fairly important, with collaboration for improved information technology and database management, basic knowledge on AqGR, and improved capacities for characterization and monitoring, genetic improvement and conservation purposes scoring as slightly higher priorities.

When analysing the data according to the extent to which the assessed need is not met or is only partially met, the highest priority is for improved communication and improved capacities for the conservation and economic valuation of AqGR, followed by improved basic knowledge, improved capacities for characterization and monitoring, improved access and distribution of AqGR, and improved information technology and database management (Table 108). With the exception of information technology and database management, the extent to which the assessed need is not or only partially met is rather high (all equal or above 74 percent). This highlights the need for an international network (Box 21).

Table 108
Average rank and extent to which the assessed need is not/partially met for international collaboration needs regarding sustainable use, conservation and management of aquatic genetic resources

Assessed need for collaboration	Average importance rank*	Extent to which the assessed need is not/partially met**
Improve information technology and database management	2	61
Improve basic knowledge on aquatic genetic resources	2	79
Improve capacities for characterization and monitoring of aquatic genetic resources	2	76
Improve capacities for genetic improvement	2	74
Improve capacities for economic valuation of aquatic genetic resources	3	80
Improve capacities for conservation of aquatic genetic resources	2	82
Improve communication on aquatic genetic resources	3	84
Improve access and distribution of aquatic genetic resources	3	74

*A score of 1 is very important; a score of 10 indicates no importance.
**Calculated as the percent of countries reporting "not met" or "only met to some extent".

Box 21

The International Network on Genetics in Aquaculture

Aquaculture does not yet take advantage of the gains in production and profitability that can be derived from the domestication and genetic improvement of aquatic species as has been practised in terrestrial agriculture for millennia.

However, domestication and genetic improvement require financial resources and human capacity in order to deliver significant and long-term gains from well-designed selective breeding programmes, to monitor the results, and to ensure the dissemination of genetic gains to farmers. Although genetic improvement does require resources and capacity, countries often have similar needs and opportunities in regard to the development, use and conservation of aquatic genetic resources (AqGR). Thus, a network of groups with similar interests and needs could facilitate the improvement, use and conservation of AqGR.

As has been highlighted elsewhere in the Report, the Genetic Improvement of Farmed Tilapia (GIFT) programme of the WorldFish Center was extremely successful in several countries. There was a desire to promote the use of GIFT genetic material, as well as the technology of continuous genetic improvement through selective breeding more widely. As a result, the International Network on Genetics in Aquaculture (INGA) was established by the WorldFish Center in 1993 to promote the exchange of technologies and information on genetic improvement between member institutions, to organize training courses in quantitative genetics and selection theory, and to propose means for the responsible exchange of genetic material. In 1999, INGA had a membership of 13 countries in Asia, the Pacific and Africa (Bangladesh, China, Côte d'Ivoire, Egypt, Fiji, Ghana, India, Indonesia, Malawi, Malaysia, the Philippines, Thailand and Viet Nam) and 12 advanced scientific institutions (Gupta and Acosta, 2001).

INGA members were committed to the responsible use of AqGR and developed common policies and practices with regard to development, transfer and use of AqGR, such as:

- The "Manila Resolution" that stressed the need for concerted regional and international efforts for advancing fish breeding and genetics through cooperation.
- African members of INGA helped formulate the Nairobi Declaration: Conservation of Aquatic Biodiversity and Use of Genetically Improved and Alien Species for Aquaculture in Africa (Gupta, 2002).
- INGA members also agreed to follow standard procedures for the exchange of AqGR through Material Transfer Agreements.

INGA not only provided a forum for information exchange and establishment of common policies, it also organized a series of international training courses in quantitative genetics. The capacity that was developed has since allowed participants to establish national aquaculture breeding programmes for tilapia as well as for a variety of other species (e.g. rohu carp, common carp, silver barb, river catfish) (Gupta and Acosta, 2001).

FAO was an observer to INGA, helped draft the Nairobi Declaration, and greatly appreciated the work of the network's members and WorldFish Center as coordinator. INGA provided a forum where FAO could easily engage experts on AqGR from a variety of countries.

However, INGA no longer exists, a surprising fact given the apparent success of the network and the substantial opportunities to increase production in aquaculture through better genetic resource

management, including selective breeding, and considering the successful example of the GIFT programme.

While all the reasons have not been examined in depth, the main issue seems to be the lack of a sustained, long-term funding mechanism (M.V. Gupta, personal communication, 26 March 2018). Since the network was project financed, the network concluded when the project ended.

In southern Africa, and perhaps elsewhere, there is renewed interest in an INGA-like network. M.V. Gupta, the former coordinator of INGA and recipient of the World Food Prize and the Sunhak Peace Prize, in a personal communication to the FAO Aquaculture Branch of 26 March 2018, recommended that a future INGA-like network should adhere to the following three points:

(i) Network activities should be part of the core funding of the coordinating organization. Project or additional donor funding for specified activities of the network would be considered as necessary.
(ii) There should be a stable leadership and coordinating institution with a strong and stable competence in aquaculture breeding and genetics.
(iii) Recognizing that genetic improvement is a long-term endeavour, the members of the network should have identified genetics projects as a core programme/project of their institutions.

The information from Country Reports was also analysed at the regional level for the five assessed needs given a higher priority by the respondents (Table 109 to Table 113). In all cases, Africa represents the region with the highest number of countries where collaboration needs are not met. The high number of countries around the globe answering “none” regarding the extent to which these important needs are met point to the need for an INGA-like network (Box 21).

