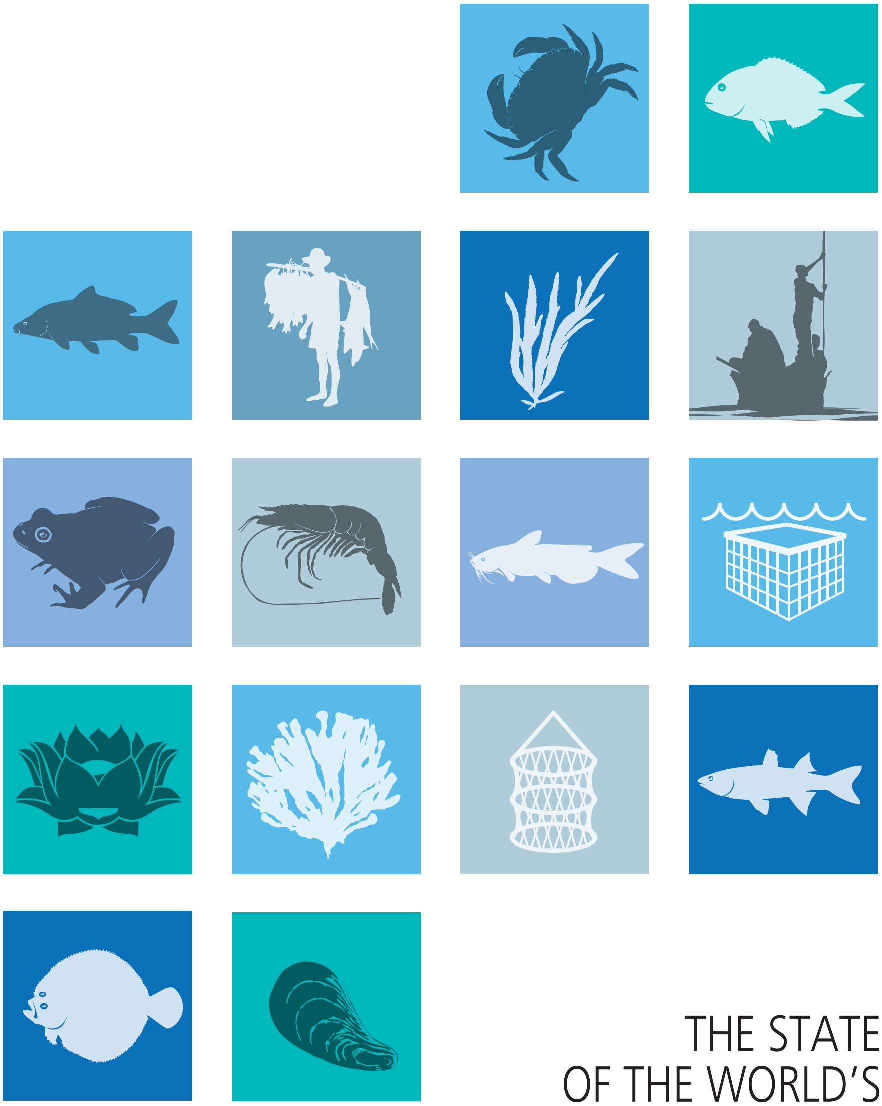
Food and Agriculture Organization of the United Nations

COMMISSION ON GENETIC RESOURCES FOR FOOD AND AGRICULTURE

ISSN 2412-5474



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

FAO COMMISSION ON GENETIC RESOURCES FOR FOOD AND AGRICULTURE ASSESSMENTS • 2019

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

ROME 2019

Required citation:
FAO. 2019. *The State of the World's Aquatic Genetic Resources for Food and Agriculture.* FAO Commission on Genetic Resources for Food and Agriculture assessments. Rome.

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ISBN 978-92-5-131608-5
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Contents

CHAPTER 8
Research, education, training and extension on aquatic genetic resources within national jurisdiction: coordination, networking and information 199

CHAPTER 9
International collaboration on aquatic genetic resources of farmed aquatic species and their wild relatives 223

Tables

Figures

Boxes

Foreword

The worldwide growth in demand for fish and fish products and improvements in production systems have driven the rapid expansion of aquaculture, making it the world's fastest growing food production sector. Today total global aquaculture production of fish and fish products for human consumption exceeds that of capture fisheries and these products are some of the world's most traded food commodities.

A growing population – estimated to reach 9.8 billion by 2050 – presents major challenges to ensure food security in the face of an expanding demand for food and against a background of climate change impacts. Given the acknowledged nutritional benefits of fish and other aquatic products, aquaculture is destined to play an increasingly vital role in supplying food from seas, rivers and lakes, providing a source of healthy diets and livelihoods for millions of people, while alleviating pressure on wild stocks. Aquaculture production has the potential to contribute to the achievement of the Sustainable Development Goals, especially SDG 2 (Zero hunger) and SDG 14 (Life below water).

While aquatic genetic resources constitute an invaluable reserve of biodiversity, they remain largely unexplored. We currently farm almost 600 aquatic species and harvest over 1800 species. Farmed aquatic species include finfish, molluscs, crustaceans, vascular and non-vascular plants, and microorganisms. For many of these organisms the production cycle depends on exploitation of their wild counterparts: wild relatives of many aquatic genetic resources are collected from their natural environment to be bred or raised under farm conditions; consequently, the aquaculture sector remains closely linked to wild aquatic genetic resources and their habitats.

The information available on the status of conservation, sustainable use and development of farmed aquatic genetic resources, and their wild relatives, is often incomplete and scattered, both at the national and international level. In addition, we have little information on aquatic genetic resources below the level of species. While FAO's annual aggregation and synthesis of production data and its reporting through the flagship biennial report *The State of World Fisheries and Aquaculture* are highly valued, production statistics are not always complete.

Building global knowledge and facilitating access to that knowledge is essential to raise awareness and address the main needs and challenges for the long-term conservation, sustainable use and development of all those aquatic genetic resources on which we depend, directly or indirectly. Responding with appropriate actions will depend on a deep knowledge of the global status and trends of aquatic genetic resources, and of the key actors playing a role in their management.

The State of the World's Aquatic Genetic Resources for Food and Agriculture, the first ever global assessment of the status of aquatic genetic resources for food and agriculture, focuses on farmed aquatic species and their wild relatives within national jurisdiction. The Report is a milestone in building the information and knowledge base required for action at the national, regional and international levels to conserve, sustainably use and develop aquatic genetic resources for food and agriculture.

Requested through the FAO Commission on Genetic Resources for Food and Agriculture and with the contributions of over 90 countries, the Report portrays the broad range of aquatic organisms farmed and fished worldwide, the diverse technologies being used to develop these resources, the status of existing conservation programmes, the roles of key stakeholders, and the main national and international policies and networking mechanisms at play. It highlights the broad and complex range of challenges for the responsible management of aquatic genetic resources, including: the acceleration of genetic improvement of key aquaculture species, developing and promoting effective access and benefit-sharing measures, addressing threats to the natural reservoirs of diversity of wild relatives of farmed species, improving or implementing well-designed and integrated *ex situ* and *in situ* conservation programmes, and supporting the development of strong policies and governance systems. International cooperation is crucial to find solutions to these many needs and challenges: all stakeholders, from policy-makers to fish farmers, from fisheries and aquaculture associations to consumers, have their role to play in contributing to reducing worldwide food insecurity through wise management of aquatic genetic diversity.

I am confident that the valuable information in the Report will be used as the basis for policy planning and technical decisions to strengthen national efforts in the conservation, sustainable use and development of aquatic genetic resources, and ensure their contributions to food security and the livelihoods of hundreds of millions of people who depend upon them.

José Graziano da Silva
FAO Director-General

Acknowledgements

The State of the World's Aquatic Genetic Resources for Food and Agriculture represents the culmination of work undertaken in member countries of the Food and Agriculture Organization of the United Nations (FAO), including capacity-building workshops and expert meetings, and in FAO. FAO gratefully acknowledges the contributions of the many colleagues who contributed their time and expertise to this endeavour.

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.

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 information on which the majority of the Report is based was derived from responses by countries to a questionnaire that was initially developed by Roger S.V. Pullin and Devin M. Bartley, and refined with input from others, including the members of the Committee on Fisheries (COFI) Advisory Working Group on Aquatic Genetic Resources and Technologies. Enrico Anello turned the questionnaire into a user-friendly dynamic PDF that was distributed to all FAO Member Countries and key partners.

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

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.

The Report was prepared by the Fisheries and Aquaculture Department of FAO, with primary input from the Aquaculture Branch and the Statistics and Information Branch. The assistance of the aquaculture statistician Xiaowei Zhou was especially important throughout the process. The valuable logistical support of Sebastian Sims in finalizing the Report is much appreciated as is the earlier support provided by Elena Irde and Chiara Sirani. Editing and layout were expertly carried out by Maria Giannini and Joanne Morgante.

FAO further thanks the members of the COFI Advisory Working Group on Aquatic Genetic Resources and Technologies (Marcela Astorga, John Benzie, Clemens Fieseler, Daniel Jamu, Anne Kapuscinski, István Lehoczky, Graham Mair, Thuy Nguyen, Ingrid Olesen and Mohammad Pourkazemi), Kuldeep K. Lal, Alexandre Wagner Silva Hilsdorf, Zsigmond Jeney and Cherdsak Virapat for their guidance, reviews, comments, feedback and information provided on drafts of the Report. The support provided by the Secretariat of the Commission on Genetic Resources for Food and Agriculture (CGRFA) and the guidance provided through two sessions of the CGRFA's Ad Hoc Intergovernmental Technical Working Group on Aquatic Genetic Resources for Food and Agriculture is greatly appreciated and was crucial to producing a balanced and complete Report. Feedback was

also provided by regional organizations, including the Lake Victoria Fisheries Organization, the Mekong River Commission, the Network of Aquaculture Centres in Asia-Pacific, the Pacific Community, the Southeast Asian Fisheries Development Center, and WorldFish.

The authors of the thematic background studies and those who provided editorial improvements to these studies were essential in adding substantial information to the Report that may not have been well covered in the Country Reports.

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

Section	Title	Author(s)
Chapter 1	The state of world aquaculture and fisheries	Graham C. Mair, Xiaowei Zhou and 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 jurisdiction	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	Key findings, needs and challenges	Graham C. Mair and Matthias Halwart

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, Dr Meng Shunlong and Dr Jing Xiaojun
Genetic resources for microorganisms of current and potential use in aquaculture	Russell T. Hill

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

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 regularly interspaced short palindromic repeats
CRISPR/Cas	clustered regularly interspaced short palindromic repeats-CRISPR associated
ddRAD-seq	DNA sequencing
DIAS	Database on Introductions of Aquatic Species
DNA	deoxyribonucleic acid
DPS	distinct population segment
EAF	ecosystem approach to fisheries
EEZ	exclusive economic zone
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
GMO	genetically modified organism
GSI	genetic stock identification
HAKI	Research Institute for Fisheries and Aquaculture (Szarvas, Hungary)
ICAR	Indian Council of Agricultural Research
ICES	International Council for the Exploration of the Sea
ICPR	International Commission for the Protection of the Rhine
IGO	intergovernmental organization/international governmental organization
INGA	International Network on Genetics in Aquaculture
ISSCAAP	International Standard Statistical Classification of Aquatic Animals and Plants

ITWG AqGR	CGRFA Intergovernmental Technical Working Group on Aquatic Genetic Resources for Food and Agriculture
IUCN	International Union for Conservation of Nature
MAS	marker-assisted selection
MPA	marine protected area
MTA	material transfer agreement
mtDNA	mitochondrial DNA
NACA	Network of Aquaculture Centres in Asia-Pacific
nei	not elsewhere included
NFPA	national framework for priority action
NGO	non-governmental organization
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
SNP	single nucleotide polymorphism
SOFIA	The State of World Fisheries and Aquaculture
TALEN	transcription activator-like effector nuclease
TBS	thematic background study
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

About this publication

Following requests from its member countries, at the Eleventh Regular Session of the Commission on Genetic Resources for Food and Agriculture (CGRFA; see Box 1) in 2007, the Food and Agriculture Organization of the United Nations (FAO) agreed to lead a process towards production of the report on *The State of the World's Aquatic Genetic Resources for Food and Agriculture* on (the Report). In the context of the Report, aquatic genetic resources (AqGR) include DNA, genes, chromosomes, tissues, gametes, embryos and other early life history stages, individuals, strains, stocks and communities of organisms of actual or potential value for food and agriculture. At the Fourteenth Regular Session of the CGRFA in 2013, it was further agreed that the scope of this first ever global assessment on AqGR for food and agriculture should be farmed aquatic species and their wild relatives within national jurisdiction.[2]

Box 1
The Commission on Genetic Resources for Food and Agriculture

With 178 countries and the European Union as its members, the Commission on Genetic Resources for Food and Agriculture provides a unique intergovernmental forum that specifically addresses biological diversity for food and agriculture. The main objective of the Commission is to ensure the sustainable use and conservation of biodiversity for food and agriculture and the fair and equitable sharing of benefits derived from its use, for present and future generations. The Commission guides the preparation of periodic global assessments of the status and trends of genetic resources and biological diversity for food and agriculture. In response to these assessments, the Commission develops global plans of action, codes of conduct or other policy instruments and monitors their implementation. The Commission raises awareness of the need to conserve and sustainably use biological diversity for food and agriculture and fosters collaboration among countries and other relevant stakeholders to address threats to this biodiversity and promote its sustainable use and conservation.

The reporting and preparatory process

Following the decision to go forward with the preparation of the Report, at its Fifteenth Regular Session in 2015, the CGRFA endorsed a timeline for its preparation and an indicative list of thematic background studies to provide input to the Report, and invited countries to prepare Country Reports with the involvement of all relevant stakeholders. The CGRFA also agreed to establish an Ad Hoc Intergovernmental Technical Working Group on Aquatic Genetic Resources For Food and Agriculture (ITWG AqGR), which was specifically tasked with guiding the preparation of the Report and its subsequent review. In addition, the Committee on Fisheries (COFI) formed the COFI Advisory Working Group on Aquatic Genetic Resources and Technologies (COFI AWG AqGR/T) to provide expert support to the preparation of the Report.

The primary sources of information for the preparation of the Report were Country Reports submitted by 92 countries over the course of two years, from June 2015 to June 2017. Following a process established by the CGRFA, FAO invited countries to nominate

2 CGRFA-14/13/Report www.fao.org/docrep/meeting/028/mg538e.pdf, paragraph 76.

National Focal Points to coordinate the gathering of information and prepare and submit Country Reports. Guidelines were provided to all National Focal Points, in the form of a structured questionnaire[3] and methodology, to aid in the preparation of Country Reports.

It was envisaged that the development of the Country Reports would be a vehicle to facilitate a national strategic exercise assessing the status of AqGR at the national level and reflecting on the needs and priorities for their conservation, sustainable use and development. Regional workshops were organized by FAO, in collaboration with partners in the aquaculture sector, to support the development of the Country Reports.

Following receipt of the Country Reports, they were reviewed and the data incorporated into a database. These data, where appropriate, were compared with official statistical data reported to FAO based on aquaculture and capture fisheries production. Data were analysed and the outputs of this analysis formed the basis of the main chapters of the Report.

Based on the identification of significant knowledge gaps, FAO commissioned the preparation of five thematic background studies (TBSs). The TBSs were intended to complement the Country Reports in thematic areas where scientific and official data and information were weak, missing or outdated. The five TBSs are:

- *Incorporating genetic diversity and indicators into statistics and monitoring of farmed aquatic species and their wild relatives;*
- *Genetic resources for microorganisms of current and potential use in aquaculture;*
- *Genome-based biotechnologies in aquaculture;*
- *Genetic resources for farmed seaweeds;*
- *Genetic resources for farmed freshwater macrophytes: a review.*

Forty-seven out of 57 Country Reports received by May 2016 were reviewed and analysed, and the outputs of these analyses were incorporated into the *First Draft Report on the State of the World's Aquatic Genetic Resources for Food and Agriculture* (the First Draft Report). The First Draft Report was reviewed during the First Session of the ITWG AqGR, held in Rome in June 2016, and a number of general and specific recommendations were provided.[4]

The reports of the First Sessions of the COFI AWG AqGR/T and the ITWG AqGR were presented to the Sixteenth Regular Session of the CGRFA in 2017. During that session, the CGRFA invited countries that had not yet done so to submit their Country Reports by 30 June 2017; countries that had already submitted a report were invited to submit a revised version by the same date.

By the end of June 2017, 35 new Country Reports had been submitted. An updated Draft Report was prepared based on all 92 submitted Country Reports (Figure 1). This Draft was reviewed and considered at another meeting of the COFI AWG AqGR/T, as well as by an expert consultant, and then presented to the COFI Sub-Committee on Aquaculture in October 2017. Feedback from these reviews was incorporated into a Revised Draft Report, which was sent to members for comment and submitted to the Second Session of the ITWG AqGR in April 2018. Based on feedback from this session of the ITWG AqGR[5] and input received from FAO member countries and from international organizations, a Final Draft Report was produced in May 2018 and submitted to the 33rd Session of COFI. Further input from members of the COFI AWG AqGR/T and from the CGRFA Secretariat was considered and incorporated into the Final Report prior to publication.

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

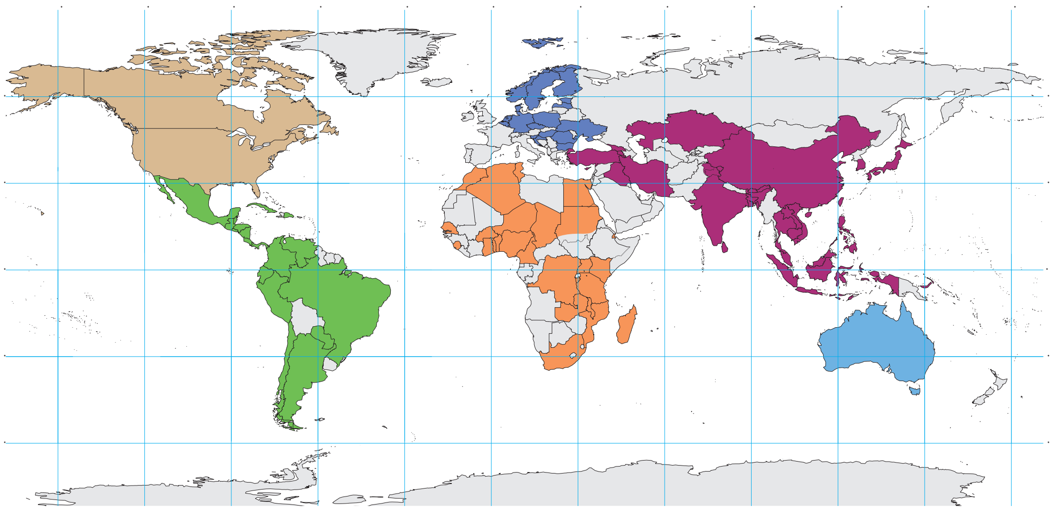
[4] CGRFA/WG-AqGR-1/16/Report, www.fao.org/3/a-mr172e.pdf

[5] CGRFA/WG-AqGR-2/18/Report paragraphs 14-22, http://www.fao.org/fi/static-media/MeetingDocuments/AqGenRes/ITWG/2018/default.htm

Classification of countries by region, economic class and level of aquaculture production

Based on the reviews of the First Draft Report, it was recommended not only to analyse data from Country Reports on a global basis, but also to break down the analyses by region, by economic class of countries, and by the level of aquaculture production of countries. The data from the 92 Country Reports were categorized accordingly. Analysis by region was consistent with FAO's regional analyses of fisheries and aquaculture statistics (Figure 1). Countries in all six regions responded, with the greatest relative levels of response from North America (100 percent of countries) and Asia (64 percent) (Table 1).

FIGURE 1
The 92 reporting countries and their assignments to region*



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

*The boundaries and names shown and the designations used on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers and boundaries. Dashed lines on maps represent approximate border lines for which there may not yet be full agreement.

Source: FAO

TABLE 1

Number and percentage of countries that submitted Country Reports, by region

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

The reporting countries were also categorized by economic class. Classification of countries by economic class in the Report is consistent with the categories used by the statistics unit of the Fisheries and Aquaculture Department of FAO (FAO/FI).[6] The distribution of the 92 reporting countries by economic class is shown in Table 2, with a minimum of 43–50 percent of the total number of member countries being represented across the three classes.

TABLE 2

Number and percentage of countries that submitted Country Reports, by economic class

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

Classification of countries with respect to the level of aquaculture production was based on the reported level of aquaculture production. Countries were divided into two categories based on aquaculture production statistics in FishStatJ in 2016 (FAO, 2018):

- major producing countries – those that produced more than 1 percent of global aquaculture production each;
- minor producing countries – those that produced less than 1 percent each.

Eleven countries were classed 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 accounted for 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 3). Together, the 92 Country Reports represent approximately 96 percent of global aquaculture production and over 80 percent of global capture fisheries production.

[6] https://unstats.un.org/unsd/methodology/m49

TABLE 3
Number and percentage of countries that submitted Country Reports, by level of aquaculture production

Category	Total number of countries	Number of reporting countries	Percentage
Major producing countries	11	11	100
Minor producing countries	185	81	44

Current status of reporting on aquatic genetic resources

Every two years, FAO publishes *The State of World Fisheries and Aquaculture* (SOFIA).[7] The process used to generate and analyse information for *The State of the World's Aquatic Genetic Resources for Food and Agriculture* is consistent with and complementary to that of SOFIA. SOFIA covers issues of, *inter alia*, production, trade, consumption and sustainability, as well as special topics of importance to fisheries and aquaculture.

The primary basis for reporting of aquaculture and capture fisheries production for SOFIA is at the level of species or species items. 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. Towards that end, an Aquatic Sciences and Fisheries Information System (ASFIS) List of Species for Fishery Statistics Purposes (see Chapter 2) was previously developed to maintain and promote a standard system of nomenclature for the analysis of the world's aquatic species that are produced in fisheries and aquaculture. Both the questionnaire on which Country Reports are based and the Report used the ASFIS nomenclature. Much of the analysis in SOFIA is based on fisheries and aquaculture statistics derived from FishStatJ, a software providing access to a number of fishery datasets.

Organization of the Report

The Report is organized into ten chapters. The first chapter provides a summary of the current status of aquaculture and capture fisheries and the markets for their products, and summarizes the outlook for these sectors. It also introduces some standard nomenclature used to describe AqGR throughout the Report and recommended for broader adoption. Chapters 2–9 deal primarily with the data from Country Reports on a range of issues. Chapter 2 reviews the use and exchange of AqGR, primarily in aquaculture, and the application of genetic technologies to AqGR. Chapter 3 explores the effects of drivers of change on farmed AqGR and their wild relatives. Chapters 4 and 5 cover, respectively, the status of *in situ* and *ex situ* conservation of AqGR. Chapter 6 identifies the stakeholders in AqGR and their roles in the conservation, sustainable use and development. Chapter 7 reviews national policies and legislation governing AqGR. Chapter 8 reviews research, training and extension on AqGR, such as national coordination and networking. Chapter 9 deals with international collaboration on AqGR, including the roles of various mechanisms and instruments through which countries cooperate. The final chapter clarifies the needs and challenges that arise from the key messages identified in the preceding chapters.

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

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FAO. 2018. Fishery and Aquaculture Statistics. FishstatJ – Global Production by Production Source 1950–2016. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 2018. (also available at http://www.fao.org/fishery/statistics/software/fishstatj/en).

Executive summary

Introduction

By definition, aquatic genetic resources (AqGR) for food and agriculture include DNA, genes, chromosomes, tissues, gametes, embryos and other early life history stages, individuals, strains, stocks and communities of organisms of actual or potential value for food and agriculture. Enhancing knowledge on their global status is an indispensable step to raise awareness on current and future needs and challenges for their conservation, sustainable use and development.

The Report on *The State of the World's Aquatic Genetic Resources for Food and Agriculture* (the Report), as the first global assessment of the status of AqGR, represents an important step forward in this regard. The main sources of information for the preparation of this assessment were reports submitted by countries on the status of their AqGR within national jurisdiction. Overall, 92 countries contributed to this country-driven process, covering approximately 96 percent of global aquaculture production and over 80 percent of global capture fisheries production.

The state of world aquaculture and fisheries

The most recent available data (from 2016) show that global fish production has risen to around 171 million tonnes. 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 this total. According to consensus, production from marine fisheries is unlikely to increase beyond current levels. On the other hand, aquaculture, which represents 53 percent of the total food fish production, experienced annual growth of about six percent in the period 2001–2016, and this growth is expected to continue, albeit at a lower rate.

In 2016, global aquaculture production of aquatic genetic resources for food reached a total of 110 million tonnes, including 80 million tonnes of fish and 30 million tonnes of aquatic plants. There was a further 38 000 tonnes of non-food production. This total 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.

Due in part to general improvement in public awareness of the health benefits of aquatic food, and expanding wealth in some countries, between 1961 and 2016 the average annual increase in global food fish consumption (3.2 percent) outpaced population growth (1.6 percent) and exceeded that of meat from all terrestrial animals combined (2.8 percent). Approximately 3.2 billion people (42 percent of the world's population) obtain 20 percent or more of their animal protein intake from fish.

Production systems for farming fish and other aquatic organisms are highly diverse. Although the number of farmed aquatic species is small relative to the over 1 800 species harvested from capture fisheries, species use in aquaculture is also extremely diverse when compared to other food production sectors. By 2016, almost 600 farmed species and/or species items had been reported to the Food and Agriculture Organization of the United Nations (FAO). The diversified portfolio of farmed AqGR is not comprehensively reported to FAO for many aquatic organisms, including microorganisms, feed organisms, aquatic plants, sea cucumbers, sea urchins, amphibians, reptiles and ornamental species.

The use and exchange of aquatic genetic resources

Although the regular reporting of production to FAO had already revealed the great diversity of AqGR used in fisheries and aquaculture, the Country Reports referred to more than 250 species and species items that had not been previously reported to the Organization. Many of the additional species reported were microorganisms, aquatic plants and ornamental fish that are not listed in the Aquatic Sciences and Fisheries Information System (ASFIS), the standard for reporting to FAO. A large number of farmed types identified were strains, hybrids and polyploids that are categorized below the level of species and therefore not included in the ASFIS list.

The process of preparing Country Reports highlighted issues with the lack of standardization of nomenclature and terminology in describing AqGR. To this end, the Report has adopted a relatively new term – farmed type – to describe farmed AqGR below the level of species and has standardized the use of existing terminology (e.g. wild relative, hybrid, strain and stock).

Although the Country Reports listed numerous farmed types used in aquaculture, these were relatively few compared to the number of breeds, hybrids and varieties used in livestock and crop production. Thus, aquaculture uses a high and expanding diversity of species, while livestock and crop production uses a large diversity of breeds and varieties. Policy-makers and fish farmers 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 conservation, sustainable use and development of AqGR.

Due to the use of the ASFIS list and the existence of species-based information systems that also use standard nomenclature, countries considered that their naming at the level of species was accurate. However, at the farmed type level, i.e. below the level of species, nomenclature and terminology were not consistent across the Country Reports.

The Country Reports indicated that non-native species are important in aquaculture. Approximately 200 species or species items are farmed in areas where they are non-native, and nine of the ten most widely cultured species are farmed in more countries where they are non-native than in countries where they are native. Given that the movement of AqGR between countries is an thus important part of the aquaculture sector, it will be essential for this movement to be well documented with standard and appropriate nomenclature. This will facilitate risk–benefit analysis and compliance with national and international policies.

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, the Country Reports indicated that 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. Selective breeding was reported to be the most widely applied genetic technology. However, adoption of this proven approach to genetic improvement is relatively low, with published estimates indicating that only around 10 percent of global aquaculture production is of improved strains resulting from well-managed selective breeding programmes. Aquaculture geneticists project that selective breeding alone could meet future demand for fish and fish products with few extra inputs such as feed and land.

The Report and a review of successful examples of aquaculture development revealed that public–private partnerships (PPP) 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 such partnerships could be further explored, especially for long-term selection programmes and where governments have included aquaculture in their poverty alleviation and economic policies.

Genetic technologies such as hybridization and polyploidization can produce significant one-time gains in the short term, whereas longer-term technologies such as selective breeding can produce gains generation after generation. New biotechnologies, such as gene editing and genomic selection, also offer opportunities for genetic gain, but are either at the experimental stage or in the early phases of adoption 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 in terrestrial agriculture, the wild relatives of all farmed aquatic species still exist in nature. This valuable resource needs to be protected and conserved. Wild relatives provide key resources to aquaculture whether as broodstock, as sources of gametes and embryos, or as early life history stages to be grown out under culture conditions or bred in captivity and 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 was 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 demand for fish and fish products, 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 to have an overall beneficial effect on AqGR for 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 of 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 the production and supply of large-volume, internationally traded fish and fish products, which may mean that production becomes increasingly dominated by a small number of species. 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.

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 fish and fish products, which will drive incentive to increase the supply from aquaculture and, to some extent, from capture fisheries. Concern remains over the use of genetic manipulation 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 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.

Climate change will have an impact on freshwater availability, inevitably affecting both farmed and wild AqGR. The potential overall impact on wild AqGR is difficult to determine, but it will likely be negative in many areas. Some positive effects on farmed AqGR may result from managed or natural selection for climate-tolerant characteristics.

In situ and *ex situ* conservation

Freshwater finfish are among the most threatened group of vertebrates utilized by humans; the Country Reports listed many wild relatives 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 and to be generally effective.

In situ conservation is the preferred strategy because it maintains populations of aquatic plants, animals or microorganisms in the habitat, environment or culture system that gave them their special characteristics and will 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. Aquatic protected areas, both marine and freshwater, are widely used to conserve AqGR *in situ.* Multiple-use protected areas that can be fished and enjoyed recreationally allow AqGR to be both protected and sustainably used.

Countries reported that aquatic protected areas were 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 maintenance of good strains for aquaculture production. It was somewhat surprising that helping adapt to impacts of climate change and to meeting consumer and market demands were cited as the least important objectives for *in situ* conservation.

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 country 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 help 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 the 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 practised through several mechanisms, including aquaria and zoos, botanical gardens and gene banks (which can be subdivided into *in vivo* captive breeding programmes and *in vitro* collections). Currently, 75 percent of the responding countries have ongoing *ex situ* conservation activities and programmes.

The Country Reports indicated that the most important objective for *ex situ* conservation (both *in vivo* and *in vitro*) at the global level is the conservation of aquatic genetic diversity, followed by future strain improvement in aquaculture and the maintenance of good strains for future aquaculture production. This ranking was similar when countries were grouped by region, by economic class and by level of aquaculture production. Multiple uses of species in *ex situ in vivo* conservation collections were reported, including for direct human consumption (the most often cited use), as live feed organisms and for a range of other purposes, including for future domestication.

The role of stakeholders

Through participatory regional workshops, 12 distinct 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 AqGR 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 12 stakeholder groups. Stakeholder interests in conservation, sustainable use and development of AqGR were consistently greatest at the species level, followed by the strain, variety and stock level 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 AqGR.

National policies and legislation

Management of AqGR for food and agriculture encompasses farming, fishing, breeding and conserving these resources. Numerous policies and legal instruments (over 600) were reported that address AqGR at the level of species. These policies 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, are often constrained by the lack of human and financial resources.

Access and benefit-sharing regimes will be different for AqGR than for genetic resources of crops and livestock. 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 have not taken place in centres of origin or as the result of the efforts of local fish farmers. Genetic improvement of farmed aquatic species is more often carried out by large companies or international institutions with modern breeding facilities, rather than by rural farmers, and for many species it occurs outside the centre of origin of the species. 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 access and benefit-sharing regimes include a policy of risk–benefit analysis, an application of a precautionary approach and actions and contingency plans agreed by the government, industry and conservation sectors.

Research, education, training and extension

In nearly all of the reporting countries there is at least one research institution and one training and education centre dealing with the conservation, sustainable use and development of AqGR.

Research on AqGR is covered under national research programmes in 80 percent of the reporting countries. 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. The most commonly reported areas of training globally were "genetic resource management" and "characterization and monitoring of AqGR". The least covered area was "economic valuation of AqGR".

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 national information systems on AqGR (over 170) were reported with major producing countries having a higher number of information systems per country than minor producing countries. The main users of national information systems on AqGR were academia and 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 level of species.

International collaboration

International collaboration on AqGR of farmed aquatic species and their wild relatives was reported to involve a wide range of mechanisms and instruments. The reported number of international agreements of relevance to conservation, sustainable use and development of AqGR varied from 1 to 24 per country, with a total of 174 unique agreements on international collaboration reported. The impact that these international agreements have on AqGR was assessed as being positive or strongly positive in approximately 85 percent of cases.

In many cases, countries' needs with respect to international collaboration on the sustainable use, conservation and management were reported to remain unmet or to be only partially met, highlighting the potential need to establish international networks. Highest priority was given to collaboration on improving communication and capacities for the conservation and economic valuation of AqGR, followed by collaboration on improving basic knowledge, improving capacities for characterization and monitoring, improving access to and distribution of AqGR and improving information technology and database management. This underlines how the establishment of regional and international collaboration can be a key driver of successful conservation, use, management and development of AqGR, as demonstrated by global and regional case studies on tilapias, common carp (*Cyprinus carpio*) and Atlantic salmon (*Salmo salar*).

Key findings, needs and challenges

The final chapter of the Report includes a summary of the key features and characteristics of AqGR, and specifically identifies areas where these differ from terrestrial genetic resources. Relative to plant and animal genetic resources for food and agriculture, farming of most AqGR is in its infancy and aquaculture is still evolving in the way it utilizes these resources. Few distinct farmed types have been developed and these tend to be poorly characterized and are described using inconsistent nomenclature. Most farmed AqGR retain levels of genetic variation similar to those of their wild relatives. Thus, compared to terrestrial genetic resources, AqGR are characterized by a large and growing diversity of species but relatively little development of distinct farmed types, contrasting with the focus on a few species but a vast diversity of breeds and varieties in terrestrial animals and plants.

There are proven genetic technologies that have generated significant production gains, particularly from well-managed selective breeding programmes, but adoption of these technologies is relatively slow, limiting their impact on global aquaculture production to date.

Wild relatives of all farmed AqGR still exist and are widespread, and there is a strong interaction between farmed AqGR and their wild relatives. Much of aquaculture production is reliant upon wild relatives as sources of broodstock and/or seed. Anthropogenic activities, including capture fisheries, threaten the viability of some of these wild relative stocks. While countries reported existence of both *in situ* and *ex situ* conservation programmes for AqGR there is a need to ensure that such programmes effectively manage genetic diversity and are focused on the resources most at risk.

Non-native species contribute very significantly to aquaculture production, and exchange of AqGR is commonplace. However it is often inadequately regulated, and this can lead to negative consequences associated with invasive species. AqGR often occur in common property water resources, including transboundary resources. Partly as a result of this and the lack of regulation of germplasm exchange, breeders' rights and access and benefit-sharing arrangements are poorly developed for AqGR future frameworks will differ somewhat from those prevalent in other sectors.

Much remains to be done to improve the management of AqGR. Action is needed across all the following strategic priority areas: responses to sector changes and environmental drivers; characterization, inventory and monitoring of AqGR; development of AgGR for aquaculture; sustainable use and conservation of AqGR; and development of policies, institutions, capacity building and cooperation. The final chapter identifies approximately 40 specific needs and challenges across these strategic priority areas.

It is hoped that the Report will serve as a catalyst for future action. The information it contains provides an excellent basis for identifying strategic priorities for action, establishing mechanisms to implement these actions, and identifying the required resources and institutional capacities for effective implementation.

CHAPTER **1**

The state of world aquaculture and fisheries

CHAPTER 1

PURPOSE: The purpose of this chapter is to present an overview of the state of the world's aquaculture and capture fisheries production, including its regional distribution, production systems and species utilization. The overview covers current global trends in both aquaculture and capture fisheries and focuses on the role of diverse aquatic genetic resources (AqGR) in these sectors. The chapter also presents some important standardized terminology that is utilized throughout the Report. The final section presents a brief outlook on fisheries and aquaculture in the coming years.

KEY MESSAGES:

- Aquaculture represents 47 percent of total fish production and 53 percent of food fish production.
- Although the rate of growth in aquaculture production has slowed in recent decades, it is still running at 5.8 percent per annum. This rate is projected to fall to 2.1 percent leading up to 2030.
- Aquaculture production systems are highly diversified. The majority of aquaculture production (64 percent) comes from inland aquaculture.
- A significant component of aquaculture production remains dependent on wild relatives and thus aquaculture and capture fisheries are closely linked production systems.
- Capture fisheries production has been stable over the past two decades. Marine capture fisheries make up 87.2 percent of harvests, but are not growing, while production from inland capture fisheries continues to grow.
- Only 7 percent of global marine fish stocks are underfished with 60 percent of marine fish stocks considered maximally sustainably fished. However, the proportion of stocks that are unsustainably fished (33.1 percent in 2015) continues to grow.
- Developing countries account for the majority of production from both aquaculture and capture fisheries.
- The wide diversity of aquatic organisms for food and agriculture is derived from multiple phyla and encompasses around 2 000 species (554 currently used in aquaculture and 1 839 currently fished).
- While there are drivers, such as niche market demands, supporting continuing species diversification in aquaculture, there are also drivers of consolidation of commercial-scale production around a small number of species.
- While there is good, if incomplete, information on species used in aquaculture and harvested from capture fisheries, there is a paucity of information below the level of species (stocks and farmed types) and a low-level understanding of genetic diversity at this level, which constrains effective management, development and conservation of these aquatic genetic resources.
- Unlike domesticated crops and livestock, where many breeds and varieties have been developed, are well established and have been recognized for centuries or millennia, aquatic species have a much smaller number of traditionally recognized strains and stocks of a few species, limiting the adaptive capacity of these species to culture under varying conditions.
- The use of genetic information in management depends on availability of accurate information and baseline data. Current information systems such as the Aquatic Sciences and Fisheries Information System (ASFIS) do not record information on strains or stocks (i.e. below the level of species).

1.1 Global trends in fisheries and aquaculture

By 2016, total global fish[8] production had risen to a level of around 171 million tonnes, with aquaculture representing nearly 47 percent of this total and 53 percent if non-food uses (such as reduction to fishmeal and fish oil) are excluded.[9] Figure 2 illustrates that the contribution of aquaculture to total global fish production has risen continuously over the past 25 years, with the aquaculture share up from just 25.7 percent in 2000. If China, the world's largest aquaculture producer, is excluded from global production data, aquaculture's share of production in the rest of the world reached 29.6 percent in 2016, up from 12.7 percent in 2000 (data not shown). If we consider all forms of production, total aquaculture production now exceeds capture fisheries production (Figure 3). In 2016, 37 countries were producing more farmed than wild-caught fish.

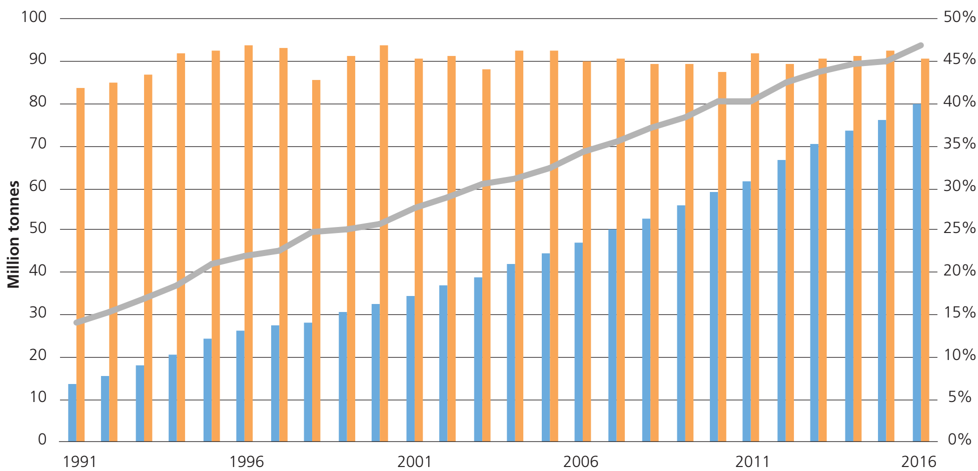
Production from capture fisheries has plateaued, while aquaculture experienced growth of about 6 percent per year over the period 2001–2016 (Figure 2). More aquatic species are being farmed now than ever before.

At the same time that pressure is being placed on aquaculture to expand production to meet increased demands for fish and fish products, existing aquaculture production systems are facing significant challenges in terms of available space and 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, 2018a). The breakdown of production from capture fisheries and aquaculture in inland and marine waters in recent years is summarized in Table 4 relative to

8 Unless otherwise specific, the term "fish" includes finfish, crustaceans, molluscs and other aquatic animals, such as frogs and sea cucumbers for human food, but excludes aquatic mammals, reptiles, seaweeds and other aquatic plants.

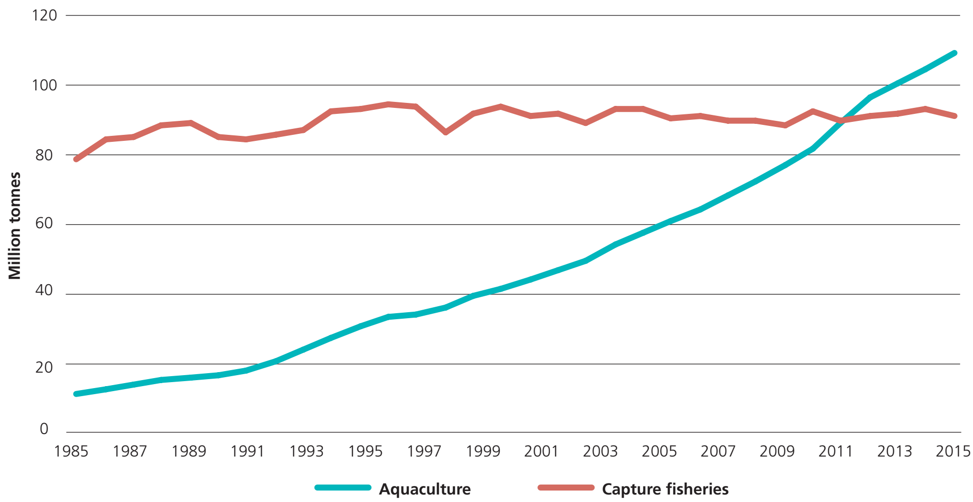
9 This chapter draws significantly on content from the FAO biennial reports on the State of World Fisheries and Aquaculture (SOFIA), particularly the latest data available from the SOFIA published in 2018 (FAO, 2018a).

FIGURE 2
Contribution of aquaculture to total fish production excluding aquatic plants, 1991–2016



Source: FAO, 2018a.

FIGURE 3
Total global fisheries and aquaculture production, including aquatic plants and non-food production, 1986–2016



Source: FAO, 2018b.

utilization of this production by the expanding global population.

1.2 The state of world aquaculture

In 2016, global aquaculture production 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 of shells and pearls. Aquaculture food production had an estimated first sale value of USD 232 billion (FAO, 2018a).

This production is derived from aquaculture operations conducted in freshwater, brackish water and marine waters. In 2016, farmed food production 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 of other aquatic animals, including amphibians (USD 6.8 billion) (FAO, 2018b), as illustrated in Figure 4.

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 5).

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 elsewhere, especially in Asia. In 2016, inland aquaculture was the source of 51.4 million

TABLE 4

World production from capture fisheries and aquaculture and its utilization relative to global population and per capita food fish supply, 2011–2016 (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)	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, 2018a (fisheries data) and United Nations, 2017 (population data).
Note: Rounding effects may mean some column totals do not sum up exactly.

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

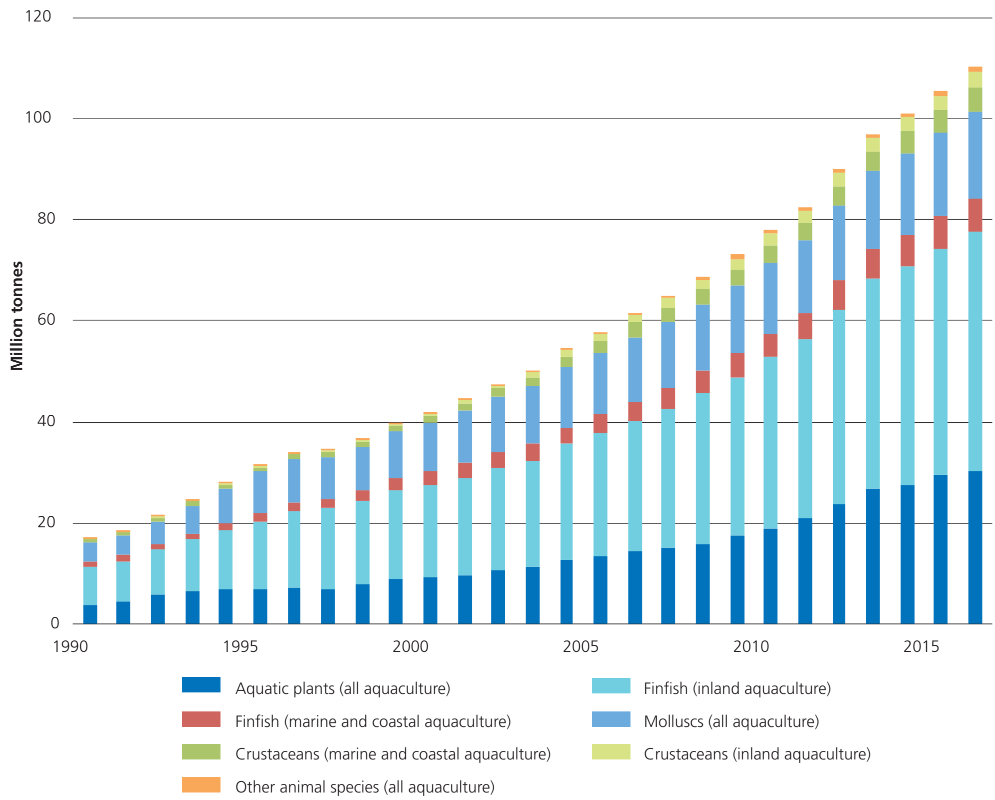
[2] Utilization data for 2014–2016 are provisional estimates.

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 (FAO, 2018a).

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. The Food and Agriculture Organization of the United Nations (FAO) recorded 28.7 million tonnes (USD 67.4 billion) of food fish production from mariculture and coastal aquaculture combined in 2016 (FAO, 2018a). 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 (FAO, 2018a).

The rate of growth of aquaculture production has declined since the 1980s and 1990s

FIGURE 4
Total world aquaculture production of food fish and aquatic plants, by sector, 1990–2016



Source: FAO, 2018b.

when annual growth rates were 10.8 percent and 9.5 percent 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 6 illustrates that, over the five-year period of 2012–2016, average annual growth rate was highest in the African region, albeit from a low base, with Asia continuing to grow at approximately 6 percent per annum. Oceania and Europe have the lowest average rate of growth of aquaculture over this period at approximately 2 percent per annum.

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

TABLE 5

Aquaculture production of main groups of food fish species by region, 2016 (thousand tonnes, live weight)

	Africa	Asia	Europe	Latin America and 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: The symbol "0" represents production quantity below 500 tonnes; "…" represents production data unavailable. Rounding effects may mean some column totals do not sum up exactly.

TABLE 6

Annual growth rate (in percent) of total aquaculture production, by region, 2012–2016

	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 and 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, 2018b.

1.3 The state of world fisheries

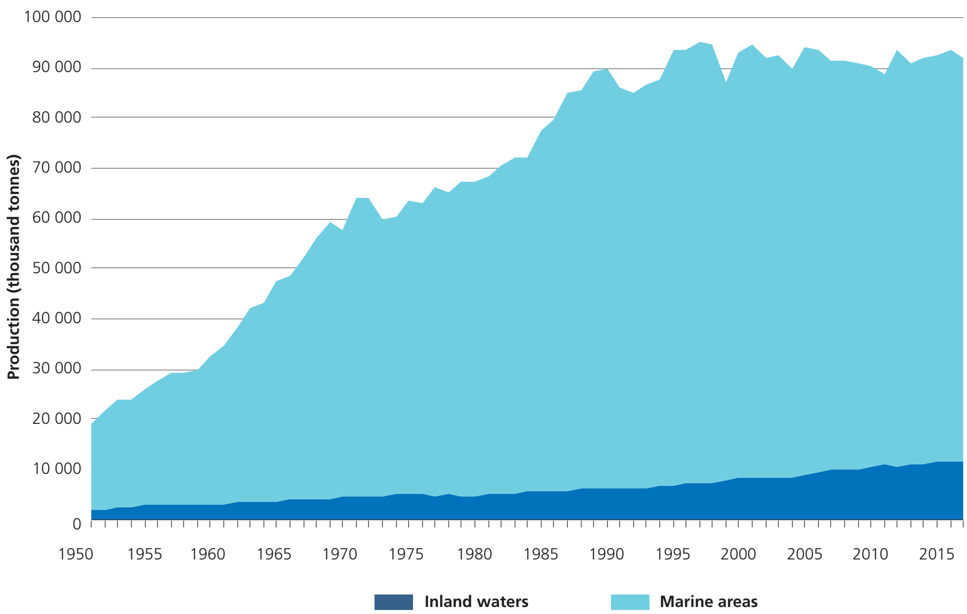
The harvest from marine and inland capture fisheries was about 91 million tonnes in 2016, and has plateaued at approximately this level over the past two decades (Figure 5).

1.3.1 Marine fisheries

The status of marine fisheries is based on an in-depth analysis of more than 450 fish stocks (FAO, 2018a). 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 capture fisheries production, with almost half of this production coming from temperate areas (FAO, 2018a). 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 6). 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 declined to just 7.0 percent.

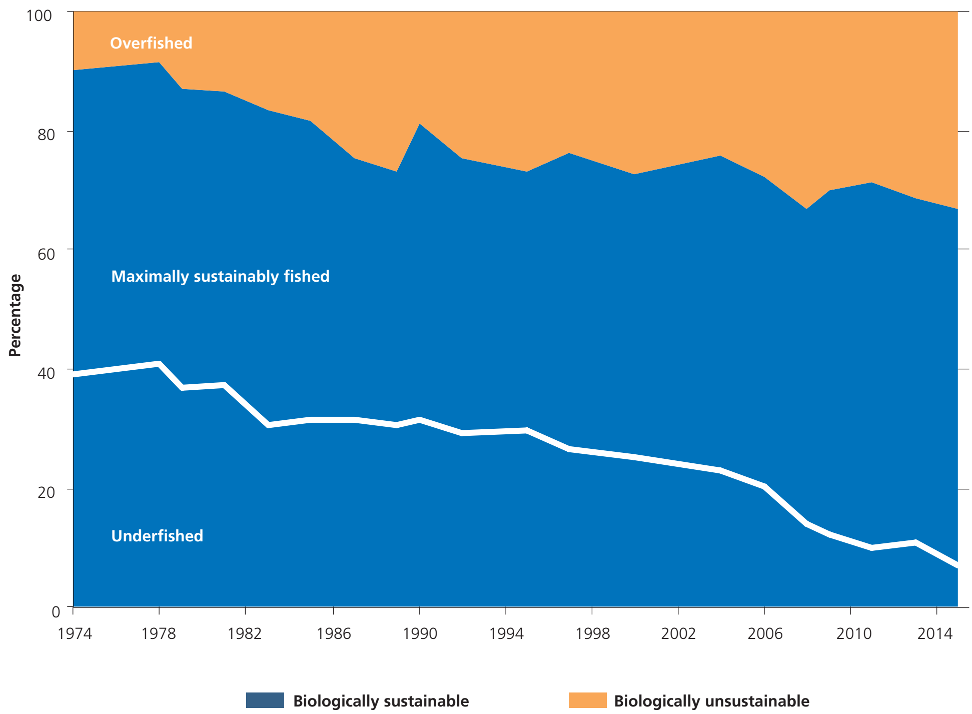
Asia harvests the majority of marine fish stocks (54 percent), followed by Europe and Latin America and the Caribbean (Table 7). As is the case with global aquaculture, there are

FIGURE 5
Production from marine and inland capture fisheries, 1950–2016 (live weight)



Source: FAO, 2018b.

FIGURE 6
Global trends in the status of world marine fish stocks, 1974–2015 (percentage)



Source: FAO, 2018a.

a relatively small number of species or species items that make up the majority of marine fishery yields.

Table 17 lists the major species or species items that yield a million tonnes or more per annum, including the highest yielding Alaska pollock *(Gadus chalcogrammus*) and the anchoveta (*Engraulis ringens*).

1.3.2 Inland fisheries

Global inland fishery harvests, unlike those in marine fisheries, have risen steadily since 1988, and were close to 12 million tonnes in 2016 (Figure 5). FAO does not have a system for tracking the status of inland fisheries in the way that it does for marine fisheries, in part due to the fact that most of the catch comes from developing countries and the absence of monitoring of individual fisheries. Production from inland capture fisheries is thus not well understood, and the majority of the catch is not identified to the species level when reported to FAO (Bartley *et al*., 2015). There are, however, credible reasons to believe that the production figures reported to FAO are underestimated (Bartley *et al*., 2015; FAO, 2018 a,b). Asia harvests the most from inland fisheries, accounting for 66 percent of global production; Africa is responsible for approximately 25 percent of production (Table 8).

TABLE 7

Production of global marine capture fisheries, excluding aquatic plants, by region, 2016 (thousand tonnes, live weight)

Geographical region	Production	Percentage of global total
Africa	6 415	8.1
Asia	42 531	53.6
Europe	13 259	16.7
Latin America and the Caribbean	9 658	12.2
North America	6 007	7.6
Oceania	1 414	1.8
Total	**79 285**	**100**

Source: FAO, 2018b.
Note: Rounding effects may mean some column totals do not sum up exactly.

TABLE 8

Global production from inland capture fisheries, by region, 2016 (thousand tonnes, live weight)

Geographical region	Production	Percentage of global total
Africa	2 864	24.6
Asia	7 713	66.3
Europe	441	3.8
Latin America and the Caribbean	549	4.7
North America	53	0.2
Oceania	18	>0.1
Total	**11 637**	**100**

Source: FAO, 2018b.
Note: Rounding effects may mean some column totals do not sum up exactly.

Unlike for marine waters, where fishing pressure is a major determinant of the status of fisheries, for inland waters it is often other factors external to the fishery sector that exert a major influence on the status of fisheries (FAO, 2016a). Habitat condition, water quality and connectivity of waterbodies often influence inland fisheries more than fishing pressure.

1.4 Consumption of aquatic genetic resources

1.4.1 The role of aquatic genetic resources for nutrition and food security

The majority of capture fishery production and nearly all of aquaculture production are destined for direct human consumption, although some by-products may be used for non-food purposes. Fish and fish products play a crucial role in nutrition and global food security. They are an excellent source of nutrients and micronutrients and can play a vital role in a diversified and healthy diet. People have never consumed as much fish as they do today.

Between 1961 and 2016, the average annual increase in global food fish consumption (3.2 percent) outpaced population growth (1.6 percent) and exceeded that of meat from all terrestrial animals combined (2.8 percent). In per capita terms, food fish consumption grew from 9.0 kg in 1961 to 20.2 kg in 2015, at an average growth rate of about 1.5 percent per year. This increase has been driven by increased production, but also by other factors, including reduced wastage and more efficient utilization, improved distribution, and growth in demand associated with population growth and rising incomes (FAO, 2018a).

Public awareness of the health benefits of aquatic food has improved and grown in recent years as consumers have become more health conscious, particularly in middle-income and developed markets. In lower-income markets, the importance of fish as a good source of protein, vitamins and minerals, is becoming more widely recognized along with its role in addressing nutritional deficiencies and contributing to the health of pregnant women and the neurodevelopment of children. Fish and fish products are excellent sources of quality protein, with the bioavailability of protein being 5–15 times higher than that from plant sources. Additionally, fish, especially marine-derived fish, contain several amino acids essential for human health. Even where per capita fish consumption is low, small quantities of fish can provide essential amino acids, fats and micronutrients that are often lacking in vegetable diets (FAO, 2018a). While fish are not without food safety risks, it is now broadly recognized that the positive effects of fish consumption outweigh the potential negative effects (FAO/WHO, 2011).

Globally, fish and fish products provide an average of only 34 calories per capita per day, but in some countries this can exceed 130 calories per capita. In 2015, fish accounted for about 17 percent of animal protein and 7 percent of all proteins consumed worldwide. Approximately 3.2 billion people (42 percent of the world's population) obtain 20 percent or more of their animal protein intake from fish; in a few countries, this figure is over 50 percent (FAO, 2018c).

Fish consumption varies widely between countries and regions and is at least three times higher in developed countries than in low-income food-deficit countries. Despite the lower consumption of fish in developing countries, fish still accounts for a higher proportion of animal protein intake than in developed countries (in 2015, fish accounted for 11.4 percent of animal protein intake in developed countries compared to 26.0 percent in least developed countries). Asia accounts for more than two-thirds of global food fish consumption (at 24 kg per capita per year), with Africa and Oceania consuming the lowest share (FAO, 2018c). In line with its dominance in fish production, China is by far the largest consumer of fish (38 percent of the global total in 2015), with per capita consumption of 41 kg per year. This contrasts with Africa, where the population is growing at a higher rate than fish supply, with only 9.9 kg per capita consumption. The lowest levels of fish consumption occur in Central Asia and some landlocked countries.

In line with the relative growth in production (Figure 3), the share of farmed fish in human diets has increased rapidly, with the contribution from aquaculture exceeding the contribution of wild-caught fish in the diet in 2013. By 2030, aquaculture is expected to provide 60 percent of fish available for human consumption. Trade in fish products is also rising, particularly among developing countries, and is likely to grow further, impacting the role of fish in food security and nutrition. In 2016, about 35 percent of global fish production entered international trade in various forms, for human consumption or as non-food products. The total export value of this trade was USD 129 billion, of which USD 70 billion was accounted for by exports of developing countries (HLPE, 2014). This international fish trade can have mixed impacts on the well-being and food security and nutrition of local fishing populations.