Table 109
Extent to which the needs for international collaboration regarding improved information technology and database management are met

Response	Africa	Asia	Europe	Latin America & the Caribbean	North America	Oceania	Total
To a great extent	3	5	3	5	1		17
To some extent	10	8	8	9	1	7	43
None	9	4	3	2			18
Unknown	3		2	2			7
Total	25	17	16	18	2	7	85

Table 110
Extent to which the needs for international collaboration regarding improved basic knowledge on aquatic genetic resources are met

Response	Africa	Asia	Europe	Latin America & the Caribbean	North America	Oceania	Total
To a great extent	4	3	4	3	1		15
To some extent	15	12	8	15	1	7	58
None	4	3	2				9
Unknown	2		1				3
Total	25	18	15	18	2	7	85

Table 111
Extent to which the needs for international collaboration regarding improved capacities for characterization and monitoring of aquatic genetic resources are met

Response	Africa	Asia	Europe	Latin America & the Caribbean	North America	Oceania	Total
To a great extent	3	6	1	1	1	1	13
To some extent	13	6	9	15	1	5	49
None	7	4	2	1		1	15
Unknown	2	1	3	1			7
Total	25	17	15	18	2	7	84

Table 112
Extent to which the needs for international collaboration regarding improved capacities for genetic improvement are met

Response	Africa	Asia	Europe	Latin America & the Caribbean	North America	Oceania	Total
To a great extent	4	4	1	3		1	13
To some extent	10	8	8	12	2	3	43
None	7	4	3	2			16
Unknown	3		3	1			7
Total	24	16	15	18	2	4	79

Table 113
Extent to which the needs for international collaboration regarding improved capacities for conservation of aquatic genetic resources are met

Response	Africa	Asia	Europe	Latin America & the Caribbean	North America	Oceania	Total
To a great extent	2	4	2	1	1		10
To some extent	19	10	10	12	1	7	59
None	3	2	1	2			8
Unknown		1	3	1			5
Total	24	17	16	16	2	7	82

9.3 Selected successful examples of international collaboration

The last section of this chapter presents some successful examples of international collaboration. The story of the collaborative development and international dissemination of tilapia is presented in Box 22.

Box 22
The case of the two tilapias

Tilapia is one of the most globally ubiquitous species for aquaculture, with production being reported in over 140 countries around the world with current world production at nearly 1.8 million tonnes. Tilapias are a species complex made up of three genera *Oreochromis*, *Sarotherodon* and *Tilapia* (Trewavas, 1983), with the maternal mouthbrooding genus *Oreochromis* dominating aquaculture production. Two species have predominated: the Nile tilapia (*O. niloticus*) and the Mozambique tilapia (*O. mossambicus*). There are contrasting histories in distribution of these species around the world, which demonstrates the value of effective management, including selective breeding, of genetic resources for aquaculture.

The first species for which potential in aquaculture was realized was *O. mossambicus*, which originates from southeast Africa. The first record of this species outside its natural range was the identification of five individuals in Indonesia in the 1930s. Subsequent generations of their progeny were transferred to other countries in Southeast Asia (Agustin, 1999). FishBase (Froese and Pauly, 2018) currently records the introduction of this species to 93 countries. It was adopted for aquaculture in many of these countries and also formed feral populations. Genetic analysis of some feral populations around Asia and Oceania (Agustin, 1999) revealed low levels of genetic variation compared to reference native populations, consistent with one or more significant genetic bottlenecks. Thus, it is quite feasible that a large proportion of the global population for this species, outside of its natural range, may have been derived from this small founder population in Indonesia. *O. mossambicus* is now rarely cultured outside its natural range (with small-scale production reported from just 14 countries in which it is non native). Widely considered to be an inferior culture species compared to *O. niloticus*, it exhibits slower growth rates, precocious reproduction and a tendency to stunting. These properties may well be a result of inbreeding depressing, resulting from genetic bottleneck effects. *O. mossambicus* has now been largely displaced by *O. niloticus* in aquaculture, although remnant feral populations are commonplace in countries to which it was introduced.

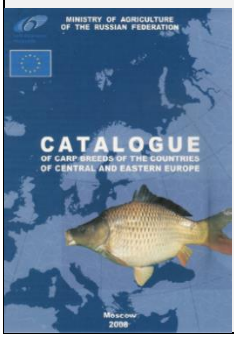
Pullin and Capili (1988) report that the initial distribution of *O. niloticus* had a broader base than outlined for *O. mossambicus*, with multiple source populations. In the past two decades, the Genetic Improvement of Farmed Tilapia (GIFT) project has played an important and proactive role in the distribution of Nile tilapia. The GIFT project was an international collaboration to improve the genetic performance of farmed Nile tilapia, implemented from 1988–1998 (Gjedrem, 2012). This project demonstrates what can be achieved through a systematic and collaborative approach to collection, development and distribution of germplasm for aquaculture. Under this project, founder populations were collected from native stocks and introduced strains and then used to create a mixed synthetic strain based on data that recorded their performance. Subsequent genetic selection for commercial traits over multiple generations produced significant enhancement of culture performance. The GIFT tilapia and GIFT-derived strains have been introduced into many countries through both the public and private sectors. In many cases, selective breeding of the strain was continued in the receiving country. This systematic approach would not only have avoided the negative impacts of inbreeding or poor genetic management, but also resulted in superior performance in many aquacultured strains as a result of maintenance of high levels of genetic variation and genetic selection for important traits.

The development and widespread introduction of the GIFT tilapia has undoubtedly had a major impact on the global prioritization and expansion of the culture of this species. Nile tilapia is now reported as being cultured in 87 countries, and through the *State of the World's Aquatic Genetic Resources for Food and Agriculture* reporting process, seven countries recorded production of GIFT tilapia, but it is likely that GIFT derived strains are impacting production in many more.

An excellent example of international collaboration regarding common carp genetic resources has been provided by the “HAKI-live gene bank of common carp” from Hungary (Box 23).

Box 23
Regional cooperation in carp gene banking

The “HAKI-live gene bank of common carp”, located at the Research Institute for Fisheries and Aquaculture (HAKI, Szarvas, Hungary), was established through intensive international collaboration worldwide. The foreign carp strains were introduced mainly from Central and Eastern Europe, including the former Soviet Union, but also from Southeast Asia, including Thailand and Viet Nam (Bakos and Gorda, 2001). Upon completion of the collection, it became a supporting genetic resource of common carp for the region and globally. Requests for the high-quality genetic material held in the gene bank came from around the world, and HAKI was able to satisfy these requests according to regulations (translocation and biosecurity), while dependent on financial resources. Often, these translocations took place under the auspices of research and development projects, including introductions to India (Basavaraju, Penman and Mair, 2003) and Viet Nam (Phuong *et al*., 2002). After deep socio-economic changes occurring in Central and Eastern Europe, most of the well-established carp genetic programmes and gene banks collapsed. As a result, demand is currently growing for high-quality strains of common carp. The Eurocarp project (http://eurocarp.haki.hu/index.php), led by HAKI and focused on the development of disease and stress-resistant carp using a range of molecular approaches, is an example of a multinational research collaboration (supported by the European Union) that utilizes the genetic diversity of carp in the HAKI gene bank. One output of the Eurocarp project is an inventory list of existing genetic resources of common carp in Central and Eastern Europe, a bilingual catalogue of strains identifying 60 national and 25 introduced strains in seven major carp-producing countries in Europe (Bogeruk, 2008).



There are also a number of restocking programmes using appropriate resources of the HAKI-gene bank (e.g. after the Tisza River pollution in Hungary, as well as after the loss of local strains due to the war in former Yugoslavia).

In conclusion, it is evident that the common carp gene bank of HAKI, originally developed using state funding, has played an important role in the management of carp genetic resources both in the region and globally.

Within the activities of the Working Group on the Black Sea of the General Fisheries Commission for the Mediterranean, an Aquaculture Demonstrative Centre unit has been established as part of the Central Fisheries Research Institute in Trabzon, Turkey. Among other objectives, the centre intends to enhance knowledge-sharing and capacity building among all the Black Sea countries in order to foster cooperation on responsible aquaculture. Within this framework, planned activities include training on restocking of turbot (*Scophthalmus maximus*) based on the native population to enhance the stock, contribute to the conservation of genetic resources, and provide ecological services to the environment with the cooperation of the coastal fisheries.

The cooperative approach to conservation of sturgeon in the Danube River, as presented in Chapter 5, provides a very good example both of international cooperation as well as of the integration of *in situ* and *ex situ* conservation. Similarly, the regional cooperation of bordering countries of the Rhine River for the reintroduction of migratory species and the successful return of Atlantic salmon into the river basin demonstrates the important role of targeted international cooperation (Box 24).

Box 24

Migratory species of the Rhine River – a successful example of regional cooperation

By the end of the nineteenth century, there were still hundreds of thousands of Atlantic salmon (*Salmo salar*) in the Rhine River, annually migrating upstream to their spawning grounds. Historical data indicate a catch of almost 250 000 salmon in 1885. After that peak, catches declined, until the complete extinction of this stock in the 1950s. This extinction is closely correlated with the construction of obstacles to migration, although there were other contributory factors, including deterioration of water quality and overexploitation of the remaining stocks.

When starting an ambitious programme for the ecological rehabilitation of the Rhine in 1987, the Member States of the International Commission for the Protection of the Rhine (ICPR) agreed that migratory fish species, such as the Atlantic salmon, should again colonize the river and its tributaries. To achieve this goal, measures were taken to improve water quality and river continuity, and a restocking programme was initiated in several areas of the Rhine basin.

The ICPR, with headquarters in Koblenz, Germany, coordinates the ecological rehabilitation programme and involves all countries in the catchment of the Rhine River. The Convention on the Protection of the Rhine is the legal basis for international cooperation for the protection of the Rhine within the ICPR (ICPR, 1999). It was signed on 12 April 1999 by representatives of the governments of the Rhine-bordering countries of France, Germany, Luxembourg, the Netherlands and Switzerland, and the European Community. These countries thus formally confirmed to continue to protect the valuable character of the Rhine River, its banks and floodplains, through increased cooperation.

One of the issues in the ICPR is ecological river restoration, for which the Atlantic salmon has become a key species since the introduction of the "Salmon 2000" programme in 1987. Today, the "Master Plan Migratory Fish Rhine" (ICPR, 2009) acts as a demonstration of how self-sustaining, stable populations of migratory fish can be reintroduced to the Rhine catchment within a reasonable period of time and at reasonable cost. On 18 October 2007, the Conference of Rhine Ministers confirmed its intent to gradually restore river continuity in the Rhine as far as Basel, Switzerland. Atlantic salmon is representative of other long-distance migratory fish species, such as sea trout (*Salmo trutta trutta*), sea lamprey (*Petromyzon marinus*), allice shad (*Alosa alosa*), and European eel (*Anguilla anguilla*). Measures aimed at reintroducing salmon and sea trout will likely have positive effects not only on the incidence of many more animal and plant species, but also on the entire ecology of the Rhine.