The High Level Panel of Experts (HLPE, 2014) noted that "limited attention has been given so far to fish as a key element in food security and nutrition strategies at national level and in wider development discussions and interventions". As debates about fisheries have traditionally concentrated on issues of biological sustainability and on the efficiency of fisheries, inadequate attention has been paid to issues linked to their contribution to reducing hunger and malnutrition and to supporting livelihoods. There remains considerable scope for increasing the amount of fish, and nutrients derived from fish, for human consumption through more efficient harvest, post-harvest and aquaculture practices. Similarly, increased consumption of fish, and particularly its addition to the diets of low-income populations, offers important means for improving food security and nutrition.

1.4.2 Non-food uses of aquatic genetic resources

Non-food uses of aquatic genetic resources (AqGR) include animal feeds (including aquaculture feeds), ornamental fish, pearls and seashells, bait, pharmaceuticals and biofuels. Data on non-food usage are often not recorded and collected alongside usage for food; such usage is not well understood. Table 4 reports the non-food use component of production of AqGR at 19.7 million tonnes in 2016, representing 11.5 percent of global production. However, the majority of this reported use relates to the reduction of wild catch into fishmeal and fish oils (FAO, 2018a) and seaweed harvested for extraction of phycocolloids,[10] in which most of the AqGR utilized would be of species that, due to not being farmed, are outside the scope of the Report. Microorganisms are cultured for a range of applications, including as larval fish diets, as probiotics, as components of food supplements, and potentially as biofuels (see Box 6).[11] However, the production of microorganisms is rarely reported in aquaculture production statistics. It is estimated that only 37 900 tonnes of aquaculture production (less than 0.05 percent) are for non-food uses (FAO, 2018a).

Non-food applications of AqGR are not a focus of the Report. However, FAO does include ornamental fish in its consideration of AqGR for food and agriculture, but here, also, reliable data are not commonly available. The global trade in ornamental fish has grown significantly in recent times, and the value of exports is estimated at USD 372 million annually, with the majority of this made up of freshwater species (annual trade in marine ornamentals is thought to be worth around USD 44 million).[12] Some data are available on the value of imports and exports, but no data are available on the number of fish traded. Monticini (2010) reports on an analysis of the ornamental fish industry based on data from 2007/08. At that time, it was estimated that there were 100 countries exporting ornamental fish, but with few major suppliers. Asia is the main region for production, representing over 50 percent of the global export value. In 2007, ornamental fish were imported into an estimated 130 countries, with the United States of America and some European countries as the major importers. Freshwater fish represented 95 percent of the total volume and 80 percent of the value of these imports with the balance made up of marine finfish and invertebrates. This extensive movement of live AqGR for the ornamental trade may have significant impact on biodiversity and biosecurity.

[10] See thematic background study *Genetic resources for farmed seaweeds* http://www.fao.org/aquatic-genetic-resources/background/ sow/background-studies/en/

[11] See also the thematic background study *Genetic resources for microorganisms of current and potential use in aquaculture* http://www.fao.org/aquatic-genetic-resources/background/sow/background-studies/en/

[12] As reported by FAO (www.fao.org/in-action/globefish/news-events/details-news/en/c/469648).

1.5 Diversity of aquaculture production systems

With the wide diversity of farmed species items, global aquaculture production systems are highly diverse. They cover a range of systems, which can be classified by the intensity of production (extensive, semi-intensive and intensive),[13] by types of aquatic environments (freshwater, brackish water and marine water), by whether feeding is required (fed and unfed systems) and by the level of integration with other production systems (e.g. monoculture, polyculture, integrated farming). Examples of such systems can be found in every inhabited region of the world.

These systems also have different characteristics with respect to the diversity and use of AqGR, ranging from the use of wild-caught seed or broodstock through to using 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 9.

[13] Intensive systems are characterized by high stocking densities and full dependence on artificial feeds; semi-intensive systems have lower stocking densities and rely to some extent on natural feed often supplemented with artificial feeds; and extensive systems are low density and depend fully on naturally available feed.

1.5.1 Stock enhancement systems

Stock enhancement sits at the interface between aquaculture and capture fisheries, commonly involving the stocking of aquaculture-produced organisms into the natural environment. Formal stocking programmes are generally recognized as an important tool to compensate for declines in fishery production due to reduced recruitment and loss of 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. Given that most inland water systems have attained their maximum potential for natural production, increasing demand for fish and fish products is driving fisheries managers to look to stock enhancement as a means to increase fishery yields (FAO, 2015a). In many countries, this

TABLE 9

Categories of aquaculture systems, indicating the species or species items typically cultured, and the common sources of broodstock and/or seed used in these systems

System type	Typical species or species items	Source of seed stock	Source of broodstock
Industrial/high-technology systems, including recirculating aquaculture systems	**Marine finfish:** Atlantic salmon (*Salmo salar*), pompano	Hatcheries	Captive broodstock; selective breeding and other genetic improvements; domestication programmes
	Marine crustaceans: *Penaeus vannamei*		
	Freshwater finfish: rainbow trout (*Oncorhynchus mykiss*), pangasius, tilapia, common carp (*Cyprinus carpio*), sturgeon, channel catfish (*Ictalurus punctatus*)		
Higher-value species fattening systems	**Marine finfish:** bluefin tuna, groupers, lobster, mangrove crabs **Freshwater finfish**: European and Japanese eel (*Anguilla anguilla* and *A. japonica*), marbled goby (*Oxyeleotris marmorata*)	Wild captured from targeted fisheries	Wild relatives
Lower-value species fattening systems	**Marine/brackish-water finfish:** mullet, milkfish (*Chanos chanos*)		
	Freshwater finfish: giant snakehead (*Channa micropeltes*), African catfish (*Clarias gariepinus*)		

(Cont.)

TABLE 9 *(Cont.)*

Categories of aquaculture systems, indicating the species or species items typically cultured, and the common sources of broodstock and/or seed used in these systems

Medium technological level commercial finfish and crustacean fed systems	**Marine/brackish-water finfish:** turbot, seabream, European seabass (*Dicentrarchus labrax*), Asian seabass (*Lates calcarifer*), milkfish, snappers, cobia (*Rachycentron canadum*) **Marine crustaceans:** *Penaeus monodon*	Hatcheries	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 carps, Chinese carp **Freshwater crustaceans:** river prawn spp., crayfish spp., Chinese mitten crab (*Eriocheir sinensis*)		
Higher-value mollusc systems	**Marine/brackis-water molluscs:** **Fed systems:** abalone, whelk spp. **Unfed systems:** Lantern net systems: scallop Lines: green-lipped mussel (*Perna canaliculus*) Racks/poles: Pacific and European oyster systems Open water: giant clam	Hatcheries	Captive broodstock
Low technology/ artisanal and backyard systems	**Marine finfish:** rabbitfish, milkfish, scats	Hatcheries	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 finfish: Indian carp (*Catla catla*), common carp, Chinese carp, tilapia, catfish, snakehead, climbing perch (*Anabas testudineus*), silver barb (*Barbonymus gonionotus*), snakeskin gourami (*Trichopodus pectoralis*), giant gourami (*Osphronemus goramy*), pacu (*Piaractus mesopotamicus*)		
Integrated or mixed systems	**Marine/brackish water:** mangrove/aqua-silviculture (crab/ shrimp/trap pond systems)	Trapped wild species ongrown; hatcheries	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, shrimp, river prawn)		
	Freshwater: wastewater improvement systems (aquatic plants and/or molluscs/herbivorous fish)	Mainly hatcheries	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
Aquaculture feed species	Invertebrates (e.g. polychaete worms)	Hatcheries	Hatchery-maintained strains or use of farm stock (in the case of worms)
	Zooplankton (e.g. *Moina* spp.)		
	Phytoplankton (e.g. *Chaetoceros, Chlorella, Skeletonema, Tetraselmis, Isochrysis* spp.)		
	Zooplankton (e.g. *Artemia* spp.)	Wild collection	Inoculation of open waters with maintained strains; wild relatives naturally recruited
Food supplements	*Spirulina* spp.	Hatcheries	Maintained strains
Seaweeds/aquatic plants	**Marine:** seaweeds (e.g. *Eucheuma, Gracilaria, Laminaria, Porphyra* spp.)	Hatcheries and vegetative reproduction	Maintained stock or hatchery-held strains
	Freshwater: aquatic plants (e.g. *Ipomoea* spp., watercress), including ornamental/aquarium plants		
Aquarium fish and other species	~1 500 marine fish, ~200 coral species. Up to ~1 000 freshwater species. Also significant use of exotic species outside of their natural range.	At least 80 percent of freshwater ornamentals are hatchery bred. Only a few species of marine ornamentals are hatchery bred	Hatchery-maintained broodstock

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 10).

There are five types of fishery enhancement systems (Table 11) that utilize AqGR (Lorenzen, Beveridge and Mangel, 2012). These are either aquaculture-related activities using farmed types or individuals produced in hatcheries for release to meet conservation or capture fishery objectives. In the latter case, these will be targeting stocks of wild relatives. Each of these systems has a different primary purpose and involves different management practices.

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, 2015a).

TABLE 10

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 aspects	Net consumer Capital-intensive Profit	Net producer Labour-intensive Production

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

TABLE 11

The five types of fishery enhancement systems that involve stocking

Enhancement type	Primary purpose(s)
Culture-based fisheries and ranching	Increased fish production
	Creation of recreational fisheries
	Biomanipulation
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
Reintroduction	Re-establishing a locally extinct population

Source: Lorenzen, Beveridge and Mangel, 2012.

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 (Zambia/Zimbabwe);
- *Neosalanx taihuensis* (Chinese icefish) introduced into many Chinese reservoirs;
- *Cyprinus carpio* (common carp) in Lake Naivasha and Tana River hydroelectric dams (Kenya);
- *Lates niloticus* (Nile perch) fishery in Lake Victoria (Uganda/Kenya);
- *Oreochromis niloticus* and *O. mossambicus* (Nile tilapia and Mozambique 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.

Recreational fisheries also engage in the stocking of open waters and rivers to enhance these fisheries (e.g. for trout, salmon) using material from aquaculture hatcheries. Recreational fishing has traditionally been a developed country activity, but it is becoming popular in developing countries. 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 cachama (*Colossoma macropomum*), Arapaima (*Arapaima gigas*) and red-tail catfish (*Phractocephalus hemioliopterus*) have been introduced to Asia.
- North American species such as rainbow trout (*Oncorhynchus mykiss*) and black bass (*Micropterus* spp.) have been introduced to Europe.
- The movement of the European (Wels) catfish (*Silurus glanis*) has resulted in its subsequent establishment beyond its natural range within Europe.

1.6 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, 2018b). Though the number of farmed aquatic species is smaller, aquaculture remains extremely species-diverse compared to other food production sectors. In 2016, over 550 species and/or species items were farmed (Table 12). 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.

According to the latest available fisheries and aquaculture statistics published by FAO, the total production in 2016 from capture fisheries and aquaculture, including aquatic plants, was 202.2 million tonnes; the production is broken down by major group in Table 13.

The species diversity of AqGR for food and agriculture is extensive and includes several phyla. AqGR can be split into major components according to phyla and other taxa (Table 14).

1.6.1 Definitions and nomenclature

AqGR include DNA, genes, chromosomes, tissues, gametes, embryos and other early life history stages, individuals, strains, stocks, and communities of organisms of actual or potential value for food and agriculture. Unlike

TABLE 12

Diversity of aquatic species identified in the wild and the number of farmed and fished species or species items and families represented in FAO production statistics, 2016

Taxon	Wild species (marine)	Wild species (freshwater)	Number of farmed species	Number of farmed families	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**

Sources: Balian *et al*., 2008; Chambers *et al*., 2008; FAO, 2018b; Lévêque *et al*., 2008; WoRMs Editorial Board, 2018.
*These include echinoderms, coelenterates and tunicates too numerous to list (many of which have no potential as food and are all marine species) and a few amphibians and reptiles.

TABLE 13

World total capture fisheries and aquaculture production, 2016 (thousand tonnes, 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, 2018b.
Note: Rounding effects may mean some column totals do not sum up exactly.

TABLE 14

Aquatic genetic resources for fisheries and aquaculture, categorized 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

Source: FAO, 2018b.

domesticated crops and livestock (FAO, 2007; 2015b), where many distinctive 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). In preparing the questionnaires and in reviewing the response to questionnaires it became evident that the terminology used to describe AqGR differs from that used to describe terrestrial livestock and plant genetic resources and also that the usage of such terms is not standardized in their application. In 2016, FAO held the Expert Workshop on Incorporating Genetic Diversity and Indicators into Statistics and Monitoring of Farmed Aquatic Species and their Wild Relatives (FAO, 2016a). This workshop also recognized that there was a lack of standardization of terms used to describe AqGR and recommended a number of operational descriptors as applicable to AqGR. Box 2 explains the operational definitions used in the Report, which are based on customs of crop and livestock nomenclature and the descriptors recommended in the above-mentioned workshop. Of note is that "strains" and "varieties", terms respectively applied to aquatic animals and plants, should be recognizable by their characteristics, making them distinguishable from other strains and varieties of the same species, and that these characteristics are maintained through the process of propagation. The term "farmed type" is used widely throughout the Report and is a relatively new term recognized in the above-mentioned workshop as being appropriate for the description of farmed aquatic organisms below the level of species. A farmed type is a descriptor applied to a species (unless it is a hybrid or introgressed strain/variety) being cultured that 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 one or more farmed types

Box 2
Standardizing nomenclature in aquatic genetic resources

Standardized use of terms is essential. The Report uses the following definitions, based in part on the customs of crop and livestock nomenclature. However, the terms "strain" and "farmed type" have been newly elaborated, and it is proposed that they be adopted as standard in the context of AqGR.

Term	Definition
Variety	A plant grouping, within a single botanical taxon of the lowest known rank, defined by the reproducible expression of its distinguishing and other genetic characteristics.[1]
Farmed type	Farmed aquatic organisms that could be a strain, hybrid, triploid, monosex group, other genetically altered form, variety or wild type.
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.

[1] The International Treaty on Plant Genetic Resources for Food and Agriculture (FAO, 2009)

associated with it, to provide more information on the genetic resource. It is proposed in the Report that the terms identified in Box 2 be adopted as standard in the description of AqGR.

Unlike in the terrestrial agriculture sector, wild relatives of all 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 Section 3.2). 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.

1.6.2 Diversity and production of farmed species

There is a large diversity of species farmed in aquaculture, and the number of species growing over time may be one contributor to rapid growth in aquaculture production. 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. It should be noted that much of the analysis in the chapter is based on FAO's global aquaculture production statistics, and that these statistics are most likely understating the number of species and hybrids used in aquaculture, due to the insufficient level of species identification detail in national data provided to FAO.

Table 12 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 in 1950 (FAO, 2018b). The 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 or species items historically recorded by FAO increased by 26.7 percent, from 472 in 2006 to 598 in 2016 (FAO, 2018b). However, the data reported to FAO do not keep pace with the actual speed of species diversification in aquaculture. Numerous single species items recorded in the official statistics of many countries actually consist of multiple species and sometimes hybrids (FAO, 2016a). Some of the issues and drivers for species diversification in aquaculture are summarized in Box 3. Despite the great diversity in the species raised, aquaculture production by volume is dominated by a small

Box 3
Species diversification in aquaculture

More than 160 000 known aquatic species with over 1 800 species or species items are being harvested from fisheries (Table 12), primarily for food, but which ones should we farm? With aquaculture expected to meet the growing demand for fish and fish products and with consumers conditioned to a wide diversity of species from capture fisheries, there are strong incentives to further diversify the number of species used in aquaculture. With nearly 560 species or species items already being farmed, there are conflicting demands for further diversification versus the need to focus and improve the efficiency of production of existing cultured species. There are advantages and disadvantages associated with the pursuit of diversification, and issues were examined in a workshop entitled Planning for Aquaculture Diversification: The Importance of Climate Change and Other Drivers (Harvey *et al.*, 2017).

A number of important drivers of diversification exist in aquaculture, including market forces such as the reduced supply of wild-caught fish and/or the

(Cont.)

Box 3 *(Cont.)*

Species diversification in aquaculture

high demand of such species. Ecological change and economic change are also drivers, as are some of the established risks associated with species grown in monoculture (e.g. effects of pathogens, parasites and pests). Diverse production systems are likely to be more resilient to challenges of environmental change (such as climate change) and/or economic change. Diversification in aquaculture can also support conservation and maintenance of aquatic biodiversity, particularly with regard to native species. Government and academia can also be drivers of diversification. Some of these drivers can be transient; for example, markets can be drivers during periods where wild catches of species are low, but the recovery of fisheries can improve the supply and reduce prices, rendering the culture uneconomic.

There are, however, significant constraints to diversification, including technological challenges associated with the development of culture systems for new species. It can take 10–15 years and significant investment to develop the culture of a new species and bring the resulting product to market.

Evidence from other agriculture sectors shows that production trends have evolved in such a way as to be dominated by a small number of species. Breeding has developed vast numbers of breeds and varieties within these species with diverse characteristics adapting them to different production systems (e.g. layer and broiler chickens). Relative to plants and livestock, the strain development of aquatic genetic resources (AqGR) in aquaculture is in its infancy. It is not clear whether the future for cultured AqGR will follow a similar pathway of consolidation of production in a few species or whether the drivers of diversification will sustain greater diversity of the production of species.

The workshop report recognized the challenges faced by countries in deciding whether it is better to increase the number of species being farmed or to focus on improving the culture of existing species or strains and in adapting strains through breeding. The report considers the following issues in resolving this dilemma:

- identification of potential means of diversification (e.g. diversify using existing aquaculture systems through strain and system development or into new species);
- choice of species for diversification using rigorous selection criteria;
- choice of culture systems for diversification (e.g. some systems can promote diversification, such as integrated multi-trophic aquaculture);
- consideration of diversification using native or introduced species;
- focus on culturing species that are unsustainably fished (however, there are risks inherent in this approach if fisheries and thus supply recover); and
- diversification as a specific response to the challenges of climate change (climate change may make existing species/systems inviable and/or create opportunities for culturing new species).

All of these issues need to be carefully considered in the development of appropriately balanced policies and investment strategies relating to diversification in support of aquaculture growth.

number of "staple" species or species items at national, regional and global levels.

Table 15 illustrates the diversity of species farmed within each major taxonomic grouping by region, and Figure 7 illustrates the relative contribution of the major aquaculture species to global production, illustrating, for example, that 50 percent of global production is made up of the top ten aquaculture species or species items.

Table 15 illustrates that Asia farms the most species of aquatic organisms, in part because it has the longest tradition of aquaculture. That relatively few species are farmed in Africa (in relation to the size and habitat diversity of the region and the potential number of species available for farming) demonstrates the potential for further use of AqGR in African aquaculture.

TABLE 15
Number of species or species items reported to FAO as under production in 2016, by region and culture environment

	Africa	Asia	Europe	Latin America and the Caribbean	North America	Oceania	World
Inland aquaculture							
Finfish	66	112	73	76	14	20	361
Molluscs	0	5	0	1	0	0	6
Crustaceans	7	16	7	7	2	5	44
Other animals	0	8	3	4	0	0	15
Algae	3	4	4	5	0	0	16
Subtotal inland	76	145	87	93	16	25	442
Marine and coastal aquaculture							
Finfish	26	107	48	28	11	14	234
Molluscs	17	26	31	27	16	24	141
Crustaceans	8	27	15	7	3	10	70
Other animals	3	9	4	0	0	3	19
Algae	5	19	14	10	0	4	52
Subtotal marine and coastal	59	188	112	72	30	55	516
All aquaculture[1]							
Finfish	81	192	108	97	24	28	530
Molluscs	17	30	31	28	16	24	146
Crustaceans	13	39	20	14	5	15	106
Other animals	3	15	6	4	0	3	31
Algae	8	23	17	15	0	4	67
Total – all aquaculture taxa	**122**	**299**	**182**	**158**	**45**	**74**	**880**

Source: FAO, 2018b.
[1] The world total in rows is not equivalent to species totals in Table 12, as species can be produced in more than one region; column totals do not equal the sum of subtotals, as some species are cultured in both inland and marine systems.

1.6.2.1 Finfish aquaculture

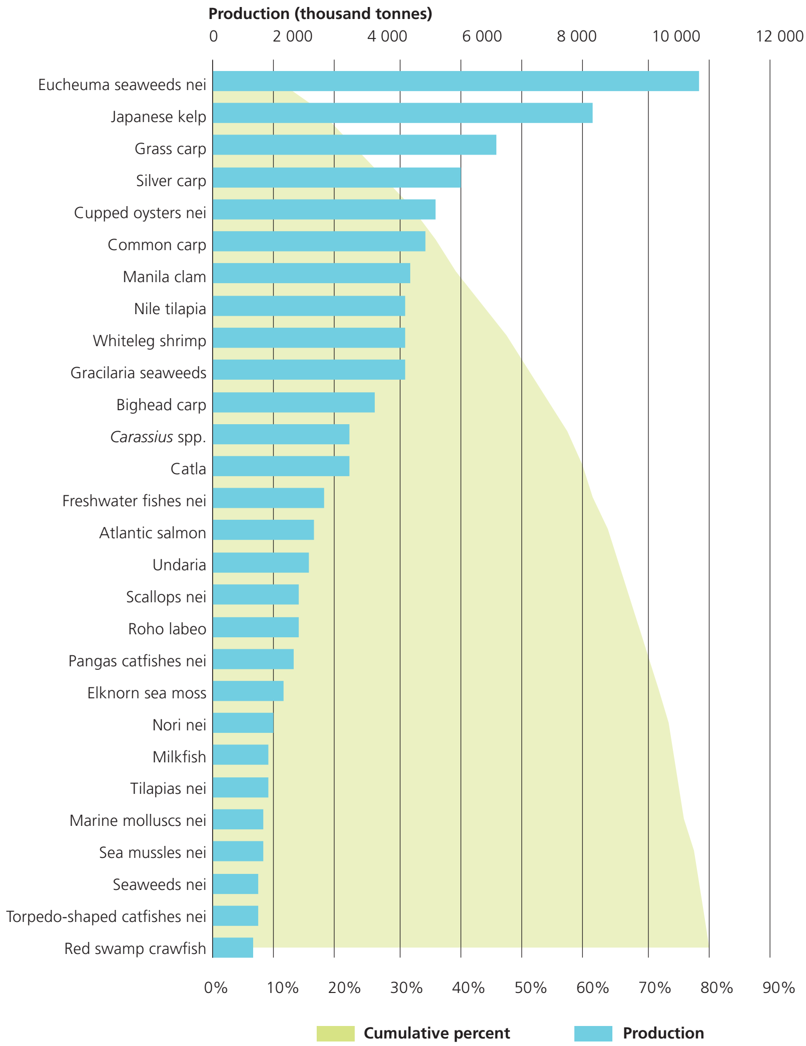
The importance of a small number of species within the large diversity is well illustrated if finfish farming is considered. This most diverse subsector relied on 27 species or species items for over 90 percent of the total production in 2016, while the 20 most produced species accounted for 84.2 percent of total production (Table 16).

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

FIGURE 7

Production (live weight) and contribution to cumulative percentage of global production, for the top cultured species or species items. Twenty-three species or species items collectively make up 75 percent of global production.



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

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 and pacu) to highly carnivorous species (e.g. salmon, eel and snakehead). The majority of the production volume is based on the lower trophic level species. This underscores the contribution

TABLE 16
Major finfish species or species items under aquaculture production and their relative contribution to global finfish production, 2010–2016 (thousand tonnes, live weight)

Species/species item	2010	2012	2014	2016	2016 share (percent)
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**	**100.0**

Source: FAO, 2018a.
Note: nei = not elsewhere included.
Note: Rounding effects may mean some column totals do not sum up exactly.

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.

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

1.6.2.2 *Mollusc aquaculture*

Compared with finfish, fewer species of crustaceans and molluscs are farmed (Table 15). Farmed molluscs can be broadly split into bivalves and gastropods, with 2016 production including 95 species in 27 families (FAO, 2018b). The overwhelming majority are cultured in marine systems (Figure 8). Bivalve molluscs are produced in unfed systems, utilizing food naturally present in the water. Some gastropod systems (abalone, conch, *Babylonia* spp.) can be relatively intensive and use feeds. There is minor production of cephalopods (octopus).

1.6.2.3 *Crustacean aquaculture*

Crustaceans can be split between marine/brackish and freshwater production systems and comprise 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 comprises the Chinese mitten crab (*Eriocheir sinensis*), various crayfish/crawfish species and *Macrobrachium* freshwater prawns.

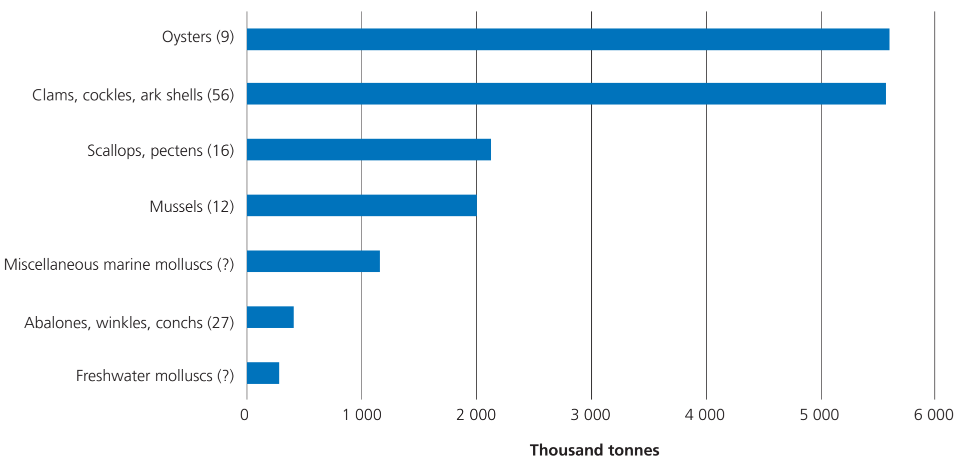
Some production of the whiteleg shrimp (*Penaeus vannamei*) is also recorded as undertaken in freshwater inland areas, although this may not be strictly freshwater, but extremely low-salinity brackish water instead. The majority of production is from warm-water systems (Figure 9).

1.6.2.4 *Aquatic plant aquaculture (seaweed)*

Farmed aquatic plants are largely marine species (seaweeds) produced in marine and brackish waters. 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, 2018b) (Figure 10).

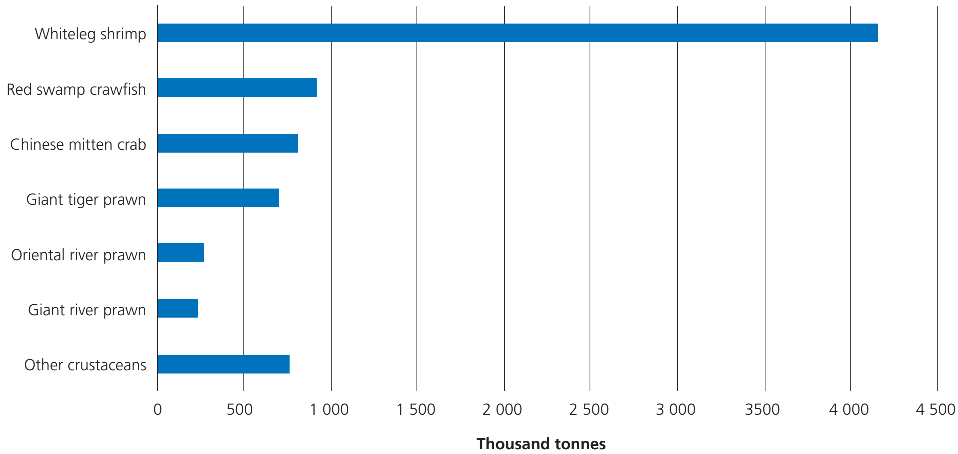
Owing to the relative paucity of information, aquatic plant aquaculture warrants more specific

FIGURE 8
Global aquaculture production of major molluscan taxa, 2016 (live weight)



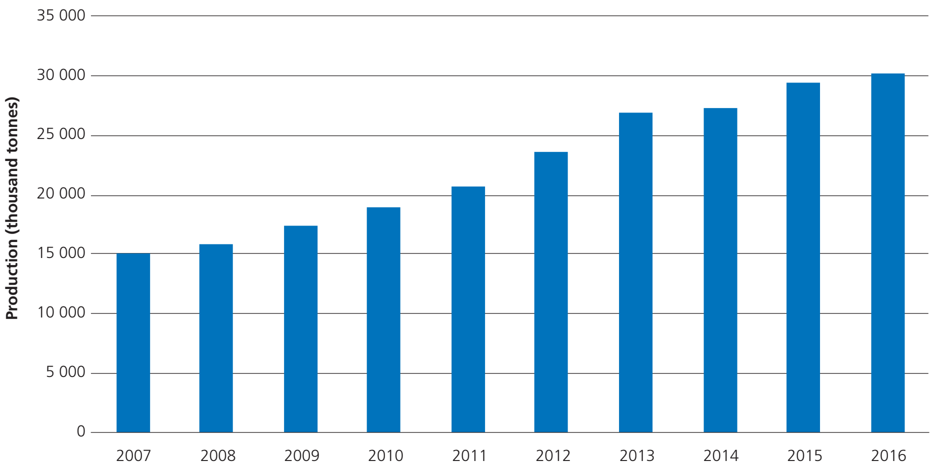
Source: FAO, 2018b.
Note: Numbers in parentheses represent the number of species or species items per taxon, where this is known.

FIGURE 9
Global production of major crustacean species or species items, 2016 (live weight)



Source: FAO, 2018b.

FIGURE 10
Global production of aquatic macrophytes, 2007–2016 (live weight)



Source: FAO, 2018b.
Note: This production may include a small quantity of freshwater macrophytes (< 90 thousand tonnes).

Box 4
Seaweed genetic resources for aquaculture

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 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)
- cyanobacteria (Cyanophyceae – 3 species items)

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

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, Pyropia* spp. and *Palmaria palmata*. Among the green seaweeds, *Caulerpa, Codium, Monostroma* and *Ulva* spp. are the main taxa farmed for commercial purposes.

Traditional selection of strains based on growth performance and resistance to disease is sometimes used in propagating farmed seaweeds. The hybridization of *Laminaria japonica* in China enabled the massive expansion in cultivation of this species. The development of plantlets from spores for outplanting is practised in some brown (*Laminaria, Saccharina, Undaria* spp.), red (*Palmaria, Pyropia* spp.), and green seaweeds (*Codium, Monostroma, Ulva* spp.). Micropropagation through tissue and callus culture is now being used to generate new and improved strains in *Eucheuma* and *Kappaphycus*, although vegetative propagation is still widely used.

This box draws from the thematic background study *Genetic resources for farmed seaweeds* (http://www.fao.org/aquatic-genetic-resources/background/sow/background-studies/en/)

attention. Seaweed production has been covered a separate thematic background paper, with some of this information summarized in Box 4.[14]

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 nutraceuticals, 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 aquaculture as a means to recycle aquaculture effluents by absorbing nutrients from other parts of the aquaculture system.

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.

[14] See thematic background study *Genetic resources for farmed seaweeds*) and thematic background study *Genetic resources for farmed freshwater macrophytes: a review* (http://www.fao.org/aquatic-genetic-resources/background/sow/background-studies/en/)

Seaweed biomass has a wide range of applications, such as:

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

1.6.2.5 Aquatic plants – freshwater macrophytes

Freshwater macrophytes are relatively under-researched and underdocumented. 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. Owing to the relative paucity of information, freshwater aquatic plant aquaculture warrants more specific attention and has been covered in a separate thematic background paper,[15] with key information summarized in Box 5.

[15] Thematic background study *Genetic resources for farmed freshwater macrophytes: a review* (www.fao.org/aquatic genetic-resources/background/sow/background-studies/en/)

Box 5

Freshwater aquatic macrophytes for food and agriculture

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. Freshwater aquatic macrophytes (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 emergent species, submersed species and floating species.

The cultivation and consumption of edible cultivated freshwater macrophytes and their impact on food security have long been under-recognized and under-recorded in both scientific and grey literature. In South and Southeast Asia, they have traditionally provided communities (often lower-income communities) with a low-cost, nutritious food for both themselves and their livestock, and even as components of aquaculture feeds. FAMs are also often used to recycle "waste" nutrients such those from livestock production. In terms of the global aquaculture development community, the scale of production and range of edible cultivated aquatic plant products is little known or practised outside South and Southeast Asia; information on FAMs is rarely taught in curricula or addressed in the research agenda of the major academic aquaculture schools and international non-governmental research organizations. Even in Asia, FAMs remain unrecorded in most national and international agriculture and/or aquaculture statistics and planning documents, despite their significant contribution to food production and nutrient recycling.

It is estimated that there are more than 40 species of edible FAMs, of which around 25 percent are either

(Cont.)

Box 5 *(Cont.)*
Freshwater aquatic macrophytes for food and agriculture

already being cultivated for food at a scalable level or have the potential to be developed into commercially viable cultivation species. There is relatively little information either in the research literature or at the grassroots production level to indicate the occurrence of genetic improvement to develop improved varieties. Traits of interest for improvement would include growth performance, productivity, capacity for phytoremediation of wastewater and even disease resistance. While there may have been relatively little genetic improvement of FAMs, it is thought that there has been significant translocation of germplasm between countries or regions over the past 600 years.

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 can and do fulfil, including being key components in multipurpose integrated production systems. Their incorporation and use in aquaculture and other wastewater treatment and remediation continues to be developed. They also have potential as aquaculture feed ingredients. There is also a large global market for ornamental aquatic plants for use in aquaria. 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 box draws from the thematic background study *Genetic resources for farmed freshwater macrophytes: a review* http://www.fao.org/aquatic-genetic-resources/background/sow/background-studies/en/

1.6.2.6 Aquatic microorganisms

Microorganisms, feed organisms and aquatic plants have not been comprehensively reported to FAO, yet they are a valuable component of AqGR. Information on microalgae is rarely 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. Due to the low level of information available on microorganisms in aquaculture, this subject has received specific attention through coverage in a separate thematic background paper,[16] with key information summarized in Box 6.

Microorganisms will play an important role in the future success and growth of aquaculture, which depends to some extent on the continued availability and more efficient culture of these important organisms. Thus, conservation and expansion of the biological diversity of micro-organism genetic resources used in aquaculture in commercial and public culture collections are required. This will include the ability to store these organisms for the long term in gene banks without them being subject to genetic drift and the increased use of genomics to characterize all key microbial species used in aquaculture.

1.6.2.7 Other species

A range of niche species are also produced in aquaculture, comprising seven families of sea cucumbers, sea urchins 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 11). Ornamental invertebrates (including corals) are also not included,

[16] Thematic background study *Genetic resources for microorganisms of current and potential use in aquaculture* (http://www.fao.org/aquatic-genetic-resources/background/sow/background-studies/en/).

Box 6
Microorganisms in fisheries and aquaculture

Aquatic microorganisms are indispensable resources for growth of shellfish and finfish in natural aquatic ecosystems and in aquaculture. These microorganisms fall into the microbial groups of microalgae and fungal-like organisms, bacteria, including cyanobacteria and zooplankton.

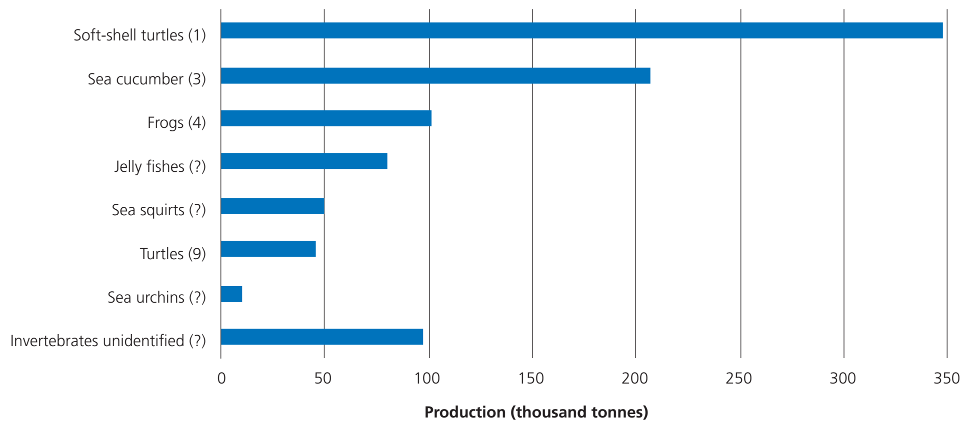
Many microalgal species are important in aquaculture, with different species being suitable as feed for shellfish and finfish larviculture, as components of "green water" widely used to enhance survival and growth of larval and adult fish, and as feeds to enhance the nutritional quality of *Artemia* spp. and rotifers. 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* spp., used for human diet supplements, and a rapidly growing suite of probiotic bacteria. These probiotic bacteria include species that improve survival and growth of finfish and shellfish larvae 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* spp. 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 *B. rotundiformis* are most commonly used. Other zooplankton used in aquaculture include copepods and cladocerans, such as *Daphnia* spp., which are widely used in freshwater larviculture.

This box draws on the thematic background study *Genetic resources for microorganisms of current and potential use in aquaculture* (http://www.fao.org/aquatic-genetic-resources/background/sow/background-studies/en/).

FIGURE 11
Aquaculture production of other aquatic animals, 2016 (live weight)



Source: FAO, 2018b.
Note: Numbers in parentheses represent the number of species or species items per taxon, where this is known.

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. Cambodia, China, Papua New Guinea, Thailand and Viet Nam all have crocodile farms; however, this production is rarely, if ever, reported in fishery or aquaculture statistics.

1.6.3 Marine and freshwater ornamental fish in the aquarium trade

Availability of data relating to utilization of AqGR in the ornamental trade is poor. In 2000, the Global Marine Aquarium Database was created, and by August 2003 the dataset contained trade records covering a total of 2 393 species of finfish, corals and other invertebrates and spanning the years from 1988 to 2003. A total of 1 471 species of marine fish are traded worldwide, however, the ten "most traded" species account for about 36 percent of all fish traded for the years 1997 to 2002 (Wabnitz *et al*., 2003).

Exactly 140 species of stony coral, nearly all scleractinians, were traded worldwide. Coral species from several genera (particularly *Euphyllia, Goniopora, Acropora, Plerogyra* and *Catalaphyllia* spp.) 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. Over 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 (Wabnitz *et al*., 2003).

More recent data on the utilization of marine ornamentals are not readily available, although a database maintained by the New England Aquarium (Rhyne *et al*., 2017) indicates that approximately 2 250 marine finfish species and 725 invertebrate species were imported into the United States of America alone during the period 2000–2011.

There is no equivalent database for the freshwater aquarium trade, and the diversity of species being produced and traded is not easy to establish. However, various aquarium guides list 650 (Sakurai *et al*., 1993) to 850 (Baensch and Riehl, 1997) common freshwater aquarium species. Monticini (2010) lists some of the most traded species of marine and freshwater fish.

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 on 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, on the other hand, 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.

1.6.4 Diversity of species in capture fisheries

As indicated in Table 12, there were over 1 800 species or species items harvested in capture fisheries in 2016, with more than 80 percent of these coming from marine fisheries. In marine, and especially in inland fisheries, production is dominated by a relatively small number of species.

Table 17 lists the top 15 species or species items contributing to marine fisheries, which together constitute 42 percent of total marine capture fisheries production. It must be noted that 12 of these are single species, and that the largest single contribution is from a group of species not elsewhere included.

There is a similar picture of species dominance in inland fisheries. Table 18 lists the top 15 species or species items produced from inland fisheries, which collectively contribute to 81.5 percent of inland capture fisheries

TABLE 17
Main species or species items harvested from marine capture fisheries and their production, 2011–2016 (thousand tonnes, live weight)

Species (ASFIS species)	2011	2012	2013	2014	2015	2016
Marine fishes nei	9 451	9 612	9 350	9 494	10 211	10 433
Alaska pollock (= walleye pollock) (*Gadus chalcogrammus*)	3 210	3 272	3 248	3 245	3 373	3 476
Anchoveta (= Peruvian anchovy) (*Engraulis ringens*)	8 320	4 693	5 674	3 140	4 310	3 192
Skipjack tuna (*Katsuwonus pelamis*)	2 529	2 702	2 909	2 991	2 810	2 830
Atlantic herring (*Clupea harengus*)	1 780	1 773	1 817	1 631	1 512	1 640
Pacific chub mackerel (*Scomber japonicus*)	1 309	1 270	1 260	1 397	1 485	1 599
Yellowfin tuna (*Thunnus albacares*)	1 145	1 304	1 261	1 347	1 356	1 462
Atlantic cod (*Gadus morhua*)	1 052	1 114	1 359	1 374	1 304	1 329
Japanese anchovy (*Engraulis japonicus*)	1 322	1 292	1 324	1 396	1 336	1 304
European pilchard (= sardine) (*Sardina pilchardus*)	1 037	1 021	1 003	1 208	1 175	1 281
Largehead hairtail (*Trichiurus lepturus*)	1 261	1 238	1 264	1 265	1 269	1 280
Blue whiting (= Poutassou) (*Micromesistius poutassou*)	108	379	631	1 161	1 414	1 190
Atlantic mackerel (*Scomber scombrus*)	950	915	987	1 424	1 248	1 138
Sardinellas nei (*Sardinella* spp.)	967	1 017	932	1 020	1 043	1 089
Scads nei (*Decapterus*)	1 232	1 267	1 230	1 261	984	998

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

production. However, we see again that species items not elsewhere included contribute the majority of this production, reflecting the limited level of detail available on the species that contribute to inland fisheries.

1.6.5 Aquatic genetic resources below the level of species

Current information systems on AqGR, *inter alia* the Aquatic Sciences and Fisheries Information System (ASFIS) species list, FishStatJ and FishBase (Busilacchi and Garibaldi, 2002; FAO, 2018b; Froese and Pauly, 2018) focus on the collection and provision of information at the level of species. There are few resources that focus on information below the level of species. Numerous research studies exist that examine the levels of genetic variation in aquatic species (cultured and/or wild relatives) or report on the development of farmed types, through methods such as selective

TABLE 18
Main species or species items harvested from inland capture fisheries and their production, 2016 (live weight)

Species or species items	Production (tonnes)	Percentage of total global inland harvest
Freshwater fishes nei	6 193 313	53.2
Cyprinids nei	774 893	6.7
Tilapias nei	436 998	3.8
Freshwater molluscs nei	326 154	2.8
Silver cyprinid (*Rastrineobola argentea*)	273 764	2.4
Nile tilapia (*Oreochromis niloticus*)	232 129	2.0
Nile perch (*Lates niloticus*)	217 444	1.9
Snakeheads (= murrels) nei	161 430	1.4
Hilsa shad (*Tenualosa ilisha*)	145 606	1.3
Oriental river prawn (*Macrobrachium nipponense*)	132 422	1.1
Siberian prawn (*Exopalaemon modestus*)	132 422	1.1
Freshwater siluroids nei	119 879	1.0
Common carp (*Cyprinus carpio*)	115 412	1.0
Lake Malawi sardine (*Engraulicypris sardella*)	109 387	0.9
Torpedo-shaped catfishes nei	101 442	0.9

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

breeding, hybridization, ploidy manipulation, sex control and the use of other biotechnologies (see reviews by Carvalho and Pitcher, 1995; Dunham, 2011; Gjedrem, Robinson and Rye, 2012; Casey, Jardim and Martinsohn, 2016, among others). There are, however, no systematic catalogues of these research findings or of farmed types. Such catalogues do exist for both plant and animal (livestock) genetic resources, for example, in the databases of accessions in various plant gene banks (FAO, 2010, 2015b) and the Domestic Animal Diversity Information System (DAD-IS).[17]

It is considered that most cultured AqGR retain high levels of genetic variation relative to their wild relatives due to the inherently high levels of variation present in large populations (Lacy, 1987) of aquatic species, many of which are highly fecund, and the relatively short history of domestication and improvement for most aquatic species. This contrasts with the situation in livestock, where many breeds are considered to have significantly reduced genetic variation relative to their wild ancestors due to their long history of domestication, allowing for significant genetic drift and associated loss of genetic variation (FAO, 2007; Kristensen *et al*., 2015). These levels of genetic variation have been shown to decline with increasing distance from the established original centres of domestication (Groeneveld *et al*., 2010). In cultured aquatic species, the presence of higher levels of genetic variation, specifically additive genetic variation, is cited as one of the reasons why responses to selection in breeding programmes for aquatic species are commonly much greater than those observed in livestock (Gjedrem, 2012; Gjedrem and Baranksi, 2010).

[17] The latest version of this database can be accessed at www.fao.org/dad-is.

1.7 The outlook for fisheries and aquaculture and the role of aquatic genetic resources

The current world population of more than 7.6 billion is projected to reach 8.5 billion by 2030 and 9.8 billion in 2050, with most of the increase occurring in developing regions (United Nations, 2017). Ensuring food security and adequate nutrition for this growing population is a major challenge. Fish is a vital source of food, including micronutrients, particularly for many low-income rural populations. The fisheries and aquaculture sector already plays a prominent role in global food security and providing livelihoods and income to millions of people engaged in fish harvesting, culturing, processing and trade. Given population growth trends, the sector needs to continue to play a prominent role in world food security, which will necessitate growth in production to meet the expected increase in new and traditional demand for fish and fishery products.

Production from capture fisheries has stabilized at 90 to 95 million tonnes per annum since the mid-1990s (Figure 5) and is not predicted to rise significantly in the foreseeable future (OECD/FAO, 2018). Growth in aquaculture has met the increasing demand for fish and fishery products (Table 4 and Figure 4). Latest projections (FAO, 2018b) of the short-term future of aquaculture and fisheries markets estimate that total world fish production[18] will continue to expand to reach 201 million tonnes in 2030, an increase of 18 percent compared to 2016 production, at an annual growth rate of 1 percent (Table 19). This growth in production is expected to be delivered almost entirely by aquaculture (World Bank, 2013; FAO, 2014, 2016a), with cultured food fish production projected to reach 109 million tonnes by 2030, 37 percent higher than 2016 levels (FAO, 2018b). While this represents substantial growth, it does reflect a slowing annual rate of growth: 2.1 percent, compared to 5.8 percent for the period 2001–2016. While aquaculture is projected to expand on all continents, growth is expected to arise predominantly from Asia, which will continue to dominate global production, representing 89 percent of total production by 2030. Freshwater aquaculture is likely to continue to be the most dominant sector at 62 percent of production by 2030. The World Bank (2013), applying a different model, produced similar projections to those from FAO.

By 2030, fish consumption across all regions is projected to grow a further 20 percent compared to 2016 levels, but with a slowing rate of growth

[18] Excludes seaweeds and other aquatic plants, aquatic mammals and reptiles.

TABLE 19

Current and future projections of key production and consumption parameters on global fish production, consumption and trade

Parameter	2016 level	2030 projection	Projected growth rate (percent)
Global fish production (million tonnes)	171	201	18
Global aquaculture production (million tonnes)	80	109	37
Global capture fisheries production (million tonnes)	91	91	<1
Percent contribution of aquaculture (million tonnes)	47	54	15
Global fish consumption (million tonnes)	151	181	20
Per capita fish consumption (kg per capita per annum)	20.3	21.5	6
Trade – exports (million tonnes)	39	48	24

Source: FAO, 2018b.

(1.2 percent annually compared to 3 percent from 2003 to 2016); Asian countries will be the main consumers (representing 71 percent of global consumption by 2030). Per capita annual fish consumption is expected to increase slightly from 20.3 kg in 2016 to 21.5 kg in 2030. In line with the increases in production and consumption, trade in fish and fish products is also projected to increase by 24 percent by 2030, with 38 percent of all production being exported.

None of these projections provide any significant detail on the likely growth of specific aquaculture systems, such as offshore cage farming, recirculating system aquaculture, pond farming, integrated aquaculture or multi-trophic aquaculture, or for the future applications of technology. While some systems have greater potential for growth than others, projecting which systems will be major drivers of growth is extremely complex. Similarly, it is difficult to project the likely changes to the role of AqGR in meeting increased production demands. Projections by the World Bank (2013) anticipated the strongest growth in production of tilapia, carp and pangasius/catfish, with these lower-value species showing more rapid growth in production than higher-value species such as salmon and shrimp.

It is not clear whether the drivers that will impact on the future status of AqGR are well understood. Will the species that currently dominate fishery and aquaculture production continue to dominate or even consolidate further with fewer species representing larger proportions of production? Or will diversification result in greater production of more species, to supply not only major commodity markets, but also niche markets?

While there is a paucity of information on the use of AqGR in aquaculture and fisheries, particularly when we consider the resources below the level of species, we know that genetic improvement currently plays a relatively minor role in production growth in aquaculture. Gjedrem and Robinson (2014) estimate that less than 10 percent of aquaculture production is of improved strains resulting from family-based selective breeding programmes, and yet the potential for sustainable increase in aquaculture production from widespread application of selective breeding is well established. In an update of their modelling, Robinson and Gjedrem (personal communication, 2018) project that if 100 percent of aquaculture production was subject to selective breeding, genetic improvement alone would deliver an increase in production of 46 million tonnes by 2030. Currently, there are very few clearly defined strains with established properties used in aquaculture, in contrast to the vast number of animal breeds and plant varieties used in terrestrial agriculture. Will the development of AqGR follow a similar path to breed development in livestock? Or are AqGR subject to different drivers? Genetic technologies based on molecular analysis and manipulation are also advancing at a rapid rate with falling costs and higher levels of resolution. It seems probable that these new generation technologies can add value to traditional technologies and may in the longer term be disruptive technologies that may change the way we characterize and develop AqGR.

Also, unlike in terrestrial agriculture, production of fish and fish products is currently highly dependent on wild AqGR through capture fisheries and capture-based aquaculture. Will this dependency decline in the near or long-term future? What will be the long-term impact of anthropogenic activities on wild genetic resources and what role can and will *ex situ* and *in situ* conservation play in preserving both wild and domesticated AqGR? We can be sure that AqGR will play a major role in the future production of fish and fish products and must therefore be subject to improved conservation, sustainable use and development; however, to best deliver this improvement, who will play the key roles in this process, what changes do we need in governance and what are the capacity-building requirements?

While the Report cannot provide answers to all of these questions, it represents a first attempt to gain a comprehensive understanding of the current global status of AqGR and provides a snapshot of this status on which future actions to support the conservation, sustainable use and development of AqGR can be predicated.

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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 review issues around the use of aquatic genetic resources (AqGR), primarily in aquaculture, and the application of genetic technologies to AqGR. This chapter includes analysis of data provided in Country Reports in response to questions 1–14 in the questionnaire.[19] These questions include key elements of the Country Reports in which countries provided inventories of AqGR for food and agriculture that are used in aquaculture and their wild relatives.

KEY MESSAGES:

- The country reporting process provided some new information, including on farmed types (AqGR below the level of species) not captured in regular reporting of production. This highlights the need for improved information systems for AqGR.
- There is a lack of standardization of nomenclature and terminology for AqGR making description and comparisons across AqGR difficult.
- Countries reported farming of nearly 700 species or species items, with Asia farming the most species and major aquaculture producing countries farming a greater diversity of species. The two most commonly reported species being farmed globally were common carp (*Cyprinus carpio*) and Nile tilapia (*Oreochromis niloticus*).
- Introduced or non-native species are very important in aquaculture, with over a third of farmed species or species items being farmed where they are non-native.
- Aquaculture production is reported as increasing in most countries and this is expected to continue for most species.
- Country Reports suggest potential gaps in the current FAO aquaculture data collection systems, with production statistics on many species potentially missing.
- Just over 40 percent of species reported by countries were farmed as wild types, with the remainder being subjected to some form of genetic change (e.g. selective breeding, hybridization, polyploidization). Selective breeding was the technology most often used to improve traits in aquatic species.
- Forty-five percent of countries reported that genetic improvement did not contribute to aquaculture production to any significant extent.
- 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 financing of genetic improvement programmes was more prevalent in the major 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 reporting countries.
- Wild relatives play a significant role in fisheries and aquaculture, with management plans existing for most of those that are fished. However, the abundance of many wild relatives is declining, due mainly to habitat loss and degradation and to pollution.
- Genetic data may exist for wild relatives, but these data are often not used in management.
- Over one-third of farmed aquatic species or species items were reported to have been exchanged (import and export), with Nile tilapia (*O. niloticus*) and North African catfish (*Clarias gariepinus*) the most exchanged species globally. There are many benefits arising from exchange of germplasm, but there are risks around biosecurity (disease and genetic) and appropriate access and benefit-sharing arrangements are often lacking.

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

2.1 Introduction

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 finfish, shellfish and aquatic plants from wetlands and coastal areas in Africa. This practice continued as humans migrated out of Africa. Artifacts found in middens around the world provide evidence of prehistoric fishing occuring during early human occupation (Sahrhage and Lundbeck, 1992).

Early evidence of fish farming has been found from over two thousand years ago in China, as well as from 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).

Aquatic biodiversity is used extensively in fisheries and aquaculture (see Chapter 1 and Bartley and Halwart, 2017); most information on this biodiversity, in terms of production and number of farmed organisms and their wild relatives, is recorded at the level of species. Little information is available on the broader genetic diversity of farmed organisms and their wild relatives. The submission of Country Reports, in response to the questionnaire given to National Focal Points, provided a unique opportunity to enhance our knowledge of the current status of farmed AqGR and their wild relatives.

2.2 Information on aquatic genetic resources in 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. 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[20] 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.

As of 2017, the ASFIS list contained over 12 700 species or species items.[21] The nomenclature included only 12 species items below the level of species (i.e. "farmed types"), with these being limited to a few commercially produced hybrids. The list did not include any other farmed types, such as stocks, strains or varieties of farmed species or their wild relatives. It will only be possible to include more farmed types within ASFIS if and when FAO member countries report production data of clearly identified and properly described types.

Information about AqGR below the level of species can be extremely useful to resource managers, policy-makers, private industry and the general public. Genetic diversity is the basis for selective breeding programmes and other genetic improvement technologies in aquaculture. It also allows for natural populations to evolve and to adapt to changing environments. 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,

[20] www.fao.org/fishery/collection/asfis/en

[21] The ASFIS list and the Country Reports contain entries that are not single species, either representing groups of species, (e.g. *Oreochromis* spp.), higher-level taxa such as Cichlidae, or farmed types that are not pure species (e.g. hybrids). Therefore, in the analyses presented here and in FAO databases, "species" also includes "species items".

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 the genetic diversity of farmed aquatic species and their wild relatives to report below the level of species, for example on stocks and strains.[22]

The Commission on Genetic Resources for Food and Agriculture (CGRFA) recognizes that substantial production from aquaculture and capture fisheries is in fact based on groups below the level of species and that genetic information has a variety of applications in both aquaculture and fishery management. It therefore requested FAO to undertake a thematic study to explore means of incorporating genetic diversity and indicators into statistics and monitoring of AqGR of farmed aquatic species and their wild relatives. FAO hosted an expert workshop on this issue (FAO, 2016), and the outputs of this workshop formed the basis for the thematic background study.[23] Some of the key findings from this study are summarized in Box 7 including a proposed format for an information system on AqGR.

Given the complexity and resources required to develop an information system for AqGR, incentives would need to be developed to motivate governments, resource managers and private industry to participate and contribute to the information system. Such incentives could include:

- access to funds aimed at helping countries meet international commitments, (e.g. from mechanisms of the Convention on Biological Diversity or the Global Environment Facility);
- access to markets for private industry through improved traceability and certification schemes; and
- opportunities for international and national organizations to become centres of excellence for information on AqGR.

To address the 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. Monitoring would require an information system into which data can be entered repeatedly over time. The cost of inputs to and maintenance of the information system would be lower with less frequent input.

The Country Reports that were provided as a basis for the Report contain much information that could be used as baseline data for incorporation into a database that would allow some monitoring of the status and trends of AqGR. Rapid advances in genetic technologies and a growing need for sustainable aquaculture production suggest that AqGR should be monitored at relatively frequent intervals to provide current information on changes, 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.

[22] The National Focal Points for AqGR have helped provide information below the level of species specifically for this report and are gratefully acknowledged.

[23] This section draws significantly on content from the thematic background study on *Incorporating genetic diversity and indicators into statistics and monitoring of farmed aquatic species and their wild relatives* (also available at www.fao.org/3/a-bt492e.pdf).

Box 7

The challenge of incorporating genetic diversity and its indicators into national statistics and monitoring 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 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 level of species for aquatic genetic resources, 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, 2016).

Nonetheless, an expert workshop proposed the development of an information system to complement FAO’s current work on fishery and aquaculture statistics (FAO, 2016). The table below identifies the types of information that could be recorded in such an information system for farmed types and 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	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 characteristics
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

A global information system on AqGR does not yet exist, and where such systems exist at national levels they are not comprehensive and only include information on the species that dominate production. Therefore, a new information system with input from countries needs to be established. This will require human and financial resources as well as significant capacity building in many areas.