Since 1990, more than 8 000 adult salmon have been registered within the catchment, and natural reproduction has been regularly recorded in an increasing number of accessible tributaries of the Rhine River. The successful return of Atlantic salmon into the Rhine River demonstrates that it is possible to reintroduce regional extinct migratory fish species, and targeted international cooperation has played a key role.

As part of the preparation of the *State of the World's Aquatic Genetic Resources for Food and Agriculture*, FAO requested feedback from international organizations working with AqGR in a development context (Box 25). The main issues prioritized by one or more of these organizations in regional cooperation included: (i) capacity building for breed improvement, especially of indigenous species; (ii) improving information on AqGR; (iii) *in situ* conservation; (iv) knowledge development on diverse locally developed aquaculture breeds; (v) capacity building on mechanisms for the biosecure exchange of aquaculture genetic material; and (vi) policy development.

Box 25

Key issues for international cooperation – feedback from international organizations

Following the initial drafting of this Report, FAO requested feedback from international organizations* working with aquatic genetic resources (AqGR) in a development context. Part of the feedback covered the issues around AqGR that are being prioritized by one or more of these organizations in regional cooperation, which included:

- Capacity building for breed improvement, especially of indigenous species (including research and development, post-graduate training and extension), to ensure quality broodstock and seed and minimize hybridization or poor genetic management that might threaten biodiversity and production. This includes programmes for small farms and community-based programmes. In this regard, selective breeding has been demonstrated to be an efficient and successful method for long-term genetic improvement of AqGR of several species while controlling inbreeding and maintaining genetic diversity. It should therefore be central in capacity-building programmes.
- Improving information on AqGR through techniques of molecular characterization, including genetic mapping, but also capacity building on techniques for cost-effective monitoring of genetic status of farmed types and simple techniques for verifiable certification of broodstock origin and purity.
- *In situ* conservation through designation of specific gene pools, genetic mapping and establishment of protected areas which should be well demarcated and monitored.
- Knowledge development on diverse locally developed aquaculture strains.
- Capacity building on mechanisms for biosecure exchange of aquaculture genetic material, including support for aquaculture broodstock exchange networks, such as those that are successful and economically self-sustaining in terrestrial domesticated animals.
- Policy development for effective conservation, management and development of AqGR.

Though the aforementioned are issues directly impacting on AqGR, regional cooperation has also dealt with issues that indirectly impact AqGR, such as transboundary issues of aquaculture; community-based aquaculture management; promotion of regional and international collaboration; collection and compilation of aquaculture-related data; dissemination of scientific information on sustainable aquaculture and food safety; and understanding of gender and entrepreneurship issues in aquaculture.

*Respondents included the Network of Aquaculture Centres in Asia-Pacific (NACA), WorldFish Center (WFC), the Pacific Community (SPC), Lake Victoria Fisheries Organization (LVFO), Mekong River Commission (MRC), and the Southeast Asian Fisheries Development Centre (SEAFDEC).

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CHAPTER 10

SYNTHESIS OF KEY FINDINGS AND CONCLUSIONS

Introduction

This chapter provides a synthesis of the key findings arising from the analysis of the *Report of the State of the World's Aquatic Genetic Resources for Food and Agriculture* and highlights corresponding recommendations.

The state of world aquaculture and fisheries

The most recent available data from 2016 show that the total of world capture fisheries and aquaculture production was estimated at around 202 million tonnes at that time. Global fish production[1] had risen to a level of around 171 million tonnes in the same year. Developing countries account for the majority of production from both aquaculture and capture fisheries.

Production from capture fisheries has plateaued at about 91 million tonnes, with marine fisheries making up around 87 percent of the total. According to general consensus, production from marine fisheries are unlikely to increase beyond current levels. On the other hand, aquaculture, which represents nearly 47 percent of the total food fish production, has experienced growth of about 6 percent per year over the past several decades, and this growth is expected to continue.

In 2016, global aquaculture production of aquatic living genetic resources reached a total of 110 million tonnes, including 80 million tonnes of food fish and 30 million tonnes of aquatic plants. There was a further 38 000 tonnes of non-food production. This production is derived from aquaculture operations conducted in freshwater, brackish water and marine waters. The Asian region is the predominant aquaculture producer, accounting for about 89 percent of world food fish production in 2016.

Production systems for farming fish and other aquatic organisms are highly diversified in terms of species and systems. Although the number of farmed aquatic species is small relative to the number of species produced from capture fisheries, it remains extremely diverse compared to other food production sectors. By 2016, almost 600 species and/or species items of finfish, molluscs, crustaceans, other animals and algae have been reported to the Food and Agriculture Organization of the United Nations (FAO) as having been farmed around the world. Marine and coastal areas contain the highest number of farmed species and their wild relatives due to the presence of several phyla that are not present in inland waters. There are over 1 800 species harvested from capture fisheries.

Asia farms the highest number of aquatic species (299), in part due to having the longest tradition of aquaculture, followed by Europe (182), Latin America and the Caribbean (158), Africa (122), Oceania (74) and North America (45).

Global production of farmed aquatic plants, overwhelmingly dominated by seaweeds, has reached just over 30 million tonnes in 2016 and is largely from marine and brackish waters. However, some microalgae are cultured in freshwaters. Farming of aquatic plants is undertaken in more than 50 countries and over the past decade has grown by 8 percent per year. Freshwater macrophytes are relatively under-researched and underdocumented but play important roles in food security and rural economic development, particularly in Asia. Microorganisms, feed organisms, aquatic plants, sea cucumbers, sea urchins, amphibians and reptiles, as well as ornamental species, have not been comprehensively reported to FAO.

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[1] The term "fish" includes finfishes, crustaceans, molluscs and other aquatic animals, such as frogs and sea cucumbers for human food, excluding aquatic mammals and crocodiles.

The use and exchange of aquatic genetic resources

Although the regular reporting of production to FAO had already revealed the great diversity of aquatic genetic resources (AqGR) used in fisheries and aquaculture, the Country Reports indicated over 250 species and species items that have not previously been reported to FAO, along with their production statistics. Many of the additional species reported were microorganisms, aquatic plants and ornamental fish that have not been well covered in reports to FAO and are not listed in the Aquatic Sciences and Fisheries Information System (ASFIS) list that is the standard for reporting to FAO. Many of the reported farmed types identified were strains, hybrids and polyploids identified which are below the species level and therefore not included in the ASFIS list.

Although the Country Reports listed numerous farmed types used in aquaculture, these were relatively few compared to the numbers breeds, hybrids and varieties used in crop and livestock production. Thus, aquaculture uses a higher diversity of species while crops and livestock use a higher diversity of breeds and varieties. Aquaculturists may need to make decisions in the future on whether to try to farm more species to meet consumer and production demands, or to continue to diversify existing species into more productive strains as has occurred in terrestrial agriculture. In either case, the use of standardized and consistent nomenclature will be essential to understand, document and monitor the future sustainable management, development, conservation and use of AqGR.

Because of the ASFIS list that countries use for standard reporting to FAO and the existence of species-based information systems that also use standard nomenclature, countries considered that their naming at the species level was accurate. However, at the farmed type level, i.e. below the species level, nomenclature and terminology were not consistent across the Country Reports. Since the movement of AqGR between countries is an important part of the aquaculture sector, it will be essential for this movement to be well documented with standard and appropriate nomenclature to facilitate risk-benefit analysis and to comply with national and international policies.

The Report and a review of successful examples of aquaculture development revealed that public-private partnerships can facilitate development of aquaculture and uptake of appropriate genetic technologies. However, in many instances, governments and private industry have not yet formed significant partnerships in the aquaculture sector. Not all governments have the resources to facilitate aquaculture development, but further examination of such partnerships should be explored, especially where governments have included aquaculture in their poverty alleviation and economic policies.

The Report has introduced new terms (e.g. *farmed type*) and/or standardized the use of existing terminology, (e.g. *wild relative*, *hybrid, strain* or *stock*). Nomenclature followed the conventions from terrestrial agriculture and traditional fishery management, as well as from the international scientific community. It will be important to promote a wider acceptance of this terminology and nomenclature for future reporting and for any information system at national, regional and international levels.

Genetic data are generally available and used in aquaculture, with major producing countries using the information more than the minor producing countries, and least developed countries using information on AqGR to a lesser degree than other countries. While genetic data may exist for wild relatives, these data are often not used in management.

As reported in the conventional scientific literature, species farmed in aquaculture are very similar to their wild relatives; the wild type was the most common farmed type reported by countries. Although the reporting of different types of genetic resource management/improvement was higher than expected – about 60 percent of the farmed types of reported species had undergone some kind of genetic change – there is great potential to further improve aquaculture production through the application of genetic technologies. In fact, aquaculture geneticists have stated that if all farmed aquatic species were subject to traditional selective breeding programmes, aquaculture production could double by 2050, thus meeting the additional need for seafood with minimum requirement for extra land, water, feed or other inputs. Public support was an important source of funds for genetic improvement programmes, although public financing was more prevalent in the major producing countries.

Short-term technologies such as hybridization and polyploidization can produce significant one-time gains, whereas longer-term technologies such as selective breeding can produce gains generation after generation. New biotechnologies, such as gene editing, may also offer opportunities but are only at the experimental phase at present. Practical application of genetic technologies appropriate to specific circumstances and consumer acceptance of new biotechnologies will need to be addressed before they can become widely used in aquaculture.

Unlike terrestrial agriculture, the wild relatives of all farmed aquatic species still exist in nature. This is a valuable resource that needs to be protected and conserved. Wild relatives provide key resources to aquaculture as broodstock, as sources of gametes and embryos, and as early life history stages to be grown out under culture conditions or stocked into waterbodies to support capture fisheries. Additionally, most wild relatives are also harvested in capture fisheries. However, in spite of policies and fishery management plans, the abundance of wild relatives were reported to be declining in many instances. Habitat loss and degradation were the main reasons cited for these declines.

Drivers and trends

The growing human population drives the demand for seafood, which in turn will drive efforts to expand and diversify the farmed species produced. This will also exert pressure on wild relatives.

Most aquaculture production occurs in freshwater environments. The demand for freshwater for agriculture, urban supply, energy production and other uses will challenge aquaculture to become more efficient in its resource use and to reduce its discharges. This will require species adapted to such systems. An expansion into brackish water will drive the demand for new brackish-water AqGR for culture. Wild relatives will be threatened by changes in priorities related to the use of water. Pollution from industry, agriculture and urban sources threatens the quality of water used both for aquaculture and to sustain wild relatives.

Increasing levels of good governance are observed as having an overall beneficial effect on AqGR in both farmed types and wild relatives. Impacts range from improved regulation of farms and their operations to greater professionalization within the sector. Impacts on wild relatives pertain to improved environmental management, better control over stocking and movements, and higher levels of conservation and protection.