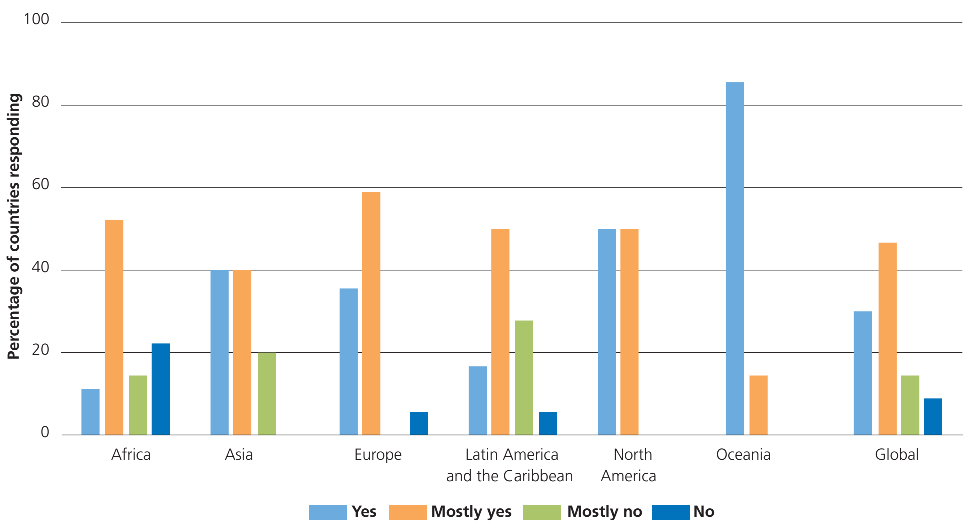
2.3 The use of aquatic genetic resources in food production

This section is based primarily on the data collected from the Country Reports, using data summarized from Chapter 1 of the questionnaire. This section of the questionnaire included 14 questions focused on identifying current and future trends in production, the availability of information and data on AqGR, the prevalence of wild caught AqGR in aquaculture and the impact of genetic improvement. It also included core questions that required countries to inventory the AqGR currently and potentially used in aquaculture in their countries, the exchanges of these AqGR and the status of their wild relatives.

2.3.1 Availability of information on aquatic genetic resources in aquaculture

Countries reported that the naming of species was generally accurate, up to date and in line with the ASFIS species list. This finding was relatively consistent across regions (Figure 12) and when countries were grouped by economic status (Figure 13) and by level of aquaculture production (data not shown). However, countries reported that there are still inconsistencies in nomenclature below the level of species.

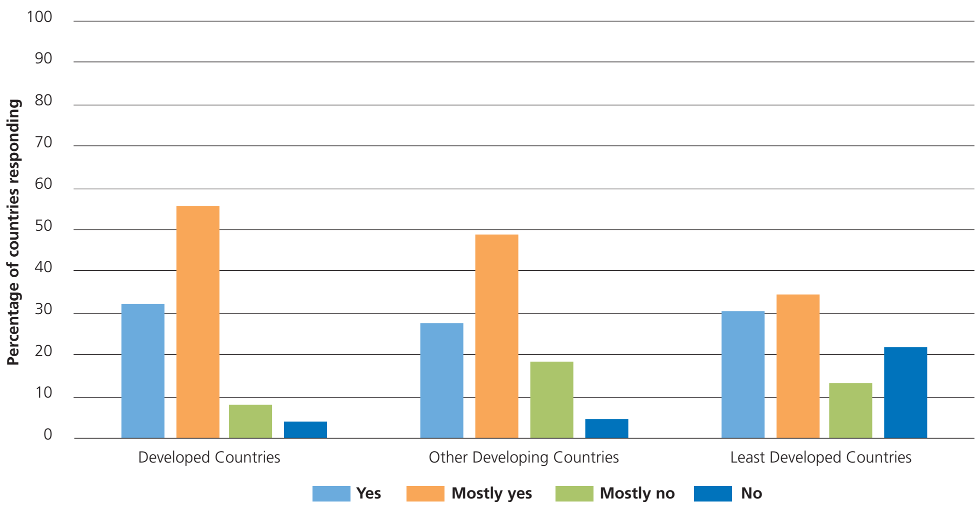
FIGURE 12
Country responses indicating if their naming of aquatic species and farmed types is accurate and up to date, by region



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q3 (n = 91).

FIGURE 13

Country responses indicating if their naming of aquatic species and farmed types is accurate and up to date, by economic class



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q3 (n = 91).

2.3.2 The diversity of farmed species used in aquaculture

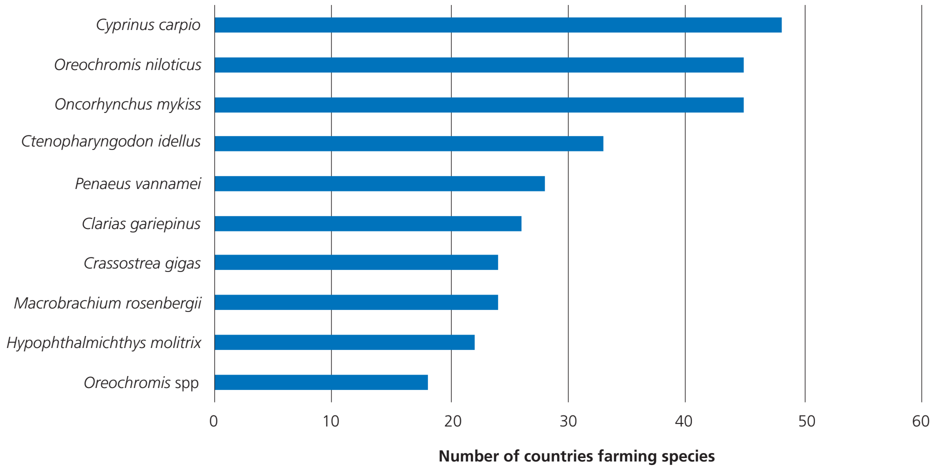
The current list of farmed aquatic species reported to FAO contains over 550 species or species items from inland, marine and coastal waters (Table 12). Farmed aquatic species are taxonomically diverse and come from multiple phyla (Table 14). It is known from production data that aquatic species are farmed throughout the world, with approximately 130 countries traditionally reporting to FAO through the annual submission of statistics by FAO member countries (FAO, 2018a).

Information from the Country Reports regarding their inventories of species or species items farmed, which is a separate process from the regular reporting of fish production statistics to FAO, revealed that, of the ten most commonly farmed species or species items (Figure 14), eight are from freshwater habitats with one crustacean and one mollusc from the marine environment.

The two species most commonly reported as being farmed were common carp (*Cyprinus carpio*) and Nile tilapia (*Oreochromis niloticus*). Both of these species have contributed significantly to global aquaculture production (Table 16) and have been widely introduced around the world. In fact, many of the commonly farmed species are not native to most of the countries that farm them (Table 20).

Countries reported the farming of 694 species or species items, 140 more than indicated in recent reporting of production data to FAO. The actual number of new species or species items reported across the Country Reports was 207, given that not all species or species items recorded in FAO's FishStatJ database are reported as farmed by the 92 reporting countries and also that 44 countries reported fewer species or species items in their Country Reports than are included in their national aquaculture reporting captured in FishStatJ (Table 21).

FIGURE 14
Top ten aquatic species or species items by number of Country Reports in which they are reported as farmed



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q9 (n = 92).

TABLE 20
The ten species or species items most commonly reported to be farmed and the number of reporting countries where they are native or introduced

Species	Native	Introduced
Common carp (*Cyprinus carpio*)	11	37
Nile tilapia (*Oreochromis niloticus*)	12	33
Rainbow trout (*Oncorhynchus mykiss*)	5	40
Grass carp (*Ctenopharyngodon idellus*)	3	30
North African catfish (*Clarias gariepinus*)	14	12
Whiteleg shrimp (*Penaeus vannamei*)	9	19
Silver carp (*Hypophthalmichthys molitrix*)	3	19
Pacific oyster (*Crassostrea gigas*)	4	20
Giant freshwater prawn (*Macrobrachium rosenbergii*)	11	13
Oreochromis (= tilapia) spp.*	3	15

**Oreochromis* spp. would probably also contain *O. niloticus*.
Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture:* responses to Q9 (n = 92).

Asia farms the most species or species items (Figure 15), with North America farming the fewest. By economic classification, "other developing countries" reported farming the most species or species items. 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 or species items than the 79 other countries that reported (Figure 16). Thus, it seems that, whereas there is little correlation between level of economic development and number of species or species items farmed, there are indications of a positive relationship between level of aquaculture production and number of species or species items farmed (Figure 16). It is difficult to attribute a cause and effect relationship, i.e. to determine whether these countries have high aquaculture production because they farm a large diversity of species or whether increasing production promotes diversification. The issues surrounding the drivers influencing diversification of species use in aquaculture are summarized in Box 3 and discussed in detail by Harvey *et al.* (2017).

In the preparation of the Report, FAO invited feedback from international organizations working with AqGR in a development context. Input was received from six organizations, and from this input a list of species prioritized in regional cooperation could be drawn up (see Box 8).

2.3.2.1 Native and introduced species diversity

Introduced species play a significant role in aquaculture production (see also Section 2.6). The Country Reports indicated that, overall, approximately 200 species or species items

Box 8

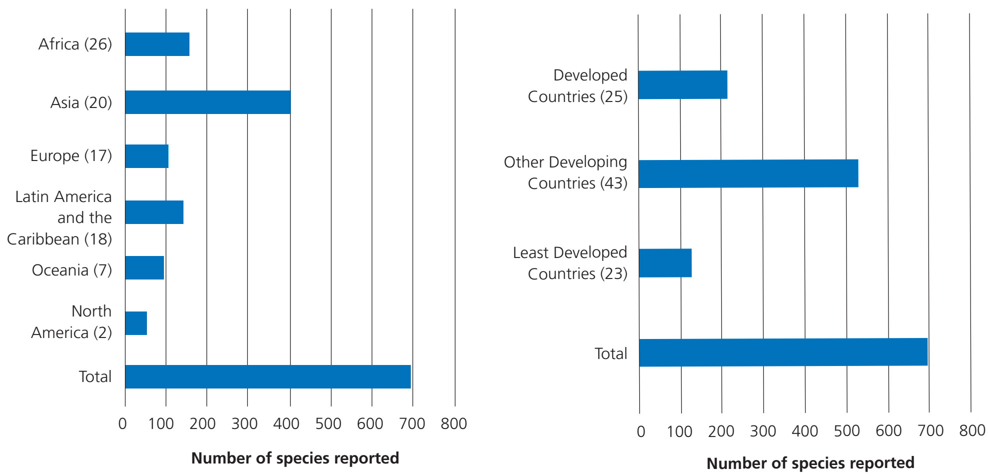
Focal species or species items for international/regional cooperation based on feedback from regional aquaculture organizations

Tilapias	For example, *Oreochromis niloticus, O. aureus, O. shiranus, O. tanganicae, O. andersonii, O. esculentus, O. mossambicus, O. variabilis*, and hybrid farmed types
Catfishes	*Clarias gariepinus, C. macrocephalus*
Cyprinids/carps	*Cyprinus carpio, Labeo rohita, L. victorianus, 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, Haliotis* spp.
Brackish-water/marine finfish	*Lates calcarifer, Chanos chanos, Epinephelus* spp., *Siganus* spp.

Source: Reports submitted by Lake Victoria Fisheries Organization, Mekong River Commission, Network of Aquaculture Centres in Asia-Pacific, the Pacific Community, Southeast Asian Fisheries Development Center and WorldFish.

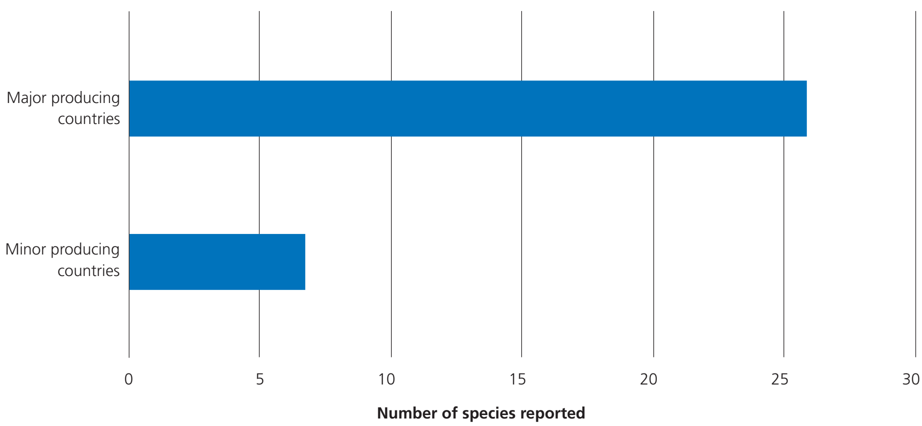
* It is recognized that some groups have assigned some species from the genus *Penaeus* to other genera, e.g. *Litopenaeus*. For consistency with the ASFIS and FishStatJ, the Report maintains the genus *Penaeus* for many of these marine shrimp.

FIGURE 15
Number of species or species items farmed by region (left) and by economic class (right) reported by countries



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q9 (n = 92).
Note: The total is the number of unique species or species items reported; some species are reported in more than one region or economic class. Numbers in parentheses refer to the number of countries in the category.

FIGURE 16
Average number of species or species items farmed per country by level of aquaculture production



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q9 (n = 92).

were reported farmed in countries where they are introduced, i.e. non-native, and almost 600 species or species items were reported farmed where they are native (Figure 17). There were over 1 000 reports by countries of farming native species or species items and over 600 reports of farming introduced species or species items (Figure 17). Although there were more reports of farming native species, nine of the ten most widely reported cultured species were more frequently reported by countries where they are non-native than by countries where they are native.

2.3.2.2 Trends in production of species

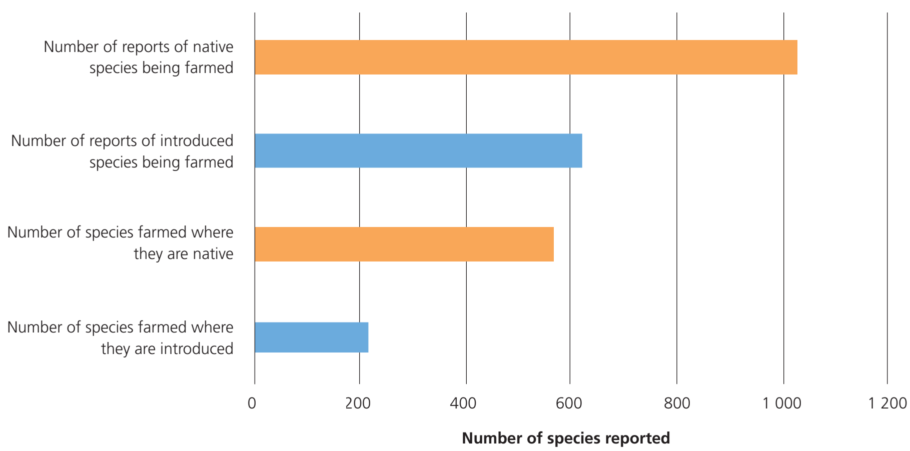
Several questions in the questionnaire recorded trends in production for all species. It is well established that aquaculture production is increasing, a trend that is expected to continue (FAO, 2018b). The Country Reports indicated that production has been and is expected to continue increasing for the vast majority of species included in the inventories (Figure 18).

However, a few countries reported that they have discontinued the farming of certain species or species items (e.g. *Argopecten ventricosus, Cherax quadricarinatus, Rachycentron canadum, Crassostrea gigas, Ctenopharyngodon idellus, Hypophthalmichthys molitrix, H. nobilis, Isochrysis galbana, Metapenaeus affinis,* and *Oreochromis aureus*). It should be noted that cessation of farming of these species was in each case reported by only one country. Furthermore, as no reasons were provided, this cannot be interpreted as being indicative of any trend.

Analysis of production trends for all species, by economic class of countries, indicated that in developing and least developed countries the most common response was that production is increasing. The most common response in developed countries was that production is stable (Figure 19).

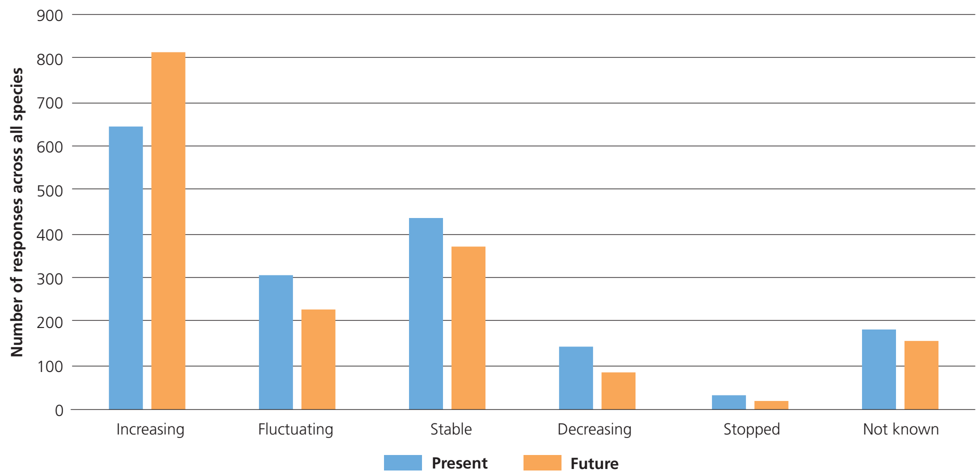
The Country Reports reflect current national reporting (as appears in the FAO FishStatJ database; FAO, 2018a), but also contain additional information not previously reported to FAO

FIGURE 17
Number of native and introduced species reported in aquaculture



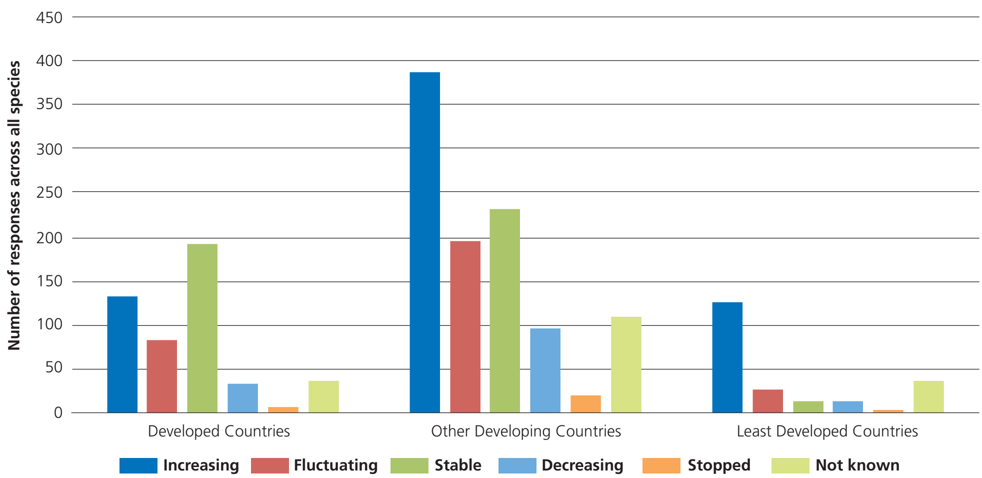
Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q9 (n = 92).

FIGURE 18
Current and predicted future trends in production for all cultured species reported by countries



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q9 (n = 92).

FIGURE 19
Production trends for all species recorded by economic class



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q9 (n = 92).

(Table 21). As mentioned above, numerous countries reported farming more species or species items than they report through the regular FAO statistic survey and mentioned species or species items not currently listed in ASFIS (Table 21, Figure 20 and Figure 21). Figure 20 illustrates that Asia has the highest number of previously unrecorded species or species items followed by Africa, with the two North American countries having the lowest number. Table 22 lists the ten countries showing the highest number of species or species items not included in the ASFIS list.

The largest groups of species or species items not previously reported to FAO were ornamental fish species (29 percent) and microalgae (25 percent). As FishStatJ focuses on species or species items cultured for food, it would not normally list species that are only cultured for the ornamental industry. The previously unreported species nevertheless included a significant proportion of

TABLE 21

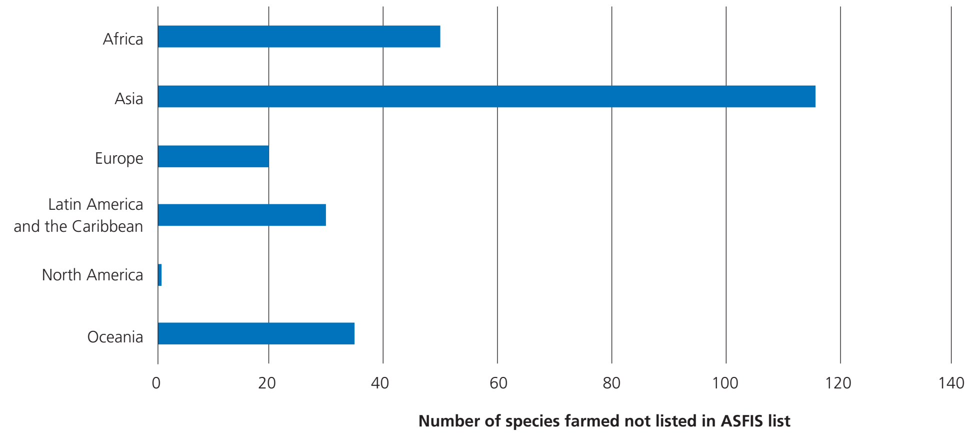
Summary of country reporting on species and farmed types, including a comparison with their regular aquaculture production reporting

Item	Count	Examples	Notes
Number of Country Reports recording more species farmed than recorded in FishStatJ	44		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 farmed than recorded in FishStatJ	44		Based on FishStatJ reports going back to 2000.
Number of reports of cultured species that have never been previously reported to FAO as farmed (i.e. not listed in FishStatJ)	253 records (207 species or species items)	**Finfish** *Clarias jaensis* (Cameroon – catfish); *Clarias magur* (India – catfish) **Molluscs** *Haliotis discus hannai* (China and 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 species or species items reported as significantly genetically improved	532	See Box 9	Any genetic differentiation or intervention recorded for a species in a Country Report. Includes strains/varieties, selected strains, hybrids, crossbreds, monosex and polyploids (based on question 8 focused on significant examples).
Total number of farmed types reported	1 085	See Box 9	Any genetic differentiation or intervention recorded for a species in a Country Report. Includes strains/varieties, selected strains, hybrids, crossbreds monosex and polyploids (based on question 9 – all examples).

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture:* responses to Q8 and Q9 (n = 92).

FIGURE 20

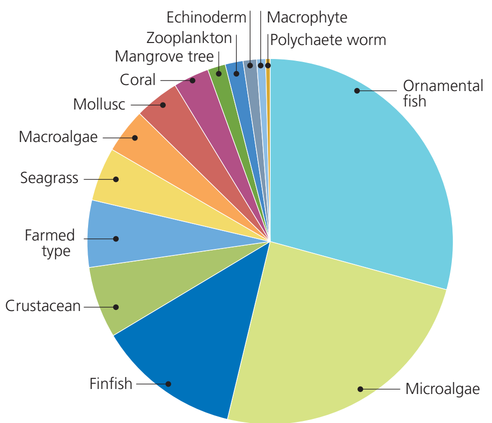
Number of species or species items, based on total number of records in Country Reports, that are not included in the Aquatic Sciences and Fisheries Information System list, by region



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q9 (n = 92) and the ASFIS list (ASFIS List of Species for Fishery Statistics Purposes; February 2018 version: www.fao.org/fishery/collection/asfis/en).

FIGURE 21

Different types of species among the 253 species reported in Country Reports that had not previously been reported as produced (i.e. never previously reported in the FishStatJ database)



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q9 (n = 92).
Note: Finfish represents edible finfish; farmed types are predominately of species which are normally reported to FAO, but where the country reported it as farmed type, and not by species.

edible finfish and crustacean species (12.6 percent and 6.3 percent, respectively).

The species items referred to in the Country Reports 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 farmed types of non-standard nomenclature; or
- be new species being farmed.

The Country Reports clearly demonstrated that more aquatic genetic diversity is being used than has been previously recognized. However, discrepancies between the number of species or species items reported in many Country Reports through the State of the World process and the number reported through the routine submission of statistics for FishStatJ indicate that improved coordination of aquaculture statistics at country level is important.

TABLE 22
The ten countries reporting the most species or species items not included in the Aquatic Sciences and Fisheries Information System list

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

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture:* responses to Q9 (n = 92) and the ASFIS list (ASFIS List of Species for Fishery Statistics Purposes. February 2018 version: http://www.fao.org/fishery/collection/asfis/en).

2.3.2.3 Reported production of farmed types – hybrids

Several countries reported 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 in their annual production reports.

2.3.2.4 Reported production of farmed types – strains

The ASFIS list does not include strains; however, some Country Reports listed numerous named farmed types of species (see Box 9 on strains).

Several of these farmed types would not be designated "strains" by applying the definition in Box 2, for example monosex tilapia, hybrid cold-tolerant tilapia, genetically male tilapia, all-female Atlantic salmon (*Salmo salar*) 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. These are strains derived from crossbreeding or hybridizing tilapia strains/species.

TABLE 23

Hybrids reported in Country Reports, but not in the Aquatic Sciences and Fisheries Information System list

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

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture:* responses to Q9 (n = 92).
Note: The female parent is listed first. Inclusion of a reciprocal cross signifies of the same combination of species with the other species as the female parent.

TABLE 24

Hybrids in the Aquatic Sciences and Fisheries Information System list and indication of whether production data were previously reported to FAO and included in FishStatJ

Family	Scientific name	FAO English name	Production data recorded in FAO database
Channidae	*Channa maculata* × *C. argus*		No
Characidae	*Piaractus mesopotamicus* × *Colossoma macropomum*	Tambacu, hybrid	Yes
Characidae	*Colossoma macropomum* × *Piaractus brachypomus*	Tambatinga, hybrid	Yes
Characidae	*Piaractus mesopotamicus* × *P. brachypomus*	Patinga, hybrid	No
Cichlidae	*Oreochromis aureus* × *O. niloticus*	Blue-Nile tilapia, 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
Moronidae	*Morone chrysops* × *M. saxatilis*	Striped bass, hybrid	Yes
Pimelodidae	*Pseudoplatystoma corruscans* × *P. reticulatum*		No
Pimelodidae	*Leiarius marmoratus* × *Pseudoplatystoma reticulatum*		No

Source: FAO 2018a and the ASFIS list (ASFIS List of Species for Fishery Statistics Purposes. February 2018 version: www.fao.org/fishery/collection/asfis/en).

Box 9
Strains in aquaculture

In terrestrial agriculture, animals and plants have been domesticated into recognizable breeds and varieties (e.g. Angus cattle, Bantu pigs, jasmine rice and iceberg lettuce). *The Second Report on the State of the World's Animal Genetic Resources for Food and Agriculture* states that there are over 8 000 breeds of farmed animals (mammals and birds) (FAO, 2015).

For plant genetic resources, there are over 7 million accessions of terrestrial crop or crop related species with 25 to 30 percent of these being distinct (FAO, 2010). According to FAO (1997):

> *Estimates of the number of varieties of the rice species,* Oryza *spp., range from tens of thousands to more than 100 000 (although some of these may not be distinct). 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 and no consistent criteria for identifying and naming a strain. 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 (see Box 2). That is, if a mirror carp breeds with a mirror carp, the offspring will be more mirror carp. Therefore, monosex populations, hybrids and triploids should not be considered strains, even if they are distinct, because they cannot be bred to yield the same strain.

The State of the World reports on plant (FAO, 2010) and animal genetic resources (FAO, 2015) rely on standardized and recognized descriptions 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 that would 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 towards more accurate information on and increased production from aquatic genetic resources (see Section 2.2).

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*).

Some Country Reports listed subspecies as being farmed or as wild relatives. Some taxonomists have recommended abolishing the use of the term subspecies due to its inconsistent application and usage (N. Baily, FishBase coordinator, personal communication, 2016).

2.3.2.5 *Species of potential importance for aquaculture*

In response to a question on species thought to have potential for domestication and future use in aquaculture, several such species were identified by countries. Some of these are wild relatives of species that are farmed in other countries, but are not yet farmed in the specific reporting country; other species are currently being developed in research stations or by private industry in pilot programmes.

The species most commonly reported as a candidate for future domestication and use in aquaculture was the flathead grey mullet (*Mugil cephalus*). The ten species most often reported as candidate species 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 a genus of interest without listing specific species. For example, *Epinephelus* spp. was reported as having future potential by 14 countries, *Lutjanus* spp. was mentioned by seven countries, *Macrobrachium* spp. in six countries, and *Centropomus* spp. in five countries.

Pullin (2017) 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, these models had limitations in predicting which species should be used in aquaculture. Pullin proposed other criteria for use in identifying 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, applying the proposed criteria, Pullin identified a species of river mullet as having potential, although this was not one of the species identified in the Country Report.

2.4 Genetic technologies applied for the characterization and use of farmed aquatic genetic resources

There is perhaps a greater range of genetic technologies that can be applied to AqGR than is generally possible for terrestrial genetic diversity. Traditional approaches of selection, hybridization and crossbreeding are applied, but there are also means of readily manipulating ploidy and sex. Notably, the first transgenic animals produced for commercial food production were fish.

Genetic technologies 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 AqGR (Table 25). Ethical, regulatory and legislative considerations regarding some of these technologies are presented in the thematic background study *Genome-based biotechnologies in aquaculture.*[24]

Some technologies can be used for immediate short-term gain, whereas others are for longer-term gain, with genetic improvements accumulating each generation (Table 25). Although new gene-editing techniques are emerging (Wargelius *et al*., 2016) that can be applied to 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.

2.4.1 Generation and use of 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, 2016) as an inclusive term to include the diversity of genetically altered and wild type organisms available for aquaculture. Many aquatic farmed types are similar to the wild type, i.e. while being domesticated or in the process of being domesticated, they have undergone relatively little genetic change compared to their wild relatives. It has been stated that less than 10 percent of reported aquaculture production

[24] This section on genetic technologies draws significantly on the thematic background study by Zhanjiang Liu in 2017: *Genome-based biotechnologies in aquaculture* (also available at www.fao.org/3/a-bt490e.pdf).

TABLE 25

Genetic technologies that can be applied for improving performance in key traits of farmed types over long and short terms and indicative responses in some farmed aquatic species

Long-term objectives using selective breeding	
Growth rate	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; 113 percent improvement after five generations 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 conformation	High heritability in common carp *(Cyprinus carpio*), catfish (*Ictalurus punctatus*) and trout (*Oncorhynchus mykiss*) (Tave, 1995; Colihueque and Araneda, 2014).
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). Reviewed by Robinson, Gjedrem and Quillet (2017).
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 10)	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 – see Box 10)	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).
	Improved growth and conversion efficiency in triploid rainbow trout (*Oncorhynchus mykisss*) 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*) shows initial growth twice as fast as selectively bred fish (Tibbetts *et al.*, 2013).

Box 10
Terminology usage for hybridization and crossbreeding

Hybridization is a term that can often generate confusion. This box attempts to introduce a degree of standardization of terminology. The terms hybrid and crossbred are often used synonymously, but are most usefully defined and distinguished as referring to interspecific and intraspecific crosses, respectively. A first-generation cross between two species (hybrid) or two strains of the same species (crossbred) 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.

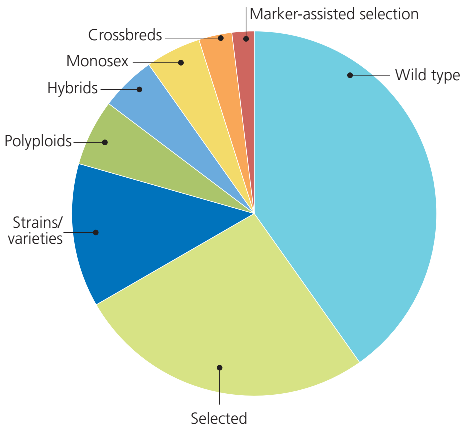
is based on genetically improved strains resulting from family-based selective breeding programmes (Gjedrem and Robinson, 2014). This statement has been misinterpreted in some forums to mean that 90 percent of aquaculture is of unimproved wild types.

The Country Reports provided information on the farmed types for each species reported in the inventory. These responses indicate that, in fact, genetic resources are being managed at some level in about 60 percent of the responses relating to species, the remaining 40 percent of species reported are cultured as wild types (Figure 22). These data are not directly comparable with the report of Gjedrem *et al.* (2012), as the former deals with the proportion of cultured species while the latter is a proportion of production resulting from family-based selective breeding programmes. Nevertheless, this finding from the Country Reports would appear to indicate that for a substantial proportion of aquaculture species farmed types that are genetically improved or managed in some way are being utilized and thus, by inference, that a substantial proportion of aquaculture production comes from such farmed types. This proportion may be higher than previously thought, but 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 or of the gains generated by the genetic programmes.

Selective breeding is a traditional genetic technology that has the longest history of use in aquaculture and is the most common form of genetic technology application reported by countries (Figure 22). 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 (Gjedrem and Robinson, 2014).

Selective breeding has proved 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 from selective breeding in Atlantic salmon (*Salmo salar*) 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 those for plants and livestock

FIGURE 22
Usage of different farmed types for all species used in aquaculture as reported by countries



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q9 (n = 92).
Note: Species can be listed within a country under more than one farmed type with all farmed types recorded for each species.

are their relatively high fecundity, allowing much higher selection intensities; higher standard deviations and high levels of genetic variation for many commercially important traits (Gjedrem and Baranski, 2010; Gjedrem, 2012). Despite the established benefits and attractive returns on investment from selective breeding, Gjedrem (2012) laments the very low rates of adoption of the use of genetically improved strains (i.e. selectively bred) in aquaculture. He estimates that in 1997 only 1 percent of production was based on improved strains, with this estimate increasing to 5 percent by 2002 and 8.2 percent by 2010. Gjedrem speculates that the reasons for the relatively slow rate of adoption of selective breeding for aquatic species include the low priority on education and training on selective breeding in most countries, inadequate documentation and communication of the impressive responses to selection in aquaculture and the belief that advanced biotechnological approaches will deliver similar gains in the short term and negate the need for long-term breeding programmes. However, many of these biotechnological approaches, such as genomic selection, will require the pedigree structure and phenotypic data coming from well-designed selective breeding programmes in order to be effectively applied and can thus be most efficient in enhancing and adding value to selective breeding. Gjedrem (2012) opines that "conventional selective breeding programs should remain the basis for genetic improvement in the future, and that hopefully such new technologies can be efficiently incorporated into these programs in order to further increase genetic gains". Misztal (2007) expounded upon the challenge arising from the shortage of quantitative geneticists in animal breeding; there is little doubt the same challenge applies in the development of selective breeding of aquatic species. As this phenomenon may be further exacerbated by the attraction of the rapidly developing research fields of molecular biotechnologies, there may be a need to specifically focus on the building of human-resource capacity in quantitative genetics to support the greater adoption of well-designed selective breeding programmes in aquaculture.

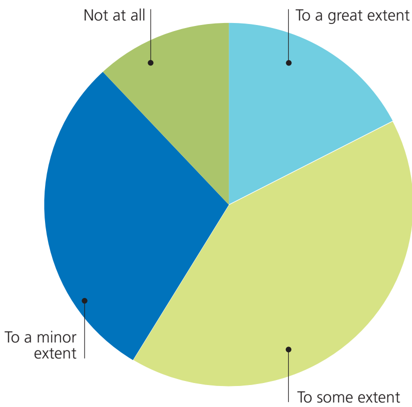
In addition to farming wild types that may not be domesticated, many aquaculture or hatchery facilities depend on organisms from the wild for a supply of seed, juveniles and broodstock.[25] In response to a separate question on the extent of use of wild caught broodstock or seed, overall, 89 percent of countries reported that aquaculture depended on aquatic organisms collected from the wild "to some extent" (Figure 23).

Analysis by region confirmed the importance of using AqGR derived from the wild in all regions (Figure 24). Analysis by economic class and level of production of countries did not reveal important differences in the extent to which AqGR were derived from the wild (data not shown).

[25] According to Bilio (2008), three generations of mating under farm or hatchery conditions are required for an organism to be considered "domesticated".

FIGURE 23

Extent to which countries reported that farmed aquatic organisms were derived from wild seed or wild broodstock



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q5 (n = 92).

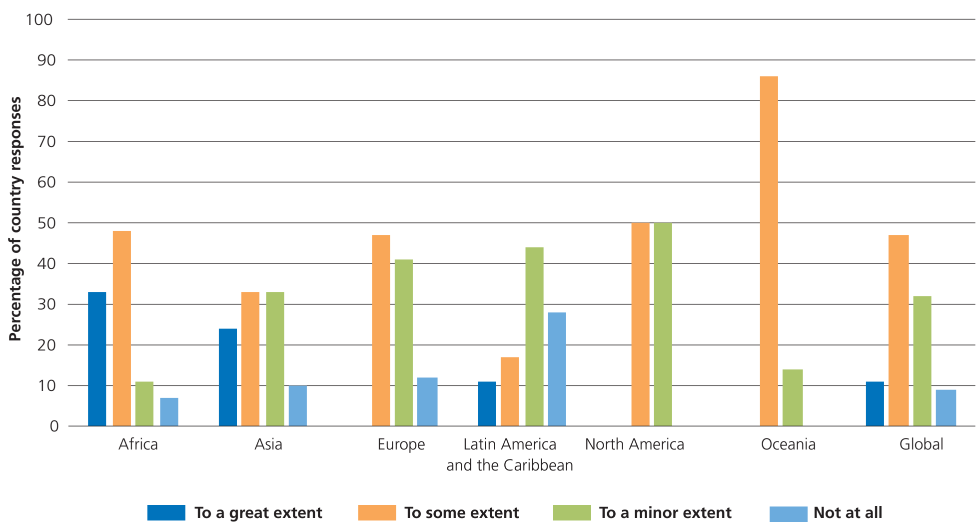
2.4.2 Extent of the use of genetics in aquaculture

Genetic improvements in traits by selective breeding produce genetic gains of about 10 percent per generation (Gjedrem, Robinson and Rye, 2012). Aquaculture geneticists have stated that if all farmed aquatic species were in traditional selective breeding programmes, improvements in aquaculture production efficiency could produce a doubling in aquaculture production by 2050, thus meeting the projected increase in demand for fish and fish products with a low proportional requirement for additional land, water, feed or other inputs (Gjedrem, 1997; Gjedrem, Robinson and Rye, 2012).

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

FIGURE 24

Extent to which farmed aquatic organisms are reported by countries to be derived from wild seed or wild broodstock, by region

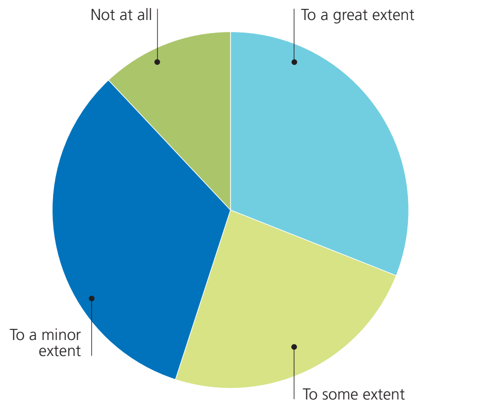


Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q5 (n = 92).

In response to questions on the impact of genetic improvement on production, 45 percent of countries responded that genetically improved aquatic organisms did not contribute to national aquaculture production or only did so to a minor extent (Figure 25). Analyses by region and level of economic development revealed the same general result, although high-level impact was relatively lower in developed and least developed countries. Analysis by level of aquaculture production revealed that genetically improved organisms contributed to production more in the major producing countries (Figure 26, Figure 27 and Figure 28). Overall, this illustrates that genetic resource management is occurring at some level in most countries, but that this is not impacting significantly on overall production in many countries.

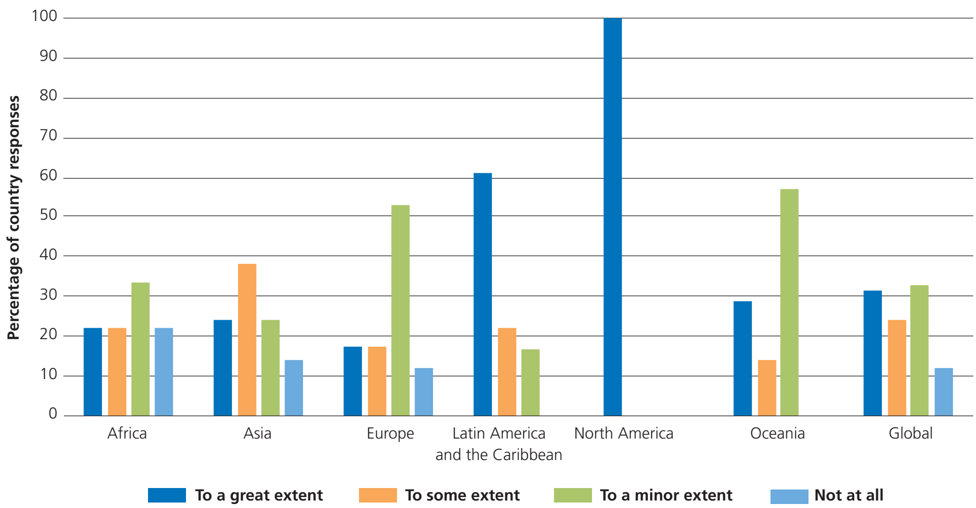
Genetic data are technically demanding and costly to collect and therefore may not often be available or used in management of farmed aquatic

FIGURE 25
Summary of information from Country Reports on the extent to which genetically improved aquatic organisms contribute to national aquaculture production



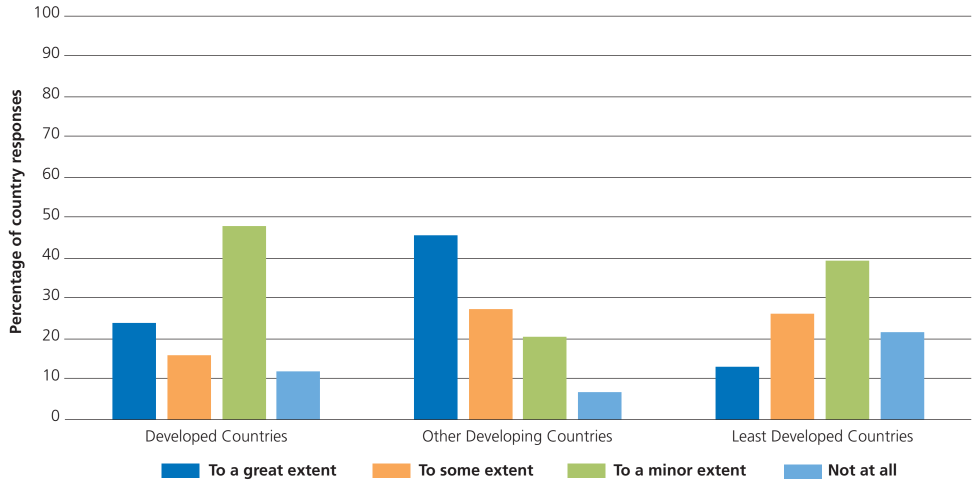
Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q7 (n = 92).

FIGURE 26
Extent to which genetically improved aquatic organisms are reported by countries to contribute to national aquaculture production, by region



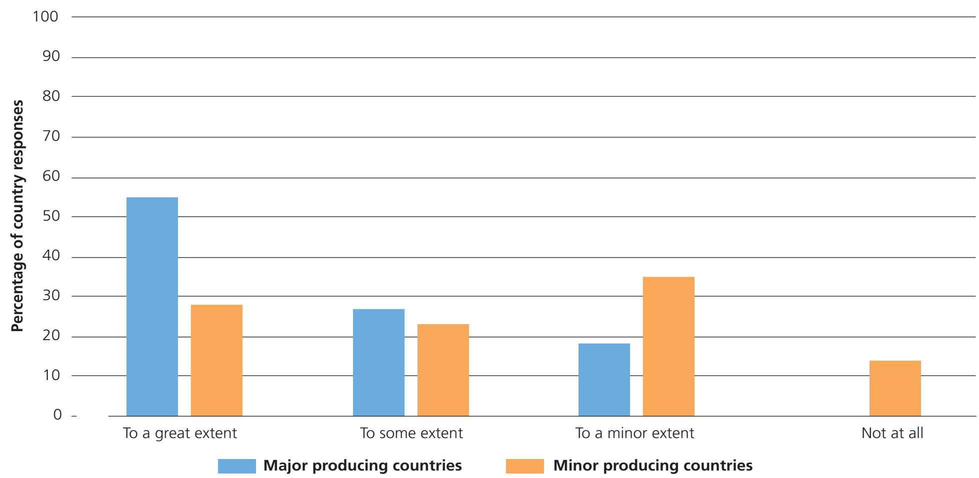
Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q7 (n = 92).

FIGURE 27
Extent to which genetically improved aquatic organisms are reported by countries to contribute to national aquaculture production, by economic class



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q7 (n = 92).

FIGURE 28
Extent to which genetically improved aquatic organisms are reported by countries to contribute to national aquaculture production, by level of aquaculture production



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q7 (n = 92).

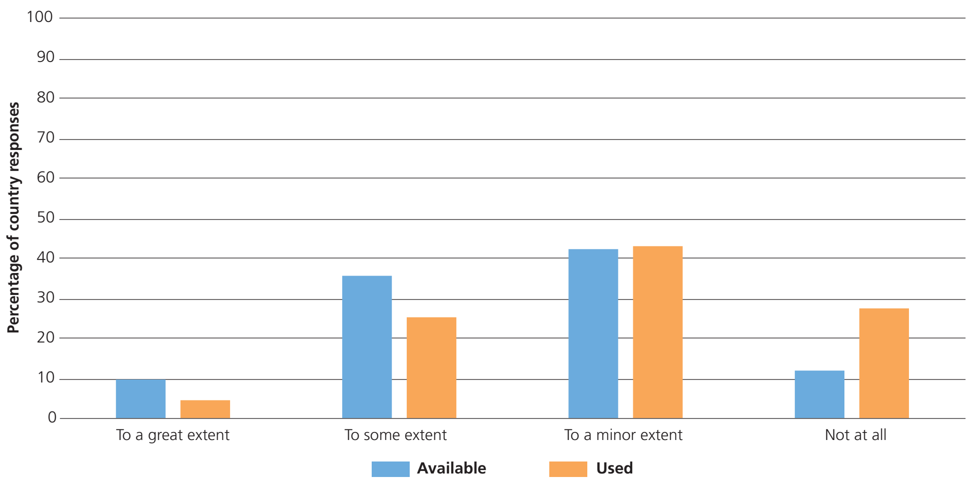
species. However, in response to a question on the availability of genetic data, countries reported that, in general, genetic data were available and used in aquaculture (Figure 29). Analysis of the "use" of genetic information revealed that only a few countries, in Asia and Latin America and the Caribbean, used genetic information to a great extent (Figure 30). Major producing countries reported using such information more than minor producing countries (Figure 31), and least developed countries reported using it to a lesser degree than other countries (Figure 32).

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 WorldFish) developed the Genetically Improved Farmed Tilapia (GIFT), which delivered gains in growth performance of 10–15 percent per generation over multiple generations (Ponzoni *et al*., 2011). The GIFT programme was supported primarily by international development donors through 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 growth rate, carcass quality and other traits in the Norwegian Atlantic salmon breeding programme were due in large part to private–public partnerships that involved a government research group (Akvaforsk, now Nofima) and private companies (Ingrid Olesen, Chair COFI Advisory Working Group on Aquatic Genetic Resources and Technologies and Chair of the ad hoc Intergovernmental Technical Working Group on Aquatic Genetic Resources, personal communication, 2018).

In response to a question on the management of genetic improvement programmes, the Country Reports revealed that the majority of strain improvement programmes in aquaculture utilized selective breeding and that most of

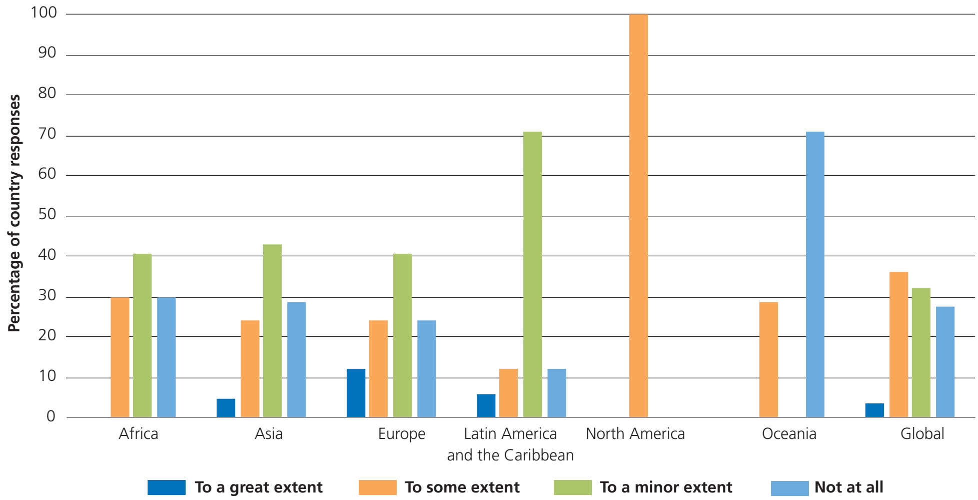
FIGURE 29

Extent of availability and use of information on aquatic genetic resources of farmed types across all reporting countries



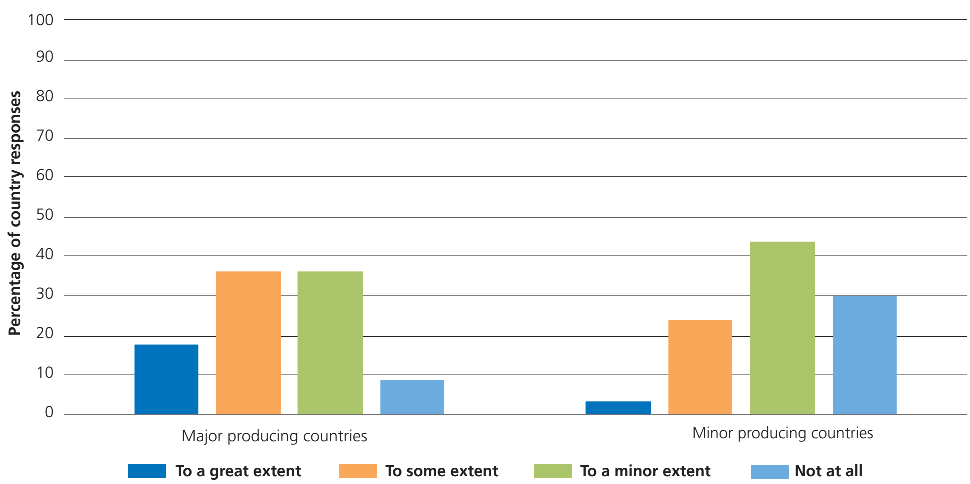
Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q4 (n = 92).

FIGURE 30
Extent of availability and use of information on aquatic genetic resources of farmed types across all reporting countries, by region



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q4 (n = 92).

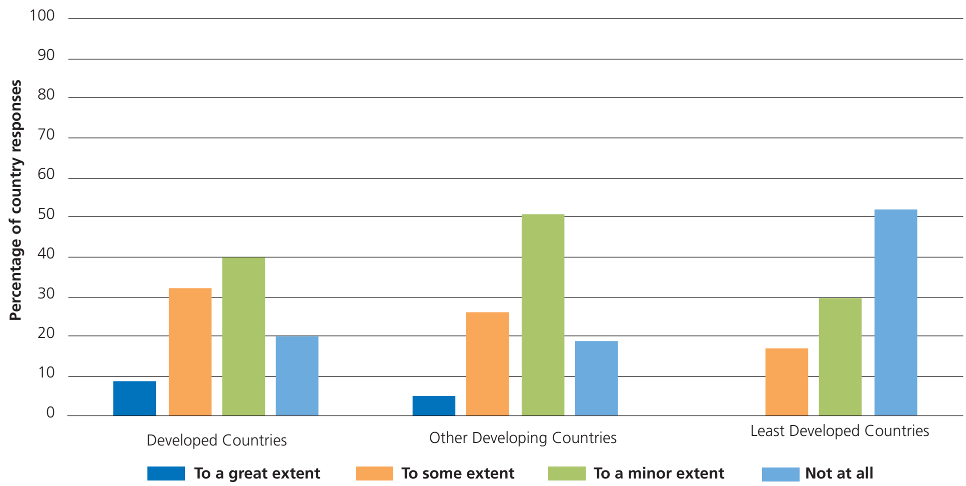
FIGURE 31
Extent of availability and use of information on aquatic genetic resources of farmed types across all reporting countries, by level of aquaculture production



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q4 (n = 92).

FIGURE 32

Extent of availability and use of information on aquatic genetic resources of farmed types across all reporting countries, by economic class



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q4 (n = 92).

these breeding programmes were funded by the public sector. The private sector was the main funder of all other technologies (Figure 33), although the differences between the number 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 publicly funded improvement programmes, both in relative and absolute terms (Figure 34). Analysis by level of production indicated that public support, i.e. finances for genetic improvement programmes, was much more prevalent in the major producing countries (Figure 35). Given that 55 percent of the reported cases of genetic improvement were supported by the public sector (Figure 35), the success of the GIFT programme (ADB, 2005) and the Norwegian Atlantic salmon programme, countries wanting to genetically improve AqGR could consider wider use of public funding and public–private partnerships.

2.4.3 Biotechnologies for improved characterization of aquatic genetic resources

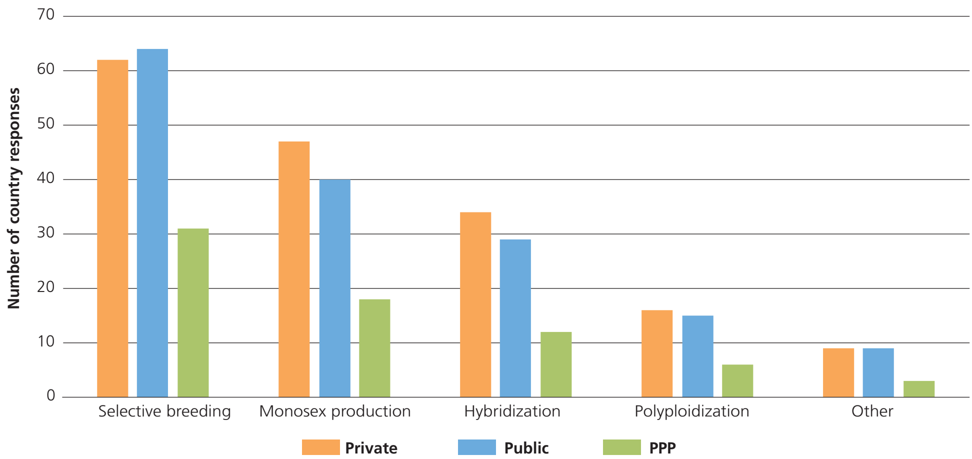
Biotechnologies can be used to increase performance under farming conditions, but can also be important in characterizing AqGR in farmed types and wild relatives (Ruane and Sonnino, 2006).[26] Improved characterization will facilitate monitoring and management of AqGR and will be necessary for incorporating 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

[26] Fermentation and bioremediation are excluded from consideration here, except when genetic alteration of the microorganisms has occurred. Selective breeding is also excluded as a biotechnology because it is covered elsewhere.

FIGURE 33

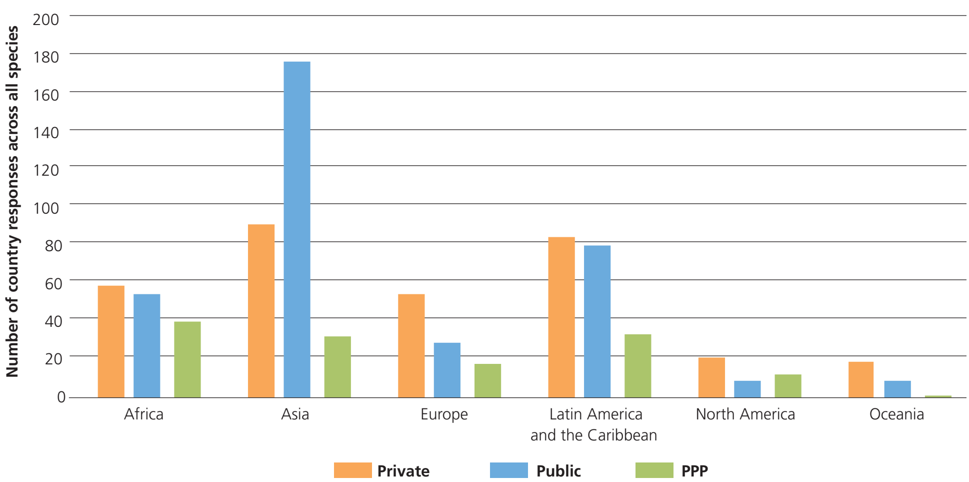
Country reports on source of funding for significant genetic improvement programmes by type of genetic improvement



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q8 (n = 92 countries and a total of 395 occurrences of genetic improvement types).
Note: PPP = public–private partnership.

FIGURE 34

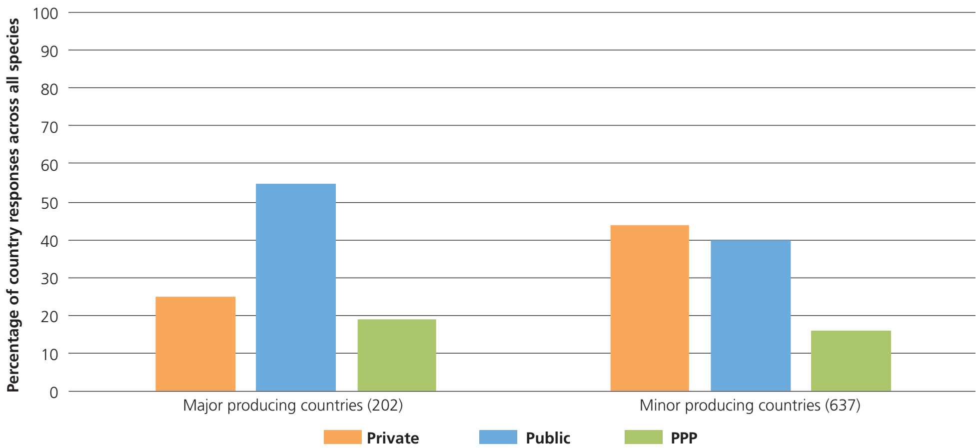
Country reporting on sources of funding for significant genetic improvement programmes for all types of genetic improvement programmes for all reported species, by region



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q8 (n = 92 countries and a total of 839 occurrences of genetic improvement types by species).
Note: PPP = public–private partnership.

FIGURE 35

Proportion of country responses on source of funding for significant genetic improvement programmes for all types of genetic improvement programmes for all reported species, by level of aquaculture production



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q8 (n = 92 countries and a total of 839 occurrences of genetic improvement types by species).
Note: PPP = public–private partnership.

have been intensely used to map the genome to understand genome structure and organization. These deoxyribonucleic acid (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 (Liu, 2016).

Various genome-mapping technologies have been developed, including both genome-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 bacterial artificial chromosome (BAC)-based fingerprinting (Liu, 2016).

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. These technologies can also be used for traceability of product and for establishing provenance in association with more advanced marketing of fish and fish products.

Technologies for improved characterization of aquatic species are listed below in approximate order of the timelines that they came into utilization and their resolution, i.e. the earliest technologies and those that have the least resolving power are listed first.[27]

- **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 level of species, while others can distinguish individual pedigrees. DNA markers include the following:
  - » **allozyme markers**: identification of species, strains and stocks based on protein analysis;
  - » **RFLP:** 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 food labelling;
  - » **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;
  - » **SNP:** 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 genomic selection, i.e. optimizing the selection of marker genes based on the analysis of the whole genetic complement of a given set of organisms.
- **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 identifying the location of sequences, markers or genes on the chromosome and how they may be inherited or manipulated. 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 location of genes underlining performance and production traits important for aquaculture.
- **Genome sequencing technologies:** These technologies facilitate the complete description of the molecular structure of DNA. Genomes of at least two dozen aquaculture species have been sequenced

[27] This list draws significantly on content provided in the thematic background study *Biotechnology and genomics in aquaculture* (also available at www.fao.org/3/a-bt490e.pdf).

or are now being sequenced, including Nile tilapia (*Oreochromis niloticus*), rainbow trout (*Oncorhynchus mykiss*), Atlantic salmon (*Salmo salar*), channel catfish (*Ictalurus punctatus*), striped bass *(Morone saxatilis*), Pacific oyster (*Crassostrea gigas*) and marine shrimps (*Penaeus* spp.). 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 coinduced 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 coinduced genes. Expressed sequence tags (ESTs) can be used to identify gene transcripts. 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.

2.4.4 Biotechnologies for improved performance in aquaculture

Numerous genetic biotechnologies exist for improving performance in aquaculture and for addressing consumer preferences in the marketplace (Figure 22, Table 25 and Box 11).

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 performance and production traits. Following mapping of QTLs, marker-assisted selection or genomic selection can be conducted. With the developments around gene editing, genomes can now be edited or modified in many ways. These technologies undoubtedly have the potential to make large contributions to 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 constraints associated with the application of genomic technologies. In response to a question about the extent to which specific biotechnologies are being used for genetic improvement, responding countries indicate a range of biotechnologies that are used to improve AqGR (Table 26 and Figure 36). In order to better identify the relative use of biotechnologies, an overall index of use for the listed biotechnologies was developed, by assigning an "extent of use" score to each response from the Country Reports and then multiplying by the percentage and summing for each biotechnology (Table 26).

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 36). The index of use indicated that after selective breeding, production of monosex animals and hybridization were the most commonly used biotechnologies (Table 26).

Box 11
Biotechnologies in aquaculture

This box presents a brief summary of the most important genetic biotechnologies for improving performance in aquaculture. It identifies specific technologies, which can be used in addition to selective breeding, that can be used to improve culture performance.

Chromosome set manipulations

It is possible to manipulate whole sets of chromosomes (ploidy) in many aquatic organisms using both physical and chemical shocks of gametes and zygotes.

- **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 finfish are viable and are usually sterile, while tetraploid finfish, if viable, can be fertile. The performance of triploid finfish and molluscs varies. Triploidy can affect growth, feed conversion efficiency, disease resistance, fertility and other traits. Triploid fish and molluscs can grow faster than, slower than or at a similar rate to 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 in aquaculture species such as ayu sweetfish (*Plecoglossus altivelis*) and bastard halibut (*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.

Sex control

Sexual dimorphism for growth is common in fish species. In some species, males grow faster, while in others females grow faster. Females of soles, eels and many other species grow much faster than the males. In contrast, males grow much faster in tilapia and catfish, among many other species. In addition to growth rate, sex also affects body shape, colouration and carcass composition. Also, the culture of a monosex population can reduce energy expenditure on reproductive growth and behaviour in favour of somatic growth.

- **Sex reversal.** Monosex populations can be created by hormonal treatment using steroid hormones. Although genotypic sex is established at the time of fertilization, phenotypic sex can be altered by administration of oestrogens or androgens during the critical period of sex differentiation. For instance, 17α-methyltestosterone is widely used for sex reversal in finfish, especially in tilapia. Several estrogenic compounds have been used to produce monosex female populations, of which β-estradiol is the most commonly used. Sex reversal can also be achieved by surgery, including removal or transplantation of sex glands in crustaceans (Aflalo *et al.*, 2006).
- **Sex reversal and breeding.** Progeny testing, and potentially genetic markers, can be used to identify

(Cont.)

Box 11 *(Cont.)*
Biotechnologies in aquaculture

male and female genotypes following sex reversal. The sex-reversed phenotypes can then be used in a breeding programme to produce novel broodstock that can yield monosex progeny such as XX males in salmonids and crustaceans, which can produce all female progeny, and YY or ZZ males in finfish and crustaceans respectively, which can produce all male progeny (Beardmore, Mair and Lewis, 2001).

Molecular-based DNA technologies

The rapidly advancing molecular revolution has opened up many opportunities for genetic improvement of aquatic organisms.

- **Gene transfer**. Gene transfer or transgenesis is a process to transfer one or a few foreign gene(s) into an organism. 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 characteristics have been 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 as biological factories for the production of pharmaceuticals. To date, there is only one transgenic fish that is known to be farmed commercially (Intrafish Media, 2019).
- **Marker-assisted selection (MAS)**. 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 QTL for traits of interest based on QTL mapping or association studies. For example, in the bastard halibut (*Paralichthys olivaceus*), a microsatellite locus is near the major QTL for resistance to lymphocystis disease. Another marker is near an infectious pancreatic necrosis resistance gene in salmon. In both cases, resistant populations were created and 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*), kuruma prawns (*P. japonicus*) 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 in the absence of phenotypic data.
- **Genomic selection** uses the estimated effect of many loci across the entire genome at once (often based on genome-wide association studies, or GWAS), not just the small number of linked loci as done with MAS. Genomic selection has been successfully applied in dairy and beef cattle and other livestock species. It is only relatively recently that applications have been initiated in some higher value aquaculture species.
- **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 regularly

(Cont.)

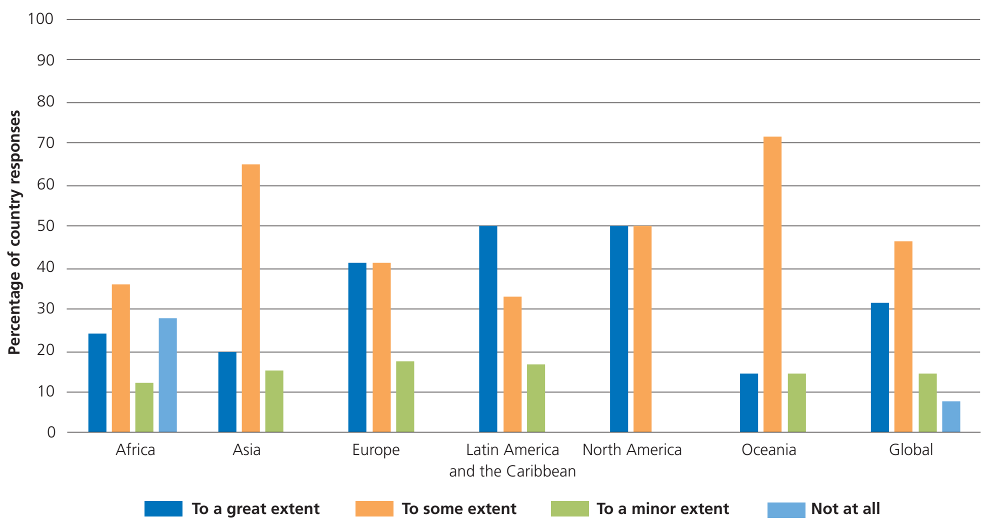
Box 11 *(Cont.)*
Biotechnologies in aquaculture

interspaced short palindromic repeats (CRISPR) technologies allow introduction or disabling of any gene without much difficulty in any finfish or shellfish species. The altered genome is able to pass on the genetic changes to future generations. While it is clear that the genome-editing technologies are different from gene transfer technologies, it is as yet unclear how government agencies will regulate any commercial products generated using gene editing technologies and how such regulation might affect its application. 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; 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.

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 to reduce the chance of escaped offspring breeding, and thus reduce the risks of genetic contamination.

FIGURE 36
Country responses on their extent of use of selected biotechnologies (number of responses), by region



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q18 (n = 88–91 countries responding on each technology).

TABLE 26
Country responses on their extent of use of selected biotechnologies (number of responses) and overall index of use

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

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture:* responses to Q18 (n = 88–91 countries responding on each technology).
Note: The index of use is calculated by applying a score from 1 (not at all) to 4 (to a great extent), multiplying this by the number of country responses for each score and then averaging this for each biotechnology across all reporting countries.

The more complex techniques of marker-assisted selection and gynogenesis/androgenesis were not used at all in 62 and 70 of the countries surveyed, respectively.

2.5 Aquatic genetic resources of 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 12). There are other species living in the wild that are closely related to farmed species (i.e. in 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.

In the Country Reports, wild relatives are reported as occurring in many habitats (Figure 37 and Figure 38). Most wild relatives and the highest diversity of taxa were reported for riverine and coastal habitats (Figure 37). 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, or 560 reported cases). Several wild relatives were reported to be transboundary and straddling stocks (Figure 38).

2.5.1 Use of wild relatives in fisheries

The vast majority of the responses indicated that wild relatives contribute to capture fishery production (622 out of 728) and have fishery management plans in place (550 out of 730) (Figure 39). Many of the wild relatives not fished were species introduced for aquaculture purposes. Wild relatives not fished also included species for which capture fisheries were highly regulated, such as sturgeons, which are listed in 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 2.5.1) calls into question both the efficacy of management plans and the ability to enforce them.

Box 12

Wild relatives of farmed aquatic species and interpretations of the term

Wild relatives of farmed species are defined for the Report as species that occur 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. The FAO FishStatJ database on aquaculture production statistics includes nearly 600 species cultured worldwide, which is indicative of the number of wild relatives that exist and could be reported by countries to FAO. 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.

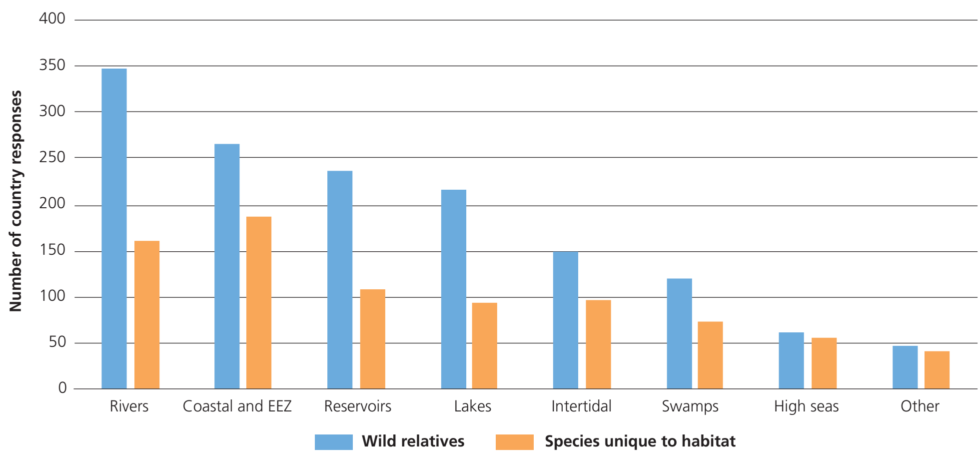
Three questions in the questionnaire[1] that formed the basis of the Country Reports refer directly to wild relatives, including an inventory of wild relatives of species farmed in the country and those farmed elsewhere, and also information on the exchange of wild relative aquatic genetic resources.

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 interpreted the term. It is further apparent that the numbers of wild relatives have been under-reported in the majority of Country Reports. When invited to list wild relatives for cultured species excluding those cultured in the country, a third of reporting countries did not list such wild relatives. When asked to complete a table of all wild relatives, with details on their management and utilization, nearly 90 percent of countries did report species, but numbers were low (with a total of 746 species reported across all countries with an average of only 8.1 species per country), 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 the Report in the interpretation of the data relating to relevant questions.

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

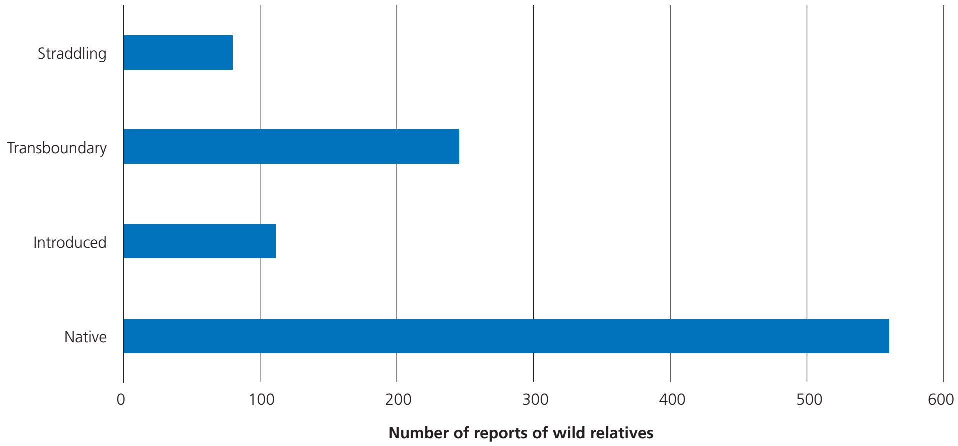
FIGURE 37

Habitats of all wild relatives of farmed aquatic species within national jurisdiction reported by countries



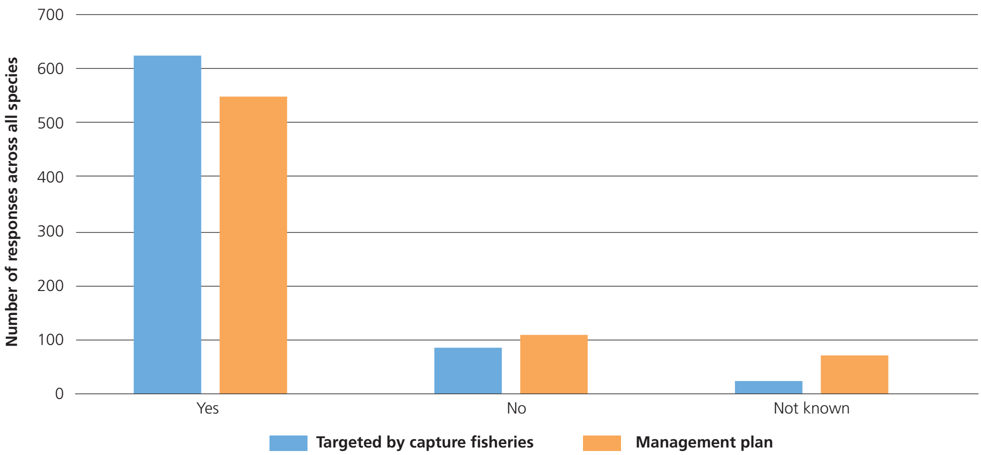
Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q14 (n = 92).
Notes: EEZ = exclusive economic zone. Information on habitats was provided by countries for a total of 2 263 species reported as wild relatives of farmed aquatic species, with many species reported by more than one country in more than one habitat.

FIGURE 38
Geographic range categories of wild relatives of farmed aquatic species reported by countries



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q14 (n = 92).
Note: A wild relative could be native, straddling or transboundary. Straddling stocks occur both within and beyond the EEZ, transboundary stocks are those that migrate across international boundaries. Geographic information was provided on all wild relative species reported.

FIGURE 39
Targeting by capture fisheries, and coverage by management plans, of wild relatives of farmed aquatic species



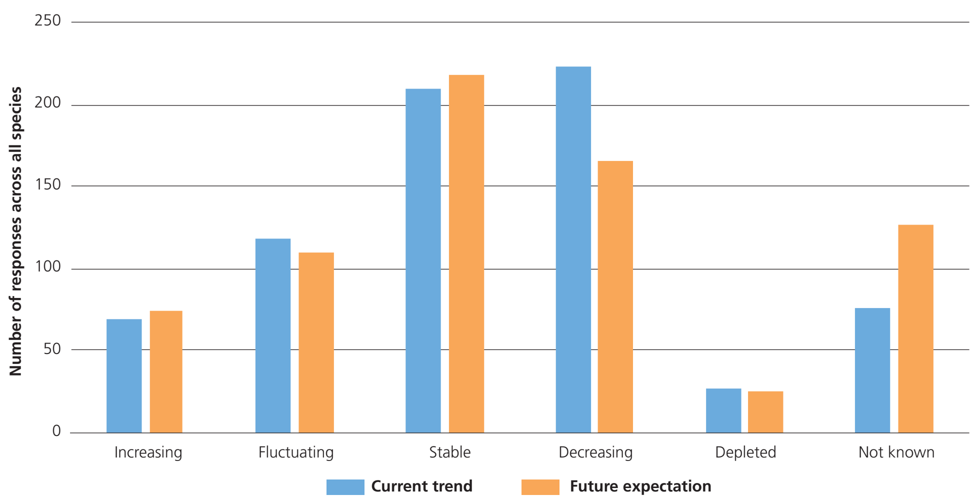
Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q14 (n = 92).

2.5.2 Trends in abundance of wild relatives

Figure 23 and Figure 24 reveal how dependent aquaculture still is on aquatic species found in natural ecosystems. In providing details on the occurrence of wild relatives, Country Reports also noted trends in catch. Countries reported numerous cases where the abundance of wild relatives was currently decreasing and was expected to decrease in the future (Figure 40). 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 (*S. salar*) and brown trout (*S. trutta*). There were reports of increasing catch, and the top five species with an increasing catch trend were Nile tilapia (*O. niloticus*), North African catfish (*Clarias gariepinus*), Mediterranean mussel (*Mytilus gallo-provincialis*), milkfish (*Chanos chanos*) and Pacific oyster (*Crassostrea gigas*). Interestingly, Nile tilapia (*O. niloticus*) populations are seen as increasing in some areas and decreasing in others.

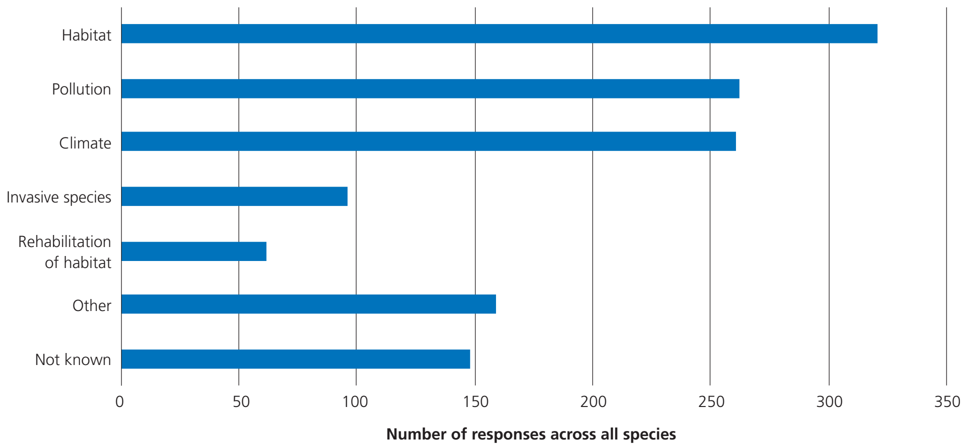
Countries reported that habitat change was the most common reason for changes in wild relatives' abundance (Figure 41), and in only a few cases was habitat reported as increasing (Figure 42). Analysis by region indicated that Asia was the region with the highest percentage of responses citing habitat as a determinant of change in numbers of wild relatives. Analysis by economic class showed that least developed countries had the highest percentage of such responses (Figure 43). These findings reinforce

FIGURE 40
Current and expected trends in catches of wild relatives reported by countries



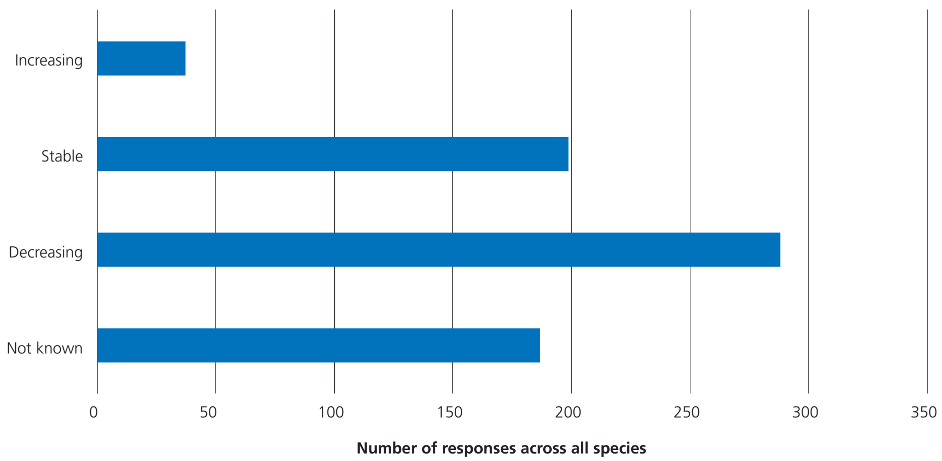
Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q14 (n = 92).
Note: Current trend reflects the ten years preceding the Country Report; future trends cover the next ten years.

FIGURE 41
Reported reasons for trends in abundance of wild relatives



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q14 (n = 92).

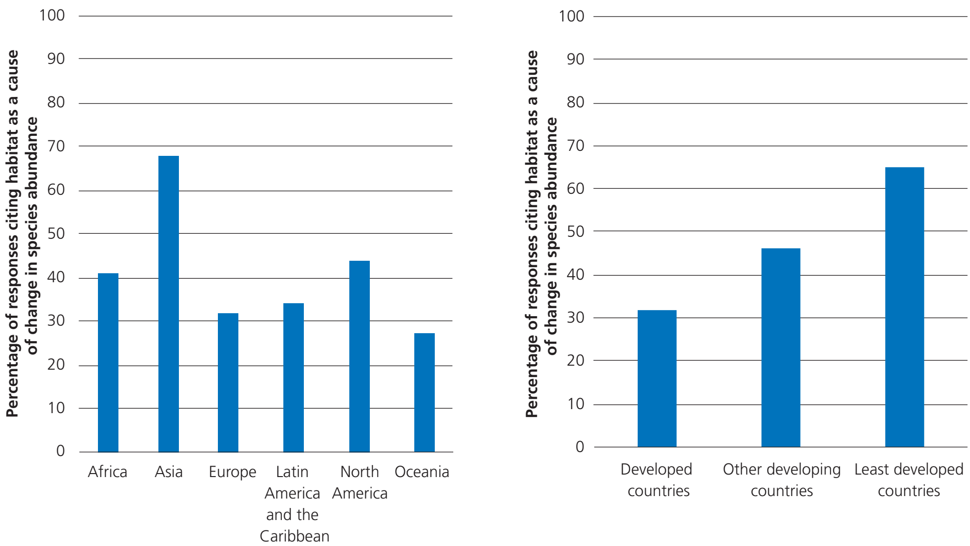
FIGURE 42
Trends in habitat of wild relatives



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q14 (n = 92).

FIGURE 43

Proportion of reported changes in abundance of wild relatives due to habitat change by region (left) and by economic class (right)



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q14 (n = 92).
Note: Percentages were calculated on the basis of the number of countries that reported habitat as a reason for change in abundance across all wild relative species reports.

the need to protect natural populations of AqGR and suggest that protecting habitats would be an effective strategy.

About one-third of the responses from developed countries cited habitat as a cause of change in the numbers of wild relatives (Figure 43, right).

Comparisons of the importance of habitat change 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. 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. Thus, in developed countries, loss of habitat in earlier centuries may have been a major reason for the decline in wild relatives, but current generations just do not recognize it as a cause.

In response to a query on the extent of use of genetic data in the management of wild relative stocks, Country Reports noted that genetic data for most species are used to only a limited extent (Figure 44).

Examples do exist where genetic data are used in the 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; Bernatchez *et al.*, 2017). For example, genetic stock identification (GSI) helps set the season, area and catch limits on commercially important species in Europe and

North America based on the genetic profile of the fishery (Beacham *et al.*, 2006). 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.

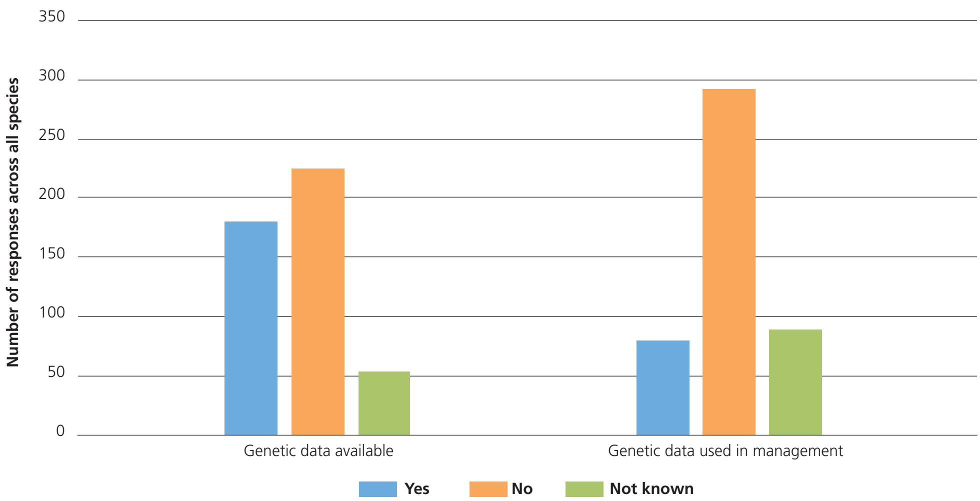
2.6 Use of non-native species in fisheries and aquaculture

As in terrestrial agriculture, non-native aquatic species (also called introduced, alien or exotic species) contribute significantly to production and value in fisheries and aquaculture (Bartley and Casal, 1998; Bartley and Halwart, 2006; Gozlan, 2008). Although the Country Reports did not contain production data, production trends from non-native species were reported to be increasing for wild relatives in fisheries and for farmed species in aquaculture (Figure 45). 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 46). This result is contrary to information provided to FAO via countries' regular reporting of production data; for example, China and Viet Nam reported increasing production from non-native species (X. Zhou, FAO Aquaculture Information Officer, personal communication, March 2018).

FAO maintains the Database on Introductions of Aquatic Species (DIAS) that contains records of introductions across national boundaries.

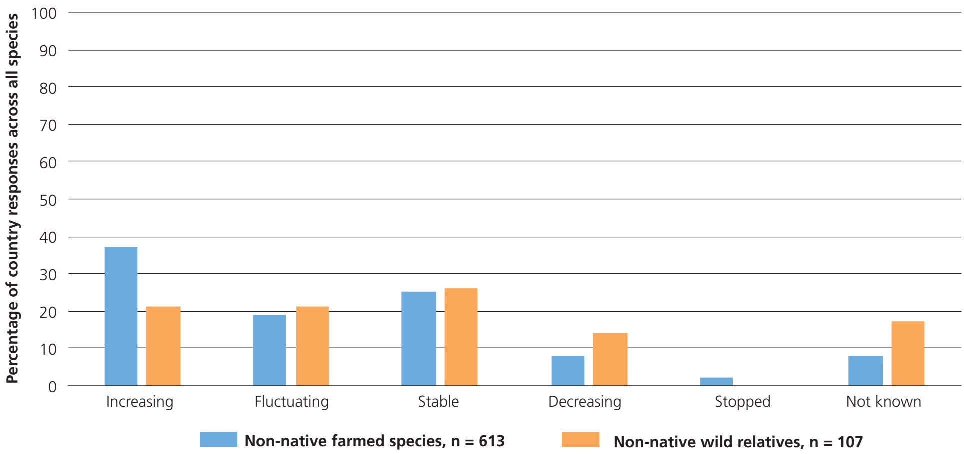
FIGURE 44

Country responses on whether or not genetic information is used in fishery management of wild relative stocks



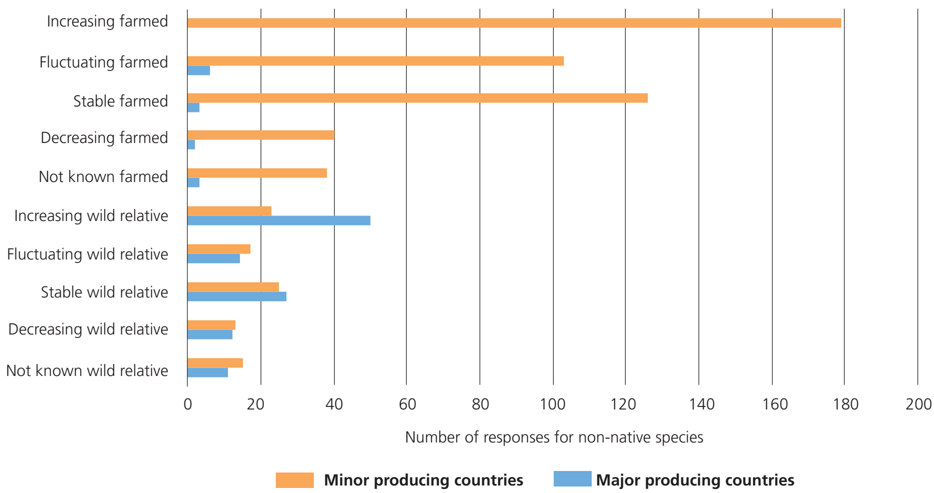
Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q14 (n = 92).

FIGURE 45
Current production trends reported by countries for non-native species in fisheries and aquaculture overall



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q14 (n = 92).
Note: n in the legend refers to the total number of species reported as non-native (either in aquaculture or as wild relatives) across all countries.

FIGURE 46
Current production trends in non-native species in fisheries and aquaculture by country level of aquaculture production



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q9 and Q14 (n = 92).

The database may be accessed online[28] and is linked to FAO production figures and species fact sheets.[29] Analysis of DIAS revealed that carps, trout, tilapia and oysters were the most widely introduced aquatic species. In response to requests for lists of farmed and wild relatives that have been transferred or exchanged with other countries, Country Reports generally confirmed this analysis, with the most often exchanged species (imports and exports) being Nile tilapia (*Oreochromis niloticus*) followed by North African catfish (*Clarias gariepinus*) (Table 27). Countries reported that over 200 species had been exchanged across international borders (data not shown).

With an average of 16 exchanges per country, Latin America and the Caribbean was the region exchanging the most AqGR (Figure 47) over the past ten years, followed by Asia (6) and Africa (3). By economic status, other developing countries reported the highest number of exchanges per country, with an average of nine over the past ten years (Figure 48). Minor producing countries (Figure 49) reported most exchanges on a per country basis. Generalizations from the results are difficult to make. The low level of exchange in major producing countries and in developed countries could indicate that there is less need to import or export AqGR in these countries, but this assumption would not explain the low rate of exchange in Africa where aquaculture is developing.

As expected, the most common form of genetic material exchanged was living specimens. Of the nearly 300 reported exchanges, about 77 percent involved living specimens, about 7 percent involved embryos and only a few involved other genetic material (Figure 50). The "other" category included various unspecified items.

The Country Reports did not indicate whether the introductions had positive or negative impacts on AqGR, and it might be useful in future

[28] www.fao.org/fishery/introsp/search/en
[29] www.fao.org/fishery/factsheets/en

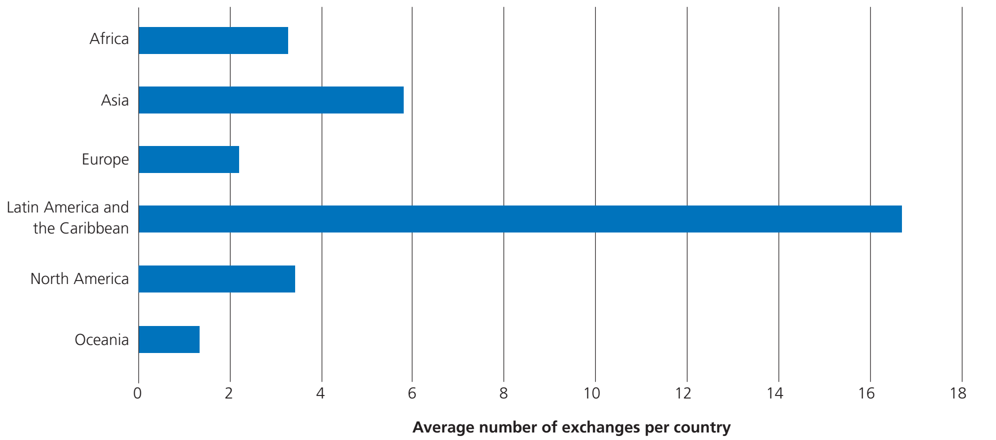
TABLE 27
Top 12 wild relative species or species items exchanged by countries (includes both imports and exports)

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

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture:* responses to Q11 and Q13 (n = 92).

FIGURE 47

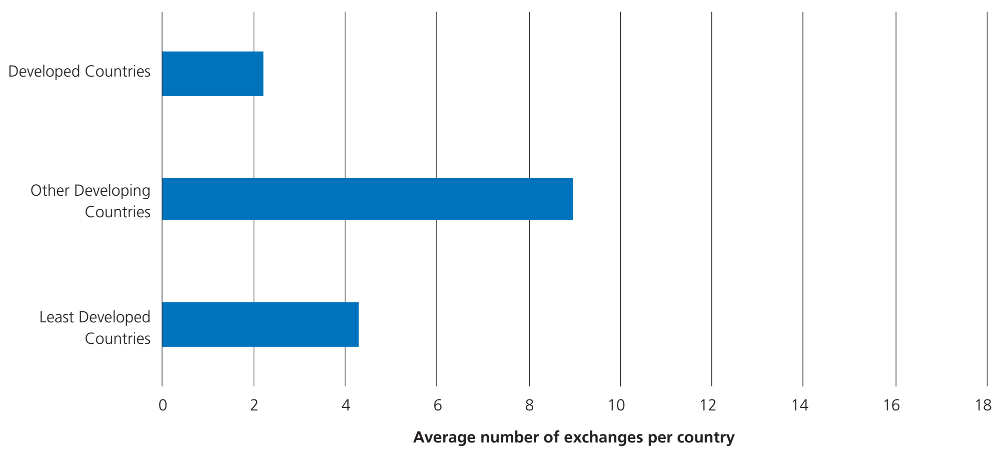
Average number of species exchanges/transfers (imports and exports) of aquatic genetic resources per country, by region



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q11 and Q13 (n = 92).

FIGURE 48

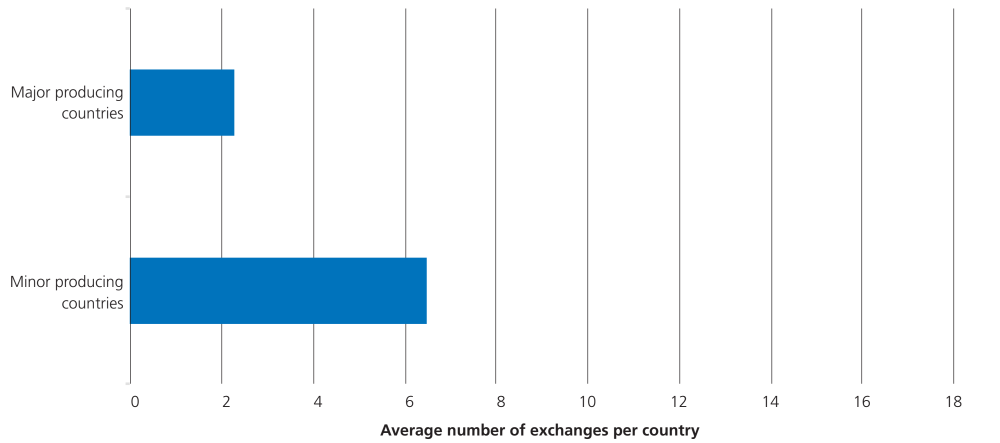
Average number of species exchanges/transfer (imports and exports) of aquatic genetic resources, by economic class



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q11 and Q13 (n = 92).

FIGURE 49

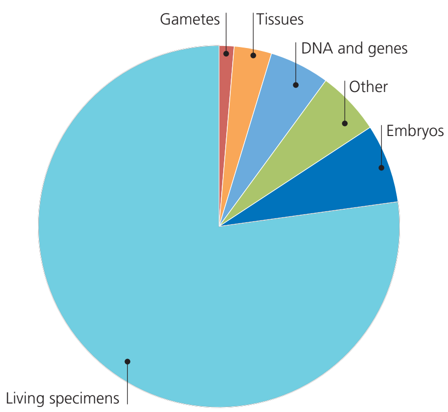
Average number of species exchanges/transfer (imports and exports) of aquatic genetic resources, by level of aquaculture production



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q11 and Q13 (n = 92).

FIGURE 50

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



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q11 and Q13 (n = 92).

such exercises if the questions were extended to invite feedback on the relative negative and positive impacts of introductions, particularly of non-native species. Some interpretation can be made on the effect of introductions through analysis of inputs into DIAS (see Box 13).

Box 13
Impacts of non-native species

Previous analyses of information from the DIAS (Bartley and Casal, 1998; Gozlan, 2008) indicated that most introductions of aquatic species had negligible impact on biodiversity or on the ecosystem. However, recent analysis of an updated DIAS with more records of introductions of aquatic species revealed that countries reported more adverse social and economic impacts than beneficial impacts from the introduction of aquatic species. Notable adverse impacts from the introduction of non-native species include the golden apple snail (*Pomacea canaliculata*), which decimated rice fields in the Philippines (Halwart, 1994) and by the crayfish plague (*Aphanomyces astaci*) in Europe, which arrived with an introduced crayfish from North America (Holdich *et al.*, 2009). Other introductions have had both adverse and beneficial impacts and are therefore difficult to categorize, for example the introduction of the Nile perch, (*Lates niloticus*) into Lake Victoria, which created a multimillion dollar fishery, but also greatly reduced the biodiversity of native fishes in the lake (Oguto-Ohwayo, 2001).

It is clear that non-native species can become invasive and have been identified as a threat to biodiversity throughout the world. The international community, including FAO, promotes the application of codes of practice and risk analysis before a non-native species is introduced into a new area (ICES, 2005; Chapter 7). Risk analysis should also include an analysis of the expected social, economic and environmental benefits from the introduction. For a collection of documents and international guidelines on non-native species, including DIAS, see Bartley and Halwart (2006).

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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 http://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)
- International Union for Nature Conservation (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

CHAPTER **3**

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 demand for fish, consumer food preferences and ethical consideration, and direct effects of climate change. 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, indirect effects of climate change, purposeful stocking and escapes from aquaculture, establishment of invasive species and introductions of pathogens and parasites, and capture fisheries.

KEY MESSAGES:

- Population increase will continue to drive demand for fish and fish products, especially aquaculture products, as capture fishery resources become limited.
- Increased demand for fish and fish products will drive efforts to expand and diversify the farmed species produced and therefore the AqGR used in aquaculture, leading to pressure on wild relatives used as seed stock or directly as food.
- 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 and to expand into brackish-water and marine systems. This will require AqGR adapted to such systems.
- Wild relatives will be threatened by overfishing (including harvest for aquaculture seed and feed), changing water use priorities, and competition from introduced species (including escapes from aquaculture).
- Demand and preference for AqGR will be driven and modified by greater intraregional and interregional trade and increasing urbanization, industrialization, consolidation and commoditization of fish and fish products, all resulting from increasing wealth in developing economies.
- With changing demographics, consumer attitudes towards fish (including towards health benefits and unsustainable fishing and aquaculture practices) are also changing, affecting the acceptability of, and demand for, different AqGR.
- There will be continuous exploration of new AqGR species to satisfy the demand for new commodities and to fill niche markets.
- Concern remains over the development and use of genetically modified organisms in some markets, generating consumer resistance.
- Demand for ornamental species will increase, driving the development of farmed types as well as demands on wild relatives.
- Good governance has an overall beneficial effect on AqGR in both farmed types and wild relatives.
- Changes in the use of land, water, coastal areas, wetlands and watersheds all have impacts on the quantity and quality of habitat for AqGR.
- 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.
- Climate change may have impacts on the availability of freshwater and implies changing ambient temperatures, which will have both direct and indirect impacts on farmed and wild AqGR, particularly in tropical regions.
- Climate change can have positive impacts, for example on farmed types that are managed or naturally selected for climate-tolerant characteristics.
- The impacts of climate change on wild relatives will have both positive and negative implications for their conservation and sustainable use.

3.1 Drivers impacting aquatic genetic resources in aquaculture and their 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, 2018a). 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). When considering drivers affecting AqGR as a whole, it is useful to examine trends in aquaculture production. In this chapter, 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. The chapter also presents and reviews Country Report responses addressing the above drivers and their effects on AqGR. It deals primarily with impacts on cultured AqGR, but also considers impacts on wild relatives of cultured species.

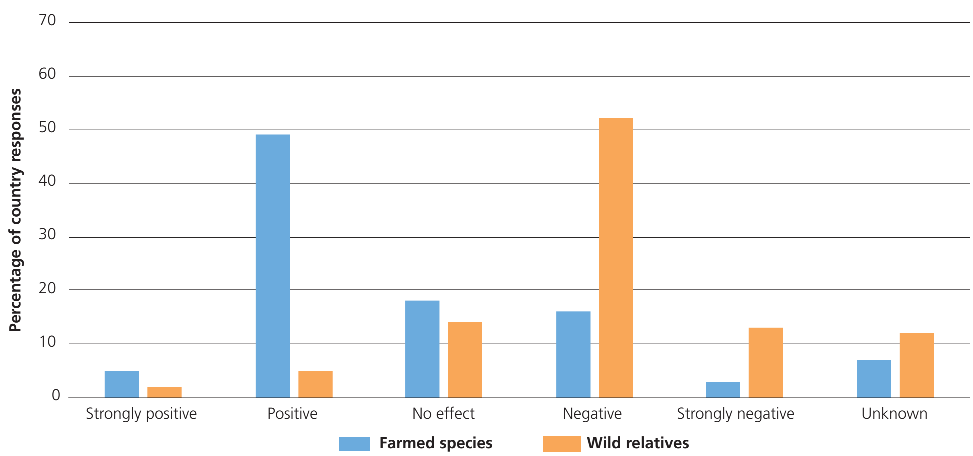
3.1.1 Human population increase

As outlined in Section 1.7, global population growth (see Table 4) is a major driver behind forecasts for significantly increased demand for fish and fish products in the future. These projections indicate that 62 percent of food fish will be produced by aquaculture by 2030 and that beyond 2030 aquaculture will likely dominate global fish supply (World Bank, 2013).

More than half (54 percent) 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 51). This appears to be linked to the

FIGURE 51

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



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q15 and Q16 (n = 90).

consequent increase in demand for aquaculture products that will occur as population increases. It was noted that some developed countries did not expect their population to rise significantly in the foreseeable future, and thus that a strong increase in demand for fish and fish products would not occur. It is expected, as the aquaculture sector grows, diversity of genetic resources will increase in farmed types, including the development of improved farmed types with traits such as tolerance to high-density production, increased disease resistance, and improved product quality traits such as colour, shape, dress-out weight, head-tail ratio and phycocolloid gel properties (Gjedrem, Robinson and Rye, 2012). It is also expected that the search for new species to culture, also known as diversification (see Box 3), will continue.

Nineteen percent of responding 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 in them. Intensification and industrialization/rationalization may narrow the range of species that are cultured as commodities. This is a similar trend to that seen in the livestock sector, as high-performing breeds displace locally adapted breeds (FAO, 2007). The intensification and globalization of movement of aquatic species associated with the increasing importance of non-native species in aquaculture (Figure 45 and Figure 46) will increase the risk of spread of diseases, which is likely to have adverse impacts on AqGR.

The impact of population growth on wild relatives was commonly expected to be negative (65 percent of respondents), with only seven percent of Country Reports stating that it would have positive effects. Respondents considered that increasing population and consequent demand for fish would drive overfishing of wild relatives, as well as negatively impacting freshwater ecosystems that support wild relatives. The absence of effective management could have profound negative influences on the most vulnerable species which are often species that have life-history traits such as late sexual maturation, low fecundity and/or complex breeding or migratory characteristics. Such characteristics also mean that these species are challenging or prohibitively expensive to domesticate and breed in captivity (e.g. bluefin tuna, eel and lobster). This places 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

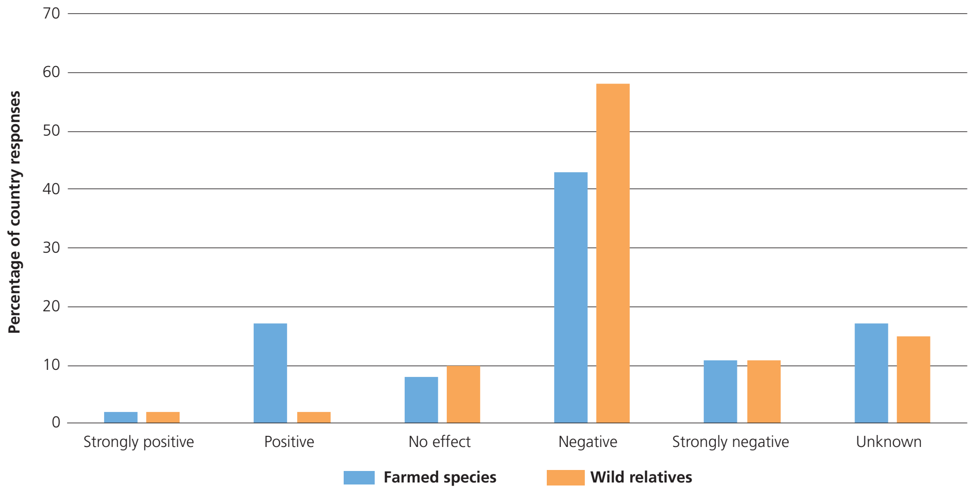
Overall, more than half of the country responses (54 percent) stated that competition for resources would have a negative effect on farmed AqGR; 19 percent stated that the effects would be positive (Figure 52). These responses were overwhelmingly concerned with the availability of freshwater and competition for it from other sectors such as agriculture, recreational uses and drinking water supply. The distribution of responses was similar across regions and across socio-economic country categories.

Changing priorities in the use of water force aquaculture to produce more with less. In many countries increasing attention is being given to the rehabilitation of inland waters, restoration of habitats and conservation of biodiversity. This in turn may limit the prospects for aquaculture expansion by limiting the availability of sites and imposing restrictions on water abstraction 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 implications for the process of domestication and selective breeding of aquaculture species, in that farmed populations will need to be adapted

FIGURE 52

Country responses on the effect of competition for resources on aquatic genetic resources of farmed species and their wild relatives



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q15 and Q16 (n = 90).

to these intensive systems. There will also be interest in developing aquaculture systems for species that are not currently cultured. Several responding countries noted that competition for resources would have a positive effect on the development of more efficient production systems with reduced nutrient discharge footprints.

It is recognized that some differences exist between the data collected through the FAO statistics updated biennially and the data provided in the Country Reports; a discussion of the causes and implications of these differences is included in Chapter 2 (see Figure 21 and Table 21).

Aquaculture production data for 2016 (FAO 2018b) indicate that a total of 554 aquatic species and species items were being farmed (Table 12). Approximately 56 percent of those were marine species, 36 percent being freshwater and 8 percent were diadromous species.

Expansion of aquaculture will inevitably lead to competition for freshwater and land resources. There is still scope for the sector to expand (and thus for expansion of AqGR of farmed types) through the development of systems and species in brackish-water and saltwater.

The highest 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 among the few areas that do not directly compete with livestock and crop production for space and water, meaning that there is considerable potential to increase 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 (Rana, Siriwardena and Hasan, 2009). 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, for example, Atlantic salmon (*Salmo salar*), channel catfish (*Ictalurus punctatus*) and Nile tilapia (*Oreochromis niloticus*).

Although availability of aquaculture feed is an important concern for the future of aquaculture development, 50 percent of the world's aquaculture production takes place in systems that do not require the addition of feed. This is achieved mainly through the production of seaweed and microalgae (27 percent), filter-feeding finfish (8 percent) and filter-feeding molluscan species (15 percent) (FAO, 2014b). The production of unfed aquatic animal species was 23 million tonnes in 2014, representing 23 percent of world production of all farmed fish species (FAO, 2016), and this proportion is relatively stable. This trend has been reasonably consistent over the past decade. There has, however, been a slight rise in the production of carnivorous species (from 8 percent to 9 percent of total aquaculture production) over the past decade, although this level of production is greatly outweighed by the production of non-carnivorous species (Table 28).

The most important unfed aquatic animal species include:

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

While many of these pressures associated with competition for resources 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.

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

The factors causing negative impacts on wild relatives include reduction in availability of freshwater, loss of habitat, and competition for 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, flood control and flood protection, hydropower development, irrigation, partitioning of wetlands and road construction. Wild relatives can also be affected by changes to water quality caused by land-use changes, soil degradation, 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 29).

3.1.3 Governance

Governance factors were overwhelmingly perceived as having a positive effect on farmed AqGR (76 percent). The distribution of responses was similar across regions and across economic class of country. 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

TABLE 28

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

	Species	2004	2009	2014	Percentage 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	n/a
Percentage of annual total	**Unfed**	**50**	**47**	**50**	**n/a**
	Fed	**50**	**53**	**50**	**n/a**

Source: FAO, 2016.
Note: Annual totals for percentage calculation exclude production of unknown species. n/a - not applicable

TABLE 29

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 water	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 affecting them 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 as in the case of the capture of natural spatfall in mollusc production (e.g. clams, oysters, mussels, cockles). The active fishing for seed for stocking may have greater impact if it 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 lalandi*, 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 that influence the stock composition in these fisheries, although the effect on wild relatives of aquaculture species has not been quantified.

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 following potential positive impacts of improved governance on farmed AqGR were identified:

- increased regulation and management of farmed types, including licensing of hatcheries (this 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 7).

Only 9 percent of responding 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 percent) was expressed for wild relatives, with responses (where provided) focusing on the importance of effective fishery management to protect wild relatives. The distribution of responses was similar across regions and across economic class of country. The existence of effective fishery assessment programmes was identified as an important element. Some examples highlighted the protection of specific habitats and the development of protected areas and sanctuaries to preserve wild stocks (Bangladesh and Benin). For marine stocks, fishery-management measures, including seasonal closures, were mentioned. Rehabilitation of freshwater resources (including habitat) was also noted in some Country Reports. 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 53).

Some problems in the management of AqGR of farmed types are related to governance structures and to the degree of regulatory control, research and communication. Concerns remain over the impact that escapees of farmed types, especially any genetically modified organisms (GMOs) that may be used in aquaculture in the future, may have on wild relatives. This highlights the need to develop more stringent measures to prevent or reduce possible harm.

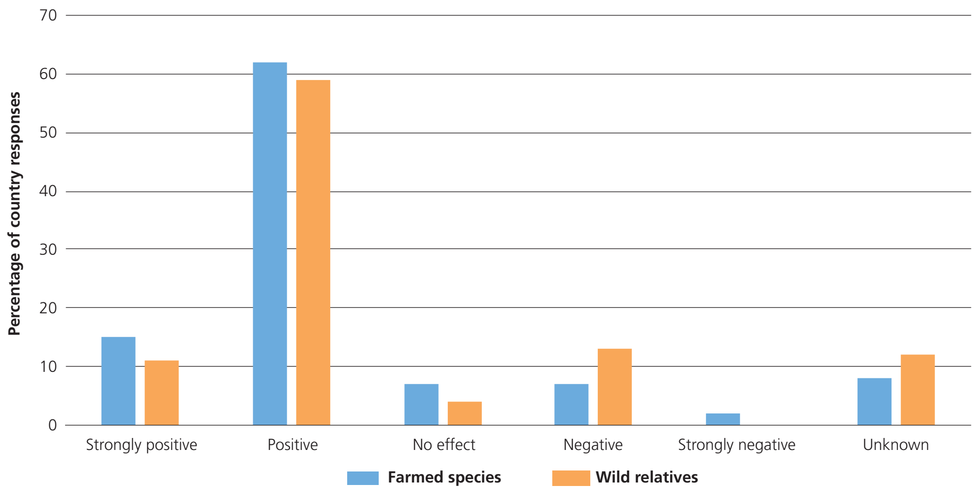
Preventing harmful impact depends on effective sector regulation and management. These issues are summarized in Table 30.

Improved governance also benefits wild relatives by strengthening controls over biosecurity and limiting farm escapees, both of which can limit 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. Governance measures that can support AqGR 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

FIGURE 53

Country responses on the effect of governance factors on aquatic genetic resources of farmed species and their wild relatives



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q15 and Q16 (n = 90).

TABLE 30

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 is 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 is evident, and it was even noted in some country responses, that the private sector had the ability to bypass government controls on importation and movement 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.

- effective biosecurity regulations, especially in relation to introductions;
- regulations based on risk assessment preventing the establishment of invasive species; and
- regulation that reduces 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 issue 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.

Some country responses indicated that a general 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 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 areas of water management, aquaculture zoning and biosecurity (see Chapter 7).

3.1.4 Increased wealth and demand for fish

Eighty percent of responding countries considered that increased wealth would positively affect farmed AqGR (Figure 54).

Expanding economies and increasing wealth drive demand for fish and fish products, and aquaculture products form part of this demand. There is some evidence that increasing urbanization leads to a slight decrease in the 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 (Delgado *et al.*, 2003; World Bank, 2013). The Country Reports indicated that the increased wealth and national economic development are seen as driving the demand for fish, which is generally a more expensive food in many countries. Trends of this kind can be observed among increasingly wealthy urban populations in countries as diverse as China and the Democratic Republic of the Congo.

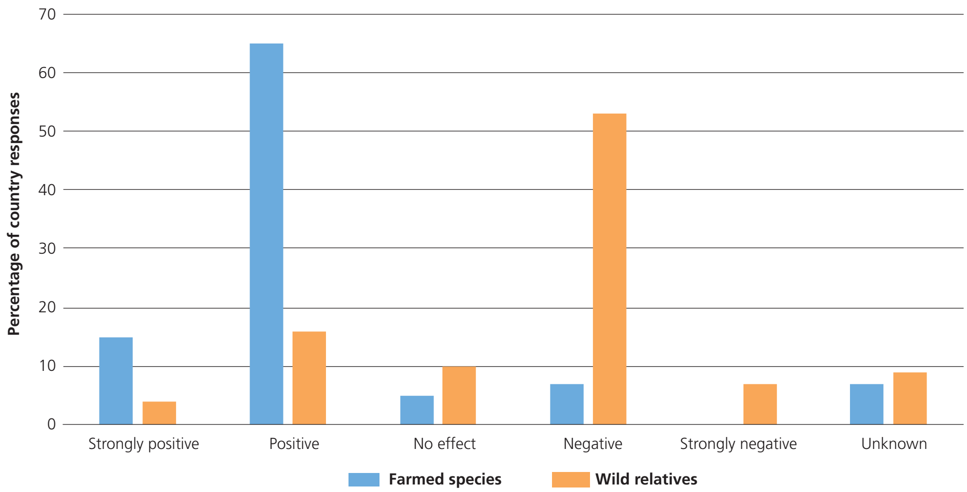
Increasing wealth and greater interest in healthy eating were considered by several responding countries to be driving the increased demand for fish and fish products. These also promoted increased demand for fish as a healthy food, particularly in middle-income families. Several countries noted that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

The lowering of fish prices through aquaculture was also seen as having a positive effect on the 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 such outcomes. Increased urbanization

FIGURE 54

Country responses on the effect of increased wealth on aquatic genetic resources of farmed species and their wild relatives



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q15 and Q16 (n = 90).

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 (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 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.

Another reported trend was increasing interest in indigenous species in aquaculture, especially as they 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.

As reported in SOFIA report (FAO, 2014a, 2016) 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. The 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 (FAO, 2014a).

Increased wealth is also linked to increased interest in high-value ornamental fish, are largely found in cities and economically developed contexts. Trade in live fish includes ornamental fish, which have high economic value but are 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, in most cases they are not officially reported at national and FAO levels.[30]

Increased wealth is leading to greater demand for niche products. The aquaculture sector's efforts to meet this demand are leading, in turn, to greater attention being paid to improving strains, diversification and experimentation with new species.

Country responses were mixed with regard to the impacts of increased wealth on wild relatives. Sixty percent considered that there would be overall negative impacts. The country responses indicated 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.