Accompanying increasing wealth in developing economies are greater intraregional and interregional trade and increasing urbanization and industrialization, all of which drive demand and preference for AqGR. There will be increasing consolidation and industrialization of large volume, internationally traded commodities such as seafood, hence the resulting preference for specific AqGR. There will also be increased emphasis on food safety and traceability, which will present challenges for smaller operators and may limit their options for production systems and the AqGR they employ. At the same time, there will be continuous exploration of new AqGR species to satisfy the demand for new commodities and to fill niche markets. Demand for ornamental species will increase, driving the development of farmed types as well as demands on wild relatives.

With changing demographics, consumer attitudes towards fish are also changing, affecting acceptability and demand for different AqGR. Fish consumption is increasingly recognized as part of a healthy and balanced diet. Correspondingly, increasing urbanization will drive demand for seafood, which will drive incentive for increasing supply from aquaculture and, to some extent, fisheries. Concern remains over the use of genetic modifification techniques in some markets, including consumer resistance to genetically modified organisms (GMOs). This may also include resistance to other farmed types (e.g. hybrids, triploids). There is increasing awareness regarding the unsustainable exploitation of wild relatives, driving demand for farmed types.

Changes in the use of land, water, coastal areas, wetlands and watersheds all have impacts on the quantity and quality of habitat for AqGR. Changes to watersheds are among the principal factors that

affect aquatic systems. Aspects that affect AqGR include, among others, damming of rivers, drainage systems, flood control and flood protection, hydropower development, irrigation, partitioning of wetlands and road construction. The establishment of invasive species can have direct impacts on AqGR through competition or predation, as well as indirect impacts on food webs and ecosystems that support wild relatives. Water pollution has strong negative impacts, particularly in freshwater, and affects both wild relatives and farmed AqGR.

In situ and *ex situ* conservation

Freshwater fish are the most threatened group of vertebrates used by humans; the Country Reports listed many wild relatives of farmed aquatic species that were declining in the wild. Therefore, increased efforts at *in situ* and *ex situ* conservation of AqGR are warranted in both freshwater and marine ecosystems. *In situ* and *ex situ* conservation of AqGR were reported to be widely used in the Country Reports and to be generally effective.

In situ conservation is the preferred strategy because it maintains the aquatic plants or animals in the habitat, environment or culture system that gave them their special characteristics and would allow them to continue to evolve. Additionally, *ex situ in vivo* conservation is resource intensive and prone to bring about genetic change (e.g. through genetic drift, domestication selection and deliberate selection for commercial traits). *Ex situ in vitro* conservation is currently only possible for male gametes, and not practical for eggs or most embryos. A common form of *in situ* conservation is aquatic protected areas, e.g. marine protected areas and freshwater protected areas. Multiple use protected areas that can be fished and enjoyed recreationally offer a range of protection to and use of AqGR, including a complete lack of human interference.

Aquatic protected areas were demonstrated as being highly effective at conservation of AqGR. However, this result was heavily influenced by a few countries that reported numerous protected areas that were very effective. The main objectives for protected areas were reported to be preservation of aquatic genetic diversity and maintain good strains for aquaculture production. It was somewhat surprising that to help adapt to impacts of climate change and to meet consumer and market demands were cited as the least important objectives for *in situ* conservation. Perhaps the aquaculture sector has more immediate issues than climate change and did not perceive consumer demands as needing to be addressed in natural aquatic habitats.

The importance of conservation as a goal for aquaculture facilities or fishery management is highlighted by the fact that about 50 percent of countries reported it as being explicitly included in their policies. Indeed, fisheries and aquaculture were seen to be effective mechanisms for *in situ* conservation in about 90 percent of the responses. The collection of broodstock and early life history stages from the wild was seen as a component of *in situ* conservation and as justification for maintaining habitats, at least to some extent, in most areas. It appears clear that the “use” aspects of AqGR helps to justify conservation of aquatic habitats and biodiversity.

The concept of “on-farm *in situ* conservation of AqGR” is difficult to differentiate from “on-farm *ex situ* conservation of AqGR” due to relatively recent development of farmed types. That is, fish farmers have not had the benefit of millennia of using and conserving aquatic farmed types that terrestrial farmers have had with crops and livestock. Fish farmers seek to improve AqGR as a first priority, not to conserve it. Those facilities that are maintaining strains for aquaculture use under farming conditions are customarily called *ex situ in vivo* conservation facilities.

Ex situ conservation is a mechanism to conserve AqGR outside of their natural habitats, targeting all levels of biodiversity, including at the ecosystem level, the species level, and at levels below the species. Broadly, *ex situ* conservation includes a variety of activities, from managing captive populations, to supporting research initiatives, to collaborating with *in situ* efforts. Several mechanisms commonly used for *ex situ* conservation exist, including aquaria and zoos, botanical gardens and gene banks (which can be subdivided into *in vivo* captive breeding programmes and *in vitro* collections).

The most important objective for *ex situ* conservation at the global level (both *in vivo* and *in vitro*) was the preservation of aquatic genetic diversity, followed by future strain improvement in aquaculture and for the maintenance of good strains for future aquaculture production. This ranking was similar when countries were grouped by region, economic level and level of aquaculture production. Multiple uses of species in *ex situ in vivo* conservation collections were reported, including for direct human consumption, as live feed organisms, and a range of other uses such as for future domestication. The most often cited use for *ex situ in vivo* conservation was for direct human consumption.

The role of stakeholders

Through participatory regional workshops, twelve groups were identified as key stakeholders in the conservation, sustainable use and development of AqGR. Government resource managers, fishing or aquaculture associations and donors played the greatest roles in the conservation, sustainable use and development of AqGR, while consumers, marketing people and fishers played lesser roles. Some differences were observed among regions in terms of how each viewed stakeholder participation in the conservation, sustainable use and development of AqGR of farmed species and their wild relatives. The importance of indigenous communities in the conservation and protection of aquatic biodiversity and aquatic ecosystems of relevance for wild relatives of farmed aquatic genetic resources is recognized by nearly all countries. Women are important in the aquaculture sector in all countries, although the qualitative information provided suggests that they may play a wider range of roles in developed countries.