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

Twenty percent of responding countries considered that the effects of increased wealth were likely to be positive. They believed that increased wealth would boost consumption of fish from capture fisheries, but that consumers' increasing wealth would bring greater awareness of the need for responsible and sustainable exploitation of wild-caught fish. Some considered that aquaculture was in a position to provide fish that were equivalent to the species currently obtained from wild stocks that were under pressure.

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 55).

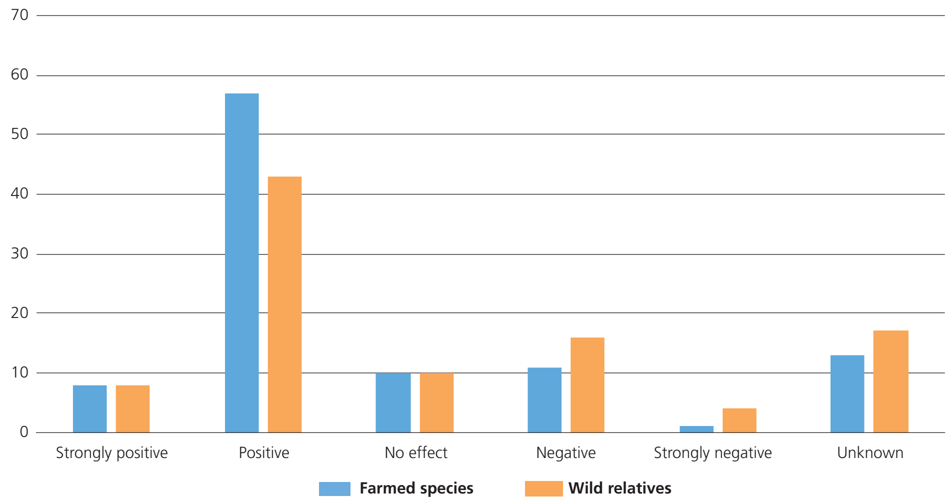
Developing interest in fish as a healthy food drives increasing demand for fish as a staple of the diet. When linked to population increase, this becomes a significant driver of global demand for fish. Consumer preferences and ethics will have an additional impact on which species and farmed types are 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 demand for particular farmed types, including the preferences listed in Table 31.

The price of fish is a strong driver of consumer choice between wild and farmed fish, as well as between particular species. As 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 responding countries 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.

FIGURE 55

Country responses on the effect of consumer preferences and ethical considerations on aquatic genetic resources of farmed species and their wild relatives



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q15 and Q16 (n = 90).

the European Union) and the development of health standards by the World Organisation for Animal Health (OIE) for welfare, slaughtering and transportation.[31] A mediating factor here is that successive breeding of captured stock results in a domestication process whereby fish become more tolerant than their wild relatives of suboptimal water quality conditions, stocking density and other stressors that may arise in culture systems (Bilio, 2007).

A major challenge in developing improved aquaculture strains will be consumer perceptions and ethical concerns regarding the sustainability and ethical basis of modern aquaculture. This links to fish welfare, perceived environmental impacts and the possibility of escapees that impacts wild populations. Another emerging concern is the use of GMOs including transgenic organisms. It is still unclear how significantly consumer perceptions will influence developments in this field. There is currently only one GMO/transgenic farmed type (Atlantic salmon – *Salmo salar*) being commercially farmed; consumer concerns had a major influence on the approval process for this fish.

Though there is general concern over the use of GMO and transgenic techniques in aquaculture relating to ethics, food safety and environmental impacts, to date only a few examples of transgenic organisms are being studied in research facilities and there is only one commercial application (see Box 11). Examples include modification to increase growth rates and performance in cold temperatures, which

[31] 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

TABLE 31

Features of consumer preferences in fish and fish products 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 and shrimp.
	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 in fish (bighead carp – *Hypophthalmichthys nobilis*) or rounder deeper shells in oysters. 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.
		Levels of aggression/competition in the culture system
		Perceptions of stress to the animal in the culture system. 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 genetically modified organisms is expressed in a number of Country Reports.
	Monosex/sex reversed	Preference for genetically manipulated monosex/sterile animals versus concern over use of hormones.

has been done, for example, in Atlantic salmon (*Salmo salar*), Chinook salmon (*Oncorhynchus tshawytscha*), rainbow trout (*O. mykiss*), cutthroat trout (*O. clarkii*, tilapia, striped bass (*Morone saxatilis*), pond loach (*Misgurnus anguillicaudatus*), channel catfish (*Ictalurus punctatus*), common carp (*Cyprinus carpio*), Indian major carps, goldfish (*Carassius auratus*), Japanese rice fish (*Oryzias latipes*), northern pike (*Esox lucius*), red and silver seabream, walleye (*Sander vitreus*), seaweed, sea urchin and *Artemia* spp. (Beardmore and Porter, 2003; Rasmussen and Morrissey, 2007). Transgenic fish have been produced commercially for the aquarium trade to alter fluorescence or colouration, for example. The same consumer concerns may apply to new farmed types developed by gene editing.

Positive impacts on wild relatives (51 percent of responding countries) 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 responding countries perceived negative impacts of consumer concerns on the AqGR of wild relatives. The effects of demand or preference for wild stocks and unregulated fishing for food were the main concerns noted.

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

3.1.6 Climate change

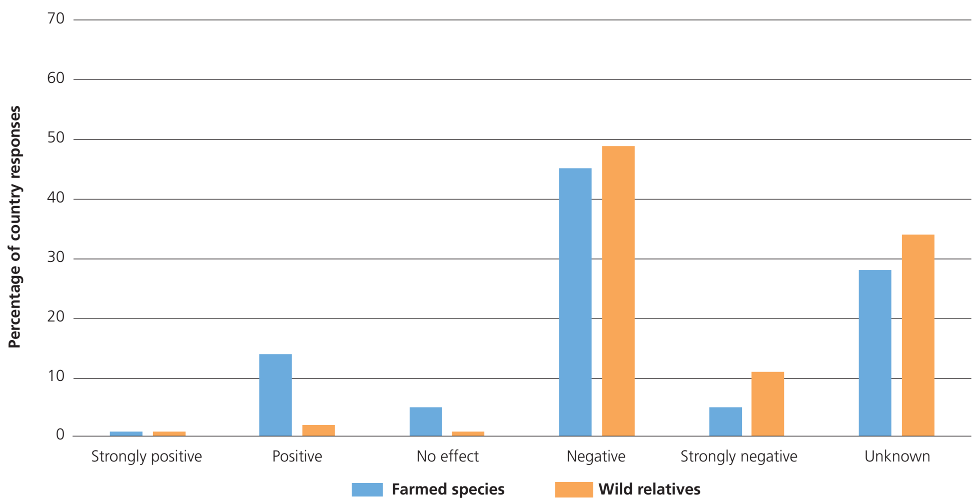
Climate change has implications for aquaculture, especially in the warm tropics where species may already be cultured at the upper end of their temperature tolerance range.

Fifty percent of 90 responding countries indicated that climate change would have a negative or strongly negative impact on farmed type genetic resources (Figure 56). Potential impacts include:

- 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

FIGURE 56

Country responses on the effect of climate change on aquatic genetic resources of farmed species and their wild relatives



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q15 and Q16 (n = 90).

- 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 affecting grow-out season, deteriorating water quality and increasing 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 [*Ctenopharyngodon idella*] and common carp [*Cyprinus carpio*] in Sweden; suckermouth catfish [*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 percent). The country responses indicated that this was largely due to the lack of scientific information and consequent uncertainty over how changes in climate-driven factors (particularly temperature rise) would affect aquaculture species.

Only 15 percent of responding countries believed that there would be a positive or strongly positive effect on farmed types. Hungary referred to positive climate impacts related to the better growth rates associated with slightly elevated temperatures in temperate-water aquaculture. Iran (Islamic Republic of) considered that increased salinity opens up 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).

3.2 Drivers that are impacting aquatic ecosystems and wild relatives

3.2.1 Habitat loss and degradation

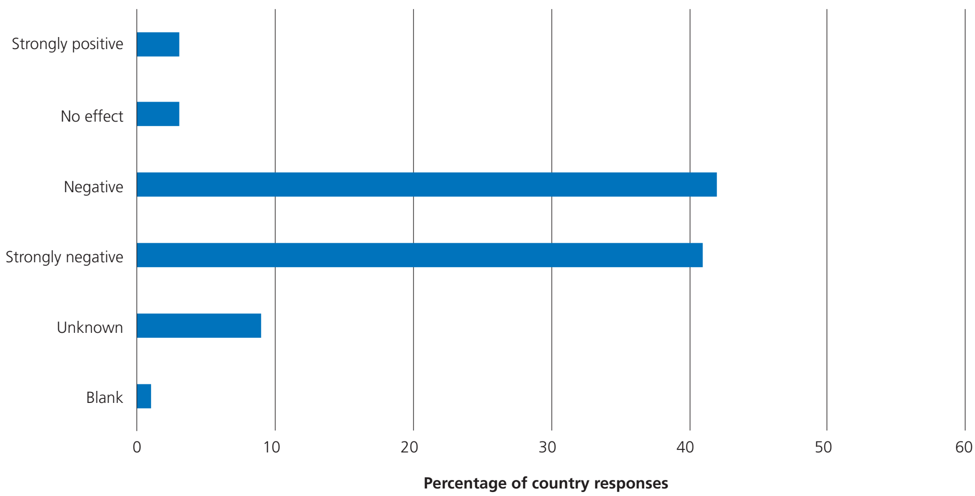
Habitat loss and degradation were almost universally considered to have a negative impact by responding countries (84 percent). The few responses that considered habitat loss in a positive way described how their countries were actively addressing its impact. Thus, all countries appeared to view habitat loss as having a negative impact (Figure 57).

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

Countries identified the need to address the hydromorphological degradation of watercourses that occurs as a result of various interventions such as dyke construction as protection against flooding, obstructing features to regulate flow, water damming and energy generation measures. This degradation occurs mainly due to the impact of water management (irrigation, damming, flood control, hydroelectric power generation). Countries recognized that in order to ensure water connectivity and

FIGURE 57

Country responses on the effect of habitat loss and degradation on aquatic ecosystems that support wild relatives of farmed aquatic species



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q19 (n = 92).

the maintenance of near-natural water flows there was a need to promote the development of regulatory measures that ensure near-natural conditions and improve the passability of waterbodies (e.g. European Union Water Framework Directive 2000/60/EC).

The need to improve the management of water in large waterbodies, including reservoirs, to ensure fish migrations was also noted. This is a particularly significant means of mitigating 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 also identified as a countermeasure in the Country Reports. These impacts are caused by water-management activities (e.g. irrigation), but also by a result of land-use change, development of floodplains and urban and industrial development. Agricultural 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 passways for other aquatic animals were recommended as remediation measures.

Several strategies were identified by a number of countries as means of mitigating the loss of natural habitats through environmental degradation, water management and land-use change. These include:

- developing conservation and protection programmes focusing on critical breeding and nursery habitats;
- delineating and protecting breeding areas in lakes and rivers and developing networks of spawning areas along larger rivers;

- establishing fish sanctuaries and dry season refuges in floodplains;
- restoring habitat in freshwaters and seeking to restore the environmental quality and habitat of spawning and juvenile grounds; and
- protecting riparian vegetation, upland forests and other terrestrial habitats that affect watersheds.

Several 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 that can increase 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, is important for the health of freshwater, estuarine, mangrove and delta systems. This can be achieved by improving agricultural 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. Limiting wastewater discharge and adjusting land management can further reduce external nutrient and solid substance loads in waters.

Reducing levels of pollution, particularly from urban and industrial sources, will have positive impacts on aquatic ecosystems and habitat. Similarly, reducing pesticide and nutrient runoff from agriculture would be an important outcome. This can be promoted by improved regulation and relevant economic incentives.

In marine areas, conservation 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 has the potential to protect habitats from further degradation from human disturbances (e.g. from active fishing gear) and can contribute to habitat restoration.

Some countries noted that strengthened regulatory systems must be established in order to achieve these outcomes. Steps include:

- effective environmental impact assessment 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;
- 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 may have both positive and negative impacts on AqGR. Recreational fishers can support the conservation of wild relatives by conserving both their habitats and their populations. In terms of reducing the impact of fishing on wild relatives, most recreational fisheries have regulations aimed at conservation of the stock.

3.2.2 Pollution of waters

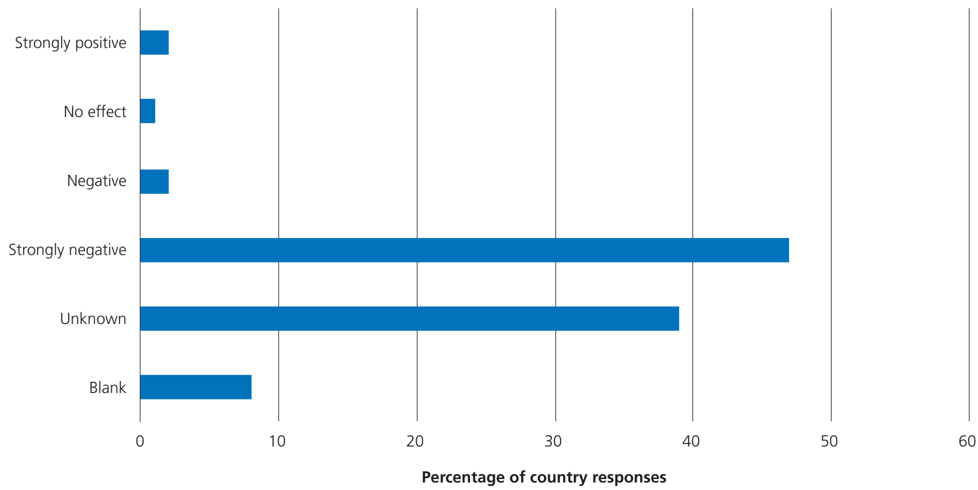
Forty-nine percent of reporting countries recognized the negative impacts of pollution on ecosystems and the consequent effect on AqGR. A further 39 percent reported that this effect was unknown (Figure 58). Human population increase and increased urban development and industrialization will augment the pollution threats to aquatic ecosystems. Both freshwater and coastal waters are impacted, to varying degrees, by pollution, which can directly affect aquatic organisms, including their reduced reproductive performance through acute toxicity or chronic sublethal effects that cause mutations, deformities and bioaccumulation.

The detailed input from countries identified actual and potential sources of pollution entering open waters including the following:

- urban sewage discharges;
- industrial and mining 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 leakages from nuclear power station accidents (e.g. Chernobyl, Fukushima).

There were comparatively few examples provided from the marine environment. The focus of the direct impacts of pollution was 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

FIGURE 58
Country responses on the effect of pollution on aquatic ecosystems that support wild relatives of farmed aquatic species



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q19 (n = 92).

than 2 percent of the countries reported no effect.

Typically, aquaculture operations are not 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. Pollution poses a significant risk to aquaculture 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). Both farmed aquatic organisms and wild relatives are directly at risk from poisoning and water-quality impacts caused by pollution. Species higher in the food chain and filter-feeding organisms are at significantly greater risk as they can concentrate toxins in their tissues. In turn, consumers are also at risk from prolonged consumption of contaminated aquatic organisms. Table 32 indicates the various types of impact where pollutants affect AqGR (farmed types or wild relatives).

Countries that provided responses indicating solutions to their problems commonly referred to the establishment of effective regulatory regimes to address pollution and its environmental impacts. These ranged 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 Climate change

In terms of wild relatives, rising water temperatures, where they occur, may extend the range of native species within large continental rivers and along coasts. Extreme rises in water temperatures can result in mass mortalities, as occurred during a marine heatwave event in Australia, described in Box 14.

In response to a question on the direct impacts of climate change, many countries (60 percent) considered that climate change would have negative effects on wild relative AqGR (Figure 56), generally driven by ecosystem impacts. The following were noted as specific examples of the current potential impacts of climate change:

- shifting species distribution because of temperature or salinity changes, or inability to shift because of geographical features (e.g. bays, lagoons, gulfs), results in the loss of stocks (Australia, China, Costa Rica, Dominican Republic); similar impacts on distributions because of temperature are observed in freshwater (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, 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 of climate change 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.

A reported positive effect of climate change on wild relatives related to the pressure to develop aquaculture stocks of species that were disappearing from wild catches. In another cases, 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.

TABLE 32

Types of pollution and their potential impact on wild relatives of aquatic genetic resources

Source of pollution	Typical pollutants	Impacts on aquatic genetic resources
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 are 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

Box 14
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. Sea surface temperatures at that time rose more than 3 °C above long-term monthly averages, with these averages exceeded by 5 °C in some locations at its peak. The 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 the heatwave, significant changes in population numbers were recorded for a number of important seafood species (Caputi *et al.*, 2015), but perhaps the most dramatic was 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 marine 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 the 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, to understand 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 respond to changing conditions. The screening of variation in samples collected from the wild shows that "neutral" SNPs (i.e. DNA markers that are not under the influence of natural selection) provide evidence for 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 had yet occurred, but this would seem likely in the longer term, due to the severe genetic bottleneck effects (Sandoval-Castillo *et al.*, 2015).

In the most severely impacted parts of this fishery, the remnant populations are either unlikely to recover or may recover slowly. Information from genetic studies can shed light on 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).

Another question referred to the ways in which wild relative AqGR have been affected indirectly by climate change via the impacts of increased frequency of extreme weather events and the effects of long-term climate change on aquatic ecosystems. Sixty percent of responding countries believed that the indirect effects of climate change through its impacts on ecosystems are negative (Figure 59). There was a relatively high level of uncertainty regarding impacts (33 percent). Notably, there is a need to assess anthropogenic and environmental factors affecting aquatic ecosystems. Efforts to address the implications of climate change for fisheries and aquaculture should strongly emphasize the ecological and economic resilience of fisheries and aquaculture operations in the development of effective and adaptive management systems.

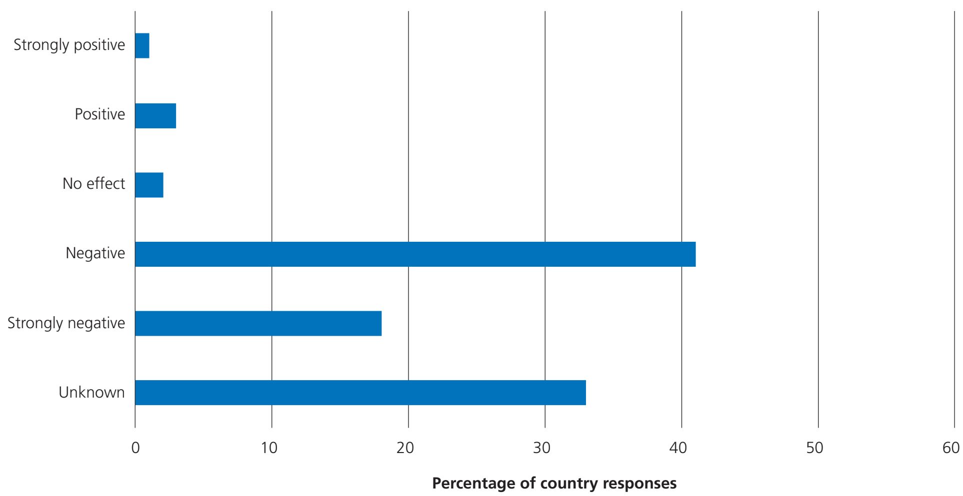
Many of the identified impacts concerned terrestrial and freshwater ecosystems and coastal environments, with correspondingly fewer concerning marine systems. The impacts were typically related to effects on wild relatives, but also included culture systems (farmed types) in some instances. General ecosystem-level changes affect water availability, hydrological regimes and habitats. This has a variety of knock-on effects on AqGR (Bangladesh, Benin, Brazil, Chile, Democratic Republic of the Congo, Ecuador, Egypt, Honduras, Kazakhstan, Kenya, Panama), particularly on 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 pertained to unseasonal or extreme weather conditions. Heavy rainfall leading to flash flooding was an identified threat. Excessive rain can cause farmed type stocks to be washed out into the wild and increases the risk of escapees. Adaptation measures identified by responding countries were concerned with improving the biosecurity of flood-prone aquaculture (ponds and cages). Unseasonal rainfall and flooding (Cuba, Nigeria, Sri Lanka, United Republic of Tanzania) can often cause 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. The loss of water area

FIGURE 59

Country responses on the indirect effects of climate change on wild relatives of aquatic genetic resources through impacts on aquatic ecosystems



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q19 (n = 92).

and/or habitat can have serious consequences for wild relatives, as well as for 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 reported as a further measure for adaptation to climate change. Stocking programmes to mitigate loss of recruitment are also being considered as another adaptation measure for some large waterbodies.

Sea level rise and reduced freshwater flows in rivers result in seawater intrusion in delta areas, such as the Mekong Delta in Viet Nam (Vu, Yamada and Ishidaira, 2018). 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.

Water temperature rise will enable species to extend their ranges in temperate areas and encourage the establishment of invasive species. Warming temperatures will also increase the range of some non-native species and support their establishment. For example, Sweden reported that common carp and grass carp (*Ctenopharyngodon idella*) have become established in the wild as a direct result of climate change. Warming can also lead to competition between indigenous species, as in the case of brown trout (*Salmo trutta*) which were being displaced by cyprinids, as reported in Hungary.

A major impact of climate change on AqGR occurs via 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). Climate change induced habitat loss or change can also include declining water coverage or even the 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).

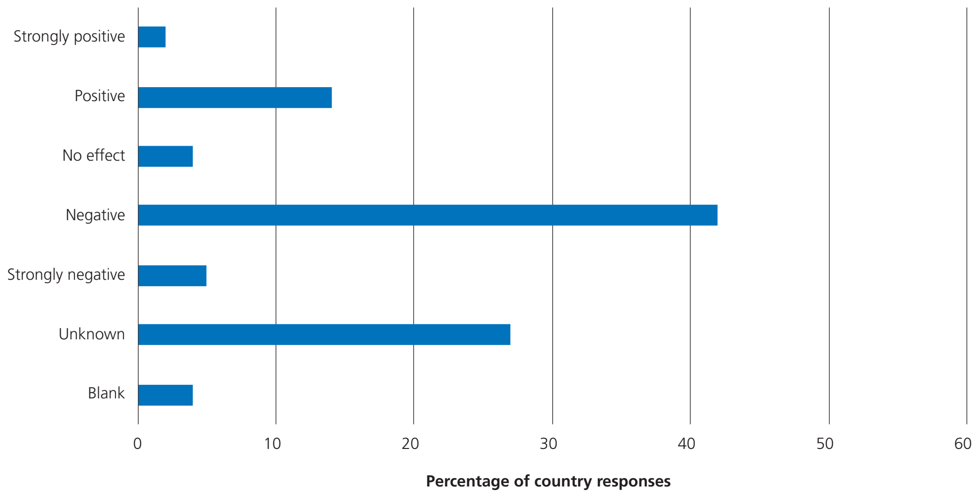
3.2.4 Impacts of purposeful stocking and escapees from aquaculture

Just under half of country responses (47 percent) indicated negative impacts on wild relatives due to ecosystem impacts from purposeful stocking and escapees from aquaculture (Figure 60). These responses mostly related to (i) genetic impacts associated with poorly managed stocking programmes and (ii) negative interactions of aquaculture stock with wild relatives. The latter include 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.

Twenty-seven percent of countries responded that the impacts of this driver on aquatic ecosystems of relevance for wild relatives of farmed aquatic species were unknown. This draws attention to the knowledge gap that exists with respect to 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 to be a means of mitigating impacts of fisheries or a fishery enhancement strategy in a number of countries. Bert *et al.* (2007) discuss the issues around effective genetic management of hatchery-based stock enhancement.

FIGURE 60

Country responses on the effects of purposeful stocking and escapees from aquaculture on wild relatives of farmed aquatic species



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q19 (n = 92).

Sixteen percent of countries acknowledged that there were positive impacts of purposeful stocking and escapees on wild relatives; the 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 percent) 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 that consider culture-based fishery and fishery enhancements as largely positive (or having no overall impacts) versus those countries that had experienced aquaculture escapes, which they consider to have a negative impact. It is not possible to disaggregate clearly between these two issues. Future questionnaires will need to treat the 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 15).

3.2.4.1 Types of impacts from purposeful stocking

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 the genetic structure of populations and stocks (Lorenzen, Leber and Blankenship, 2010).

Box 15
Useful information contained in the FAO Database on Introductions of Aquatic Species

The FAO DIAS was initiated in the early 1980s. Initially, the database 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 names 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 provide lists of known introductions according to purpose of the introduction including: accidental introduction, for aquaculture, as an ornamental species, for angling/recreational fishing and for biological control.

DIAS can be used to compare the outcomes (positive and negative) of introductions undertaken for different purposes (including accidental introductions) and via different pathways.

The 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.

Although the stocking and introduction of species may have had obvious benefits, they are not without cost, and the issue of introducing fish species can be highly controversial.

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

Of particular concern are potential shifts in the food-web structure and trophic status of the ecosystem, 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 and their ecosystems. The potential impacts of purposeful stocking are summarized in Table 33.

A major weakness of many stocking programmes is the failure to fully evaluate 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 16.

3.2.4.2 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 include:

TABLE 33

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

Impact	Causative stocking activity
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
Changes in relative abundance of species	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 these populations and even the breakdown of population structure, which can impact the adaptive fitness of the stocks.
Loss of genetic diversity and fitness	Lack of attention to genetic management of broodstock within the aquaculture 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 low genetic diversity. This is more likely where the wild stock is reduced to low levels prior to stocking. This situation 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 of species following stocking events, possibly resulting in the loss of ecosystem services

Source: Adapted from FAO, 2015.

Box 16

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 (*Salmo trutta*), lake trout (*Salvelinus namaycush*), barbel (*Barbus barbus*), burbot (*Lota lota*), grayling (*Thymallus thymallus*) and tench (*Tinca tinca*). 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.[1] 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[2] for those active in the fish-related management of bodies of water.

[1] https://www.genres.de/en/sector-specific-portals/fish-and-other-aquatic-organisms/
[2] https://agrdeu.genres.de/agrdeu

- flooding of aquaculture ponds releasing fish into nearby waterways (this can result in massive releases, e.g. in the case of 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 (including aquarium species) into waterways; and
- small numbers of animals can be translocated by predatory birds and some aquatic species are capable of travel across land. Such translocations are limited to small numbers but are 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 34.

3.2.4.3 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. Regulation and monitoring of ornamental fish movement are often carried out separately to that for aquaculture of food species. 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 causes of escapes; 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 red lionfish (*Pterois volitans*) and devil firefish (*P. miles*) that have become established throughout the Western Atlantic Ocean and the Caribbean Sea. These species are believed to have escaped from aquaria or related facilities between the

TABLE 34

Range of threats presented by aquaculture escapees to aquatic genetic resources of wild relatives and farmed types

Resource 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 silver barb (*Barbonymus 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). Escaped farmed types that become established may compete with indigenous fauna and flora.
	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 maladaptations for wild relatives may include less aggressive behaviour. Some of these maladaptations may limit the success of the escapee in 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.

late 1980s and 1990s, and are thought to be responsible for declines of native fish in the region (Green *et al*., 2012; Ballew *et al*., 2016).

3.2.5 Establishment of invasive species

Numerous examples exist of non-native species that have become established accidentally or deliberately beyond their natural range. Some of these introductions have had adverse environmental and economic impacts, i.e. these species became invasive or introduced pathogens (Hilsdorf and Hallerman, 2017). Well-known cases that 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 (*Cyprinus carpio*) in the Murray River in Australia (Koehn, 2004). However, some introductions have resulted in the establishment of significant commercial food fisheries, particularly in human-constructed waterbodies, with examples including tilapia in Sri Lanka (De Silva, 1985) and the clupeid *Limnothrissa miodon* in Lakes Kivu and Kariba in Africa (Spliethoff, De Longh and Frank, 1983; Marshall, 1991).

Despite the abovementioned invasions having negative impacts on ecosystems, it was previously considered that the majority of introductions recorded in DIAS have had many more positive social and economic impacts than negative environmental impacts (Bartley and Casal, 1998). However, more recent data indicate that negative impacts of non-native species are increasingly being identified (see Box 13).

The Global Invasive Species Database (GISD, 2016) recognizes 131 invasive species of freshwater, marine and brackish-water ecosystems (Table 35). Not all introductions result in the establishment of the species.

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 impacting native species or the changes to foodchain linkages. Sometimes the impact is not directly apparent, and the species is simply

TABLE 35

Global Invasive Species Database lists taxa 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.

regarded as an unwanted species, less preferred than similar native species. Examples of the types of impacts are presented in Table 36.

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 61). This echoes the finding, as reported by 47 percent of countries, that purposeful stocking and escapees from aquaculture (as a source of invasive species) had predominately negative impact, with only 16 percent reporting a positive impact (Figure 60). 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 wild AqGR from invasive species and the transfer of aquatic pathogens through movements and introductions.

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 of translocations (Box 17). There is also a need to limit or prevent further movement within a country once a species has become established. This is clearly an area where there is strong justification for more effective and comprehensive monitoring of AqGR in general and invasive species in particular (Germany, Republic of Korea).

Countries also indicated the impacts of some non-fish species that 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 control 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 International Council for the Exploration of the Sea code of practice (ICES, 2005) on introductions has been adopted, in principle, by FAO's

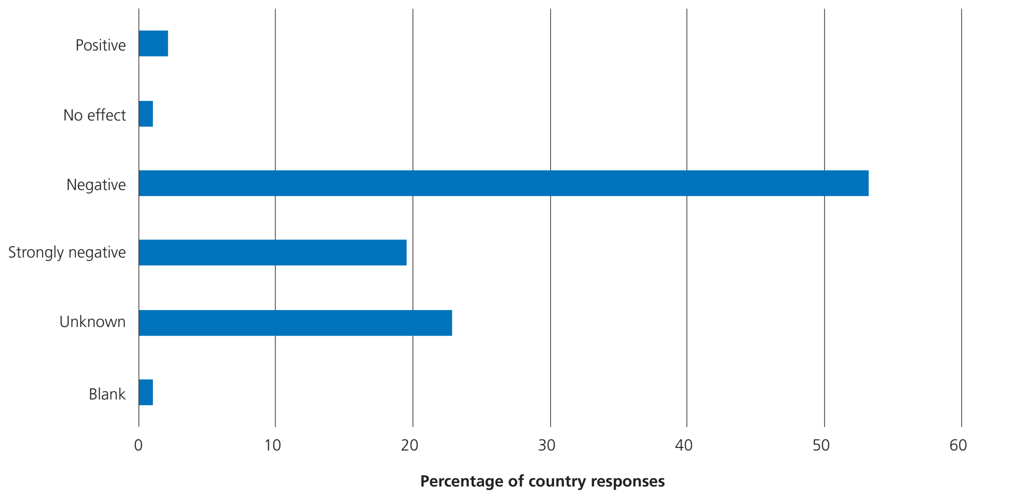
TABLE 36

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

Type of Impact	Causes and examples
Introduction of disease	• Disease in native and non-native species cause by pathogens/parasites carried by introduced species
Effect on food webs	• Direct predation on native species including on eggs and larvae • Transmission of parasites/disease to both wild and farmed types • Predation on prey species (e.g. insects, zooplankton) of native fish
Competition	• Higher fecundity can assist a species to outcompete a similar but less fecund native species • Introduced species can have a greater tolerance for adverse environmental conditions • Exclusion of native species from breeding areas or disruption of breeding areas • Competition for mates and/or mating sites • Crowding out of native species
Engineering of ecosystems, undesirable behaviour or characteristics	• Burrowing into river banks, affecting stability, etc. • Causing an increase in turbidity, for example by benthic feeding introduced species • Removal of vegetation • Clogging of aquatic habitats impacting flow, for example by the floating water hyacinth (*Eichhornia crassipes*) or the benthic fouling zebra mussel (*Dreissena polymorpha*)

FIGURE 61

Country responses on the effects of establishment of invasive species on wild relatives of farmed aquatic species



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q19 (n = 92).

inland regional fisheries bodies (see Bartley and Halwart, 2006).

Existing regulations include, for example the European Union Council Regulation (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. ecological consequences and the introduction of diseases and parasites).

Various efforts have been made 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* spp.) in the Philippines;
- harvest and direct use as fish or livestock feeds: e.g. golden apple snail (*Pomacea canaliculata*) in Bangladesh and the Philippines.

3.2.6 Introductions of parasites and pathogens

A majority (69 percent) of the responding 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

Box 17

Impact of invasive mussels on local genetic diversity

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

One of the impacts of the invasive species can be introgression with local species, as has been documented in California, United States of America. Here, the Mediterranean mussel (*Mytilus galloprovincialis*) was introduced through human activities and has been present for at least several decades, establishing extensive populations in the wild. In some locations, these have displaced the native *M. 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 (double digest restriction site-associated DNA, or ddRAD-seq). 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 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 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.

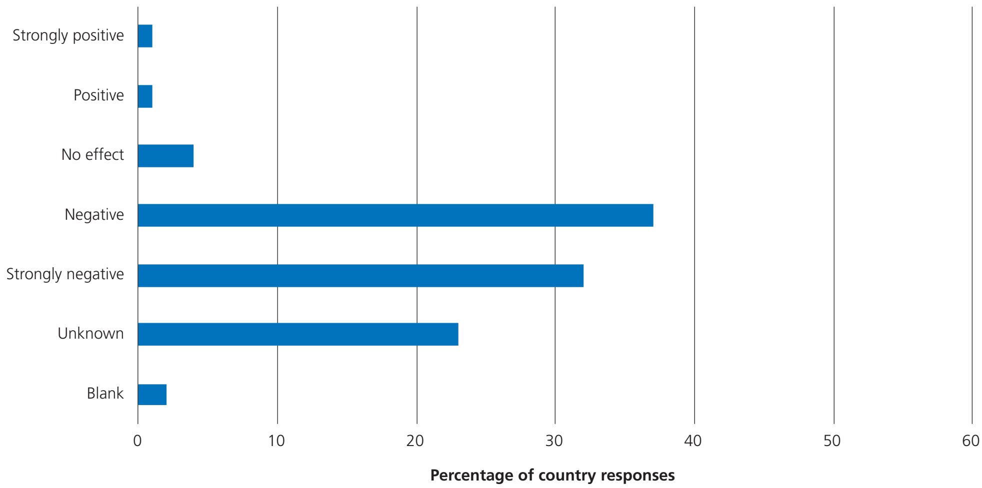
as ballast water and migrations. Only 2 percent of countries believed the impacts were positive (Figure 62).

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

- the introduction of crayfish plague (*Aphanomyces astaci*), which spread following the introduction of the signal crayfish (*Pacifastacus leniusculus*) and devastated noble crayfish (*Astacus astacus*) populations (Alderman, 1996; Söderhäll and Cerenius, 1999; Edgerton *et al.*, 2002);
- the spread of *Bonamia* parasites through European oyster stocks as a result of the movement of non-native oysters, 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, largely as a consequence of the largescale translocations of post-larvae or introduction of new species for aquaculture. Common shrimp diseases include Taura syndrome virus, white spot syndrome virus, infectious hypodermal and hematopoietic necrosis virus, yellow-head virus disease, and

FIGURE 62

Country responses on the effects of introduction of parasites and pathogens on wild relatives of farmed aquatic species



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q19 (n = 92).

acute hepatopancreatic necrosis syndrome (Lightner, 1999; Tran *et al.*, 2013);

- mortalities in tilapia caused by *Streptococcus* infections or the more recently identified tilapia lake virus (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 analyses show that problems with the spawning migration of the European eel can occur if infestation is serious enough (Székely *et al.*, 2009; Lefebvre *et al.*, 2012);
- various carp viruses (e.g. koi herpes virus, carp edema virus), which have been transferred through movements of fish for aquaculture and for the aquarium trade (Adamek *et al.*, 2018; OIE, 2018);
- transmission of various salmon parasites and diseases (e.g. infectious salmon anaemia and pancreas disease, furunculosis, *Gyrodactylus salaris*), which have affected the cultured salmon industry and wild relatives, in some cases due to interactions (bidirectional) between the two (Bakke and Harris, 1998; Olivier, 2002; Pettersen *et al.*, 2015);
- viral haemorrhagic septicaemia, infectious haematopoietic necrosis and whirling disease in salmonids (Warren, 1983; Bartholomew and Reno, 2002; Dixon *et al.*, 2016); and
- 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).

The actions that need to be taken to prevent or minimize the impacts of the spread of aquatic pathogens are similar to those needed to do this for introductions and movements of aquatic species, as the spread of invasive species and the 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.

In contrast to the examples above, there are cases 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 (*Cyprinus carpio*) from the Murray-Darling River (Australia).[32]

3.2.7 Impacts of capture fisheries on ecosystems and wild relatives

Capture fishery impacts on AqGR are most commonly linked to impacts on wild relatives in situations where they are directly targeted; these are generally negative (Figure 63). Seventy-three percent of country responses considered these impacts to be negative or strongly negative.

Threats to AqGR via ecosystem impacts are linked to the level of fishing pressure, the extent to which or not it is effectively managed, and whether a fishery targets vulnerable or critical life stages. In the latter case, this includes fisheries that 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 food or as a source of juveniles for fattening in aquaculture systems (e.g. eel, bluefin tuna, yellowtail, grouper, marble or sand goby). Two examples of the relationship between aquaculture and wild relatives as a source of seed are discussed in Box 18.

[32] www.carp.gov.au

More general impacts of fishing 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 (caused by gear interactions with habitat and consequent impacts on a non-target species). Examples of bycatch issues include the capture of juvenile wild relatives in trawl and push net fisheries (FAO, 2014c).

Country comments on how to mitigate or prevent such impacts proposed the adoption of an ecosystem approach to fisheries (EAF) management, an approach that takes into account the broader ecosystem impacts of the fishing activity beyond the target stocks, and that incorporates habitat and environmental considerations. The comments also emphasized the need for more effective measures to minimize the impact of fisheries on critical life stages and habitats.

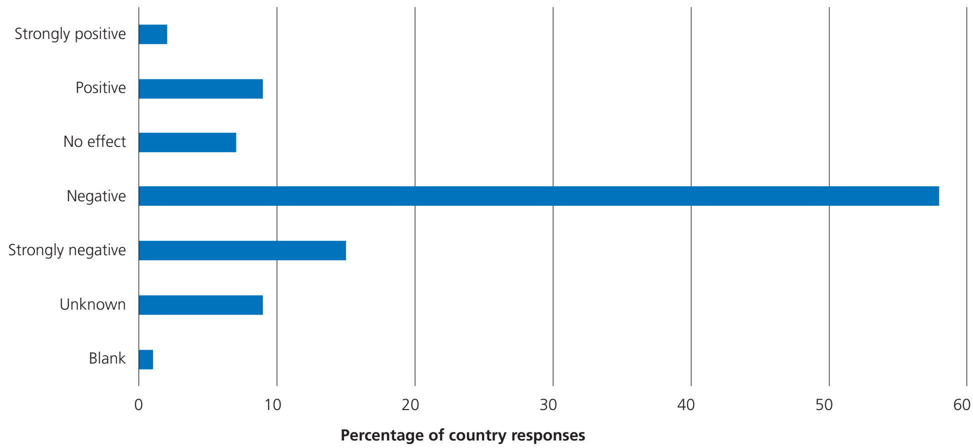
Eleven percent of countries considered that capture fisheries had a positive impact on the ecosystem and consequently on AqGR (Figure 63). This response was difficult to interpret, although it appeared to refer to situations in which effective fishery management measures were being put in place to address potential impacts on AqGR.

Belize reported that fishing pressure on invasive tilapia has been keeping the species under control. Bulgaria has implemented a fishing ban on sturgeon, which has driven the development of sturgeon aquaculture. In the case of freshwater fisheries in Germany, there is an obligation of fishery management to achieve a diversity of fish species adapted to waterbodies and fisheries.

Responsibly managed fisheries, for example using EAF, can be considered to constitute a form of *in situ* conservation (see Chapter 4). This requires the fisheries sector to commit to the protection of aquatic habitats and the protection of aquatic species in addition to the species being targeted by the respective fishery.

FIGURE 63

Country responses on the effects of capture fisheries on wild relatives of farmed aquatic species



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q19 (n = 92).

Box 18

Links between wild relatives and aquaculture that depends 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. The production is exclusively based on wild-caught seed, which is either collected directly from mussel beds on rocky shores or obtained via natural spatfall on collectors hung from the rafts (Perez-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 amberjack culture in Japan (Ottolenghi *et al.*, 2004). The Japanese have traditionally fished and cultured three *Seriola* species (*S. quinqueradiata, S. dumerili* and *S. lalandi*) 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). This level of production has been maintained, with 2016 production estimated at 140 868 tonnes (FAO, 2018b). 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.

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 populations, 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 reported the impact of capture fisheries to be unknown.

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Online resources

- FAO Database on Introductions of Aquatic Species (www.fao.org/fishery/dias/en)
- 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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In situ conservation of farmed aquatic species and their wild relatives within national jurisdiction

CHAPTER 4

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), as it maintains the link between the resource and the environment, regardless of whether that environment is in nature or on-farm.
- Priorities reported for aquatic protected areas, one of the mechanisms available for *in situ* conservation, were different among regions.
- Countries reported on over 2 300 protected areas, with the large majority considered to be very or somewhat effective for conservation.
- Responsible and well-managed aquaculture and culture-based fisheries were reported to be mechanisms for *in situ* conservation.
- On-farm *in situ* conservation, which is commonplace in terrestrial agriculture for varieties and breeds developed and maintained on farms, is rarely applicable to AqGR, due to the relatively recent domestication of most aquatic species.

4.1 Introduction

Many of the drivers threatening aquatic genetic resources (AqGR), including wild relatives, have been discussed in Chapter 3, highlighting the need for conservation of key resources, particularly those under threat. Wild relatives of all 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. Therefore, effective *in situ* conservation is a critical component of the work to preserve and enhance the role that AqGR play in ensuring food security.

In situ conservation, as defined by the Convention on Biological Diversity (CBD, 1992), 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.*

The CBD further 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 and to adapt to *in situ* conditions. *In situ* conditions could be a fish farm, pristine aquatic ecosystems, or ecosystems impacted by development (e.g. damming of rivers or coastal erosion).

The Code of Conduct for Responsible Fisheries (FAO, 1995) states that:

> *States and subregional and regional fisheries management organizations should apply a precautionary approach widely to the conservation, management and exploitation of living aquatic resources in order to protect them and preserve the aquatic environment, taking account of the best scientific evidence available. The absence of adequate scientific information should not be used as a reason for postponing or failing to take measures to conserve target species, associated or dependent species and non-target species and their environment.*

Scientists and conservationists have long recognized the importance of the conservation of aquatic resources and the need for effective policy to support action in this regard. Issues on the conservation of AqGR were comprehensively reviewed at an international conference "Towards Policies for Conservation and Sustainable Use of Aquatic Genetic Resources", held in Italy in 1998. The proceedings of this meeting included reviews of cases of AqGR conservation and related policy in specific countries and regions and in relation to specific species (Pullin, Bartley and Kooiman, 1999). The publication also covered the implications of the biotechnological developments of the time and issues related to intellectual property rights, governance and legal regimes. Much of this information remains pertinent today.

There are a range of *in situ* conservation strategies that can be applied. These should in general protect aquatic resources in ways that will preserve habitats and ecosystems. Mechanisms can include aquatic diversity management areas, aquatic protected areas, bioregional management and effective fisheries management. Such mechanisms should incorporate information on threatened or endangered species designations and research findings where available. Specific measures that can be taken in support of these mechanisms can include increasing public awareness, specific restoration or mitigation efforts, specific regulatory measures and local community actions.

Numerous examples exist of *in situ* conservation of AqGR. The most widely cited are marine protected areas (MPAs), freshwater protected areas (FPAs), Ramsar[33] sites, and the International Union for Conservation of Nature (IUCN)[34] 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.

Aquatic diversity management areas were proposed by Moyle and Yoshiyama (1994) based on five tiers of approach, from conserving individual threatened and endangered species through to bioregional landscape plans for integrated use. This approach does not appear to have been widely adopted.

Aquatic protected areas have been widely promoted and adopted for conservation and fisheries management over the past two to three decades, but they are not without controversy given the differing ideologies of resource uses in many aquatic areas (Agardy *et al.*, 2003). MPAs are defined as "a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values" (Day *et al.*, 2012). MPAs have been created in many parts of the world, predominantly in developed countries. In a review of relevant literature from 2000 to 2013, Rossiter and Levine (2014) identified and discussed six factors critical to the success of MPAs: level of community engagement; socio-economic characteristics; ecological factors; MPA design; governance; and enforcement. Edgar *et al.* (2014) further identified five critical elements that appeared to contribute to successful outcomes from MPAs. Based on a review of 87 MPAs worldwide, they identified that the conservation benefits increased with the accumulation of five features, which are: no take (i.e. no fishing); strong enforcement; maturity (being in place for more than ten years); being larger (more than 100 km²); and being isolated by deep water or sand. MPAs exemplify circumstances in which fishery management and conservation can have common goals. MPAs are not without controversy, however, as their efficacy as tools for fishery management and increasing fish production has been questioned (Adams *et al.*, 2004; Weigel *et al.*, 2014). As indicated above, there can often be tension between those

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

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

seeking more conservation from a protected area and those seeking more livelihood benefits. The issues around the effectiveness of MPAs are comprehensively debated in Pendleton *et al.* (2017).

The threats to inland aquatic environments are in many ways more challenging than for marine environments. For example, in the case of inland fisheries there is a lack of information on what and how much is being harvested from the world's freshwater ecosystems. In addition, as outlined in Chapter 3, the threats from habitat destruction and the competition for resources can be relatively greater for inland waters. This increases the need for conservation, especially given that freshwater finfish are considered to be the most threatened group of vertebrates used by humans (Ricciardi and Rasmussen, 1999; IUCN, 2010; Carrizo, Smith and Darwall, 2013; NSW DPI, 2018).

The uptake of use of protected areas in freshwater environments has been relatively slow compared to MPAs; even the term freshwater protected areas, or FPAs, has not entered common usage. However, Suski and Cooke (2007) report on many examples in which FPAs have been incorporated into successful management approaches for freshwater environments; they discuss some of the reasons why FPAs have not proliferated to the same degree as MPAs and present some of the challenges that managers and scientists must overcome. These challenges include the difficulty involved in identifying areas or species in need of protection and in addressing all threats to the freshwater environment, as well as the myriad of issues involved in implementing FPAs, many of which are common to MPAs. Yang *et al*., (2018) provide an overview of a national programme of Aquatic Genetic Resource Reserves in China, which are predominantly focused on inland waters. From 2007 to 2014, China established 464 reserves, 90 percent of which were inland (63 percent covering rivers, 24 percent lakes, 2 percent reservoirs and 1 percent estuaries). These reserves were listed as protecting a total of 453 species, of which more than 75 percent were finfish. Crustaceans, shellfish, other aquatic animals and aquatic plants accounted for 9.3 percent, 3.9 percent, 5.4 percent and 1.3 percent of the protected species, respectively.

Rice fields are an example of a modified ecosystem that can serve as a site for *in situ* conservation of biological diversity if properly managed. Rice fields in Asia have been shown to contain over 100 species, including finfish, 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.

The Ramsar Convention is critical to conservation of inland and coastal aquatic resources. The Ramsar List of Wetlands of International Importance, which includes more than 2 300 sites, is the world's largest network of protected areas, and these sites provide an excellent means of *in situ* conservation of AqGR. In 1996, the Sixth Meeting of the Conference of Contracting Parties adopted criteria, based on characteristics of aquatic biodiversity and important traditional use of fisheries, for identifying wetlands of international importance. This allowed wetlands that support traditional fisheries and fishing communities to be included in the listing.

Aquatic protected areas, both MPAs and FPAs, have been strongly promoted as a method for conserving biological diversity. Aichi Biodiversity Target 11 of the CBD calls 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 19). These categories reflect different objectives of protected areas or of *in situ* conservation.

In addition to protected areas, 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 adequately evaluated on a global scale (Roni *et al.*, 2005).

This part of the Report evaluates the extent to which the use of AqGR through aquaculture and fisheries contributes to its conservation in the member countries. The findings below are based on country responses to a section of the questionnaire that included a total of seven questions focused on the extent of, and rationale for, *in situ* conservation and the roles played by aquatic protected areas, fisheries and aquaculture.

Box 19

International Union for Conservation of Nature Protected Area Categories System[1]

IUCN categories classify protected areas according to their management objectives (Dudley, 2008). 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.

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

4.2.1 Conservation of wild relatives

The Country Report responses indicated that many populations of wild relatives are decreasing in abundance (Section 2.5.1, including Figure 40). Information on the conservation status of such species will be important in identifying future actions for their conservation. A decreasing fishery yield, i.e. catch, combined with a decreasing habitat could provide a proxy indicator for the level of endangerment of 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, for example salt marshes or vernal pools.

4.2.1.1 Priority species

Table 37 lists the top ten wild relative species most frequently identified from the Country Reports for which habitat is decreasing. A comparison with the IUCN Red List[35] shows that only one species, European eel (*Anguilla anguilla*), was listed as critically endangered, one as near threatened – the clown knifefish (*Chitala chitala*); and one as vulnerable – the common carp (*Cyprinus carpio*). While several species are assessed as being of least concern, their population trends are unknown. The majority of the species are in the top ten freshwater or diadromous fishes, for example the European eel (*Anguilla* spp). The European seabass (*Dicentrarchus labrax*) is the only marine species.

Although, at the level of species, tilapia (*Oreochromis* spp.) are not generally threatened, the concern has been raised that many natural populations are being introgressed with genes from other stocks and species (Gregg, Howard and Snhonhiwa, 1998; ADB, 2005). Thus, the genetic differences between natural stocks of tilapia may be lost. Brazil and Colombia reported populations

[35] www.iucnredlist.org.

TABLE 37

Top ten species most frequently reported by countries as having decreasing catches of wild relatives, including the status of the species on the International Union for Conservation of Nature Red List

Species name	Common name	Number of responses indicating population decrease	Number of responses indicating habitat decrease	IUCN Red List Categories and Criteria	Population trend from Red List
Oreochromis niloticus	Nile tilapia	7	9	NA	U
Anguilla anguilla	European eel	6	4	CR	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	0	LC	U
Lates calcarifer	Barramundi	3	2	NA	U

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q14 relating to trends in catches of wild relatives (n = 92).
Note: The IUCN Red List; NA = not assessed; LC = least concern; V = vulnerable; NT = near threatened; CR = critically endangered. For population trend: D = declining; U = unknown.

of Arapaima (*Arapaima gigas*) as declining. This species is listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (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 according to IUCN's Red List, the available data were deficient to make an assessment. An improved global information system, the need for which was identified in Section 2.2, would help communicate authoritative information to help resolve such issues.

4.2.1.2 Objectives of in situ *conservation*

The Country Reports expressed differing objectives for *in situ* conservation, with "preservation of aquatic genetic diversity" and "maintain good strains for aquaculture production" accorded the highest priority and "to help adapt to the impacts of climate change" and "meet customer and market demands" the lowest priority (Table 38). The analysis revealed a similar trend across all regions, with the exception of North America, which listed "maintain good strains for aquaculture production" and "future strain improvement in aquaculture" as the highest priorities.

These priorities for *in situ* conservation varied somewhat among economic classes of countries, but in all cases "preservation of aquatic genetic diversity" had the highest priority (Table 39). Surprisingly, "meet customer and market demands" scored low, even in developing and least developed countries. This may be attributed to the fact that 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.

Other specific objectives reported by individual countries included:

- conservation of endemic species;
- maintenance of national heritage species;
- promotion of sustainable wild populations of aquatic organisms;
- maintenance and recovery of resources for commercial and recreational fishing; and
- conservation and restoration of 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 general trend described above (data not shown).

TABLE 38

Ranking of objectives for *in situ* conservation of aquatic genetic resources by region

Objective	Rank*						
	Africa	Asia	Europe	Latin America and the Caribbean	North America	Oceania	Global
Preservation of aquatic genetic diversity	2.1	1.4	2.5	1.7	3	1.3	1.9
Maintain good strains for aquaculture production	2.7	2.8	3.5	2.8	2.5	2.9	2.9
Future strain improvement in aquaculture	2.9	2.8	4.1	3.1	2.5	4.3	3.2
Meet consumer and market demands	3.4	3.8	5.4	3.6	3.5	4.9	4
To help adapt to impacts of climate change	3.4	3.7	5.6	3.4	3	5.4	4

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q23 relating to importance of objectives for *in situ* conservation (n = 90).

* Ranks were determined by averaging the rankings provided in the Country Reports. 1= very important; 10 = no importance.

TABLE 39
Ranking of objectives of *in situ* conservation of aquatic genetic resources by countries according to their economic classification

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
Future strain improvement in aquaculture	3.2	3.7	3.1	3
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

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture:* responses to Q23 relating to importance of objectives for *in situ* conservation (n = 90).

* Ranks were determined by averaging the rankings provided in the Country Reports. 1= very important; 10 = no importance.

4.2.1.3 Role of aquatic protected areas

Country Reports confirmed the importance of aquatic protected areas for *in situ* conservation. Overall, countries reported on 2 364 protected areas, with over 2 100 (89 percent) reported as being very or somewhat effective (Table 40 and Box 20). Very few countries reported aquatic protected areas as being ineffective. The regional data on the relative effectiveness are somewhat 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.

The trend was consistent across economic classes of countries (Figure 64) and also between major and minor aquaculture producing countries (data not shown).

TABLE 40
Number of aquatic protected areas and country assessments of their effectiveness in conserving aquatic genetic resources of wild relatives, by region

Effectiveness	Number of protected areas per region						
	Africa	Asia	Europe	Latin America and the Caribbean	North America	Oceania	Global
Very effective	104	296	7	394	797	14	1 612
Somewhat effective	217	156	85	70	0	1	529
Not effective	11		2	8	0	1	22
Unknown	11	37	16	115	0	2	181
No answer	5	3	9	1	1	1	20
Total	348	492	119	588	798	19	2 364

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture:* responses to Q27 (n = 71).

Box 20
***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*) (National Murray Cod Recovery Team, 2010). The federal government and all state governments with jurisdiction over the Murray-Darling River Basin, to which the fish are endemic, support this plan. The Murray cod is an important species in this large river basin, formerly supporting significant commercial and recreational fisheries. The objectives of the 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 of Murray cod conservation; and
- managing the Recovery Plan implementation.

The National Recovery Plan includes a review of knowledge of population genetics, current and future gene flow, and identification of any particular genetic units that need additional attention.

Bulgaria
As indicted in the Country Report from Bulgaria and in accordance with the European Union's Habitats Directive[1], a number of waterbodies in Bulgaria are designated as areas of national importance due to the presence of fish species of community importance, as listed in Annex 2 of the Directive. The effective management of protected areas with fish 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 Bulgaria's commitments under Article 8 of the Habitats Directive, a national framework for priority action (NFPA) under Natura 2000 for 2014–2020 was developed. The purpose of the 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
As reported in the Country Report, the *cyprinid Gymnocypris przewalskii* is endemic to the Lake Qinghai basin in China. The population of this species has decreased significantly since the 1970s. Most fish in the current population are less than 25 cm in length 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 *G. 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 the stock in the lake, including environment inspection.

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

In addition, the Rescue Centre for *G. przewalskii* was established (Xiong, Chen and Duan, 2010). The

(Cont.)

Box 20 *(Cont.)*

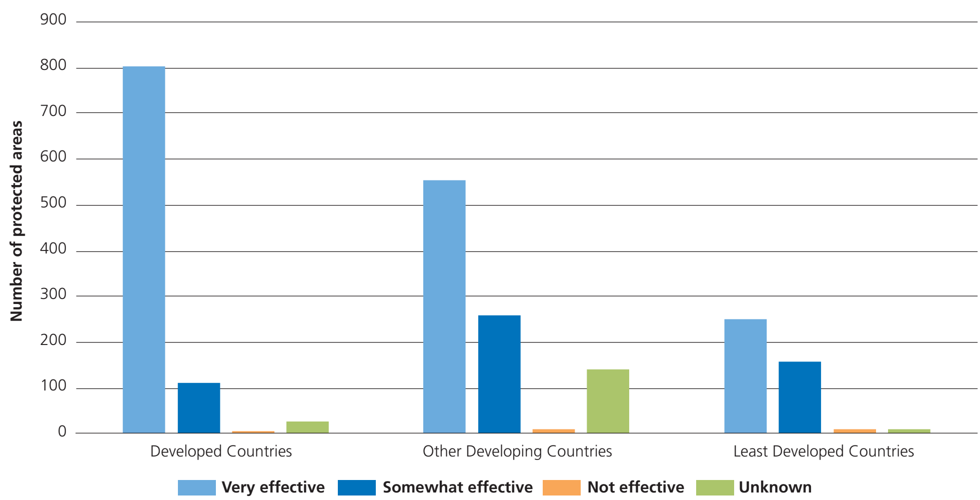
In situ **conservation examples: Australia, Bulgaria and China**

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.

[1] Directive 92/43/EEC of the European Union on the conservation of natural habitats and of wild fauna and flora.

FIGURE 64

Effectiveness of aquatic protected areas for *in situ* conservation of wild relatives of aquatic genetic resources (total number of protected areas per economic class)



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q27 (n = 71).
Note: Data from 20 protected areas for which no effectiveness level was provided are not included here.

4.2.1.4 The role of aquaculture and fisheries management

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 21).

The ecosystem approach to fisheries (EAF) (FAO, 2003) encompasses a 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

Box 21

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. In the case of livestock many of these breeds are at risk of extinction, and various actions are taken to support their continued maintenance and use in their usual production systems. In the case of crop resources many of these varieties are managed on-farm which might be considered a form of on-farm *in situ* conservation. However, the situation with AqGR is somewhat 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 28 in Chapter 9). 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 as forms of *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 to rebuild or to enhance 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.

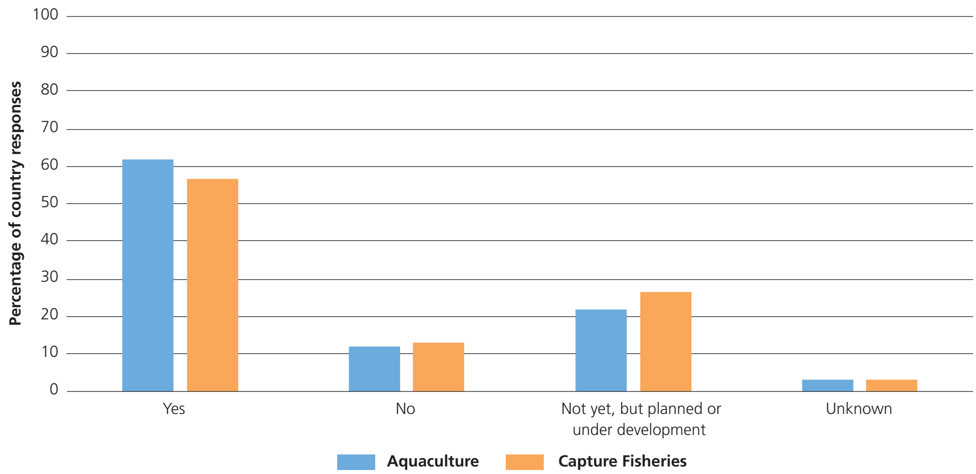
It is thus apparent that examples of "on-farm *in situ* conservation" are relatively rare for AqGR. Whether a conservation programme is labelled *in situ* or *ex situ* and/or "on-farm" is of less importance than is a clear statement outlining the objectives of the programme.

non-native rainbow trout, *Oncorhynchus mykiss*, 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 65). Over 60 percent of countries reported that conservation was an objective of aquaculture policies in their countries and over 55 percent responded similarly for fisheries policies. This was also evident when countries were analysed by region (Figure 66 and Figure 67), although Latin America and the Caribbean, and to a lesser extent African and Oceanic countries, indicated that these objectives were not yet incorporated into either aquaculture or fisheries policies. There were no major differences in responses based on economic class or level of aquaculture production (data not shown).

FIGURE 65

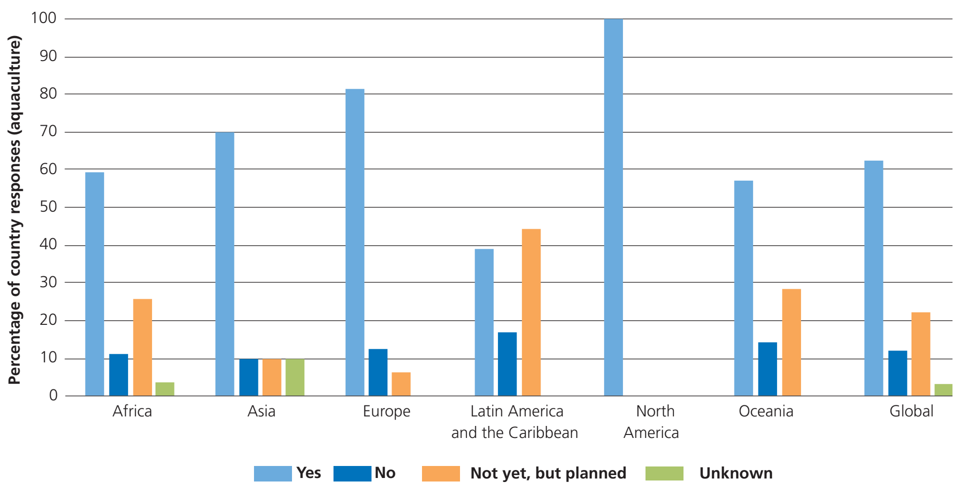
Countries reporting conservation of aquatic genetic resources as an objective of aquaculture and/or fisheries management policies (total for all countries)



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q24 (n = 90) and Q26 (n = 90).

FIGURE 66

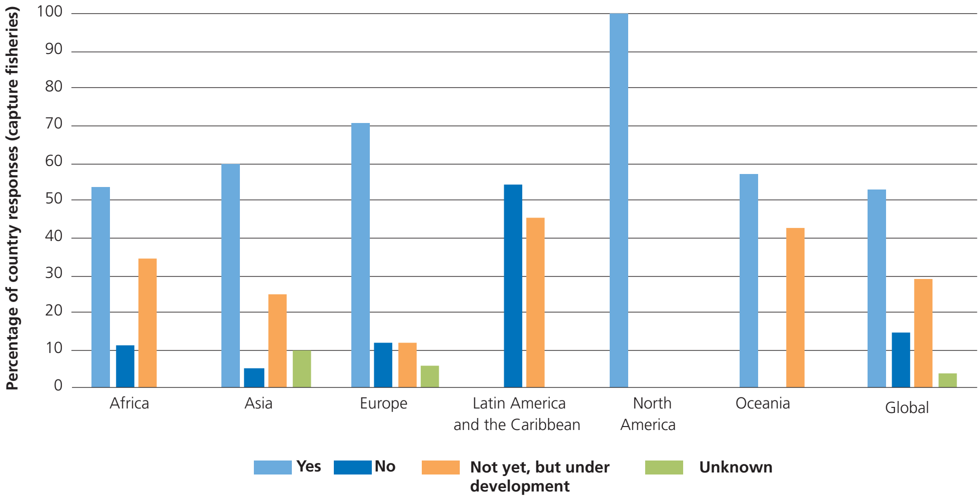
Countries reporting on whether conservation is included as an objective of aquaculture and/or culture-based fisheries policies, by region



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q24 (n = 92).

FIGURE 67

Countries reporting conservation of wild relatives of aquatic genetic resources as an objective of capture fisheries policies, by region



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q26 (n = 90).

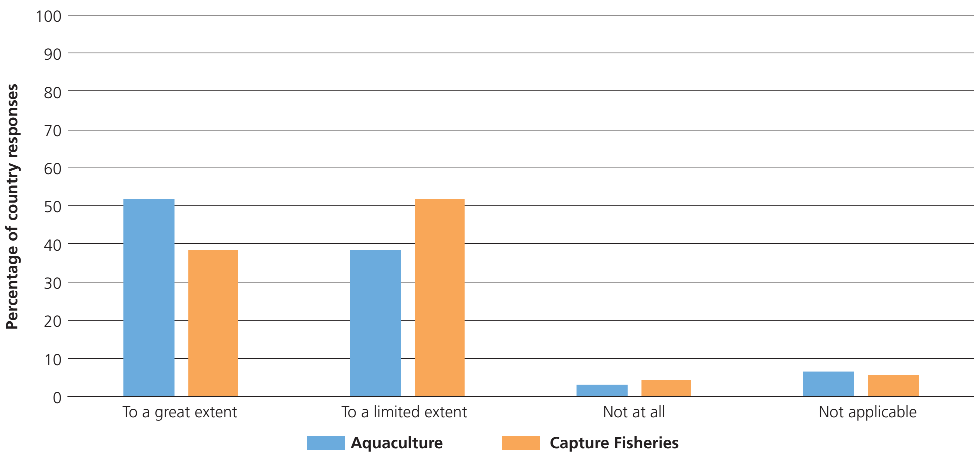
Countries reported generally positive messages with regard to whether they considered aquaculture and fisheries management to provide effective *in situ* conservation (Figure 68). This trend was present across categories in the analysis of countries grouped by region, economic class and level of aquaculture production (data not shown). It is noteworthy that both aquaculture and fisheries, when well managed, were seen as contributing to the conservation of AqGR to about the same extent. These results would appear to be in contrast to the findings in relation to drivers where the majority of countries (73 percent) identified capture fisheries as having a negative or strongly negative impact on wild relative AqGR. This may reflect alternative perspectives of different stakeholders that may have responded to these questions on the role of drivers and the impacts on conservation or may reflect the specific role of effectively managed aquaculture and fisheries.

The practice of the 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 regions, especially in North America and Oceania (Figure 69). Analysis of the impact of this practice by economic class indicated a lesser role (or perception of this role) in the least developed countries. It was noted that 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.

The "not applicable" reported in some regions, 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 58, Figure 69 and Figure 70). Thus, it is important that the objectives of *in situ* conservation should be explicitly stated in aquaculture

FIGURE 68

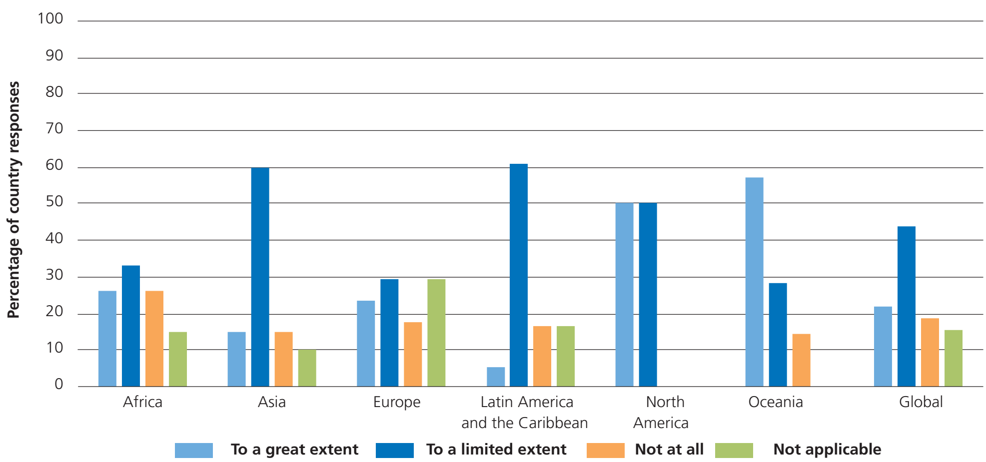
Country responses on the extent of effectiveness of culture-based fisheries and aquaculture in providing *in situ* conservation of farmed aquatic species and their wild relatives



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q20 (n = 91).

FIGURE 69

Country responses on the extent to which collectors of wild seed and broodstock for aquaculture and culture-based fisheries are contributing to the conservation of aquatic genetic resources (by maintaining habitats and/or limiting the quantities collected), by region



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q25 (n = 92).

and fisheries management policies and operating plans, and communicated to resource managers, fishers and fish farmers.

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 relative to the long history of domestication in terrestrial agriculture.

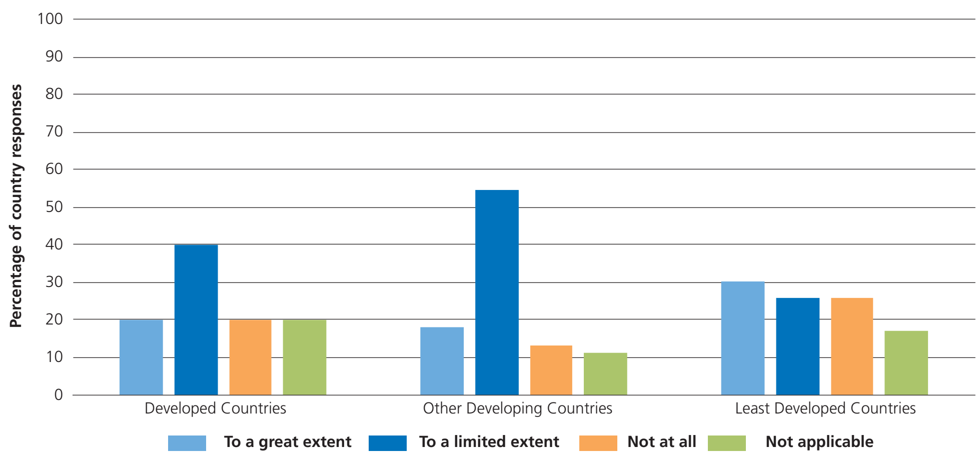
Living on-farm gene banks that would qualify as on-farm *in situ* conservation do exist for some countries (see Chapter 5). However, on-farm *in situ* and on-farm *ex situ* conservation are often difficult to distinguish. For the former, the farm must maintain a production environment and allow no further genetic alteration or manipulation of the conserved population. Under these conditions the conserved species or farmed type would adapt to the production environment over time.

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 21). The Fish Culture Research Institute in Szarvas, Hungary, maintains numerous strains of common carp (*Cyprinus carpio*) 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, Hungary).

FIGURE 70

Country responses on the extent to which collectors of wild seed and broodstock for aquaculture and culture-based fisheries are contributing to the conservation of aquatic genetic resources (by maintaining habitats and/or limiting the quantities collected), by economic class



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q25 (n = 92).

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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Ex situ conservation of aquatic genetic resources of farmed aquatic species and their wild relatives within national jurisdiction

CHAPTER 5

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

- existing *ex situ* conservation of 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);
- objectives and priorities of *ex situ* conservation of AqGR with emphasis on those that are threatened or endangered.

KEY MESSAGES:

- *Ex situ* collections, both *in vivo* and *in vitro*, are common mechanisms for the conservation of AqGR.
- Most reporting countries have *ex situ in vivo* conservation programmes, collectively covering approximately 290 different species. The majority of these programmes focus on endangered species, mostly finfish. Nile tilapia was the species most often reported to be conserved *in vivo*.
- *Ex situ in vitro* conservation programmes were less common, but collectively covered more than 133 aquatic species in various types of facilities.
- Gametes were the type of AqGR most often conserved *in vitro* (almost exclusively male gametes) and research facilities were the common type of facility where these programmes were housed.
- Common carp (*Cyprinus carpio*) and rainbow trout (*Oncorhynchus mykiss*) were the two species most often reported to be conserved *in vitro*.
- The most important objective for *ex situ* conservation at the global level (both *in vivo* and *in vitro*) was the conservation of aquatic genetic diversity, irrespective of region, economic class or level of aquaculture production. The least important objective was for adaptation to climate change.

5.1 Introduction

In order to help mitigate 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 on non-native species and on genetically altered farmed types (e.g. distinct strains, hybrids, polyploids), whether developed from introduced or native species, is important (see Chapter 2).

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

- *in situ in vivo*, e.g. free-living, wild and feral populations (see Chapter 4);
- on-farm *in situ,* e.g. captive populations on-farm in which conservation is the objective (see Box 21 in Chapter 4);
- *ex situ in vitro*, e.g. collections of cryopreserved sperm, embryos and other tissues/DNA;
- *ex situ in vivo*, e.g. aquarium and research populations.

The forms of *in situ* conservation 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* conservation programmes

Conservation programmes can be broadly grouped into two complementary strategies: *in situ* and *ex situ*. In *ex situ* conservation, the AqGR are maintained outside of their natural habitats, 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.

As discussed in Chapter 2, *in situ* conservation is the preferred mode of conservation. *In situ* measures 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 backup strategy that serves as a form of insurance 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 conservation goals more effectively.

5.3 *Ex situ* conservation overview

Ex situ conservation is a mechanism to conserve AqGR outside their natural habitats, targeting all levels of biodiversity, including the ecosystem and species levels (Kasso and Balakrishnan, 2013), and potentially farmed types such as selectively bred strains. Broadly, *ex situ* conservation includes a variety of activities, from managing captive populations, education and raising awareness and 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 material for (re)stocking or as base populations for selective breeding programmes. Note that selective breeding programmes deliberately shift allelic frequency, selecting for favourable traits, and are thus 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 can sometimes 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, 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 must also be considered. Gene banks (also known as genome banks) that are primarily used to support conservation of wild relatives can also be used to support conservation and distribution of farmed types, as in the case of common carp in Hungary (Box 22), which also highlights the need for sustained resourcing of gene banks for their long-term sustainability.

5.3.1 Methods for *ex situ* conservation

Several types of site are 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 method of conservation, arguably the simplest, occurs in aquaria, zoos and botanical gardens. These places can serve as reservoirs of genetic diversity, often distributed far from the natural range of the organisms. They are often run by universities or other scientific research organizations, and often have associated research programmes. Zoos, aquaria and botanical gardens have started to take a progressively greater role in conservation, especially for threatened species, and they also play an important role in education given their contact with the general population and the media (Packer and Ballantyne, 2010; Conde *et al.*, 2011). However, maintenance of genetic diversity (avoiding inbreeding, etc.) is often of secondary importance and may not be considered at all, and zoos, aquaria and botanical gardens are more likely to focus on charismatic species (McClenachan *et al.*, 2012). The 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 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 plans 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 the original species, stock, strain or farmed type as closely as possible, as this will increase the chances of successful

Box 22

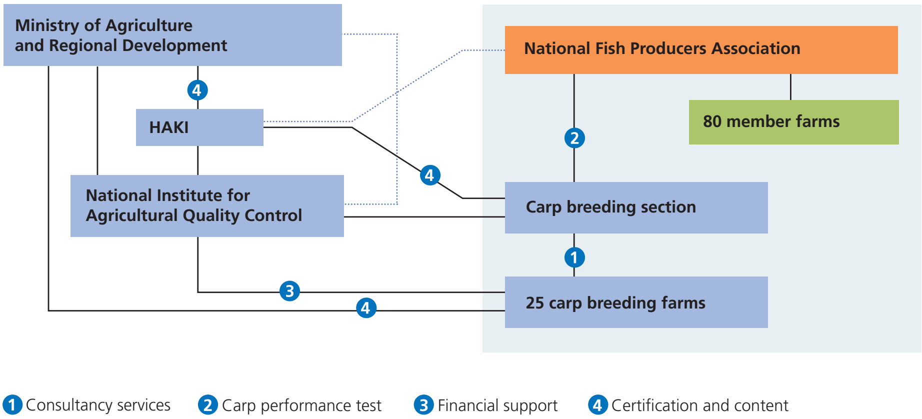
The case of carp – a live *ex situ* gene bank in Europe

A live gene bank of common carp (*Cyprinus carpio*) was first established by Dr János Bakos in 1962 at the Research Institute for Fisheries and Aquaculture (HAKI), in Szarvas, Hungary.[1] The original objectives of this live gene bank were to collect, maintain and preserve the strains of common carp available at that time in Hungary, produce hybrids with enhanced productivity, and the facilitation of genetic exchange. As a result of an intensive exchange programme, the gene bank contained 15 Hungarian strains (termed "landraces") collected from different fish farms in Hungary, these having been isolated from each other at that time. These strains were supplemented by 15 foreign strains collected mainly from Central and Eastern Europe, but also from Asia. As a result of an intensive crossbreeding programme, three highly productive crossbred or introgressed common carp farmed types were established by Dr Bakos. The crossbred known as Szarvas 215 mirror carp was the most successful, representing 80 percent of Hungarian carp production in the mid-1980s. As part of the exchange programme, Hungarian strains were transferred to different parts of Europe and Asia. Knowledge about the carp strains was summarized in an FAO publication (Bakos and Gorda, 2001). In addition, a complete system for carp performance testing was developed, published and implemented in Hungary. Many of the results from the characterization of these genetic resources have also been published. The infrastructure, the gene bank, its maintenance and associated systems (see figure) was based on state financial support.

Following the deep socio-economic change in Hungary in 1990 (shifting from a centralized state-managed economy to a market economy), as well as a new Law on Animal Breeding in 1993, state support for the system disappeared. Private farms took over ownership of some of the strains and partially financed the system with some state support. The reduced gene bank (Hungarian strains) is now maintained by internal HAKI funding. As a result, the overall size of the gene bank has declined, with lower numbers of each strain being maintained. The objectives of the gene bank have also changed, with the current focus on studying genetic diversity and disease resistance, and providing stock for rehabilitation purposes and gene exchange.

[1] The information in this box was provided by Z. Jeney (pers. comm. 2018)

Framework of gene bank maintenance and the National Carp Breeding Programme before the socio-economic changes in 1990 (based on Varadi *et al.*, 2002, and Bakos *et al.*, 2006).



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). Snyder *et al.* (1996) outline other challenges of captive breeding *ex situ*, especially when dealing with endangered species, including problems with setting up self-sufficient captive populations, poor success from reintroductions, high costs, disease outbreaks and maintaining administrative continuity.

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 escapees). 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). It is difficult to rely on captive breeding of cultured stocks as an *ex situ* conservation measure, as the aforementioned principles are rarely adhered to outside of formal, well-managed selective breeding programmes. This was illustrated recently in the case of the cachama (*Colossoma macropomum*), where analysis of levels of variation in multiple domesticated stocks revealed very significant reductions in genetic diversity (Aguiar *et al.*, 2018).

The above principles apply to sexually reproducing animals maintained as individuals or in pools such as finfish. Microorganisms such as microalgae, bacteria and zooplankton present some different challenges for *ex situ* conservation. Microorganisms can be maintained in live cultures, and there are many such collections that are acting as gene banks and these are described in the thematic background study *Genetic resources for microorganisms of current and potential use in aquaculture*.[36] Cultures of live microalgae have a tendency to revert to wild type, and all such live cultures are susceptible to contamination, which can destroy the culture. Fortunately, many microorganisms can be stored cryogenically or at specific stages of their life cycle, such as cysts (e.g. *Artemia* spp.). Storage in this way prevents genetic change and cultures can be restored by thawing or rehydrating dormant cysts.

[36] *Genetic resources for microorganisms of current and potential use in aquaculture*: http://www.fao.org/aquatic-genetic-resources/background/sow/background-studies/en/

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 the aforementioned 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 avoiding 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. Issues around the successful application of cryopreservation in fish and other aquatic species are summarized in Tiersch and Green (2011) and Martínez-Páramo *et al.* (2017). Sperm has now been effectively cryopreserved in over 200 species of finfish, predominantly of freshwater species. Cryopreservation of sperm can be achieved with relatively simple technology provided that liquid nitrogen is reliably available. As a result, cryopreservation has been used for conservation of finfish in developing country situations (Agarwal, 2011; Hossain, Nahiduzzaman and Tiersch, 2011; Sarder, Sarker and Saha, 2012). Cryopreservation of fish eggs is more problematic due to the large size of the cell and the presence of yolk; some progress is being made, but further research is required on optimizing freezing protocols for early stage ovarian follicles and *in vitro* maturation of these follicles. Despite much research, successful embryo cryopreservation in fish remains elusive (Martínez-Páramo *et al.*, 2017).

Cryopreservation of sperm has been achieved in some invertebrates, including bivalve molluscs and corals, but again much further research is required to standardize protocols for species before these techniques can be widely applied. Cryopreservation of embryos and larvae is more achievable in invertebrates due to their limited size and low yolk content, and this has been achieved in a number of mollusc species, although survival rates are low (Martínez-Páramo *et al.*, 2017). There is optimism that further technical improvements can improve the applicability of embryo cryopreservation.

The application of cryopreservation in aquaculture and conservation is very much in its infancy compared to its application in livestock and more technical development is required to standardize technology. Martínez-Páramo *et al.* (2017) review the development of cryobanks in different regions, and Torres and Tiersch (2016) emphasize the importance of the development of quality control and assurance in the development of repositories of cryopreserved AqGR.

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

- **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 stored in quiescent form.
- **Long-term security:** with well designed and managed *in vitro* conservation (FAO, 2012), there can be relatively low risk that human error, environmental change, disaster or political changes will affect a small scale cryolaboratory, whereas *in vivo* programmes need to plan for these contingencies.

However, a 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 to render it useless.

5.4 *In vivo* collections identified in Country Reports

Countries were asked to provide a detailed list of their 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 existing collections 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 of aquatic species being conserved in *ex situ* conservation programmes were reported (Table 41). The countries with the largest number of such cases (in order) 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 that around 55 species (marine and freshwater) are being maintained in "real" *ex situ* conservation programmes, although the information is incomplete at this stage because many private stakeholders (fish breeders) maintain their own *ex situ* conservation facilities.

Although the questionnaire did not specifically enquire as to who was funding *ex situ* conservation, Sweden stated that most *ex situ* conservation actions for live aquatic organisms are being conducted by private fish farmers and fish breeders, as well as by private fishing (recreational fisheries) associations. As a result, it is difficult for the government to obtain accurate information regarding these efforts. Asia was the region that reported most *ex situ in vivo* conservation programmes, followed by Latin America and the Caribbean (Figure 71). More *ex situ in vivo* conservation programmes were reported by other developing countries than by countries classified as least developed; the major producing countries reported more cases of *ex situ* conservation per country than the minor producing countries (Figure 72 and Figure 73).

5.4.2 Endangered species

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

A total of 197 examples of endangered aquatic species were reported as being conserved under *ex situ in vivo* programmes (Table 42). 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 successful regional collaboration on the *ex situ* conservation of AqGR is described in Box 23.

5.4.3 Main species being conserved

The top ten species most often reported as being maintained in *ex situ in vivo* conservation programmes were either finfish or microorganisms (Table 43). The finfish among these top conserved species included major aquaculture species (see Table 20), but also sturgeon species that are threatened, which are of commercial value. Approximately 90 percent of AqGR species reported as conserved are finfish species and 10 percent are aquatic microorganisms such as rotifers and microalgae, with the latter being among the most reported species due to their importance in aquaculture.

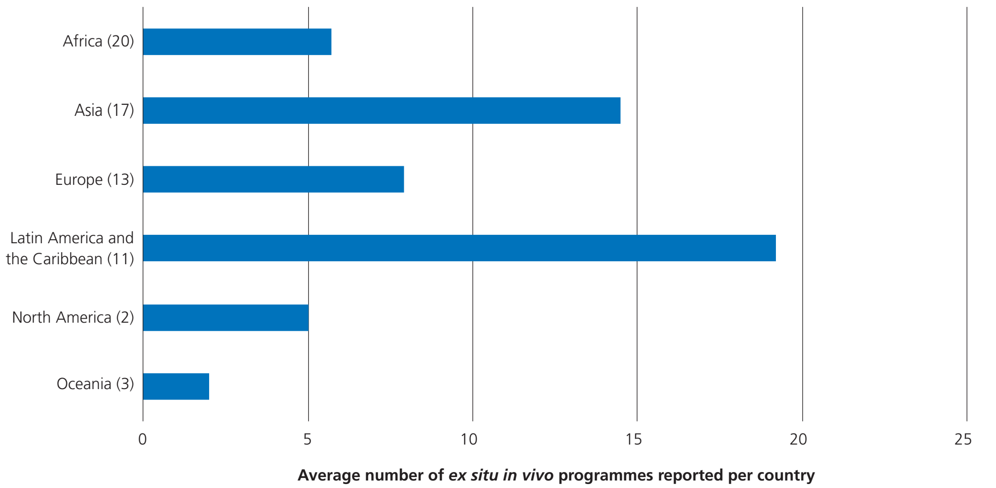
TABLE 41

Countries reporting cases of *ex situ in vivo* conservation

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		

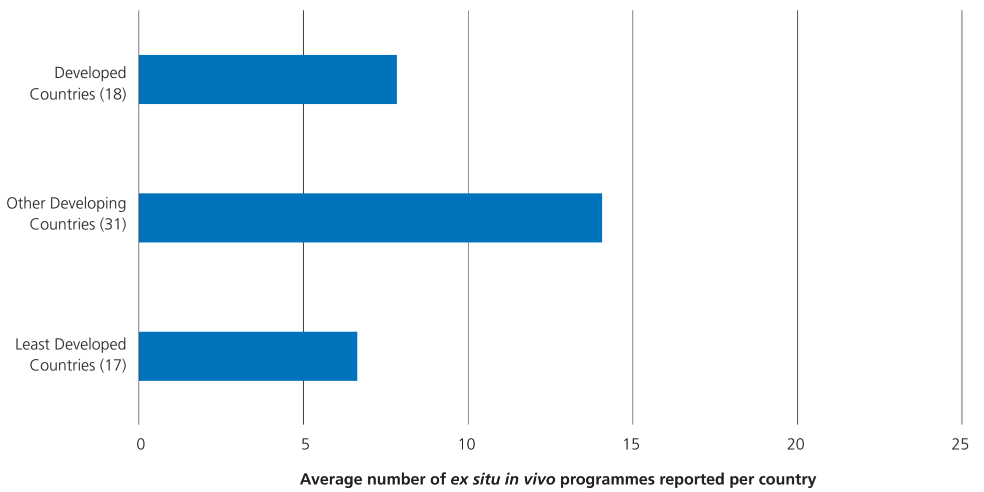
Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture:* responses to Q28 (n = 69).
Notes: n.s. = not specified. Australia reported *ex situ in vivo* gene banks of several hundred species of marine algae, including multiple strains of many species.

FIGURE 71
Distribution of cases of *ex situ in vivo* conservation by region



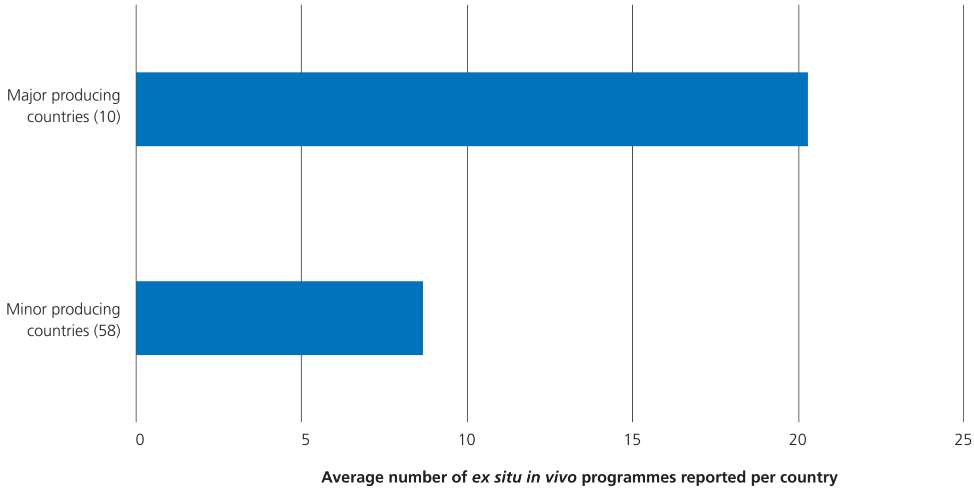
Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q28 (n = 69).

FIGURE 72
Distribution of cases of *ex situ in vivo* conservation by economic class



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q28 (n = 69).

FIGURE 73
Distribution of cases of *ex situ in vivo* conservation by level of aquaculture production



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q28 (n = 69).

5.4.4 Main uses of conserved species

Countries were asked to indicate the main destination or use of each aquatic species maintained through *ex situ* conservation programmes or actions, including those used as live feed, for direct human consumption and for other purposes. For conserved finfish species, reported types of use included direct human consumption and use as live feed for aquaculture. In most cases, the type of use reported for conserved microorganism species was use as live feed for aquaculture.

Among the 690 reported *ex situ in vivo* conservation programmes, in 398 cases (involving 290 individual species), the targeted species was reported to be used for direct relevant measures, methods and fishing regulations within the Danube River Basin, and research on the possibility of developing and introducing aquatic species maintained through *ex situ* conservation programmes or actions, including use as live feed, for direct human consumption and for other purposes. For conserved finfish species, reported types of use included direct human consumption and use as live feed for aquaculture. In most cases, the type of use reported for conserved microorganism species was use as live feed for aquaculture. Among the 690 reported *ex situ in vivo* conservation programmes, in 398 cases (involving 290 individual species), the targeted species was reported to be used for direct human consumption; for 127 species the reported type of use was as live feed in aquaculture or other primary industries; for 212 species, "other uses" were reported, including 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 (Figure 74 and Table 44).

TABLE 42

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

Country	Number of cases of endangered species under conservation	Total number of cases of *ex situ in vivo* conservation	Proportion of conserved species that are endangered (%)
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

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture:* responses to Q28 (n = 69).

Box 23

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 relevant measures, methods and fishing regulations within the Danube River Basin, and research on the possibility of developing and introducing 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 the World Sturgeon Conservation Society–FAO guidelines (Chebanov *et al*., 2011) to support targeted stocking and reintroduction programmes, which will follow the International Union for Conservation of Nature guidelines (IUCN, 1998).

Neither *in situ* (see Chapter 4) nor *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.

Source: M. Pourkazemi, pers. comm. 2018.

TABLE 43
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* spp.	3
Acipenser gueldenstaedtii	7	*Tor putitora*	3
Huso huso	7	*Undaria pinnatifida*	3
Acipenser stellatus	6	*Artemia salina*	3
Chlorella spp.	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 spp.	5	*Hypophthalmichthys molitrix*	3
Acipenser baerii	4	*Lutjanus guttatus*	3
Artemia spp.	4	*Macrobrachium rosenbergii*	3
Chaetoceros spp.	4	*Moina* spp.	3
Penaeus monodon	4	*Nannochloropsis* spp.	3
Penaeus vannamei	4	Rotifers	3
Brachionus spp.	4	*Microcyclops* spp.	1

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture:* responses to Q28 (n = 69).

Certain species are being conserved for several uses. For example, Nile tilapia (*Oreochromis niloticus*) is used both for direct human consumption and as live feed for aquaculture in certain countries where carnivorous species are fed Nile tilapia juveniles. Among AqGR used for live feed, rotifers (e.g. *Brachionus* spp.) were the most frequently reported to be subject to *ex situ in vivo* conservation (Table 44 and Table 45). The main aquatic species used as live feed organisms for aquaculture activities are listed in Table 45, along with the number of *ex situ in vivo* conservation programmes reported for each species.

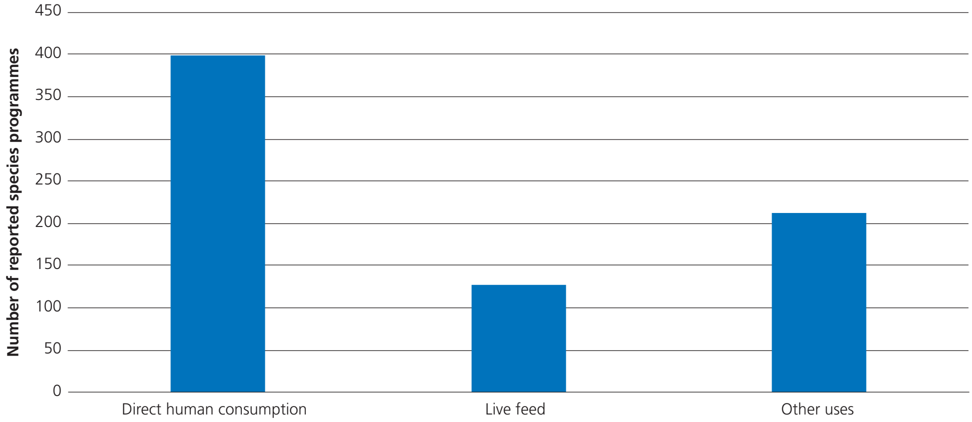
5.5 *In vitro* collections identified in Country Reports

5.5.1 Overview

This section provides a global review, based on the Country Reports, 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.

FIGURE 74

Uses of aquatic species conserved *ex situ in vivo* (number of reported species programmes)



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q28 (n = 69).

TABLE 44

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* spp.	5	LF
Acipenser stellatus	5	DHU	*Artemia* spp.	4	LF
Acipenser baerii	4	DHU	*Brachionus* spp.	4	LF
Penaeus monodon	4	DHU	*Chaetoceros* spp.	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* spp.	3	LF

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture:* responses to Q28 (n = 69).
Note: DHU = direct human use; LF = live feed organism.

TABLE 45

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

Category	Species	Number of programmes
Rotifers	*Brachionus plicatilis*	11
	Brachionus rotundiformis	3
	Brachionus spp.	4
Artemia*	*Artemia salina*	4
	Artemia franciscana	1
	Artemia urmiana	1
Copepods	*Thermocyclops* spp.	1
Cladocerans	Cladocerans	1
	Daphnia magna	1
	Daphnia pulex	1
Microalgae	*Isochrysis galbana*	8
	Tetraselmis tetrahele	6
	Dunaliella 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 spp.	5
	Dendrocephalus affinis	1
	Diaphanosoma spp.	1
Cyanobacteria	*Spirulina* spp.	3
Live finfish	*Clarias anguillaris*	1
	Clarias gariepinus	1
	Oreochromis niloticus	2

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture:* responses to Q28 (n = 69).
*Lavans and Sorgeloos (1996) report uncertainty over the taxonomy of *Artemia* spp. 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 in the culture of *Artemia* spp. are dealt with in detail in the thematic background study *Genetic resources for microorganisms of current and potential use in aquaculture.*

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 AqGR of both farmed and wild relatives. Countries reported 295 cases of aquatic species (about 133 individual species in total)being maintained in *in vitro* collections (Table 46). 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 in the Country Reports; 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. In some cases, the diversity of freshwater conservation programmes may have been so high that it was not practical to list all conserved species in the Country Reports.

The country with the largest number of species being maintained in *in vitro* collections is Malaysia (reporting 73 aquatic species being conserved for future aquaculture use, for biodiversity retention, and other uses), followed by India and Mexico. There was no apparent correlation between the respective numbers of *in situ* and *ex situ* conservation programmes reported by countries (data not shown).

Table 47 and Table 48 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

TABLE 46

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		

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture:* responses to Q29 (n = 35).

TABLE 47

Reported *in vitro* collections by region – total number of species maintained and average number of species maintained per country

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

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture:* responses to Q29 (n = 35).

TABLE 48

Reported *in vitro* collections by economic class (total number of species maintained and average number of species maintained per country)

Economic class	Number of reporting countries	Number of species	Average species/country
Developed Countries	10	78	7.8
Other Developing Countries	17	131	7.7
Least Developed Countries	4	23	5.8

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture:* responses to Q29 (n = 35).

number of *in vitro* collections, but the differences among the economic groupings were not large (Table 48). 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).

5.5.2 Main species being conserved

Table 49 provides a list 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 economic class levels is provided in Section 5.6.

5.5.3 Type of material conserved *in vitro*

Countries were asked to provide information on the *in vitro* conservation mechanisms and strategies used for each species. Options provided in the questionnaire for type of *ex situ* conservation collection *in vitro* include gametes, embryos, tissues, spores and others.

As a result of this assessment (Table 50), it was observed that:

- gametes (almost exclusively male gametes) are the genetic material most often conserved *in vitro*, with about 46 percent of species maintained in this form (mostly for 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* spp., oysters and mullets);

TABLE 49
The species or species items reported 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* spp.	1
Oreochromis niloticus	5	*Clarias gariepinus*	1	*Oncorhynchus tshawytscha*	1
Artemia spp.	4	*Colossoma macropomum*	1	*Oreochromis* spp.	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* spp.	1
Pangasius pangasius	2	*Haliotis rufescens*	1	*Pseudoplatystoma corruscans*	1
Psetta maxima	2	*Heteropneustes fossilis*	1	*Pseudoplatystoma* spp.	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* spp.	1
Bagrus docmak	1	*Labeo victorianus*	1	*Tenualosa ilisha*	1
Barbodes carnaticus	1	*Lates calcarifer*	1	*Tetraselmis c.*	1
Barbus altianalis	1	*Lates niloticus*	1	*Tilapia guineensis*	1
Brachionus spp.	1	*Leiarius marmoratus*	1	Tilapia	1
Brycon moorei	1	*Leporinus obtusidens*	1	*Tinca tinca*	1

(Cont.)

TABLE 49 *(Cont.)*

The species or species items reported conserved in *in vitro* collections

Brycon spp.	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 spp.	1	*Nannochloropsis* spp.	1		
Chlorella vulgaris	1	*Odontesthes bonariensis*	1		
Cirrhinus cirrhosus	1	*Ompok malabaricus*	1		

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture:* responses to Q29 (n = 35).
Note: N = number of countries maintaining *in vitro* collections of the species.

TABLE 50

Summary of the number of species being maintained by each mechanism, including the percentage out of 248 total *in vitro* collections for which mechanisms were reported

Mechanism	Number of species	Percentage of all collections
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
Total	**248**	**99**

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture:* responses to Q29 (n = 35).

- 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);
- fifteen percent of aquatic species are conserved in undefined other ways.

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. Options provided in the questionnaire included in 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 for which facilities were reported, 56 were conserved in aquaculture facilities, 146 were conserved in research facilities, 59 were conserved in universities and academia, two were conserved in zoos and aquaria, and six were conserved in other types of facilities (Table 51).

5.6 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 (see Table 52 for the options provided in the questionnaire).

Each objective was ranked by countries 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 (i.e. with the highest ranking value) for *ex situ* conservation at the global level was the "preservation of aquatic genetic diversity" (Table 52), 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

TABLE 51

Number and proportion of species collections being maintained in each type of *in vitro* conservation facility

Type of facility	Number of collections	Percentage of total number of collections
Aquaculture facilities	56	21
Research facilities	146	54
Universities and academia	59	22
Zoos and aquaria	2	1
Others	6	2
Total	**269**	**100**

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture:* responses to Q29 (n = 35).

TABLE 52

Priority rankings of objectives for *ex situ* conservation of aquatic genetic resources by region

Objective	Rank						
	Africa	Asia	Europe	Latin America and the Caribbean	North America	Oceania	Global
Preservation of aquatic genetic diversity	2.2	1.8	1.3	3.6	1.0	2.1	2.18
Maintain good strains for aquaculture production	2.3	2.4	3.1	2.8	5.5	3.3	2.70
Future strain improvement in aquaculture	3.5	3.9	4.2	5.1	7.0	5.4	2.82
To help adapt to impacts of climate change	3.8	4.1	2.6	6.1	2.5	6.9	4.26
Meet consumer and market demands	2.6	2.7	2.4	3.4	5.5	2.9	4.29

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture:* responses to Q30 (n = 87).
Note: Values represent the average rankings assigned by countries from 1 = very important to 10 = no importance.

these resources "to help adapt to impacts of climate change". The relative rankings of these objectives were very similar to those of *in situ* conservation (Table 38), indicating there are no major differences in the rationale for the application of these two forms of conservation.

Analysis by region (Table 52) 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. North America ranked future strain improvement as a low priority compared to preservation of AqGR, which was ranked the highest. This is perhaps indicative that conservation is the dominant driver with relatively little attention given to potential aquaculture benefits. Meeting consumer demands was also listed as a relatively less important objective in North America, confirming this previous observation.

Analysis by economic class and level of production (Table 53 and Table 54) revealed similar results across the classes, although maintaining strains for aquaculture was a higher priority in major producing countries. Surprisingly, meeting consumer and market demands was reported to

TABLE 53

Priority rankings of objectives for *ex situ* conservation of aquatic genetic resources by economic classification

Objective	Rank			
	Overall	Developed Countries	Other Developing Countries	Least Developed Countries
Preservation of aquatic genetic diversity	2.2	3.2	1.6	1.9
Maintain good strains for aquaculture production	2.6	2.6	2.1	3.0
Future strain improvement in aquaculture	4.3	5.0	3.6	4.2
To help adapt to impacts of climate change	4.4	5.3	4.2	3.7
Meet consumer and market demands	2.8	3.2	2.4	2.8

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture:* responses to Q30 (n = 87).
Note: Values represent the average rankings assigned by countries from 1 = very important to 10 = no importance.

TABLE 54

Priority rankings of objectives for *ex situ* conservation of aquatic genetic resources by level of aquaculture production

Objective	Rank	
	Major Producing Countries	Minor Producing Countries
Preservation of aquatic genetic diversity	1.6	2.3
Maintain good strains for aquaculture production	2.0	2.8
Future strain improvement in aquaculture	5.5	4.1
To help adapt to impacts of climate change	4.1	4.3
Meet consumer and market demands	3.1	2.8

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture:* responses to Q30 (n = 87).
Note: Values represent the average rankings assigned by countries from 1 = very important to 10 = no importance.

have a lower priority in countries that have the highest level of aquaculture production (Table 54). 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.

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Stakeholders with interests in aquatic genetic resources of farmed aquatic species and their wild relatives within national jurisdiction

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:

- Activities related to conservation, production and advocacy were the most common roles played by the 12 diverse stakeholder groups identified in the questionnaire that provided the basis for this analysis.
- Stakeholder interests in conservation, sustainable use and development of AqGR were consistently greatest at the level of species. 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 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.
- Continued work towards further identifying and clarifying the roles and needs of the many stakeholders in the conservation, management and use of AqGR will be important.

6.1 Introduction

Sevaly (2001) highlighted the benefits of stakeholder engagement in aquaculture development, indicating that this engagement can be instructive, consultative or cooperative. However, there is a paucity of literature on the roles of stakeholders in the conservation, sustainable use and development of aquatic genetic resources (AqGR), highlighting the need for research in this area. The benefits of stakeholder engagement in AqGR management are likely to be similar to those for aquaculture development in general.

There are many stakeholders with an interest in the conservation, sustainable use and development of AqGR of farmed aquatic species and their wild relatives be it for income-generating or other purposes. Yet, in specific terms, little knowledge exists concerning where these interests lie or what they entail. This chapter addresses the findings and knowledge gaps from analyses of a total of 91 national responses (one Country Report did not include information on stakeholders) to the question "Please indicate the principal stakeholder groups with interests in AqGR".

6.2 Identification of stakeholders

The list of stakeholders assembled for the section of the questionnaire relating to this Chapter 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 could have included scientists, regional fisheries management bodies and aquaculture networks; and indeed, in the future, consideration could be given to the primary list of stakeholders considered in the questionnaire.

Twelve stakeholder types were ultimately chosen for inclusion in the Country Report questionnaire. 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, the various possible roles of stakeholders are open to interpretation. Post hoc definitions are provided in Table 55 and Table 56; future studies may wish to review the distinctions in the definitions 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 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, sustainable 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 and 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.

It is evident that 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 fish farmers. This should have helped foster an understanding of stakeholder roles and types of conservation, sustainable use and development of AqGR among respondents.

Excluding "other", nine types of AqGR conservation, use and development were distinguished for the purpose of this first attempt to capture stakeholder roles. Most are self-explanatory (e.g. advocacy, breeding, conservation, marketing, outreach/extension, production, research), while two are not: feed manufacture and processing. Similarly, processors of farmed aquatic species by definition use AqGR. Nevertheless, there may have been uncertainty among respondents over these two categories.

The category "other" was included both for AqGR conservation, sustainable use and development and for AqGR of interest to stakeholders, to include stakeholder roles and interests not covered by the other categories.

Little attention was paid in the process to defining roles beyond the categories developed for the purposes of the questionnaire. Countries did not provide much supplementary information in support of their answers to questions, thus leaving open to interpretation what stakeholders exactly do in fulfillment of their roles. This should be taken into account when interpreting data from the Country Reports.

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 and assessed the roles of 12 stakeholder types. These stakeholders are identified in Table 55.

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

6.3.2 Roles of different stakeholder groups in the conservation, sustainable use and development of aquatic genetic resources

In order to provide a simple global-level indicator of stakeholder activity in the conservation, sustainable use and development of AqGR, data were summed from the number of countries that found various stakeholder groups to be involved in each of the ten categories (Table 57). Out of a possible maximum score of 1 092 (i.e. all 91 responding countries reporting that all 12 stakeholder types are involved in a particular aspect of AqGR conservation, sustainable use and development), the highest scores were found for conservation (681, equivalent to 62 percent of the maximum score), production (653, or 60 percent) and marketing

TABLE 55
Brief description of 12 stakeholders in conservation, sustainable use and development of aquatic genetic resources, identified based on 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 (see Chapter 4).
Consumers	People who purchase goods and services (in this case related to AqGR) for personal use.
Donors	Any individuals, organizations or institutions that make a gift, in this case this applies mainly to donors supporting development of aquaculture, fisheries or conservation of AqGR.
Fish farmers	Professionals involved in raising aquatic organisms commercially by controlling the whole 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	IGOs are composed primarily of sovereign states (referred to as member states) or of other IGOs.
NGOs	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.

TABLE 56

Brief description of ten roles that stakeholders play in the conservation, management and use of aquatic genetic resources, identified based on discussions at national consultations and at 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 of aquatic animals or plants
Conservation	Preserving, guarding or protecting wise use
Feed manufacture	Production of aquaculture feeds from primarily wild-sourced 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

[1] Definition from the Chartered Institute of Marketing (www.cim.co.uk)

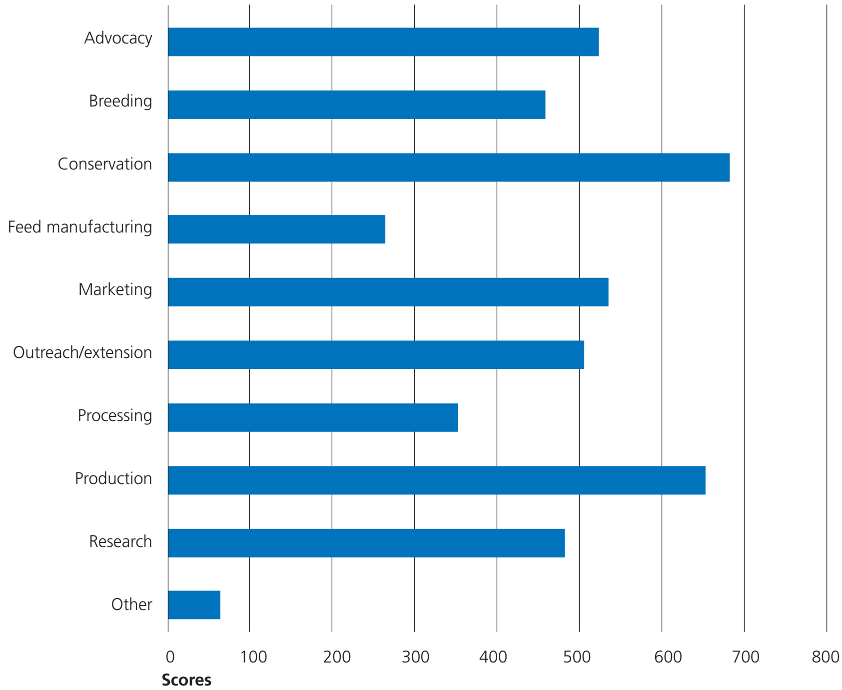
(537, or 49 percent). The lowest scores were found for processing (355, or 33 percent), feed manufacturing (262, or 24 percent), and other (65, or 6 percent), as illustrated in Figure 75.

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 identified roles. 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, sustainable use and development of AqGR (i.e. 91 × 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 percent of reporting countries), 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 – international governmental organizations (IGOs), non-governmental organizations (NGOs) and 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, sustainable use and conservation. 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 75

Total scores (number of responding countries × number of stakeholder categories in the conservation, sustainable use and development of aquatic genetic resources) for each identified stakeholder group*



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q31 (n = 91).
Note: Data derived from Table 57.
*See text for explanation of scoring system. This analysis identifies the relative importance of roles across all stakeholders.

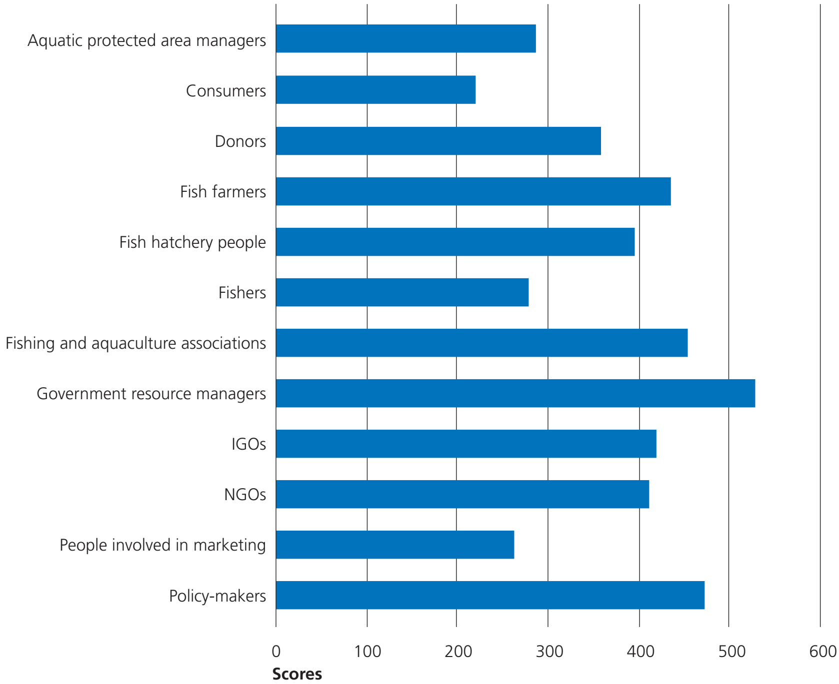
If the results are presented in terms of the top three stakeholders by roles played in AqGR conservation, sustainable use and development (Table 58), then fish farmers and fisheries and aquaculture organizations were assessed as playing the greatest number of roles (five out of ten roles), followed by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

At a global level, the results from the questionnaire show clear differences among stakeholders in terms of their roles – actual and perceived – in conservation, sustainable use and development of AqGR of farmed aquatic species and their wild relatives. According to the roles accorded by the responding countries, one-third of all stakeholder groups are seen as being involved in all of the roles.

The majority of responding countries concurred that fish farmers play roles in conservation, research, production, advocacy and extension. This result is also reported in Chapter 4 on *in situ* conservation. Leaving aside the issue of how exactly they implement these roles and

FIGURE 76

Total scores (number of responding countries × number of roles in the conservation, sustainable use and development of aquatic genetic resources) for each identified stakeholder group*



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q31 (n = 91).
Note: Data derived from Table 57.
*See text for explanation of scoring system. This analysis identifies the relative importance of stakeholders across all roles.

whether or not they are effective, the results are not surprising. Some critics of aquaculture, including in countries with wild stocks of Atlantic salmon (*Salmo salar*), might point to a conflict between a conservation role of salmon farmers and the role that farmers might play in the development of genetically improved strains and the inadvertent introduction of farmed fish to the environment. Inadvertent introductions increase the risk of introgression of alien aquatic genetic material, with possible effects on the fitness of wild stocks (McGinnity *et al.*, 2003). Similar issues about the role of aquaculture and the impact of alien genetic material on wild stocks have been made by other authors (Youngson *et al.*, 2001; Lind, Brummett and Ponzoni, 2012; Lorenzen, Beveridge and Mangel, 2012).

Fish and fish hatchery operators often claim to be managing *ex situ* AqGR, but it is unclear whether they are sufficiently knowledgeable to manage the resources in a way that creates more productive farmed types 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

TABLE 57

Level of stakeholder groups' involvement in key aspects of the conservation, sustainable use and development of aquatic genetic resources, as indicated by country responses

Stakeholder roles											
Roles	**Advocacy**	**Breeding**	**Conservation**	**Feed manufacturing**	**Marketing**	**Outreach/ extension**	**Processing**	**Production**	**Research**	**Other**	**Total**
Aquatic protected area managers	64 (70)	16 (18)	87 (96)	2 (2)	4 (4)	46 (50)	1 (1)	12 (13)	52 (57)	3 (3)	287
Consumers	30 (33)	5 (5)	21 (23)	3 (3)	51 (56)	16 (18)	38 (42)	37 (41)	4 (4)	14 (15)	219
Donors	47 (52)	34 (37)	59 (65)	18 (20)	27(30)	43 (47)	22 (24)	41 (45)	54 (59)	12 (13)	357
Fish farmers	21 (23)	76 (84)	37 (41)	42 (46)	72(79)	27 (30)	47 (52)	87 (96)	25 (27)	2 (2)	436
Fish hatchery operators	22 (24)	85 (93)	53 (58)	23 (25)	43 (47)	35 (38)	7 (8)	77 (85)	49 (54)	2 (2)	396
Fishers	23 (25)	7 (8)	48 (53)	5 (5)	57 (63)	17 (19)	42 (46)	64 (70)	11 (12)	5 (5)	279
Fisheries and aquaculture organizations	49 (54)	48 (53)	49 (54)	43 (47)	61 (67)	53 (58)	43 (47)	76 (84)	27 (30)	4 (4)	453
Government resource managers	67 (74)	58 (64)	85 (93)	32 (35)	37 (41)	70 (77)	30 (33)	69 (76)	76 (84)	3 (3)	527
IGOs	57 (63)	35 (38)	72 (79)	17 (19)	33 (38)	55 (60)	23 (25)	53 (58)	67(74)	6 (7)	418
NGOs	64 (70)	34 (37)	77 (85)	20 (22)	31 (34)	59 (65)	21 (23)	51 (56)	51 (56)	3 (3)	411
People involved in marketing	23 (25)	16 (18)	9 (10)	20 (22)	78 (86)	29 (32)	42 (46)	30 (33)	13 (14)	2 (2)	262
Policy-makers	56 (62)	42 (46)	84 (92)	37 (41)	43 (47)	54 (59)	39 (43)	56 (62)	52 (57)	9 (10)	472
Total	**523**	**456**	**681**	**262**	**537**	**504**	**355**	**653**	**481**	**65**	**4 517**

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q31 (n = 91).
Note: Figures in the table indicate the number (and percentage in brackets) of the 91 responding countries that indicated the respective stakeholder group plays a role in the respective activity.

TABLE 58

Top three stakeholder groups, in terms of involvement in key aspects of the conservation, sustainable use and development of aquatic genetic resources, as indicated by country responses

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

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q31 (n = 91).

[1] Where two stakeholder groups share third place, the top four are shown.

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 of "conserving" AqGR.

Caution must be applied in interpreting these results in the absence of supporting information. Take the issue of conservation of AqGR, for example. Approximately 90 percent of responding countries believed policy-makers were involved in conservation of AqGR. However, it may simply have been assumed that policy-makers develop policies that conserve AqGR. 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 level of species; 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).

6.4 Analysis of stakeholder engagement

This section analyses Country Report responses on stakeholder roles according to region, economic class and level of aquaculture production in the countries.

6.4.1 Stakeholder interest in aquatic genetic resources by geographic region

Few consistent interregional 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. Similarly, there were no clear trends in stakeholder interest based on economic class or level of aquaculture production (data not shown).