Out of ten identified categories of activity, conservation, production, marketing and advocacy were the most common roles played by the twelve stakeholder groups. Stakeholder interests in conservation, sustainable use and development of AqGR were consistently greatest at the species level, followed by strain, stock or variety, and lastly, at the genome level. Little information was provided on what stakeholder groups would like to see take place with respect to the conservation, sustainable use and development of aquatic genetic resources.

National policies and legislation

There is a large range of policies relevant to AqGR for food and agriculture because their management encompasses farming, fishing, breeding and conserving aquatic species. Numerous policies and legislation (over 600) were reported that address AqGR. Policies, primarily aimed at the species level, often include fisheries management, fishing closures, and restrictions on import/export of a variety of types of AqGR. The monitoring and enforcement of these national policies, however, is often constrained by the lack of human and financial resources.

Access and benefit sharing (ABS) from the use of AqGR has been an important topic in the negotiations of the Convention on Biological Diversity and has most often been associated with crop genetic resources. Sustainable Development Goal (SDG) Target 2.5 and SDG Target 15.6 require countries to "promote access to and fair and equitable sharing of benefits arising from the utilization of genetic resources and associated traditional knowledge, as internationally agreed."[2] However, ABS regimes will be different for AqGR than for genetic resources of crops and livestock. Genetic improvement of farmed aquatic species is often done by large companies or international institutions with modern breeding facilities, and in areas outside of the centre of origin for many species rather than by rural farmers. Although countries have taken steps to improve access to AqGR, they have encountered obstacles in accessing or importing AqGR, primarily resulting from their own restrictive national legislation. Measures that would facilitate ABS regimes include a policy of risk-benefit analysis, an application of a precautionary approach where target and limit reference points are established, and actions and contingency plans agreed by government, industry and the conservation sectors.

[2] https://unstats.un.org/sdgs/metadata?Text=&Goal=2&Target=2.5.

Research, education, training and extension

This chapter of the Report has focused on reviewing the status and adequacy of national research, education and training, extension, coordination and networking systems related to AqGR. In nearly all of the countries there is at least one research institution dealing with use, conservation and management of AqGR; 80 percent of Country Reports noted that research on AqGR is covered under their national research programmes. The most common theme for research was at the level of basic knowledge of AqGR, and the strongest needs for research capacity building were in characterization and monitoring of AqGR and in genetic improvement of these resources.

Similarly, nearly all countries identified education and training activities focused on AqGR with genetic resource management and characterization of genetic resources being the most common focus of these activities. While all thematic areas were quite well covered by education and training, the economic valuation of AqGR and genetic improvement were the least well-served themes globally.

Nearly 75 percent of countries reported on one or more intersectoral collaboration mechanisms related to management and conservation of AqGR, with Asia reporting the highest average number of mechanisms per country. Increasing the technical capacities of institutes was reported to be the most important capacity requirement to strengthen intersectoral collaboration. A similar proportion of countries reported the existence of national networks with the major responsibility to improve communication on AqGR. Indeed, a high number of over 170 national information systems on AqGR was reported, with major producing countries having a higher number of information systems per country than the minor producing countries. The main users of national information systems on AqGR are academia as well as government resource managers. However, these information systems were commonly focused at the level of species, their distribution and their production; there were few systems that included information below the species level.

International collaboration

Countries participate through a wide range of mechanisms and instruments relating to international collaboration on AqGR of farmed aquatic species and their wild relatives. The number of international agreements of relevance to conservation, sustainable use and development of AqGR varies from 1 to 24 per country, with a total of 169 unique agreements of international collaboration reported. The impact of these international agreements has been assessed from positive to strongly positive for 85 percent of the agreements.

Countries identified eight different needs for collaboration. The extent to which these assessed needs are not met or are only partially met is high (all equal or above 74 percent). The highest priority need from cooperation was for improved communication and improved capacities for the conservation and economic valuation of AqGR, followed by improved basic knowledge, improved capacities for characterization and monitoring, improved access and distribution of AqGR, and improved information technology and database management. This highlights the need for an international or regional networks supporting cooperation and collaboration in the sustainable management, development, conservation and use of aquatic genetic resources

Key gaps and recommendations

The current national production statistics reported to FAO often aggregate and report production at or above the species level. On the other hand, the Country Reports in this *State of the World* Report listed over 250 species and species items that have not previously been reported with their production statistics to FAO, indicating that better information is available in some countries but is not necessarily coordinated when reported to FAO. A strengthened reporting system from countries will need to be based on an improved knowledge of the characterization of AqGR combined with an improved coordination among national offices responsible for reporting on AqGR and on aquaculture production and use of standardised nomenclature and terminology. This will, among other necessities, require improved national capacity to manage farmed type genetic resources by establishing or rehabilitating

facilities to hold and improve AqGR collections and manage their dissemination. The development of an improved reporting and information systems (e.g. a registry of strains) may be considered at global, regional and national levels.

Research, education and training centres on AqGR are widespread, but may lack capacity in more advanced areas of AqGR characterization and improvement, particularly in selective breeding. It is important that any capacity building relates to the appropriate application of constantly advancing technology. The existing high level of intersectoral cooperation and networking can be helpful in advancing conservation, sustainable use and development of AqGR. However, some countries appear to lack this capacity and should be supported in developing improved cooperation and networking. Many information systems already exist within national jurisdiction, although these focus at the level of species and above. Any attempts to develop regional or global systems for information on AqGR should consider how such systems can utilize and/or interface with these existing national level systems.