6.4.2 Interest of stakeholders in types of aquatic genetic resources by economic class and by level of aquaculture production

Reported stakeholder interest in the conservation, sustainable use and development of

TABLE 59

Interest of stakeholders in aquatic genetic resources by region (percentage of stakeholder roles by reporting countries)

	Africa	Asia	Europe	Latin America and 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
Total	**581**	**445**	**478**	**456**	**570**	**450**

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q31 (n = 91).
Note: percentages were calculated based on the selections by each country from the ten possible roles of interest for each stakeholder group, averaged across all the countries within each region.

farmed AqGR and their wild relatives was consistently high (69 to 88 percent of responding countries depending on the stakeholder group) at the level of species, the interest being greatest among fisheries and aquaculture associations (88 percent), closely followed by aquatic protected area managers, fishers, government resource managers and NGO (87 percent in each case) (Table 60). At the level of strains, stock and varieties, responding countries reported lower and more variable interest among stakeholder groups (ranging from 27 to 77 percent of responding countries) with the greatest interest at this level being among fish hatchery operators (77 percent), fish farmers (75 percent) and government resource managers (74 percent). Reported interest among stakeholders in AqGR at the genome level was the lowest (ranging from 0 to 33 percent of responding countries depending on the stakeholder group). Reported levels of interest were unsurprisingly lowest among consumers and fishers (Table 60).

In summary, interest in AqGR among stakeholders is greatest at the level of species, lower at the level of the strain, stock or variety, and lowest at the genome level. These results contained few surprises regarding the role of stakeholders in different types of conservation, sustainable use and development of AqGR of farmed species and their wild relatives. The results from the questionnaires indicated that fish farmers and hatchery operators, for example, are especially interested in AqGR at the level of the strain. However, only a few aquaculture subsectors – most notably salmon and tilapia farmers – currently have access to such varieties (Olesen *et al.*, 2007). Similarly, few stakeholders are yet interested in AqGR at the genome level.

TABLE 60
Summary of type of aquatic genetic resources of interest to different stakeholder groups by number of responding countries and percentage of total responding 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**
Average across all stakeholder groups	**76 (84)**	**51 (56)**	**13 (14)**	**7 (7)**

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q31 (n = 91).

TABLE 61

Interest of different economic classes of countries in aquatic genetic resources, as determined across all stakeholder groups

Economic class of country	Countries that reported stakeholder interest (percentage)	AqGR of interest
Developed Countries	85 56 17	Species Strain, stock, variety Genome
Other Developing Countries	81 54 12	Species Strain, stock, variety Genome
Least Developed Countries	88 59 17	Species Strain, stock, variety Genome

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q31 (n = 91).

TABLE 62

Interest in aquatic genetic resources of countries grouped by level of aquaculture production, as determined across all stakeholder groups

Level of aquaculture production	Countries that reported stakeholder interest (percentage)	AqGR of interest
Major producing countries	89 71 30	Species Strain, stock, variety Genome
Minor producing countries	83 54 12	Species Strain, stock, variety Genome

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q31 (n = 91).

Interest at this level can be expected to increase as the importance of marker-assisted selection and of conserving genetic diversity of AqGR at the population level in the wild becomes more apparent.

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).

In summary, the relative roles of stakeholders are broadly consistent across regions, economic classes of countries and irrespective of the level of aquaculture production.

6.5 Indigenous and local communities

The questionnaire on which Country Reports are based included a separate section inviting countries to indicate the most important role played by indigenous and local communities with regard to AqGR. 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, it was reported that small-scale hatcheries and aquaculture production are common among indigenous and local communities. The Country Report from the United Republic of Tanzania mentioned the involvement of communities in fingerling production, aquaculture producer associations, marketing of fingerlings, and collection of wild relatives of farmed fish as broodstock.

Of the 83 countries that responded to the above-mentioned question, 70 provided details of the involvement of indigenous and local communities in AqGR management activities. A number of countries reported that while indigenous and local communities were involved in the conservation 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, indicated the importance of indigenous knowledge in the formulation of policies that protect AqGR. Others pointed 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 mentioned included support of culture-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 the roles of communities are readily apparent between economic classes of country or geographic regions.

One country that provided an example of the important role of indigenous communities in the conservation of genetic resources for food and agriculture at a national level was 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.*

The reports from responding countries revealed a lack of clarity of the open-ended question in the questionnaire. Some respondents did not reply to this question due to the absence of indigenous communities in their countries (e.g. five European countries). Others provided limited detail as to the employment of individuals from such communities in hatcheries and fish farms. Answers were also often explicitly or implicitly indicating that while the respondents were sure that indigenous and local communities played a role in the conservation, sustainable use and development 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.

6.6 Gender

The Country Reports include responses to an open-ended question about the most important role of women with regard to AqGR, with the roles summarized in Table 63. Only 8 percent of reporting countries failed to provide any information in response to this question these omissions were unrelated to geography or country

TABLE 63

Reports of the roles of women in the conservation, sustainable use and development of aquatic genetic resources

Role	Country
No information provided	Algeria, Burkina Faso, Canada, Japan, Palau, Togo, Ukraine
All categories in which men are involved	Argentina, Australia,[1] Bulgaria,[3] Chile, China, Croatia, Cuba, Czechia, Dominican Republic, Ecuador, Estonia, Finland, Germany,[4] Guatemala, Kiribati, Latvia, Norway,[3] Philippines, Republic of Korea, 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, Peru
Shellfish collecting	Benin,[2] Morocco, Tunisia
Fishing	Cabo Verde
Fisheries management	Cabo Verde, Peru
Consultancy	Netherlands[3]
Professional organizations	Dominican Republic, Georgia, Morocco
Conservation	Burundi, Cabo Verde, Cameroon, Fiji, Honduras, Peru
Advocacy	Bhutan, Fiji
NGOs	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)

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q31a (n = 92).

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.

economic status. While often pointing out that women make up a relatively small part of the agricultural labour force (e.g. Brazil, 13 percent; Bulgaria, 10 percent), the majority of the least developed and other developing countries mentioned the important role of women in the use of AqGR directly related to the aquaculture and fisheries sectors, for example in hatcheries or in harvesting, post-harvest processing or marketing activities. While many such countries omitted to mention the specific roles that women play in the conservation and management of AqGR, some did not (e.g. Bangladesh, Benin, Bhutan and 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. Specific mention was sometimes made of gender equality in law.

Some responding countries pointed to their lack of knowledge of the role of women in conservation, sustainable use and development of AqGR. The Philippines, for example, 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."*

Women seem to have been comprehensively engaged in all activities related to the conservation, sustainable use and development of AqGR. The developed countries mentioned a wider range of activities than developing countries.

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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

CHAPTER 7

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 wide 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, lack of technical capacity and insufficient resources were identified as key gaps in effective policy implementation.
- While numerous and diverse national policies exist, there are gaps in these policies with reference to how they affect AqGR when these are considered below the level of species.
- Monitoring and enforcement of national policies are often constrained by a lack of human and financial resources.
- Due to the distinctive features of AqGR, including the integral role of wild relatives in aquaculture and the relative lack of development of farmed types, access and benefit-sharing will be different for AqGR than for genetic resources of other sectors of agriculture.
- Genetic improvement of farmed aquatic species is often carried out by large companies or institutions in areas outside of the centre of origin for many species rather than by local rural farmers. Thus, aspects of "Farmers' Rights" applied to plant genetic resources that have been developed over the long term are much less relevant to genetic resources in aquaculture than to those in terrestrial systems.
- Countries have encountered obstacles in accessing or importing genetic resources, primarily resulting from their own restrictive national legislation.

7.1 Introduction

The FAO Code of Conduct for Responsible Fisheries (CCRF) 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 articles on fishery management, fishing operations, coastal area management, aquaculture development, post-harvest practices and trade, international cooperation, research and the special needs of developing countries. Each biennium, member countries report to the FAO Committee on Fisheries (COFI) regarding their progress on implementation of the CCRF. However, rarely do countries specifically report on aquatic genetic resources (AqGR) below the level of species. In its discussions related to preparation of the Report, the COFI Advisory Working Group on Aquatic Genetic Resources and Technologies (AWG AqGR/T) recommended the development of a framework of minimum requirements to assist countries in the development of strategies and policies on AqGR, including at the level below species, and this Framework has been developed and published (FAO, 2018) (see Box 24).

Due to the relatively recent emergence of the aquaculture sector and thus the relative lack of domesticated and improved farmed types, there is little research on policy development directly related to AqGR. This is in contrast, for example, to plant genetic resources, for which institutions such as the International Food Policy Research Institute are promoting the development of pro-poor genetic resource policies and Bioversity International is proactively developing policy for access and benefit-sharing (Lewis-Lettington *et al.*, 2006).

Because AqGR encompass farming, breeding, fishing and conserving aquatic species, the range of policies relevant to their management is extremely broad. It was noted at the international conference "Towards Policies for Conservation and Sustainable Use of Aquatic Genetic Resources", held in Italy in 1998, that 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 level of species in capture fisheries and aquaculture, for example those for setting catch limits and seasons for capture fisheries (FAO, 2003) or regulating the import/export of species considered to be invasive (Bartley and Halwart, 2006). In the German national technical programme on the conservation and sustainable use of AqGR, it is noted that there is no separate policy or legal area for AqGR and that it is largely governed by the rules of fisheries, the environment, nature conservation as well as consumer protection policies (BMELV, 2010). A similar situation may exist in other countries. The same report summarizes the role of international, European Union and national regulatory

Box 24

Framework of minimum requirements for sustainable management, development, conservation and use of aquatic genetic resources

The Thirty-first Session of the COFI established the COFI AWG AqGR/T in order to advise FAO and increase international cooperation on AqGR. The COFI AWG AqGR/T recommended the development of a framework of minimum requirements (FAO, 2016a) 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.

The Framework (FAO, 2018), developed following further consultation with the COFI AWG AqGR/T[1], 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 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 farmed type
  b. monitoring programme on impact of farmed types on human well-being
  c. monitoring programme on impact of farmed types 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

(Cont.)

Box 24 *(Cont.)*

Framework of minimum requirements for sustainable management, development, conservation and use of aquatic genetic resources[1]

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 issues, 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
(v) Capacity building is needed on all of the above components and would be facilitated by effective extension services.

[1] The Framework 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", 27–29 September 2017, in Lusaka, Zambia. The Government of Germany's 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.

frameworks and international regional agreements. This type of information is difficult to source from the literature for other countries but is provided in many of the Country Reports submitted to FAO.

Often, ministries and policies promoting fishery and aquaculture development (e.g. the use and exchange of AqGR) can be 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 have been subsequently moved around the world with little regard for environmental risks. The relatively recent development of aquaculture and the domestication of aquatic species are occurring with 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). This approach is 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 (see Chapter 9 and Barlow, 2016). For example, local trade of species listed on the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) appendices[37] may be legal within a country, but would require special permits if the species were to be traded internationally.

[37] https://www.cites.org [Cited 9 January 2019].

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 discussed.

7.2 Overview of national policies and legislation

The majority of Country Reports were submitted by signatories to the Convention on Biological Diversity (CBD) (73 percent of countries that reported on international agreements; see Chapter 9). Under that Convention, countries are required to develop National Biodiversity Strategic Action Plans (NBSAPs).[38] The emphasis of the NBSAPs is primarily at the level of species for aquatic organisms. Some national legislation contains opportunities for protecting genetically distinct populations or stocks of a species that are of special evolutionary importance (Box 25).

Countries reported a total of 619 policies and legal instruments 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, finfish and shellfish. Globally, most policies are primarily aimed at the level of species; however, there are examples of policies directed below the level of species (see example from the United States of America in Box 25).

Countries were invited to identify gaps in the coverage of policies or constraints in implementing policies. Diverse responses were received from 68 countries. Responding 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 AqGR below the level of species is implied in legislation

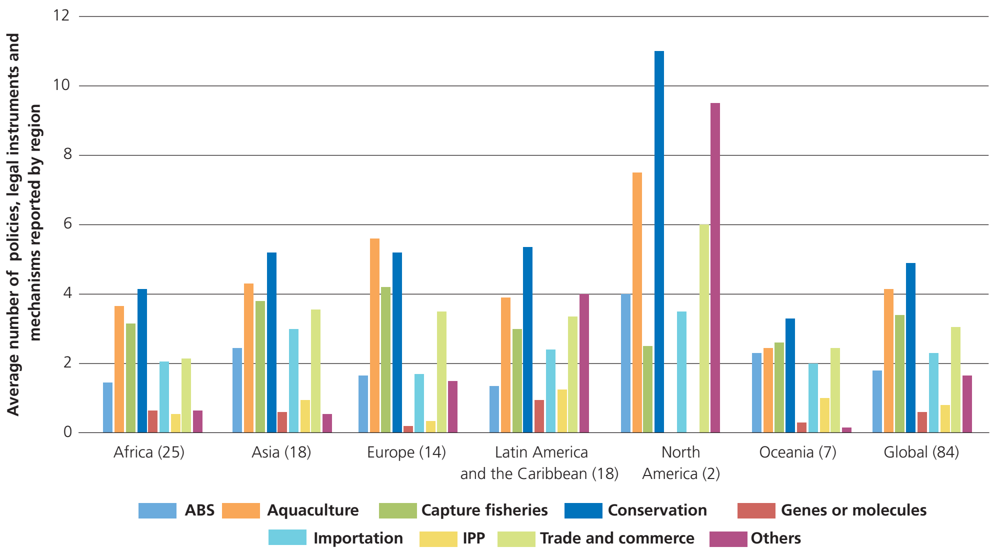
[38] https://www.cbd.int/nbsap [Cited 9 January 2019].

Box 25
Conservation of aquatic genetic resources below the level of species

Whereas national legislation on conservation is usually directed at the species level, 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* spp.) on the west coast of North America have substantially declined and are at a fraction of their historical abundance (NMFS, 2016). 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 listed 28 stocks of salmon and steelhead in California, Idaho, Oregon and Washington as "endangered species" under the ESA.

According to the United States of America 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.

FIGURE 77
Overview of extent and scope of national legal instruments, policies and/or mechanisms that address aquatic genetic resources across regions



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q32 (n = 84).
Note: ABS = access and benefit-sharing; IPP = intellectual property protection. Numbers in parentheses represent the number of reporting countries in each region.

and its implementation, but is rarely explicit, even in legislation for conservation and aquatic protected areas. As a result, there is little, if any, monitoring of AqGR at this level, other than on specific research and development projects (e.g. as reported by Australia and Morocco).

Other policy gaps identified include:

- 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 mechanisms to harmonize legislation (Zambia).

Additionally, some countries reported that significant problems in monitoring and enforcing national policies arose from lack of human resources and finances. In countries with extensive wetlands and coastal areas (e.g. Brazil and Indonesia), "monitoring of environmental laws to protect genetic resources is a difficult task" (Brazil).

7.3 Access and benefit-sharing

The Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity was adopted in 2010 as a supplementary agreement to the CBD.[39] The Protocol provides a legal framework for the effective implementation of the third objective of the CBD, the fair and equitable sharing of benefits arising from the utilization of genetic resources, thereby contributing to the conservation and sustainable use of biodiversity. Another specialized access and benefit-sharing instrument is the International Treaty on Plant Genetic Resources for Food and Agriculture.[40] The Treaty was developed by the Commission on Genetic Resources for Food and Agriculture (CGRFA) in harmony with the CBD and adopted by the FAO Conference in 2001. The Treaty includes the concept of "Farmers' Rights", and also addresses benefit sharing. Farmers' Rights refer to and recognize 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 include the protection of traditional knowledge and the right to participate equitably in benefit-sharing and in national decision-making about plant genetic resources. The Treaty gives governments the responsibility for implementing Farmers' Rights. The AqGR sector has no equivalent to the Treaty or to Farmers' Rights.

The CGRFA has produced a guide (known as the ABS Elements – with explanatory notes), developed by international technical and legal experts, to facilitate domestic implementation of access and benefit-sharing (ABS) for different subsectors of genetic resources for food and agriculture, including AqGR (FAO, 2019). The ABS Elements aim to assist governments that are considering developing, adapting or implementing ABS measures to take into account the importance of genetic resources for food and agriculture, their special role for food security and the distinctive features of the different subsectors (including AqGR) while complying, as applicable, with international ABS instruments.

[39] https://www.cbd.int/abs [Cited 9 January 2019].

[40] http://www.fao.org/3/a-i0510e.pdf [Cited 9 January 2019].

Access to AqGR and the sharing of benefits derived from their use warrant special considerations in aquaculture and fisheries. Unlike in 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 fish farmers (Bartley *et al*., 2009). Often genetic improvement of AqGR has been the result of advanced breeding programmes implemented by relatively large-scale private sector ventures or by public sector organizations.

For example, the establishment of a 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 (*Crassostrea gigas*), native to Japan, took place in North America, Australia and New Zealand; and the genetic improvement of a tilapia, native to Africa, took place in the Philippines (Bartley *et al.*, 2009). Thus, the aspects of Farmers' Rights that refer to rural people maintaining and developing local genetic resources often over very many generations, within or outside the centres of origin of the species (Andersen and Winge, 2003), are not relevant to aquaculture at this early stage in the development of AqGR.

7.3.1 Principles guiding access to aquatic genetic resources

Genetic resources for food and agriculture have been recognized by the Conference of the Parties to the CBD to be essential to meeting human needs for food and to supporting livelihoods and to have a number of distinctive features (FAO, 2019). These features include the following: management by farmers (and regulation for or by fishers); greater interdependence between countries (in some subsectors); genetic diversity within species being as important as that between species (less so for AqGR than for terrestrial genetic resources, as outlined in Chapter 2); conservation of many resources in gene banks and/or as breeders' materials (again less so for AqGR relative to terrestrial); and interaction between the environment and genetic resources and management practices within agricultural (including aquaculture) ecosystems that contributes to a dynamic portfolio of biodiversity.

The Nagoya Protocol explicitly recognizes the importance of genetic resources for food and agriculture to food security and that their distinctive features and problems require distinctive solutions. In its operational provisions, the Nagoya Protocol requires Parties to consider these factors in developing and implementing their ABS agreements. This protocol contributes to the conservation and sustainable use of biodiversity, establishing more predictable conditions for access to genetic resources and helping to ensure benefit-sharing after genetic resources leave the contracting Party that provides them.

Parties to the Nagoya Protocol shall also create conditions to promote and encourage research that contributes to the conservation and sustainable use of genetic resources. The Protocol does not prevent its Parties from developing and implementing other relevant international agreements provided they are supportive of and do not run counter to the objectives of the CBD and the Nagoya Protocol.

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. Although it predates the Nagoya Protocol and did not specifically address AqGR, a well-known example of a bilateral ABS agreement concerns Costa Rica and the international pharmaceutical company Merck. Guiding issues and principles that were used to promote access to native biodiversity in Costa Rica included: access to genetic resource permits; registration of interested parties; requests for access; and formulation and management of prior informed consent agreements between providers and stakeholders (Coughlin, 1993). The arrangement between Costa Rica and Merck may not be reproducible in many areas as it relied upon a strong financial partner. Many groups wishing to access AqGR are not so well resourced.

Material transfer agreements (MTA) that can govern the rules of exchange of genetic resources have also been established on a case-by-case basis. These outline the general conditions and obligations associated with accessing genetic resources and should take into account both ABS and biosecurity issues. WorldFish of the CGIAR (formerly the Consultative Group for International Agricultural Research) required MTAs before distributing their genetically improved farmed tilapia. The principles and obligations in Box 26 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.

7.3.2 Facilitating and restricting access to aquatic genetic resources

This section reviews the responses from countries in their Country Reports in relation to their sovereign rights to determine access to AqGR. At the genome, stock/strain and species levels, restrictions reported by countries ranged 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, whereas in the case of Malawi, access is highly restricted unless national approval is obtained.

Certain countries identified individual species to which access was restricted. 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 which also restricts international trade). Some countries also identified restrictions on specific sizes or life-cycle phases, mostly in relation to fisheries management rather than as specific ABS measures. A few countries specified specific policies or acts under which AqGR were protected.

Species was the level of AqGR for which access restrictions were often reported to be in place (Figure 78). This trend was also seen when countries were grouped by region and by level of aquaculture

Box 26
Indicative elements of material transfer agreements for accessing aquatic genetic resources

A country planning to import new or exotic species should look to conduct the transaction under a MTA. MTAs should look affirm that the recipient agrees to:

- abide by the provisions of the CBD and the FAO CCRF;
- 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 (see Chapter 9).

Source: WorldFish: www.worldfishcenter.org; Bartley *et al*., 2008; FAO, 2019.

production. There was no important difference seen among country groupings. For example major producing countries did not restrict access any more than minor producing countries (data not shown).

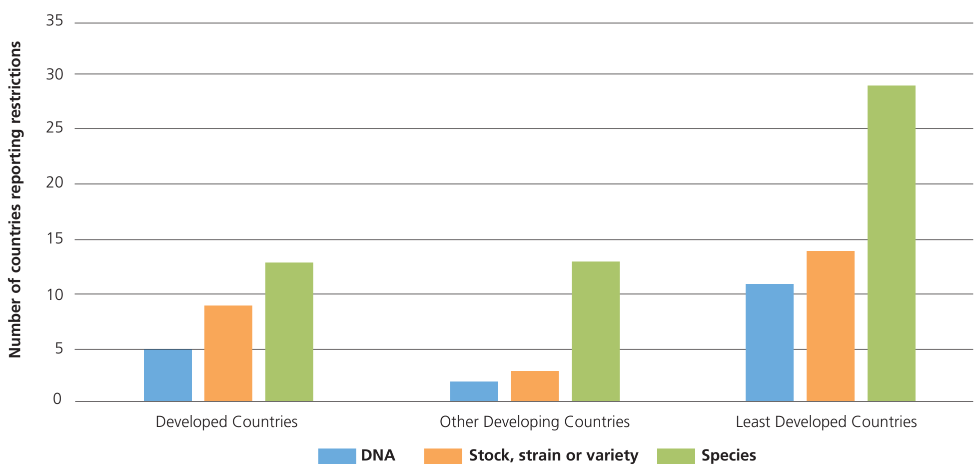
Whereas access to AqGR has been restricted in some instances, countries also report actions taken to maintain or enhance their access to AqGR from other countries (Figure 79). Overall, living specimens were the group of organisms most commonly reported for which action to facilitate access was most common followed by embryos, genes, deoxyribonucleic acid (DNA) and gametes (Figure 79). This trend was similar when countries were grouped by region, economic class and level of aquaculture production (data not shown). The predominance of facilitation for living organisms is consistent with the dominance of this form of genetic resources in exchanges between countries (see Chapter 2, including Figure 50).

7.3.3 Obstacles to accessing aquatic genetic resources

Countries seeking to access AqGR have also encountered obstacles to this access. The most widely reported obstacle was national legislation in the receiving country; however, legislation in exporting countries was also seen as an obstacle (Figure 80). National legislation can include, *inter alia*, instruments relating to access and benefit-sharing, but the questionnaire did 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 in Asia it was reported that donor country laws and expense were the major obstacles to accessing AqGR (Figure 81). This finding is indicative of the existence of some national legislation that places controls on exchange of

FIGURE 78

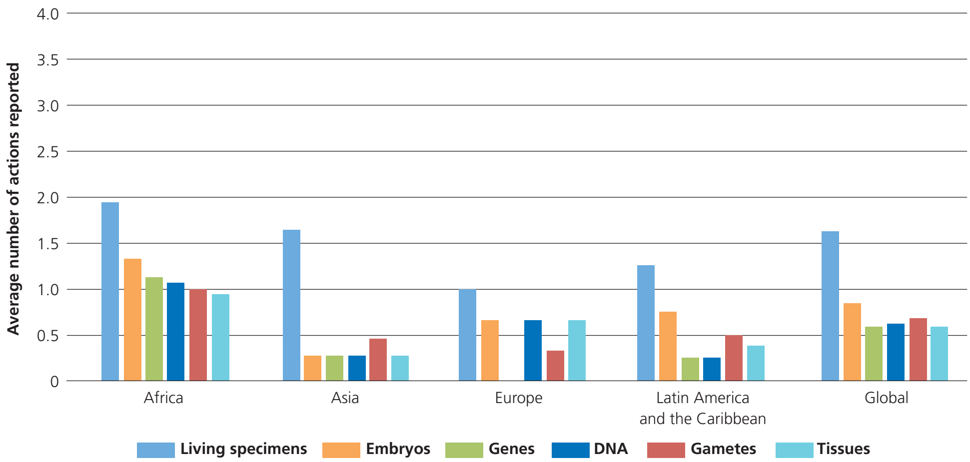
Frequency of reporting of access restrictions for different types of aquatic genetic resources, by economic class of country



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q34 (n = 55).
Note: DNA = deoxyribonucleic acid.

FIGURE 79

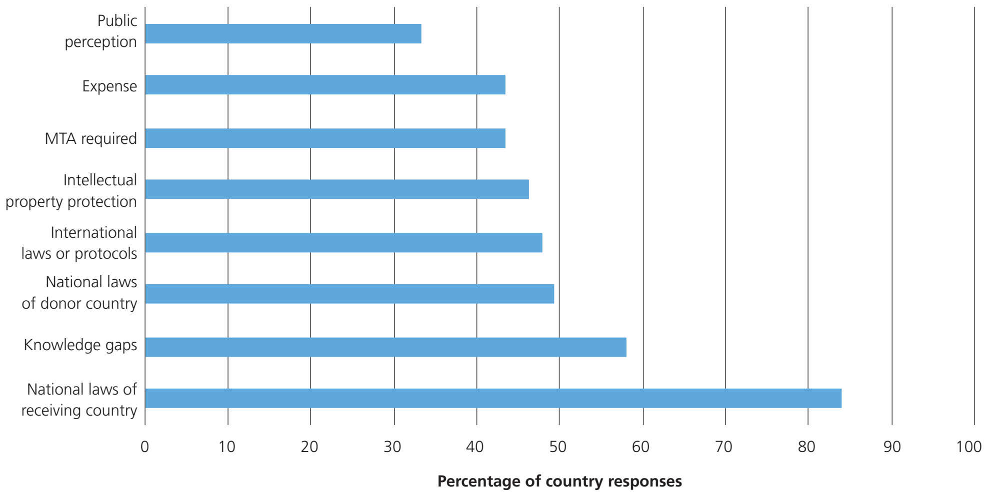
Average number of actions taken per country (by region) to facilitate access to aquatic genetic resources in other countries over the preceding ten years (i.e. approximatively 2007–2017), for example by establishing germplasm acquisition agreements or material transfer agreements



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q35 (n = 37).
Note: No relevant data reported from North America. DNA = deoxyribonucleic acid.

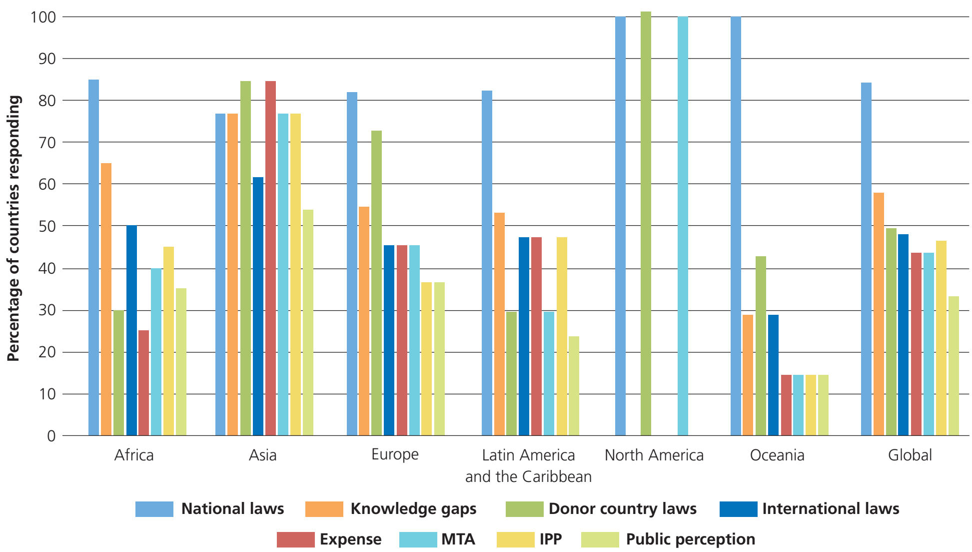
FIGURE 80

Types of obstacles encountered in accessing aquatic genetic resources from other countries



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q36 (n = 69).
Note: MTA = material transfer agreement.

FIGURE 81
Types of obstacles encountered in accessing aquatic genetic resources from other countries, by region

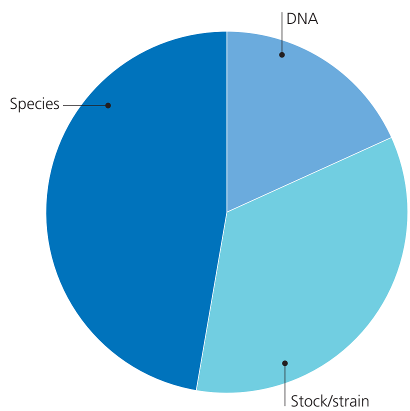


Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q36 (n = 69).
Note: IPP = intellectual property protection; MTA = material transfer agreement.

AqGR, but it cannot be determined from this analysis whether this legislation is effective and based on appropriate assessment of risks and benefits.

Species was the type of AqGR where most obstacles to access (47 percent) were encountered (Figure 82), but obstacles in accessing strains were also mentioned in about one-third of the responses; countries reported having problems accessing DNA in 18 percent of the responses.

FIGURE 82
Proportional breakdown of reported obstacles to access, by type of aquatic genetic resources



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q36 (n = 69).
Note: Proportion of responses is based on total number of responses by country and by type of obstacle.

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CHAPTER **8**

Research, education, training and extension on aquatic genetic resources within national jurisdiction: coordination, networking and information

CHAPTER **8**

PURPOSE: The purpose of this chapter 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, and 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:

- Nearly all countries reported at least one research institution dealing with conservation, sustainable use and development of AqGR, with most noting that research on AqGR is covered under national research programmes.
- "Basic knowledge on AqGR" was the most often reported research area, with "characterization and monitoring of AqGR" and "genetic improvement of AqGR" the highest ranked in terms of strengthening research-related capacity.
- Ninety percent of countries reported at least one training and education centre dealing with the conservation, sustainable use and development of AqGR.
- The main reported areas of training at the global level were "genetic resource management", "conservation of AqGR" and "characterization and monitoring of AqGR".
- A high number of intersectoral collaboration mechanisms were reported by countries, but countries also reported the need to build capacity to strengthen intersectoral collaboration, particularly the need to increase technical capacities of institutions and to improve awareness and information sharing.
- A high number of national networks and information systems were listed by most countries, particularly major producing countries, indicating good linkages that can be utilized for sharing information on AqGR. The most important objectives of these networks and systems were improving communication on AqGR and improving capacity for characterization and monitoring of AqGR.
- National information systems are most commonly focused on AqGR at the level of species. The main users of these systems were reported to be academia and government resource managers.

8.1 Introduction

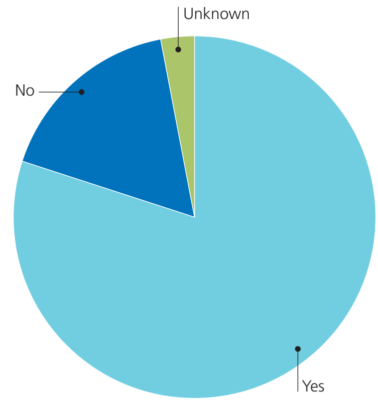
Appropriate capacities, knowledge and skills are key requirements to better characterize, sustainably use, develop and conserve the aquatic genetic resources (AqGR) of importance for food and agriculture, and therefore support livelihoods and national economies. Pertinent knowledge and skills, including at national, subregional and regional levels, will help to ensure the sustainable management 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 involving a range of disciplines, including genetics, physiology, health, nutrition, environment and food science. Furthermore, education, training and capacity building are crosscutting 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.

FIGURE 83

Proportion of responding countries where conservation, sustainable use and development of aquatic genetic resources are included in national research programmes



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q37 (n = 90).

8.2 Research on aquatic genetic resources

Countries were asked whether 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).

The majority of countries (>80 percent) reported national research programmes that supported the management of AqGR with no clear differences between the regions (Table 64) or the economic class of countries (Table 65). Analysis of countries based on economic class did not reveal substantial differences (Table 65).

The questionnaire also sought 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 often implemented by academia and research institutes in close collaboration with governments. Reported examples of subjects covered by the national research programmes included: conservation and sustainable use of AqGR (BMELV, 2010; Dekker and Beaulaton, 2016; Wennerström, Jansson and Laikre, 2017); analysis of phylogenetic origin; genetic structure of farmed and wild AqGR (Horváth *et al*., 2013); genetic improvement (Ali *et al*., 2017; Mwanja *et al*., 2016); and industrial development (Stévant, Rebours and Chapman, 2017).

Developed countries noted that the participation of the private sector in research is certainly increasing, mostly applied to the 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 and

TABLE 64
Levels of reporting of reporting national research programmes that support the conservation, sustainable use and development of aquatic genetic resources of farmed aquatic species and their wild relatives, by region

Region	Yes	No	Unknown
Africa	19	7	1
Asia	18	1	1
Europe	13	2	1
Latin America and the Caribbean	13	5	0
North America	2	0	0
Oceania	7	0	0
Total	**72**	**15**	**3**

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q37 (n = 90).
Note: Yes = number of countries with supporting research programmes; no = number of countries without supporting research programmes.

TABLE 65
Levels of reporting of reporting national research programmes that support the conservation, sustainable use and development of aquatic genetic resources of farmed aquatic species and their wild relatives, by economic class

Economic class	Yes	No	Unknown
Developed Countries	20	2	2
Other Developing Countries	36	7	0
Least Developed Countries	16	6	1

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q37 (n = 90).
Note: Yes = number of countries with supporting research programmes; no = number of countries without supporting research programmes.

other developing countries reported a general lack of involvement of the private sector in research on AqGR. The most frequently reported pattern was that of governments, academia and research institutes implementing research activities based on funds for short-term projects coming from external sources, including foreign donors.

Funding is one of the key limiting factors in research and dissemination of research results. Notwithstanding, research is a key step towards responsible management of AqGR and its funding should be considered of critical importance by stakeholders (Anetekhai *et al*., 2004).

8.2.1 Research centres

Countries were asked to list main research centres (institutions, organizations, corporations and other entities) in their respective national jurisdictions 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. Overall 89 countries out of 92 (97 percent) affirmed the existence of such institutions.

A total of 483 research centres were identified by these 89 countries at the national level (about 5.4 institutions per country). Mexico was the country that reported the most research centres covering AqGR, followed by China and the Philippines (Table 66). The two regions with the highest number of research centres per country were North America and Asia (Table 67).

TABLE 66

Countries reporting ten or more research centres covering aquatic genetic resources

Country	Number of centres
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

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q38 (n = 89).

TABLE 67

Distribution of reported research centres engaged in conservation, sustainable use and development of aquatic genetic resources, by region

Region	Number of centres	Number of countries reporting	Average centres/ country
Africa	101	25	4.0
Asia	141	20	7.0
Europe	86	17	5.0
Latin America and the Caribbean	109	18	6.0
North America	17	2	8.5
Oceania	29	7	4.1
Total	**483**	**89**	**5.4**

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q38 (n = 89).

"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).

8.2.2 Major areas of research

Of the main research areas listed for the 483 research centres reported by countries (Table 69), "basic knowledge on aquatic genetic resources" was the most often reported focus (79 percent of institutions) across all regions (regional data not shown). Other areas of research were less well covered by research centres with "economic valuation of aquatic genetic resources" being the least covered area of research.

Some minor differences were observed in the ranking of priority research areas between economic classes of country (Table 70), for example the relatively higher ranking of "conservation of aquatic genetic resources" in developed countries. It is worth noting the relatively low emphasis of institutions on "genetic improvement" in all economic classes despite the slow rate of adoption of genetic improvement and this being recognized as an important priority for aquaculture development (see Chapter 2). Genetic improvement is still significantly constrained by the necessity of long-term funding, which is essential for example in the initial five to ten generations of selection of a given species, particularly if that species has a long generation interval (Olesen *et al*., 2015).

Table 71 provides a summary of distribution, by geographic region and economic class, of the reported centres working on various aspects of research on AqGR.

8.2.3 Capacity needs for research

Countries reported on the main aspects of capacity that need to be strengthened in order to improve national research in support of the conservation, sustainable use and development of AqGR of farmed aquatic species and their wild relatives.

Capacities were assessed by countries, ranked from very important (1) to not important at all (10), as shown in Table 72.

At a global level, the capacities ranked the highest were "improve capacities for the characterization

TABLE 68

Distribution of research centres engaged in conservation, sustainable use and development of aquatic genetic resources by economic class

Economic class	Number of centres	Number of countries reporting	Average centres/ 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**

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture:* responses to Q38 (n = 89).

TABLE 69

Main areas of research undertaken by research centres working on aquatic genetic resources

Area of research	Number of centres 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

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q38 (n = 89).

TABLE 70

Summary of information on main areas of research across reported research centres, including number of mentions, averages per country and rank, by economic class

Areas of research	Developed countries		Other developing countries		Least developed countries	
	Response count[1]	Average per country (rank)	Response count	Average per country (rank)	Response count	Average per country (rank)
Basic knowledge on aquatic genetic resources	103	4.3 (=1)	211	5.1 (1)	67	4.1 (1)
Conservation of aquatic genetic resources	90	4.3 (=1)	153	4.1 (4)	52	3.7 (3)
Characterization and monitoring of aquatic genetic resources	94	3.5 (3)	154	4.5 (=2)	44	3.4 (4)
Communication on aquatic genetic resources	79	3.3 (5)	140	4.5 (=2)	54	3.9 (2)
Genetic resource management	73	3.4 (4)	115	3.5 (6)	42	2.8 (5)
Genetic improvement	53	2.8 (=7)	134	3.8 (5)	36	2.6 (6)
Access and distribution of aquatic genetic resources	56	2.8 (=7)	107	3.3 (7)	33	2.1 (8)
Economic valuation of aquatic genetic resources	51	3.1 (6)	82	2.9 (8)	25	2.5 (7)

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q38 (n = 89).
Note: 1 = very important, 10 = no importance.
[1] Based on the number of institutions reporting activities in each research area per country.

TABLE 71

Distribution of research centres working specifically on "genetic resource management" by region and by economic class

Region	Number of centres	Number of countries reporting	Average centres/country
Africa	47	17	2.8
Asia	68	17	4.0
Europe	51	16	3.2
Latin America and the Caribbean	38	13	2.9
North America	13	2	6.5
Oceania	19	6	3.2
Total	**236**	**71**	**n/a**
Economic class	**Number of centres**	**Number of countries reporting**	**Average centres/country**
Developed Countries	79	23	3.4
Other Developing Countries	115	33	3.5
Least Developed Countries	42	15	2.8
Total	**236**	**71**	**n/a**

Source: Country Reports prepared for The State of the World's Aquatic Genetic Resources for Food and Agriculture: responses to Q38 (n = 89).

TABLE 72
Ranking of reporting capacity needs on research applied to aquatic genetic resources, at the global level

Capacity need	Average ranking
Improve capacities for characterization and monitoring of aquatic genetic resources	1.9
Improve capacities for genetic improvement	2.0
Improve basic knowledge on aquatic genetic resources	2.1
Improve capacities for conservation of aquatic genetic resources	2.4
Improve capacities for genetic resource management	2.4
Improve capacities for economic valuation of aquatic genetic resources	3.1
Improve communication on aquatic genetic resources	3.4
Improve access to and distribution of aquatic genetic resources	3.5

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q39 (n = 90).
Note: 1 = Very important, 10 = No importance

TABLE 73
Ranking of capacity needs on research applied to aquatic genetic resources at the regional level

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 and 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

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q39 (n = 90).

and monitoring of aquatic genetic resources" and "improve capacities for genetic improvement" (Table 72). The capacity needs ranked the lowest were "improve access to and distribution of aquatic genetic resources" and "improve communication on aquatic genetic resources".

At a regional level, "improve capacities for genetic improvement" and "improve capacities for characterization and monitoring of aquatic genetic resources" were often the highest ranked research capacity need (Table 73).

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 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 percent 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 74 provides a regional breakdown of reported information on AqGR, including the average number of training centres per country. The regions with the higher number of education and training centres on AqGR per country are Asia, followed by Europe.

Table 75 provides a summary of reported information on AqGR centres by economic class, including the average number of training centres per country. There is no significant difference among the three economic classes.

Table 76 lists the countries that reported ten or more training centres that cover AqGR, with Germany reporting the most institutions. Only three of these countries (Bangladesh, India and Mexico) were also included in the list of countries reporting the highest number of research facilities (Table 67). The data indicate that the number of training centres and/or research facilities is not necessarily correlated or specifically linked to the level of aquaculture

TABLE 74
Total and average number (per country) of training centres on aquatic genetic resources, by region

Region	Number of institutions	Number of countries	Average number of training centres per country
Africa	120	26	4.6
Asia	109	16	6.8
Europe	80	16	5.0
Latin America and the Caribbean	67	16	4.2
North America	9	2	4.5
Oceania	13	7	1.9
Total	**398**	**83**	**4.8**

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q40 (n = 83).

TABLE 75
Total and average number (per country) of training centres on aquatic genetic resources, by economic class

Economic class	Number of institutions	Number of countries	Average
Developed Countries	103	22	4.7
Other Developing Countries	185	39	4.7
Least Developed Countries	110	22	5.0
Total	**398**	**83**	**4.8**

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q40 (n = 83).

TABLE 76

Total number of training centres for aquatic genetic resources in countries reporting ten or more training centres

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

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q40 (n = 83).

TABLE 77

Number of courses covering different key thematic areas related to aquatic genetic resources by academic/technical level

Thematic area	Undergraduate	Post-graduate	Training	Extension	Total number of courses
Genetic resource management	173	168	175	110	221
Conservation of aquatic genetic resources	175	180	188	111	219
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
Mean number of courses per country	**3.6**	**3.2**	**3.2**	**2.7**	

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q40 (n = 83).
Note: Numbers represent courses by institution for each thematic area. Many institutions offered courses in thematic areas at multiple academic/technical levels.

production of the country. A number of minor producing countries reported relatively large numbers of training institutions.

Countries reported on the education levels and thematic areas or disciplines offered by these training centres. There are relatively more courses available for "genetic resource management", "conservation of aquatic genetic resources" and "characterization and monitoring of aquatic genetic resources"; the fewest courses available are for "economic valuation of aquatic genetic resources" (Table 77). This trend was similar to the research priorities described above (Table 69 and Table 70). "Genetic improvement" also had a lower total number of reported courses than the top three thematic areas. This is consistent with the information provided in Chapter 2, which identifies the shortage of quantitative geneticists as an important constraint to the implementation of successful genetic improvement programmes.

8.4 Coordination and networking on aquatic genetic resources

Responsible management of AqGR, both on a national and international scale, can be greatly facilitated by coordination, collaboration and cooperation on a national and regional scale. Networking at these levels can promote information exchange and cooperation among the key stakeholders in AqGR identified in Chapter 7.

A good example of national coordination is the Indian Council of Agricultural Research (ICAR),[41] an autonomous organization under the Department of Agricultural Research and Education of the Indian Ministry of Agriculture and Farmers Welfare. ICAR is considered one of the largest national agricultural systems in the world and its broad mandate covers issues relating to AqGR. Networking relies on a wide system of agricultural research and education institutes, including the ICAR-National Bureau of Fish Genetic Resources (ICAR-NBFGR). Established in 1983, ICAR-NBFGR is especially focused on AqGR and includes activities such as collection, classification and cataloguing of fish genetic resources of the country; maintenance of fish genetic material for the conservation of endangered fish species, and evaluation and valuation of indigenous and exotic fish species. It plays an active role in national capacity development programmes for different stakeholders, including researchers, fish farmers, state fisheries department officials and students. It has been instrumental in the development, *inter alia*, of several information systems on AqGR, molecular characterization of commercially important AqGR, production of high-quality seed for state fisheries departments and farmers, and developments of sperm cryopreservation protocols for 30 fish species.

At an international level, some networks established over time have strongly contributed to strengthen both national capacities and countries' cooperation in the aquaculture development. The Network of Aquaculture Centres in Asia-Pacific (NACA) and the Network of Aquaculture Centres in Central-Eastern Europe (NACEE)[42] are effective regional aquaculture networks. Both of these networks support their member countries in capacity building on varying components of aquaculture development. For example, NACA has seven main thematic areas of work, which include "genetics and biodiversity" and "training and education".[43] These themes incorporate regular training activities on various topics of regional priority in aquaculture development, such as broodstock management, marine finfish seed production and management for sustainable aquaculture development.

The following subsections highlight the findings from Country Reports in response to a part of the questionnaire requesting information on national mechanisms for networking and coordination on AqGR and identifying further capacity-strengthening needs.

8.4.1 Networking mechanisms

Countries reported mechanisms within their respective borders that are responsible for coordinating the aquaculture, culture-based fisheries and capture fisheries subsectors with other sectors that utilize the same water resources (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 development of aquaculture establishments in Ghana.

[41] www.nbfgr.res.in/en [Cited 14 December 2018].

[42] www.nacee.eu/en [Cited 14 December 2018].

[43] https://enaca.org [Cited 14 December 2018].

TABLE 78

Total number of coordinating mechanisms relating to aquatic genetic resources, detailed by 67 responding countries

Country	Number of mechanisms	Country	Number of mechanisms
Algeria	2	Lao People's Democratic Republic	2
Argentina	6	Madagascar	12
Australia	1	Malawi	2
Bangladesh	6	Malaysia	5
Belgium	6	Mexico	6
Benin	5	Morocco	2
Bhutan	1	Mozambique	1
Brazil	2	Netherlands	5
Bulgaria	5	Nicaragua	1
Burkina Faso	1	Niger	1
Cambodia	1	Nigeria	4
Cameroon	2	Norway	7
Chile	1	Palau	1
Colombia	4	Panama	4
Costa Rica	1	Paraguay	1
Croatia	1	Peru	2
Cuba	1	Philippines	20
Cyprus	2	Republic of Korea	1
Denmark	1	Romania	1
Djibouti	1	Senegal	3
Dominican Republic	2	Sierra Leone	2
Ecuador	2	Slovenia	1
Egypt	1	South Africa	1
El Salvador	2	Sri Lanka	6
Estonia	1	Sweden	5
Fiji	2	Thailand	7
Germany	5	Tunisia	1
Ghana	1	Turkey	1
Guatemala	1	Uganda	5
Hungary	1	Ukraine	1
India	2	United Republic of Tanzania	1
Indonesia	3	United States of America	2
Iran (Islamic Republic of)	3	Venezuela (Bolivarian Republic of)	6
Japan	3		
		Total	**199**

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q41 (n = 67).

A total of 199 different mechanisms of intersectoral coordination were identified by 67 countries (Table 78). Therefore, 70 percent of the responding countries (92 countries in total) indicated the presence of mechanisms responsible for coordination between the aquaculture and fisheries sector and other sectors.

Countries that did not report the existence of any intersectoral coordinating mechanisms were 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, Sudan, Togo, Tonga, Vanuatu, Viet Nam and Zambia.

The regions with the highest average number of intersectoral mechanisms per country were Asia and Europe. The regions with the lowest level of intersectoral mechanisms were Oceania and North America (Table 79).

Other developing countries and least developed countries were the economic classes with the highest number of intersectoral mechanisms per country (Table 80).

TABLE 79

Number of intersectoral coordination mechanisms on aquatic genetic resources by region and the average number of mechanisms per country in each region

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 and the Caribbean	42	16	2.6
North America	2	1	2.0
Oceania	4	3	1.3
Total	**199**	**67**	**3.0**

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q41 (n = 67).

TABLE 80

Number and average number per country of intersectoral coordination mechanisms on aquatic genetic resources, by economic class

Economic class	Number of mechanisms	Number of countries	Average
Developed Countries	47	17	2.8
Other Developing Countries	108	35	3.1
Least Developed Countries	44	15	2.9
Total	**199**	**67**	**3.0**

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q41 (n = 67).

8.4.2 Capacity needs for coordination and networking

Countries were requested to provide a ranking of the importance of each of the three aspects of capacity strengthening for intersectoral collaboration could be improved in support of the conservation, sustainable use and development of AqGR. Each of three different capacities were ranked by countries, from 1 (very important) to 10 (no importance). "Increase awareness in institutions" was identified by countries as the most important (i.e. had the lower overall importance rank score), followed by "increase technical capacities of institutions" and "increase information sharing between institutions" (Table 81).

The three capacity-strengthening activities were generally ranked similarly in level of importance; however, "increase awareness in institutions" ranked most important in five of the six regions (Figure 84). In less developed

TABLE 81

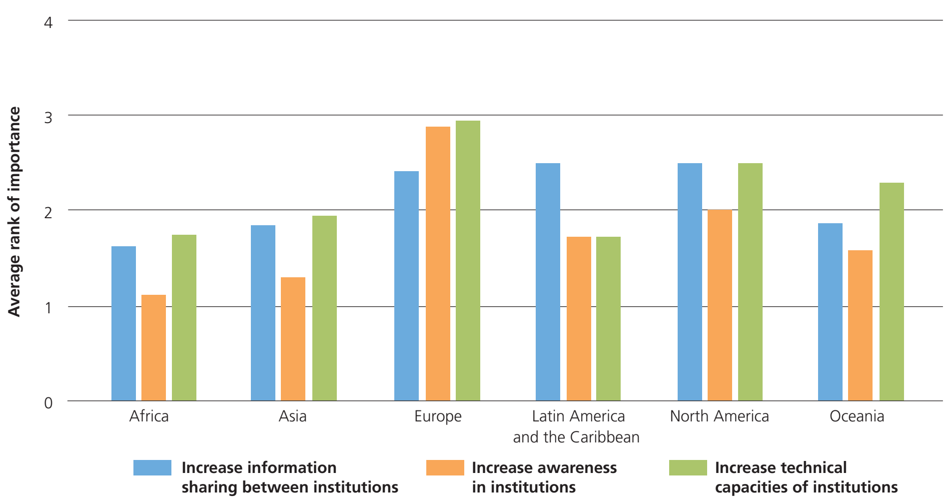
Average overall rank of importance of capacity-strengthening needs for intersectoral coordination in support of the conservation, sustainable use and development of aquatic genetic resources

Capacities to be improved	Average rank
Increase information sharing between institutions	2.2
Increase awareness in institutions	1.7
Increase technical capacities of institutions	2.1

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q42 (n = 91).
Note: 1 = very important, 10 = no importance.

FIGURE 84

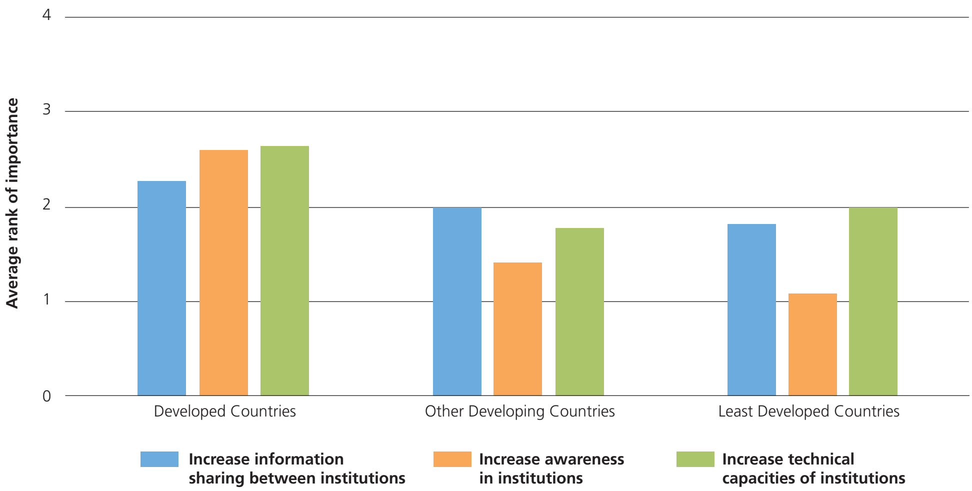
Rank of the importance of capacity-strengthening needs on intersectoral coordination in support of conservation, sustainable use and development of aquatic genetic resources, by region



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q42 (n = 91).
Note: replace: 1 = very important, 10 = no importance. With this ranking system used in the questionnaires the graphing of the derived data reflects the relative lack of importance of issues.

FIGURE 85

Rank of the importance of capacity-strengthening needs on intersectoral coordination in support of conservation, sustainable use and development of aquatic genetic resources, by economic class



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q42 (n = 91).
Note: 1 = very important, 10 = no importance. With this ranking system used in the questionnaires the graphing of the derived data reflects the relative lack of importance of issues.

countries "increase awareness in institutions" was ranked relatively much higher than in developed countries (Figure 85).

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 the conservation, sustainable use and development 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 largest number of national networks, while several countries listed only one national network (see Table 82).

Countries provided information on several examples of the intersectoral mechanisms referred to above (Section 8.4.1) through which they coordinate the fisheries and aquaculture sectors with other sectors whose management can have an impact on AqGR. Some of these mechanisms are implemented as part of specific national strategies, for example, through the coordination of different ministries with the aim of pursuing joint management of natural resources. In other cases, the coordination and networking mechanisms are implemented as part of international (often regional) strategies, such as in the case of the Marine Strategy Framework Directive to improve the effectiveness of the European Union's marine environmental protection. The region with the highest number of national networks, as well as the most networks per country, is Asia (Table 83).

TABLE 82

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	Thailand	2
Bangladesh	10	Slovenia	4	Viet Nam	2
China	10	Argentina	3	Zambia	2
Philippines	10	Bulgaria	3	Algeria	1
Cambodia	9	Dominican Republic	3	Belize	1
Uganda	8	Hungary	3	Benin	1
Canada	7	Norway	3	Burundi	1
Romania	7	Palau	3	Chad	1
El Salvador	6	Republic of Korea	3	Colombia	1
Ghana	6	Tunisia	3	Costa Rica	1
India	6	Turkey	3	Czechia	1
Mexico	6	Belgium	2	Egypt	1
Nigeria	6	Brazil	2	Fiji	1
Senegal	6	Cabo Verde	2	Mozambique	1
Croatia	5	Cuba	2	Niger	1
Malawi	5	Democratic Republic of the Congo	2	Panama	1
Malaysia	5	Guatemala	2	Paraguay	1
Netherlands	5	Japan	2	Poland	1
Sweden	5	Madagascar	2	Togo	1
Australia	4	Sierra Leone	2	Ukraine	1
Cameroon	4	Sri Lanka	2	United Republic of Tanzania	2
				United States of America	1

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q43 (n = 67).

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 84).

Countries reported the various objectives of national networks on AqGR (Table 85). On a global level, the main objective of most national networks was to "Improve communication on aquatic genetic resources". Networks with various objectives exist in most countries.

However, analysis by region and level of economic development revealed difference in the number of networks for the various objectives (Figure 86 and Figure 87). Asian countries had the highest average number of networks with Oceania having the lowest (Table 83). Least developed countries had the lower number of networks (Table 84). The major producing countries consistently had more networks for a given objective than the minor producing countries (Figure 88).

TABLE 83

Total and average number (per country) of national networks related to aquatic genetic resources, by region

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 and the Caribbean	54	13	4.2
North America	8	2	4.0
Oceania	8	3	2.7
Total	**253**	**67**	**3.8**

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q43 (n = 67).

TABLE 84

Total and average number (per country) of national networks related to aquatic genetic resources, by economic class

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**

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q43 (n = 67).

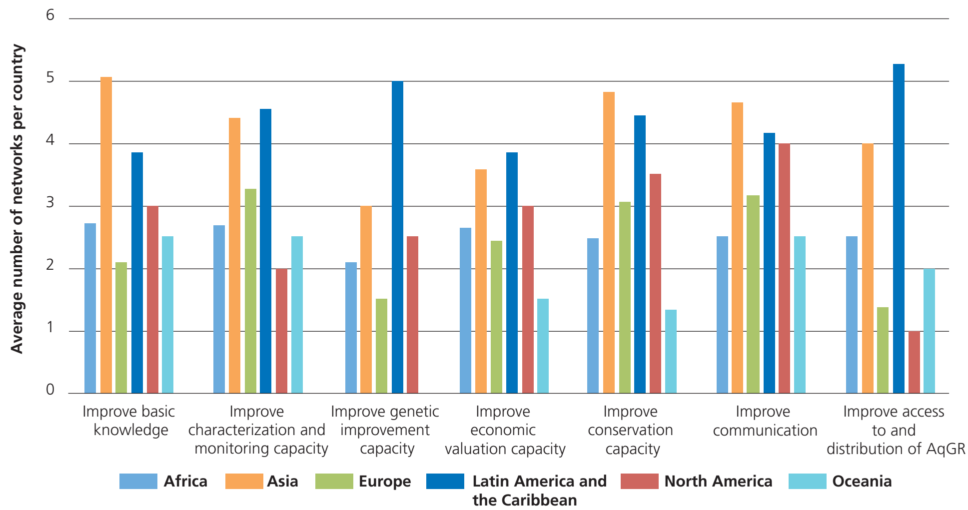
TABLE 85

Total and average (per country) number of networks addressing each of the specified networking objectives

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

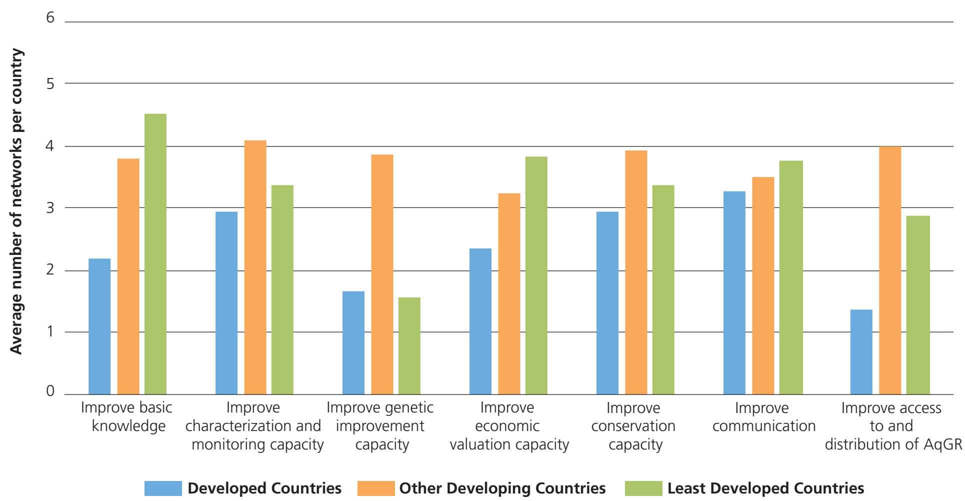
Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q43 (n = 67).

FIGURE 86
Average (per country) number of networks addressing each of the specified networking objectives, by region



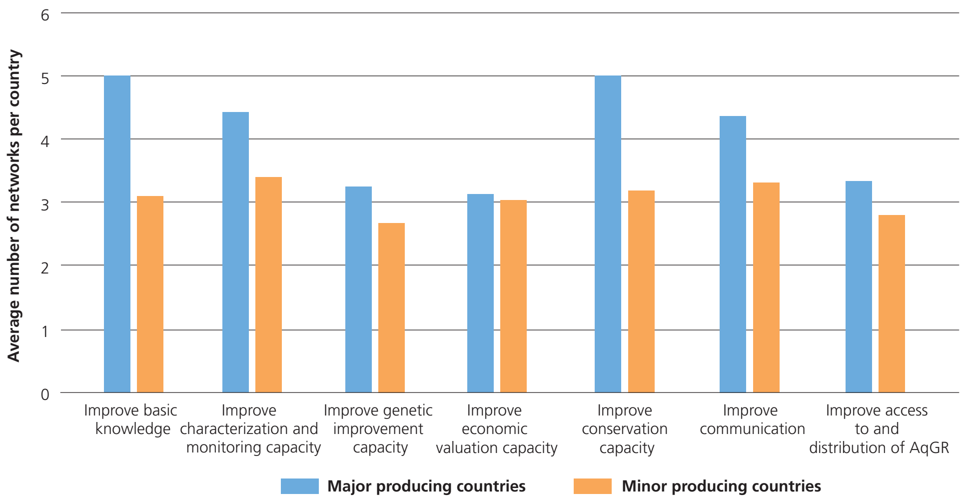
Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q43 (n = 67)

FIGURE 87
Average (by country) number of networks addressing each of the specified networking objectives, by economic class



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q43 (n = 67)

FIGURE 88
Average (by country) number of networks addressing each of the specified networking objectives, by level of aquaculture production



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q43 (n = 67)

"Improve capacities for genetic improvement" was the least cited objective of networks. This was in line with the finding that this was also one of the main thematic areas of research and education on AqGR where capacity needs to be strengthened.

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 percent 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 86).

The region that reported the highest absolute number of information systems on AqGR was Africa; the region that reported the highest average number of information systems per country related to AqGR was Latin America and the Caribbean, followed closely by Asia (Table 87).

Other developing countries reported an average of 3.0 information systems on AqGR per country, while developed countries reported an average of 2.3 information systems per country (Table 88). The major producing countries reported on average more information systems on AqGR than the minor producing countries (Table 89).

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. The main users identified by countries and the extent of use of the aforementioned 171 information systems are shown in Table 90.

TABLE 86
Number of information systems on aquatic genetic resources, by reporting country

Country	Number of information systems	Country	Number of information systems
Algeria	4	Japan	3
Argentina	2	Madagascar	7
Bangladesh	2	Malawi	5
Belgium	1	Malaysia	4
Benin	4	Mexico	18
Bhutan	2	Morocco	7
Brazil	1	Mozambique	1
Bulgaria	1	Netherlands	6
Cabo Verde	1	Niger	1
Cambodia	1	Nigeria	6
Cameroon	1	Norway	4
Chile	1	Palau	1
China	1	Panama	1
Colombia	5	Philippines	9
Costa Rica	2	Poland	2
Croatia	3	Republic of Korea	1
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	Thailand	3
Germany	5	Tunisia	2
Ghana	1	Uganda	3
Guatemala	1	Ukraine	1
Honduras	1	United Republic of Tanzania	1
Hungary	2	United States of America	1
India	9	Viet Nam	1
Iran (Islamic Republic of)	3	Zambia	2
		Total	**171**

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q44 (n = 64)

TABLE 87

Total and average (per country) number of information systems on aquatic genetic resources, by region

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 and the Caribbean	37	12	3.1
North America	1	1	1.0
Oceania	2	2	1.0
Total	**171**	**64**	

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q44 (n = 64)

TABLE 88

Total and average (per country) number of information systems on aquatic genetic resources, by economic class

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**	

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q44 (n = 64)

TABLE 89

Total and average (per country) number of information systems on aquatic genetic resources, by level of 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**	

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q44 (n = 64)

TABLE 90

Main users of information systems on aquatic genetic resources and the total number of information systems utilized by these stakeholders

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

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture:* responses to Q44 (n = 64)

The main users of information systems identified by responding countries were "universities and academia" and "government resource managers". Stakeholder groups reported to have limited use of these information systems, were consumers, politicians, donors and people involved in marketing. Aquaculture producers (hatcheries, farmers), fishers in capture fisheries and people involved in the marketing of AqGR were reported to have a medium level of use of the information systems (Table 90).

8.5.2 Type of information stored in information systems on aquatic genetic resources

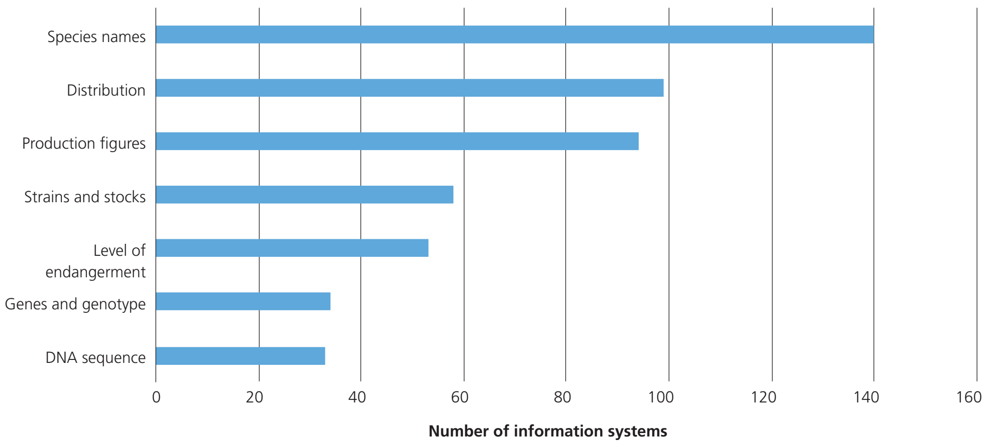
The type of information stored in national information systems on AqGR was assessed by countries, as shown in Figure 89.

Most of the information systems available at national level 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 91). 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).

Major producing countries reported, on average, more information on the following categories: DNA sequences, genes, strains, species names, distribution and endangerment than minor producing countries.

FIGURE 89

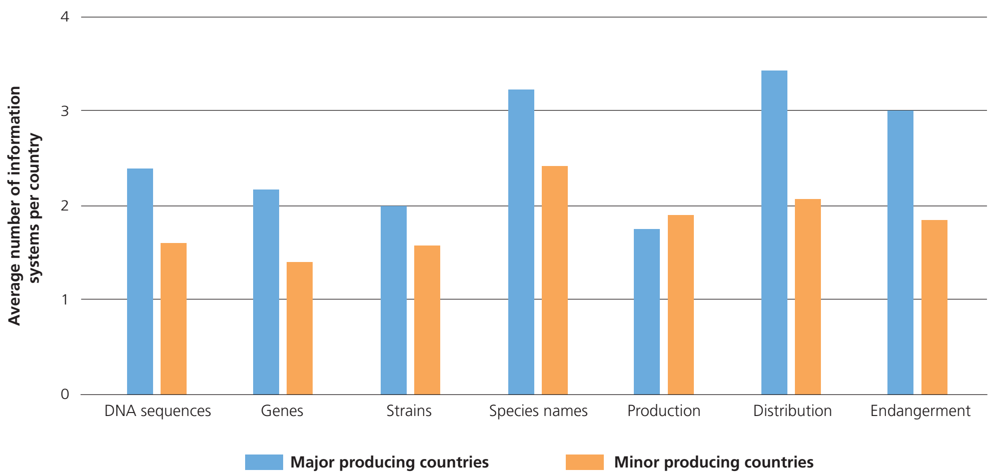
Types of information stored across all reported information systems on aquatic genetic resources



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture:* responses to Q44 (n = 64)

FIGURE 90

Types of information stored across all reported information systems on aquatic genetic resources, by level of production



Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture:* responses to Q44 (n = 64)

TABLE 91
Types of information stored across all reported information systems on aquatic genetic resources, 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**

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q44 (n = 64)

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CHAPTER **9**

International collaboration on aquatic genetic resources of farmed aquatic species and their wild relatives

CHAPTER 9

PURPOSE: The purpose of this chapter is to review, based on the information provided in Country Reports, the mechanisms and instruments through which countries participate in international collaboration on aquatic genetic resources (AqGR) of farmed aquatic species and their wild relatives. The specific objectives are to:

- identify countries' current participation in bilateral, subregional, regional and global collaboration on AqGR;
- 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 collaborate on AqGR through a wide range of mechanisms and instruments.
- A large number of international agreements of relevance to collaboration on conservation, sustainable use and development of AqGR were reported (nearly 170 unique agreements in total).
- The Convention on Biological Diversity (CBD) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) were the most often cited agreements, followed by the Nagoya Protocol, the Cartagena Protocol and the Ramsar Convention.
- The impact of international agreements on conservation, sustainable use and development of AqGR was mostly reported to be positive to strongly positive.
- Countries reported that their needs from collaboration on conservation, sustainable use and development of AqGR are not adequately met, highlighting the need for more effective international networking.
- Regional and international collaboration can be a key driver for successful conservation, sustainable use and development of AqGR.

9.1 Introduction

In the relevant section of the questionnaire that formed the basis of the Country Reports, countries were requested to list their national memberships or status as a party to agreements, as well as other forms of affiliation to agreements, conventions, treaties, international organizations, international networks and international programmes. In a further question, countries were asked to rank the importance of various needs or rationales for collaboration and the extent to which these needs are being met. Lastly, countries were requested to describe the collaborations of greatest benefit, their need to expand collaboration, and what key roles they perform in their regions.

The Reports reveal that 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 chapter lists several key international instruments that have been reported by countries as being of relevance to AqGR use, conservation and management.

9.2 Conventions

9.2.1 Convention on Biological Diversity

The Convention on Biological Diversity (CBD) is an international treaty for the conservation of biodiversity that entered into force in December 1993 (CBD, 1992). The Convention covers the sustainable use of the components of biodiversity, and the equitable sharing of benefits derived from the utilization of genetic resources. As of December 2018 there are 196 Parties to the Convention which represents near universal participation among countries.[44] The Convention seeks to address global threats to biodiversity and the ecosystem services this diversity provides and includes the impacts of climate change. It promotes the active engagement of stakeholders including women, youth, indigenous people, local communities and the business community. Threats are addressed through the promotion of science, the development of appropriate tools and best practices and the development of technologies, processes and incentives.

The CBD has important supplementary agreements including The Cartagena Protocol on Biosafety and the Nagoya Protocol on Access and Benefit Sharing. Coming into force in September 2003, and to date (December 2018) ratified by 171 Parties, the Cartagena Protocol seeks to protect biological diversity from the potential risks posed by living modified organisms resulting from modern biotechnology.[45] The Nagoya Protocol came force in October 2014, and as of December 2018 has been ratified by 114 Parties.[46] It aims to promote sharing of the benefits arising from the utilization of genetic resources, in a fair and equitable way, including by enabling appropriate access to genetic resources and by appropriate transfer of relevant technologies, thereby contributing to the conservation and sustainable use of biodiversity.

Farmed AqGR and their wild relatives are included in the scope of the CBD and its protocols, and have been made the target of some of the thematic programmes of work (e.g. “Inland Waters Biodiversity” and “Marine and Coastal Biodiversity”) established by the CBD Conference of Parties.

[44] www.cbd.int/information/parties.shtml [Cited 6 December 2018].

[45] http://bch.cbd.int/protocol [Cited 6 December 2018].

[46] www.cbd.int/abs/nagoya-protocol/signatories/default.shtml [Cited 6 December 2018].

9.2.2 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)[47] 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. The Convention was opened for signature in 1973 and entered into force on 1 July 1975 and has been ratified by 183 parties [July, 2019].

The species covered by CITES are listed in three distinct appendices:

- Appendix I includes species threatened with extinction (e.g. shortnose sturgeon, *Acipenser brevirostrum*) and for which trade in specimens of these species is allowed only in exceptional circumstances under particularly strict regulation.
- Appendix II includes species not necessarily threatened with extinction, but that may become extinct unless strict trade regulations are undertaken (e.g. all other sturgeon species). This appendix further includes the so-called look-alike species, namely those species that are controlled because of their similarity in appearance to the regulated species in order to facilitate a more effective control thereof.
- Appendix III contains species that are subject to regulation in at least one country that has asked other CITES Parties for cooperation in controlling the trade. CITES regulation in international trade on aquatic species may help in the reduction of fishing pressure on wild relatives and support the conservation of AqGR.

9.2.3 Ramsar Convention

The Convention on Wetlands of International Importance especially as Waterfowl Habitat, called the Ramsar Convention, is an intergovernmental

[47] https://www.cites.org/sites/default/files/eng/disc/CITES-Convention-EN.pdf

treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. As of December 2018, it has 170 Contracting Parties and there are 2 299 Ramsar Sites distributed across the globe, with a total surface area for the designated sites of 225 517 367 hectares (Ramsar, 2018).[48]

The Ramsar Convention also has a critical role in recognizing the importance of wetlands as a key natural infrastructure supporting those human activities, including aquaculture, that contribute to food security and poverty alleviation. In this sense, the Convention uses a wide definition of wetlands covering both natural and human-made sites, with the latter including fish ponds, rice paddies, reservoirs and salt pans (Ramsar, 2014).

In November 2006, the Parties to the Convention adopted a resolution to address specific issues on the sustainable use of their inland and coastal resources for capture fisheries and aquaculture.[49] The Ramsar Convention thus makes an important contribution to *in situ* conservation of AqGR, as outlined in Chapter 4.

To further promote wise management of both habitats and resources, the Convention has also recommended to its Parties that the Code of Conduct for Responsible Fisheries (CCRF) should be considered as a guidance document in regulating marine and freshwater fisheries and aquaculture (Ramsar, 2007).

9.2.4 United Nations Framework Convention on Climate Change

The United Nations Framework Convention on Climate Change (UNFCCC) has 197 Parties 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. Within the Convention 185 Parties [as of July 2019] have further ratified the Paris Agreement which deals further with mitigation of greenhouse gas emmissions and sets targets for limiting rises in global temperatures.[50] The UNFCCC does not make direct reference to biodiversity or genetic resources, but clearly climate change is a driver of change in AqGR, as outlined in Chapter 3, and thus the Framework has strong implications for its future conservation, sustainable use and development.

9.2.5 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[51] came into force in 1994 and has been ratified by 168 Parties [as of December, 2018].[52]

One of the most revolutionary points introduced by this Convention is the exclusive economic zone (EEZ), which has had an essential impact on the management and conservation of AqGR in the oceans. Within their exclusive EEZ, coastal states have certain responsibilities and obligations, such as to pursue a sustainable use of fish stocks. For each fish species, each coastal state has to determine the total allowable catch within its EEZ and estimate its harvest capacity. In case of surplus over the allowable catch, a coastal state must guarantee access to that surplus to neighbouring and land-locked countries. At the

[48] https://www.ramsar.org/country-profiles. [Cited 9 December 2018].

[49] http://archive.ramsar.org/cda/en/ramsar-documents-resol-resolution-ix-4-the/main/ramsar/1-31-107%5E23518_4000_0_ [Cited 6 December 2018].

[50] https://unfccc.int/process-and-meetings/the-paris-agreement/what-is-the-paris-agreement

[51] https://treaties.un.org/doc/Publication/MTDSG/Volume%20II/Chapter%20XXI/XXI-6.en.pdf

[52] www.un.org/Depts/los/reference_files/chronological_lists_of_ratifications.htm [Cited 8 March 2018].

same time, the modality of access should conform to the conservation measures established by the national laws of the coastal state.[53]

9.2.6 The Barcelona Convention

The Barcelona Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean was adopted in 1995 to replace the Mediterranean Action Plan of 1975. It aims to protect the Mediterranean marine and coastal environment and to foster regional and national plans to achieve sustainable development. As of December 2018, the Convention has 22 Contracting Parties.[54] The main objectives of the Barcelona Convention include the sustainable management of natural marine and coastal resources, the assessment and control of marine pollution, the protection of natural and cultural heritage, and the cooperation between Mediterranean coastal states.

9.2.7 The Convention on the Conservation of Migratory Species of Wild Animals

The Convention on the Conservation of Migratory Species of Wild Animals (CMS)[55] is an environmental treaty under the aegis of the United Nations Environment Programme. It was established in 1979 to provide a global platform for the conservation and sustainable use of migratory species and their habitats, providing the legal framework for coordination of the conservation measures adopted by states through which migratory animals pass, known as the range states. As of 1 December 2018, the CMS has 127 Parties.[56]

The importance of this international agreement is related to the fact that it is the only global convention focused on the conservation of migratory species, their habitats and migration routes. The migratory species covered by the Convention include aquatic species such as the many different sturgeon species.

The species targeted by this agreement fall into one of the two following appendices:

- Appendix I includes those migratory species that are threatened with extinction. CMS Parties strive towards strictly protecting these animals, conserving or restoring the places where they live, mitigating obstacles to migration, and controlling other factors that might endanger them. Besides establishing obligations for each state joining the Convention, CMS promotes concerted action among the range states of many of these species.
- Appendix II includes those migratory species that need or would significantly benefit from international cooperation. For these species, the Convention encourages its range states to conclude global or regional agreements.

9.3 Other relevant agreements

9.3.1 The Code of Conduct for Responsible Fisheries of the Food and Agriculture Organization of the United Nations

The 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 (1995) – the FAO Governing Bodies recommended the formation of a global CCRF that would be consistent with these instruments. FAO's CCRF, in a non-mandatory

[53] www.un.org/depts/los/convention_agreements/convention_historical_perspective.htm [Cited 9 December 2018].

[54] http://ec.europa.eu/environment/marine/international-cooperation/regional-sea-conventions/barcelona-convention/index_en.htm [Cited 7 December 2018]

[55] https://www.cms.int/sites/default/files/instrument/CMS-text.en_.PDF

[56] https://www.cms.int/en/legalinstrument/cms [Cited 7 December 2018].

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 FAO Members, 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 UNCLOS. 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).

Beyond the aforementioned conventions and the CCRF, countries reported other intergovernmental, bilateral, trilateral and multilateral agreements. The objectives of these agreements ranged from the extremely specific, such as in the case of some bilateral agreements, to the more general, as in the case of some broad-scope regional fisheries management organizations (RFMOs), including the Northwest Atlantic Fisheries Organization, the North East Atlantic Fisheries Commission, and the South East Atlantic Fisheries Organization. These organizations play a role in determining the future of AqGR, particularly in the case of wild relatives with transboundary stocks.

9.4 International agreements and their impacts on aquatic genetic resources and on stakeholders

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 or impact upon AqGR of farmed species and their wild relatives. Countries were also asked to assess the impact of those agreements on AqGR and stakeholders, for example:

- 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.

9.4.1 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 92). This amounted to a total of 515 responses referring to 174 unique 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 93 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 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 reported the same agreements (e.g. 60 countries reported on CBD).

Seventy-eight percent of the countries reported only one international agreement of relevance to AqGR, possibly indicating a low level of awareness of the relevance of these agreements despite the growing global importance of farmed aquatic production.

TABLE 92

Number of reported international, regional, bilateral or subregional agreements relevant to aquatic genetic resources, by reporting country

Country	Number of international agreements	Country	Number of international agreements	Country	Number of international agreements
Algeria	8	El Salvador	8	Palau	7
Argentina	8	Estonia	1	Panama	16
Armenia	5	Fiji	1	Paraguay	1
Australia	11	Finland	11	Peru	8
Bangladesh	8	Georgia	4	Philippines	12
Belgium	3	Germany	20	Republic of Korea	3
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	Thailand	4
Cameroon	3	Lao People's Democratic Republic	2	Togo	6
Canada	2	Madagascar	5	Tonga	2
Chad	7	Malawi	6	Tunisia	13
Colombia	10	Malaysia	6	Turkey	9
Democratic Republic of the Congo	5	Mexico	7	Uganda	11
Costa Rica	8	Morocco	8	Ukraine	3
Croatia	9	Mozambique	3	United Republic of Tanzania	6
Cuba	6	Netherlands	5	United States of America	11
Czechia	4	Nicaragua	4	Vanuatu	2
Djibouti	1	Niger	3	Venezuela (Bolivarian Republic of)	3
Dominican Republic	11	Nigeria	10	Viet Nam	5
Ecuador	8	Norway	24	Zambia	11
Egypt	1				

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q46 (n = 82).

TABLE 93

Top ten important international agreements dealing with use, conservation and management of aquatic genetic resources, by region

International agreements	Asia	Africa	Europe	Latin America and the Caribbean	North America	Oceania	Total countries
CBD	12	17	12	13	1	5	60
CITES	15	18	10	12		5	60
Nagoya Protocol	10	10	11	13		2	46
Cartagena Protocol	11	9	7	12		1	40
Ramsar Convention	8	13	4	9		1	35
UNCLOS	7	7	8	2		1	25
CCRF	5	8	4	2		2	21
UNFCCC	2	9	1	3			15
Barcelona Convention	1	4	1				6
CMS		4	2				6

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responsesto Q46 (n = 82).
Note: Number refer to the number of countries in each region referencing the agreement. CBD = Convention on Biological Diversity; CITES = Convention on International Trade in Endangered Species of Wild Fauna and Flora; CCRF = Code of Conduct for Responsible Fisheries; CMS = Convention on the Conservation of Migratory Species of Wild Animals; UNCLOS = United Nations Convention on the Law of the Sea; UNFCCC = United Nations Framework Convention on Climate Change.

TABLE 94

Number of international agreements reported by countries, by region

Regions	Number of international agreements reported	Total number of responding countries	Average number of agreements per country
Africa	147	26	5.7
Asia	93	17	5.6
Europe	119	13	9.1
Latin America and the Caribbean	116	17	6.8
North America	13	2	6.5
Oceania	27	7	3.9

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q46 (n = 82).
Note: Number of international agreements reported is the number of country responses and not the number of unique agreements.

TABLE 95

Number of international agreements reported by countries, 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

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q46 (n = 82).
Note: Number of international agreements reported is the number of country responses and not the number of unique agreements.

The number of international agreements (i.e. the total number of responses referring to such agreements and not the number of unique agreements) reported per region ranged from 13 in North America to 147 in Africa (Table 94), and by economic class from 115 in the least developed countries to 243 in other developing countries (Table 95). The numbers of international agreements reported by minor and major producing countries were 448 and 67, respectively (Table 96).

The impact on AqGR was reported for 469 out of the 515 agreements reported by countries (recalling this refers to the number of country responses and not to the number of unique Agreements). In the vast majority of cases (399) the impact of the agreement was reported to be positive or strongly positive; in 67 cases the agreement was reported to have no effect; in three cases the impact of the agreement was reported to be negative (Table 97).

TABLE 96

Number of international agreements reported by countries, by level of aquaculture production

Economic class	Number of international agreements reported	Total number of responding countries	Average number of agreements per country
Major producing countries	67	9	7.4
Minor producing countries	448	73	6.1

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q46 (n = 82).
Note: Number of international agreements reported is the number of country responses and not the number of unique agreements.

TABLE 97

Impact of international agreements on aquatic genetic resources, presented as number of responses by individual countries for each impact category

Impact on aquatic genetic resources	Number of international agreements reported	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); Lao People's Democratic Republic (1); Malawi (1); Malaysia (3); Mexico (7); Nicaragua (1); Niger (1); Paraguay (1); Peru (6); Philippines (12); Republic of Korea (1); Senegal (1); Sierra Leone (2); Sweden (2); Togo (1); Tunisia (3); Turkey (1); Uganda (5); United Republic of Tanzania (4); 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); 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); Republic of Korea (2); Romania (6); Samoa (2); Senegal (3); Sierra Leone (2); South Africa (2); Sri Lanka (4); Sudan (6); Sweden (1); Thailand (4); Togo (3); Tonga (2); Tunisia (8); Uganda (6); Ukraine (3); United Republic of Tanzania (2); 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)

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q46 (n = 82).
Note: Number of international agreements reported is the number of country responses and not the number of unique agreements.

The impact of international agreements on stakeholders was reported for 465 out of the total 515 agreements (recalling that this refers to the number of country responses and not to the number of unique agreements).

The results are similar to those for impacts on AqGR. In 387 cases the impact of the agreement was reported to be positive or strongly positive; in 66 cases the agreement was reported to have no effect; in 12 cases the agreement was reported to have a negative impact (Table 98).

Analysis by region confirms that in all regions the impact of international agreements on AqGR was largely considered to be either positive or strongly

TABLE 98

Impact of international agreements on stakeholders, presented as number of responses by individual countries for each impact category

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); Tunisia (3); Turkey (1); Uganda (4); Ukraine (1) ; United Republic of Tanzania (4)
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); 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); Republic of Korea (3); Romania (6); Samoa (2); Senegal (4); Sierra Leone (2); South Africa (2); Sri Lanka (4); Sudan (6); Sweden (3); Thailand (4); Togo (4); Tonga (2); Tunisia (8); Uganda (7); Ukraine (2); United Republic of Tanzania (2); United States of America (7); Vanuatu (2); Viet Nam (5); Zambia (9)
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)

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q46 (n = 82).

TABLE 99

Impact of international agreements on aquatic genetic resources, by region

Region	Impact on aquatic genetic resources			
	Strongly positive	Positive	No effect	Negative
Africa	30	93	7	2
Asia	25	44	10	1
Europe	3	76	25	0
Latin America and the Caribbean	29	72	12	0
North America	0	9	4	0
Oceania	0	18	9	0
Total	**87**	**312**	**67**	**3**

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q46 (n = 82).
Note: Numbers refer to the number of agreements reported by countries in each region for which the nature of the impact was reported.

positive. Europe, followed by Latin America and the Caribbean, Asia and then Africa, was the region that reported the highest number of cases in which international agreements have "no effect" (Table 99).

9.4.2 International collaboration – needs assessment: overview by region, subregion and economic class

Countries were requested to prioritize a predefined list of needs for international collaboration on conservation, sustainable use and development of AqGR and indicate the extent to which these needs are being met. All the needs were ranked as being fairly important, but the following areas were given slightly higher priority: improving information technology and database management; improving knowledge on AqGR; improving capacities for characterization and monitoring; improving capacities for genetic improvement and improving capacities for conservation.

The needs most frequently reported to be unmet or only partially met were: improve communication on aquatic genetic resources; improve capacities for conservation of aquatic genetic resources; and improve capacities for economic valuation of aquatic genetic resources (Table 100). With the exception of information technology and database management, the extent to which the assessed need is not met or only partially met is rather high (all equal to or above 74 percent). This highlights a need for greater cooperation. Establishment of international collaborations can represent a valuable tool for countries to overcome limitations in national capacity in one or more of the areas indicated to have priority importance. Box 27 describes on an international network that was successful in supporting countries and building capacity.

The information from Country Reports was also analysed at the regional level for the five assessed needs that were given a higher priority by the respondents (Table 101). The high number of countries around the globe answering "none" regarding the extent to which these important needs are met points to the need for a network, perhaps along the lines of the International Network on Genetics in Aquaculture (Box 27).

TABLE 100

Reported importance of the need for international collaboration in various areas of aquatic genetic resources management and reported extent to which these needs are not being or only partially being met

Assessed need for collaboration*	Average importance rank	Extent to which the need is met or 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

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q47 (n = 90).
Note: 1 = very important, 10 = no importance.
* From a list predefined in the Country Report questionnaire.
**Calculated as the percentage of countries reporting "not met" or "only met to some extent".

Box 27
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, infrastructure 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 with 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 Genetically Improved 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 more widely, as well as the technology of continuous genetic improvement through selective breeding. 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).

Members of INGA 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 following:

- Develop the "Manila Resolution" which 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 agreed to follow standard procedures for the exchange of AqGR through material transfer agreements (MTAs).

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, for example *Labeo rohita*, common carp (*Cyprinus carpio*), silver barb (*Barbonymus gonionotus*), and 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 that of the 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 the successful example of the GIFT programme.

While all the reasons have not been examined in depth, the main reason for its closure seems to have been the lack of a sustained, long-term funding mechanism (M.V. Gupta, personal communication, 26 March 2018). As the network was project financed, it ended when projects ended.

(Cont.)

Box 27 (*Cont.)*
The International Network on Genetics in Aquaculture

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 of 26 March 2018 to the FAO Aquaculture Branch, recommended that a future INGA-like network should adhere to the following three points:

- 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.
- There should be a stable leadership and a coordinating institution with strong and stable competence in aquaculture breeding and genetics.
- Recognizing that genetic improvement is a long-term endeavour, members of the network should identify genetics projects as a core programme/ project of their institutions.

Given the potential for AqGR, the common interests of many countries, the information generated by the Report and the National Focal Points that helped to create it, it may be opportune to consider developing a new network on AqGR.

9.5 Selected successful examples of international collaboration

The last section of this chapter presents some successful examples of international collaboration. A discussion of the collaborative development and international dissemination of tilapia is presented in Box 28.

An excellent example of international collaboration regarding common carp (*Cyprinus carpio*) genetic resources has been provided by the "HAKI-live gene bank of common carp" in Hungary (Box 29).

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 the restocking of turbot (*Scophthalmus maximus*) based on the native population to enhance the stock, contributing to the conservation of genetic resources, and providing 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 of both international cooperation as well as 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 (*Salmo salar*) to the river basin demonstrates the important role of targeted international cooperation (Box 30).

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 31). The main issues prioritized by one or more of these organizations in regional cooperation included: (i) capacity building for genetic improvement, especially of indigenous species; (ii) improving information on AqGR; (iii) *in situ* conservation; (iv) knowledge development on diverse locally developed aquaculture strains; (v) capacity-building on mechanisms for the biosecure exchange of aquaculture genetic material; and (vi) policy development.

TABLE 101

Overview of Country Report responses by region, on the extent to which the five highest priority needs for international cooperation are being met

Assessed need for international collaboration	Response	Africa	Asia	Europe	Latin America and the Caribbean	North America	Oceania	Global
Improved information technology and database management	To a great extent	3	5	3	5	1	0	17
	To some extent	10	8	8	9	1	7	43
	None	9	4	3	2	0	0	18
	Unknown	3	0	2	2	0		7
	Total	**25**	**17**	**16**	**18**	**2**	**7**	**85**
Improved basic knowledge on aquatic genetic resources	To a great extent	4	3	4	3	1	0	15
	To some extent	15	12	8	15	1	7	58
	None	4	3	2	0	0	0	9
	Unknown	2	0	1	0	0	0	3
	Total	**25**	**18**	**15**	**18**	**2**	**7**	**85**
Improved capacities for characterization and monitoring of aquatic genetic resources	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	0	1	15
	Unknown	2	1	3	1	0	0	7
	Total	**25**	**17**	**15**	**18**	**2**	**7**	**84**
Improved capacities for genetic improvement	To a great extent	4	4	1	3	0	1	13
	To some extent	10	8	8	12	2	3	43
	None	7	4	3	2	0	0	16
	Unknown	3	0	3	1	0	0	7
	Total	**24**	**16**	**15**	**18**	**2**	**4**	**79**
Improved capacities for conservation of aquatic genetic resources	To a great extent	2	4	2	1	1	0	10
	To some extent	19	10	10	12	1	7	59
	None	3	2	1	2	0	0	8
	Unknown	0	1	3	1	0	0	5
	Total	**24**	**17**	**16**	**16**	**2**	**7**	**82**

Source: Country Reports prepared for *The State of the World's Aquatic Genetic Resources for Food and Agriculture*: responses to Q47 (n = 90).
Note: Numbers refer to the number of countries in each region identifying the extent to which each need is met.

Box 28
The case of the two tilapias

Tilapias are among the most globally ubiquitous species for aquaculture, with production being reported in over 140 countries around the world and current world production over 5 million tonnes. Tilapias are a species complex made up of three genera – *Oreochromis, Sarotherodon* and *Tilapia* spp. (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*). This box highlights the contrasting histories of distribution of these species around the world, and the impact this history is likely to have had on the culture potential of the two species. This case demonstrates the value of effective management, including selective breeding, of genetic resources for aquaculture.

Oreochromis mossambicus

The first species for which potential for 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 for stunting. These properties may well be a result of inbreeding depression, resulting from genetic bottleneck effects. *O. mossambicus* has now been largely displaced by *O. niloticus* in global aquaculture, although remnant feral populations are commonplace in countries to which it was introduced.

Oreochromis niloticus

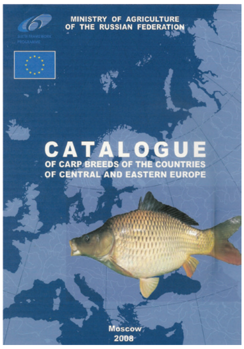
The authors Pullin and Capili (1988) report that the initial distribution of *O. niloticus* had a broader base than outlined for *O. mossambicus*, with multiple source populations. In the past two decades, the Genetically Improved Farmed Tilapia (GIFT) project has played an important and proactive role in the distribution of Nile tilapia. The GIFT project was an international collaboration to improve the genetic performance of farmed Nile tilapia, and was implemented from 1988 to 1998 (Gjedrem, 2012). This project demonstrates what can be achieved through a systematic and collaborative approach to the collection, development and distribution of germplasm for aquaculture. Under this project, founder populations were collected from local 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 has not only avoided the negative impacts of inbreeding or poor genetic management, but has also resulted in superior performance in many aquaculture strains as a result of maintenance of high levels of genetic variation and genetic selection for important traits.

While the likely inbreeding resulting from a genetic bottleneck in *O. mossambicus* may have damaged the potential for global aquaculture of this species, 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 *O. niloticus*. Nile tilapia is now reported as being cultured in 87 countries, and through the reporting process for the Report, seven countries recorded production of GIFT tilapia, but it is likely that GIFT-derived strains are impacting production in many more countries.

Box 29

Regional cooperation in carp gene banking

The "HAKI-live gene bank of common carp", located at the Research Institute for Fisheries and Aquaculture (HAKI), in Szarvas, Hungary, was established through intensive international collaboration (see Box 22).[1] 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 (*Cyprinus carpio*) 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 where regulations (translocation and biosecurity) and financial resources allowed. 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 occurred 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 (English and Russian) 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 from the HAKI-gene bank (e.g. after the pollution events in the Tisza River 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.

[1] The information in this box was provided by Z. Jeney (pers. comm. 2018)

Box 30

Migratory species of the Rhine River – a successful example of regional cooperation

At 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 the stock in the 1950s. This extinction was closely correlated with the construction of obstacles to migration, although there were other contributory factors, including the deterioration of water quality and overexploitation of the remaining stock.

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.

(Cont.)

Box 30 *(Cont.)*

Migratory species of the Rhine River – a successful example of regional cooperation

The ICPR, with headquarters in Koblenz, Germany, coordinates the ecological rehabilitation programme and involves all the countries of the catchment of the Rhine. 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 that they would continue to protect the valuable character of the Rhine, its banks and its 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 implementation of 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 on the incidence of many other animal and plant species and on the entire ecology of the Rhine.

Since 1990, more than 8 000 adult salmon have been recorded within the catchment, and natural reproduction has been regularly recorded in an increasing number of accessible tributaries of the Rhine. The successful return of Atlantic salmon to the Rhine demonstrates that it is possible to reintroduce regionally extinct migratory fish species, and targeted international cooperation has played a key role.[1]

[1] The information in this box was provided by C. Fieseler (pers. comm. 2018)

Box 31

Key issues for international cooperation – feedback from international organizations

Following the initial drafting of the Report, FAO requested feedback from international organizations[1] working with 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.

(Cont.)

Box 31 *(Cont.)*
Key issues for international cooperation – feedback from international organizations

- Capacity building on mechanisms for biosecure exchange of aquaculture genetic material, including support for aquaculture broodstock exchange networks similar to those that are successful and economically self-sustaining for terrestrial domesticated animals.
- Policy development for effective conservation, management and development of AqGR.

Though the aforementioned issues directly impact 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.

[1] Respondents included the Network of Aquaculture Centres in Asia-Pacific, WorldFish, the Pacific Community, Lake Victoria Fisheries Organization, Mekong River Commission, and the Southeast Asian Fisheries Development Centre.

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CHAPTER **10**

Key findings, needs and challenges

This chapter provides a brief synthesis of the key findings from the review of *The State of the World's Aquatic Genetic Resources for Food and Agriculture*, and identifies the main challenges and needs that should be addressed to facilitate the development of future actions to enhance the conservation, sustainable use and development of aquatic genetic resources (AqGR).

The first section summarizes some of the key features and characteristics of AqGR, including identification of some of the unique characteristics of AqGR relative to plant and animal genetic resources. The second part of this chapter outlines some of the major needs and challenges arising from the review of the status of AqGR. These needs and challenges are considered, *inter alia*, in the context of the current and future drivers acting on AqGR, the importance of characterizing and monitoring these resources, the development of these resources to support the growth of aquaculture, and their sustainable use and conservation. A common thread across all of these issues is the important need to build relevant capacity in governance, policy, institutions and the private sector. The final section identifies the role that the Report can play as a catalyst for future actions to enhance conservation, sustainable use and development of AqGR.

10.1 The key features and unique characteristics of aquatic genetic resources

While the capture and harvest of wild aquatic genetic resources (AqGR) has a long history, the farming of AqGR is a recent phenomenon, especially relative to the millennia-old farming of livestock and crops. In recent decades, aquaculture has undergone a very rapid expansion that is concentrated predominantly in developing countries and is still evolving in terms of how it utilizes AqGR. The expansion of aquaculture is predicted to continue, albeit with a slowing rate of growth. Given the absence of growth in capture fisheries production, projected increases in demand for aquatic food can only be met from aquaculture.

We currently exploit a large diversity of our AqGR, fishing more than 1 800 species and culturing over 550 species. However, in aquaculture, relatively few distinctive farmed types have been developed, compared to the vast numbers of breeds of livestock and varieties of crops, and thus our domesticated AqGR are not particularly well adapted to our production systems or specifically tailored to market demands. Farmed types that do exist, particularly in the case of strains, are poorly characterized. Additionally, in many cases farmed types do not have stable characteristics that clearly distinguish them from other farmed types, certainly not in the way that most livestock breeds are clearly distinguished, often leading to confused messaging for farmers. Contributing to this confusion is a lack of standardization in the use of terminology to describe AqGR and a general paucity of reliable and available information on AqGR below the level of species.

In response to the growing demand for food fish, the industry is constantly exploring the diversity of species that can be cultured and developing culture systems for new species. Concentration in production of large quantities of food fish is occurring for a small number of globally important species, including higher value species high up in the food chain, such as Atlantic salmon (*Salmo salar*). However, many of the most important species are those that feed low in the food chain, such as carps and tilapias, which are produced in very large quantities in extensive and semi-intensive systems. Many major aquaculture species are produced primarily in regions to which they are not native and, as a result, exchange of AqGR is relatively commonplace.

Due to the relative infancy of aquaculture, many of our important production species are not yet domesticated or are still in the early phases of domestication and thus there is a heavy reliance on wild types. Consequently, most cultured AqGR retain high levels of genetic variation relative to their wild relatives. These high levels of genetic variation are in contrast to the situation with many livestock breeds and plant varieties, which have lost genetic variation relative to their wild ancestors through genetic bottlenecks and genetic drift over many generations of domestication.

Genetic improvement is a vitally important component of modern day agriculture and has contributed very significantly to production and food security in terrestrial agriculture. Responses in the Country Reports, however, indicate that genetic improvement of cultured AqGR is having a relatively low impact on aquaculture production and that in many countries wild types still prevail as the main farmed type for many species. A wide variety of technologies can be applied to genetic improvement of AqGR, particularly when compared to those available for livestock breeding. Selective breeding is considered the core genetic technology for improvement of cultured AqGR, but is only reported to be occurring in a quarter of all cases (a case being a report of a given cultured species by a given country), with no indication of the scale or quality of these breeding programmes. Atlantic salmon may be the only cultured species in which selective breeding is ubiquitous. The potential impact on aquaculture production efficiency and the benefit–cost ratio of such programmes is well understood. However, the uptake of well-designed selective breeding programmes is low (estimated at little more than 10 percent of global production) and expanding only slowly. In such breeding programmes, pedigrees are recorded, inbreeding is effectively managed and good quality phenotypic data are collected. While such breeding programmes are capable of generating large genetic gains, such programmes are also considered essential precursors to the successful application of most modern molecular genetic advances such as genomic selection.

Unlike in livestock and most plant genetic resources, a strong connection and interaction exists between farmed AqGR and their wild relatives. Many farmed AqGR are derived directly or indirectly from the wild. In addition, there are occurrences of aquaculture affecting wild relative AqGR through habitat disruption, invasive species, escapes from aquaculture and deliberate introductions for restocking or enhancement.

Poorly managed harvesting of wild relatives, as in the case of the almost one-third of global marine fishery stocks considered to be overfished, threatens the sustainability of these wild relatives and any farmed types dependent upon them. The viability of types of wild relatives is further compromised by habitat degradation or loss, competition for water resources, pollution and climate change.

Both aquaculture and the effective management of wild catch fisheries are considered important components of the conservation of AqGR. Spatial management, including aquatic protected areas (both marine and inland), also plays an increasing role in the *in situ* conservation of wild relative AqGR, although conservation of AqGR is not always an explicit goal of such initiatives. While *in situ* conservation is considered a vital component of conservation of AqGR, countries reported on a number of *ex situ* conservation programmes for AqGR. Such programmes can play an important role in conservation, particularly where *in situ* conservation is lacking or species are endangered.

There are many stakeholders with an interest in the conservation, sustainable use and development of AqGR, but there is a need for clarification both of the roles and of the priorities of these stakeholders. AqGR often occur in common property water resources, including transboundary resources; partly as a result, breeders' rights and access and benefit-sharing systems are poorly developed and will differ from those prevalent in other sectors, presenting both opportunities and challenges for management of these resources. Many countries report the need for capacity development in the characterization and development of AqGR and the need for support in the development or refinement of policies specific to AqGR that will support their effective conservation, sustainable use and development.

10.2 Needs and challenges

This section presents the main needs and challenges that arise from review of the key messages presented in each chapter of the Report. Some of these needs and challenges are common to key messages from more than one chapter and so are restructured and presented here under a number of strategic priority areas. Specific needs and challenges identified are highlighted in bold.

10.2.1 Response to sector changes and environmental drivers

The demands of changing markets and niche markets, conditioned in some cases by availability in the market of wild relatives derived from capture fisheries and combined with the desire to culture fish in new or changing environments, are driving an ever-expanding search for new species for aquaculture. However, there are constraints to the development of new species and associated production systems, which can be time-consuming and resource-intensive. Evidence from the livestock and plant sectors indicates future production may be driven by a small number of species adapted to different systems and markets through breeding and genetic improvement. It is not clear whether the future for cultured AqGR will follow a similar pathway of consolidation of production in a few species. Given the finite resources available for aquaculture development, there is a **need for countries to find an appropriate balance of investment in the development of aquaculture of new species (including refinement of the existing systems to culture them), and development of farmed types of existing cultured species.**

While the principal use of AqGR is for food, demand is growing for AqGR for non-food uses, such as biological control, use as animal feed ingredients, production of bioactives such as nutraceuticals, and use as ornamental species. As this often utilizes different species to food species, the culture and exchange of these species may be governed under separate policies and regulations than those for food fish. **It is important to monitor the use and exchange of AqGR for non-food use, such as ornamental species, alongside that of food fish and to identify related risks and needs.**

As the human population grows, there is increasing pressure on aquatic environments, including changing land and water use, which can impact significantly on AqGR. It is important to **enhance understanding of how changing land and water use affects AqGR, to identify where these resources are at risk, and to promote their conservation.**

Many countries considered climate change to be an important driver of predominantly negative change in AqGR, although some changes will be positive. Climate change will have direct and indirect impacts on both farmed AqGR and their wild relatives and is likely to have a disproportionate effect in equatorial/tropical regions. Despite recognizing the potential impacts of climate change on AqGR, countries did not prioritize adaptation to climate change as an objective of conservation of AqGR. **It will be important to monitor and anticipate the current and future impacts of environmental change on AqGR and respond accordingly, for example, through conservation of threatened resources and the development of climate change adapted farmed types for aquaculture.**

10.2.2 Characterization, inventory and monitoring of aquatic genetic resources

Strong characterization, cataloguing and monitoring of AqGR will lead to a stronger understanding of the state of AqGR and necessary actions that will help develop the right governance and conservation frameworks to ensure their sustainable use.

The State of the World reporting process highlighted the need for a more standardized use of terminology and nomenclature for the characterization and description of AqGR. Without this, it will be difficult to fully understand and communicate the status of these resources. The Report identifies and utilizes harmonized and standardized terminology (see Chapter 1). There is a **need to promote the globally standardized use of terminology, nomenclature and descriptions of AqGR.**

The Report has also highlighted discrepancies in the reporting systems in many countries, with the National Focal Points reporting culture of species that are not recorded in country production data reported to FAO and vice versa. **There is thus a need to improve and harmonize reporting procedures and to expand existing species-based information systems to cover unreported AqGR, including aquatic macrophytes, ornamental species and microorganisms.**

Existing reporting systems for both aquaculture and capture fisheries are focused at the level of species. Given the absence of established criteria for the characterization of farmed types used in aquaculture, there is an important **need to develop, promote and commercialize/institutionalize national, regional and global information systems for the collection, validation and reporting of AqGR below the level of species (i.e. farmed types and stocks).**

10.2.3 Development of aquatic genetic resources for aquaculture

There is a diversity of genetic technologies that can be applied to the improvement of AqGR for aquaculture, each with its own properties, advantages and disadvantages, and associated benefits and risks. The properties of technologies are often not well understood, particularly for new generation molecular approaches. **Raising awareness and understanding of the properties, roles and risks of genetic technologies and their application to AqGR, including traditional selective breeding and new generation molecular technologies, will help to ensure that limited resources are utilized for effective and sustainable genetic gains.** Related to this is the need to promote the uptake and appropriate application of genetic improvement technologies, and the associated resourcing of these approaches, to significantly expand the global impact of genetic improvement on aquaculture production. In many cases, **the focus should be on the core technology of development of well-managed and long-term selection programmes,** to which other technologies can add value, given the proven application of this approach for many aquatic species. **Development of public and public–private partnership funding initiatives is often needed to initiate such long-term breeding programmes.** Selective breeding will generally focus on improving commercially important traits, but can also be used to develop strains that are adapted to different production environments, strains with acceptable levels of risk to native AqGR, and strains with resilience to specific impacts of climate change.

An important consideration here is the capacity to implement well-designed long-term selective breeding programmes incorporating accurate characterization and measurement of phenotypic traits and design of good data management and analysis systems. Effective application of selection requires the input of trained quantitative geneticists. Specific human resource capacity in quantitative genetics is often in poor supply. Thus, there **is a need to conduct appropriate training and capacity building in the quantitative skills necessary to implement well-designed breeding programmes.**

10.2.4 Sustainable use and conservation of aquatic genetic resources

Given the importance of non-native species and their major contribution to aquaculture production, exchange of AqGR is commonplace and often goes unrecorded or is inadequately recorded. These introductions can often lead to the establishment of invasive, non-native species. In order to ameliorate this problem **existing policies governing introductions and use of AqGR need to be adapted to effectively**

address the risks posed by use of non-native species in aquaculture including AqGR at the level below species. Such policies should be based on assessment of risk and include controls on introductions and the implementation of monitoring systems to understand the impacts of non-native species and reduce their negative impacts on both farmed and wild relative AqGR. Such policies should consider strengthening biosecurity, controlling escapes from aquaculture and observing responsible stocking of open waters, taking into account genetic diversity and impacts on wild relatives.

Given the importance of many wild relative AqGR to both wild catch fisheries and aquaculture, there is a **need to identify and/or focus conservation and management efforts on those wild relative AqGR that are most at risk**, to ensure that they are managed sustainably and that, where necessary, appropriate conservation measures are implemented. This includes **strengthening, expanding and diversifying *in situ* and *ex situ* conservation programmes,** and **sustaining or improving habitat and environments for wild relatives,** including improving management to reduce the impact of capture fisheries on wild relatives. This broad approach to sustainable use and conservation is a key aspect of the ecosystem approach to fisheries, which is being adopted by resource managers around the world.

In line with the priorities of the CBD, ***in situ* conservation should be promoted as the primary means of protecting threatened wild relative AqGR.** With habitat degradation and loss being major causes of the declining abundance of wild relatives, **habitat protection should be prioritized as a component of *in situ* conservation**. Also important is **identifying threatened wild relative AqGR that are critical to aquaculture development and wild catch fisheries and prioritizing these for *in situ* conservation.** Well-managed fisheries are recognized as an important contributor to *in situ* conservation, and **fisheries management needs to be considered and incorporated into conservation efforts**. At the same time, **the conservation of AqGR should be actively considered in the development of fisheries management plans, particularly for threatened species.**

Spatial management of fisheries, including marine and freshwater aquatic protected areas, can play an important role in the conservation of wild relative AqGR. Thus, spatial management and **aquatic protected areas should be considered in the development of *in situ* conservation of key AqGR.** Additionally, the **conservation of AqGR, including below the level of species, should be explicitly taken into account in the establishment and effective management of planned and existing protected areas.**

Ex situ conservation of AqGR can be an important adjunct or alternative (where wild relative stock cannot be effectively conserved) to *in situ* conservation, where necessary. It is thus important **to identify priority threatened and important AqGR as candidates for effective *ex situ* conservation**. As recognized in the Report, **the role of aquaculture in the conservation of AqGR needs to be considered and incorporated into conservation efforts, while at the same time recognizing the challenge of integrating conservation objectives within commercial systems.** Management of genetic variation, for example through the maintenance of minimum effective population sizes in the transition of generations and the control of deliberate or accidental selection, is essential to the effective application of *ex situ* conservation. Where *ex situ* conservation is important or necessary, **there is a need to develop guidelines and best practices for both *in vivo* and *in vitro ex situ* conservation**, for example, in how to most effectively manage genetic variation in such programmes. *In vitro* conservation can be effective for certain AqGR, particularly microorganisms, fish sperm and some early life history stages of molluscs. However, broader applications are more limited for other AqGR, such as finfish, due to the difficulty of cryopreserving eggs and embryos. In circumstances where *ex situ in vitro* conservation has the potential to play an important role in conservation of AqGR, its effectivity can be improved by the **development of technologies for *in vitro ex situ* preservation for eggs and embryos.**

On-farm *in situ* conservation is a well-understood concept in livestock and plant genetic resource conservation when applied to domesticated and cultivated species that are conserved on-farm, in the surroundings or the environment in which they have developed their distinctive properties. In the case of AqGR, there are few distinctive strains recognized as having developed their properties on farms. Thus, at the present time, the concept of on-farm *in situ* conservation has limited application to AqGR. **It is necessary to clarify the understanding and terminology of on-farm *in situ* conservation of AqGR and identify potential roles it might play in the future**.

Countries should examine how they can design effective conservation programmes in which *in situ* conservation, in the form of protected areas, can be effectively integrated with *ex situ* conservation, to support fisheries and aquaculture and to conserve AqGR. As the conservation benefits of well-managed capture fisheries and aquaculture are clear, these should be promoted more widely in both the fishing/aquaculture industry and the conservation sector, and there may be win–win scenarios resulting from greater collaboration between industry and conservation factions.

10.2.5 Policies, institutions, capacity building and cooperation

National policies are key tools for the regulation of access to and conservation and effective utilization of AqGR. The Report highlights that, while national policies do exist, government exhibits a relative lack of focus on AqGR, particularly below the level of species. There is thus **an overarching need to promote development, monitoring and enforcement of policies and good governance that adequately consider issues affecting conservation, sustainable use and development of AqGR. A review of good policies and practices would provide a good basis for this work.** Such a review should include risk–benefit analysis and specific national needs and goals in order to enhance the use of AqGR. Given the important role that non-native species play in aquaculture, **national policy reviews should include a focus on legislation governing non-native AqGR, including responsible use and exchange based on appropriate assessments of risk.**

The Report specifically highlights that access and benefit-sharing systems for AqGR are poorly developed and documented, and recognizes that the specific characteristics of AqGR often necessitate the development of AqGR-specific ABS. It is thus **important to promote the development of national and regional policies on access and benefit sharing specific to properties of AqGR and to promote safe and sustainable exchange of AqGR.** There are few systems for AqGR that can effectively protect the intellectual property of those developing AqGR; consequently, there is a need to consider measures to protect intellectual property in the development of ABS agreements.

The development of policy should consider the value of **harmonization of policies related to AqGR across different sectors of government**. It is necessary to integrate AqGR into national policies, *inter alia* to **address gaps in policy, including transboundary management of AqGR, import and export of AqGR, including for non-food uses, long-term development strategies for aquaculture, breeding programmes for genetic improvement, genetic manipulation, stock enhancement, conservation, climate change and the role of financial subsidies.**

Given the relative paucity of information and lack of comprehensive understanding of the diverse issues impacting AqGR, **it is important to improve communication on – and raise awareness of – AqGR among stakeholders from consumers to policy-makers,** not only at the level of species, but also at the level of farmed types and the genome. As an example, many FAO member countries are aware of and are signatories to international agreements and instruments that can and do play a role in conservation, sustainable use and development of AqGR. It is important to raise **awareness and promote the roles that these agreements and instruments can play in order to improve their effective utilization for positive impact.**

The differing roles and interests of stakeholders in AqGR need to be understood by regulators and policy-makers, who also need to develop an understanding of how to cooperatively engage these stakeholders, including indigenous communities and women (who both have key specific roles to play), in the conservation, sustainable use and development of AqGR.

In line with the need to develop policy to promote conservation, sustainable use and development is **the need to build capacity to support policy-makers.** The Report also highlights the need to **build capacity in both research and development and education and training.** Priority for this capacity building should be placed on technologies related to characterization and genetic improvement of AqGR, but may also include building capacity for economically valuing AqGR. In addition to building individual capacity in these areas, the Report also identifies **the need to improve technical capacity of institutions and improve their awareness of AqGR issues in order to promote more effective intersectoral collaboration on AqGR.**

In the past, regional and global networks have facilitated communication on conservation, sustainable use and development of AqGR, but these networks specific to AqGR have not been long-lived. There are opportunities for effective cooperation, including strengthening of international frameworks and collaborative development of AqGR for aquaculture and the appropriate exchange of resources. **The opportunity to enhance cooperation on AqGR should be explored through the promotion and development of sustainable regional and global networks on AqGR and/or the strengthening of AqGR aspects within existing networks** to support cooperation and collaboration on the conservation, sustainable use and development of AqGR.

10.3 The way forward

AqGR are underutilized resources that hold great potential to improve food security and enhance livelihoods, but they are a resource that must be managed, conserved and developed sustainably. The Report – *The State of the World's Aquatic Genetic Resources for Food and Agriculture* – provides a unique snapshot of the status of the world's AqGR and identifies some expected future trends. Thanks to the global and interactive approach taken in its development, the Report captures the perspectives of many FAO member countries, and the process itself has undoubtedly enhanced awareness of the importance of AqGR.

The Report reveals the tremendous diversity of AqGR found in the world's fresh and brackish waters and marine environments, and the value of its wide use by both fishers and fish farmers to improve livelihoods, increase food supply and provide nutritional security. The Report also highlights some areas for improvement, such as the standardization of terminology and the development of information systems for AqGR for the effective characterization and monitoring of the use of AqGR, especially at the level below species, and the need to accelerate the uptake of genetic improvement in aquaculture. The Report identifies the importance of the policy and institutional setting relevant to AqGR, at local, regional and international levels.

A growing human population and associated increase in demand for fish and fish products are putting increased pressure on the habitats of farmed species and their wild relatives. AqGR are essential resources that will need to be more fully developed to realize the potential for aquaculture and capture fisheries to provide food and livelihoods for this growing human population, in a responsible manner. Urgent action is needed to raise awareness of the value of AqGR and develop or improve cross-sectoral policies and management plans that address AqGR, especially at the level below species. Capacity building will be required at all levels.

The Report reaffirms the strong connection between aquaculture and fisheries and between farmed AqGR and their wild relatives, and identifies that some wild relative resources are under threat. Habitat loss and degradation, potentially including that caused by both native and non-native escaped farmed fish, are a major factor in the decline some stocks of wild relatives. Policies and actions will need to address the conservation not only of AqGR, but also of the aquatic habitats that support them, and to promote the responsible exchange and use of native and especially non-native AqGR.

It is hoped that the Report serves as a catalyst for future action. The information it contains provides an excellent basis for identifying strategic priorities for action, establishing mechanisms to implement these actions, and identifying the required resources and institutional capacities for effective implementation.

The conservation, sustainable use and development 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 conservation, sustainable use and development of these valuable resources, at national, regional and global levels.

ISBN 978-92-5-131608-5 ISSN 2412-5474

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CA5256EN/1/07.19