Importantly, the conservation, sustainable use and development of AqGR will need to help bridge the gap between supply and demand for aquatic food. To achieve this, breeding strategies and programmes will need to be strengthened. Aquatic production systems with low trophic level farmed types will need to be promoted together with more efficient resource use in aquaculture systems by developing farmed types with higher tolerance to intensive production systems and improved feed conversion ratio. At the same time, there is need for improving the integration of aquaculture and fisheries with agriculture and irrigation and water management to reduce impacts of lost connectivity and regulated water flow.

The close interaction and interrelationship of aquacultured species and their wild relatives are particularly important elements of AqGR. Aquatic food production systems need to produce safely and sustainably. In this regard, strengthening biosecurity, controlling escapes from aquaculture, and developing effective quarantine systems will be important. Risk analyses should be performed prior to importations, introductions and translocations, including assessments of invasiveness, genetic impacts and disease transmission. Responsible stocking of open waters, including effective monitoring of post-stocking impacts, needs to be ensured, and farm management improved to reduce escapees, especially in open water, and to strengthen disease control to prevent interaction between farmed types and their wild relatives. Other actions include reducing the impacts of pollution and developing effective stocking programmes that take into account genetic diversity and impacts on wild relatives.

Sustainable use of AqGR in responsible food production systems relies on good management of AqGR at all levels, including for wild relatives. This includes strengthening, expanding and diversifying *in situ* and *ex situ* conservation programmes, and sustaining or improving habitat and environments for wild relatives, including by improving management to reduce the impact of capture fisheries on wild relatives. Given the multiple levels of protection and objectives in the various categories of aquatic protected areas, the establishment and management of aquatic protected areas should explicitly state the objectives of the areas and what kind of use elements would be permitted. Protected areas have been clearly effective at conservation of biodiversity, but their use as a tool for fishery management has been more controversial. Additional examination of how *in situ* conservation in the form of protected areas, integrated with *ex situ* conservation, can be used to support fisheries and aquaculture, as well as conserve AqGR, would help countries design effective conservation programmes.

The conservation benefits of well-managed capture fisheries and aquaculture are clear and should be promoted more widely to both the fishing/aquaculture industry and the conservation sector. There are win-win scenarios resulting from a collaboration between industry and conservation factions. The fact that natural and biodiverse ecosystems provide economic value to capture fisheries and aquaculture can be used to help justify maintenance of these important habitats for AqGR.

Lack of awareness of national policies and lack of technical capacity and insufficient resources were identified as key gaps in effective policy implementation; other gaps in policy concerned transboundary watercourses, import and export of AqGR, long-term aquaculture development, breeding and genetic manipulation, climate change, objective evaluation of policy efficacy, financial subsidies to implement

policies, and ownership and harmonization of policies. Numerous national policies do exist, but there are gaps with reference to how they impact on genetic resources when considered below the species level. This will need to be addressed through a strengthening of international frameworks as well as through cooperation and strategic partnerships between aquaculture farmers, public sector and research institutes.

The international community has recognized the differences between ABS regimes for aquatic species and those for terrestrial species and has begun work on identifying the distinctive features of AqGR.[3] It will be important to continue this work to ensure not only that the aquaculture industry is not overly burdened with restrictive policies, but also that fishing dependent communities are not deprived of appropriate benefits. In light of the reports that often national policies are impeding access to AqGR and that often policies do not address AqGR below the species level, a review of good policies and practices could be conducted and disseminated. Such a review should include risk-benefit analysis and specific national needs and goals of FAO Members in order to help improve the use of AqGR.

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[3] **FAO.** 2018. Draft explanatory notes describing, within the context of the ABS elements, the distinctive features of aquatic genetic resources for food and agriculture. Ad Hoc Intergovernmental Technical Working Group on Aquatic Genetic Resources for Food and Agriculture. CGRFA/WG-AqGR-2/18/5. Rome. (also available at www.fao.org/fi/static-media/MeetingDocuments/AqGenRes/ITWG/2018/5e.pdf).

The sustainable management, development, conservation and use of aquatic genetic resources (AqGR) is critical to the future supply of fish. The State of the World's Aquatic Genetic Resources for Food and Agriculture is the first ever global assessment of these resources, with the scope of this first Report being limited to cultured AqGR and their wild relatives, within national jurisdiction. The Report draws on 92 reports from FAO member countries and five specially commissioned Thematic Background Studies. These reporting countries are responsible for 96 percent of global aquaculture production.

The Report sets the context with a review of the state of world's aquaculture and fisheries and includes overviews of the uses and exchanges of AqGR, the drivers and trends impacting AqGR and the extent of *ex situ* and *in situ* conservation efforts. The Report also investigates the roles of stakeholders in AqGR and the levels of activity in research, education, training and extension, and reviews national policies and the levels of regional and international cooperation on AqGR. Finally, needs and challenges are assessed in the context of the findings from the data collected from the countries.

The Report represents a snapshot of the present status of AqGR and forms a valuable technical reference document, particularly where it presents standardised key terminology and concepts. There is little doubt that the process of preparing this global Report and the work done within countries to prepare Country Reports has improved the level of understanding and awareness of the vital importance of AqGR. This volume thus represents the first step in building a broad knowledge base on AqGR as a basis for future actions towards improved management, development and conservation of this valuable resource, at national, regional and global levels.