Food and Agriculture
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THE STATUS OF APPLICATION, CAPACITIES AND THE ENABLING ENVIRONMENT FOR AGRICULTURAL BIOTECHNOLOGIES IN THE ASIA-PACIFIC REGION

Regional background study

WORKING DOCUMENT

The status of application, capacities and the enabling environment for agricultural biotechnologies in the Asia-Pacific region

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Abbreviations and acronyms

ACIAR	Australian Centre for International Agricultural Research
ADB	Asian Development Bank
AI	Artificial insemination
APAFRI	Asia Pacific Association of Forestry Research Institutions
ASEAN	Association of Southeast Asian Nations
ASTI	Agricultural Science and Technology Indicators
BFRI	Bangladesh Forest Research Institute
BIOTEC	National Centre for Genetic Engineering and Biotechnology (Thailand)
Bt	*Bacillus thuringiensis*
CAGR	Compound annual growth rate
Cas	CRISPR-associated systems
CAS	Chinese Academy of Sciences
CRCs	Cooperative Research Centres (Australia)
CRISPR	Clustered Regularly Interspaced Short Palindromic Repeats
CRISPR-Cas9	Clustered Regularly Interspaced Short Palindromic Repeats-CRISPR-associated protein-9
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
DBT	Department of Biotechnology (India)
DNA	Deoxyribonucleic acid
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FTE	Full-time equivalent
GDP	Gross domestic product
GE	Genetic engineering
GEF	Global Environment Facility (United Nations Environment Programme)
GM	Genetically modified
GMO	Genetically modified organism
ICAR	Indian Council of Agricultural Research
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFAD	International Fund for Agricultural Development

ILRI	International Livestock Research Institute
IMF	International Monetary Fund
IP	Intellectual property
IUCN	International Union for Conservation of Nature
IUFRO	International Union of Forest Research Organizations
JICA	Japan International Cooperation Agency
LDC	Less developed country
MAS	Marker-assisted selection
OECD	Organisation for Economic Co-operation and Development
OIE	World Organization for Animal Health
PCR	Polymerase chain reaction
QTL	Quantitative trait locus
R&D	Research and development
RIS	Research Information System for Developing Countries
RNA	Ribonucleic acid
SARDI	South Australian Research and Development Agency
SDG	Sustainable Development Goal
SEAFDEC	Southeast Asian Fisheries Development Center
SNP	Single nucleotide polymorphism
SPC	Pacific Community
SPS Agreement	Agreement on the Application of Sanitary and Phytosanitary Measures (World Trade Organization)
TALENs	Transcription activator-like effector nucleases
TBT Agreement	Agreement on Technical Barriers to Trade (World Trade Organization)
TRIPS	Trade-Related Aspects of Intellectual Property Rights
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCAP	United Nations Economic and Social Commission for Asia
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UNIDO	United Nations Industrial Development Organization
UPOV	International Union for the Protection of New Varieties of Plants
USAID	United States Agency for International Development

USDA	United States Department of Agriculture
USP	University of the South Pacific
WHO	World Health Organization
WTO	World Trade Organization

1 Executive summary

The share of agriculture in the gross domestic product (GDP) of some countries in the Asia-Pacific region has declined in recent years as their economies transition from agrarian to industrial and service-oriented; however, agriculture is still important in terms of employment and its role as a buffer in phases of deceleration in other sectors. Agricultural biotechnologies have the potential to enhance the contribution of agriculture to these countries' economies.

This study presents overviews of the applications adopted by countries in the Asia-Pacific region and the main gaps in applications, capacities and enabling environments, and makes a few suggestions about what could be done for better utilization of agricultural biotechnologies in the region.

Key findings

The study found that agricultural biotechnologies are well entrenched in the Asia-Pacific region and their use is expanding, as are the capacities and enabling environments needed to support their use.

There are, however, significant differences among countries in their application of biotechnology in all four agricultural sectors: crops, livestock, fisheries and forestry. Small island states and many least developed countries (LDCs), such as Afghanistan and Mongolia, are yet to benefit appreciably from the biotechnology revolution. Multiple factors such as low capacity and the small size of their markets constrain them from reaping the benefits of biotechnology. Some countries, such as Cambodia, the Lao People's Democratic Republic and Uzbekistan, are in the initial stages of applying biotechnology but they have the potential to move forward. A few, such as Sri Lanka and Nepal, have not yet started to apply biotechnology but have the potential capacity and a good policy framework to move ahead. Recent changes in Viet Nam and Myanmar indicate the establishment of an enabling milieu that can take the countries forward in agricultural biotechnology. Larger and emerging economies, such as China, India and the Republic of Korea, are using biotechnology extensively in all four sectors.

State-driven biotechnology policy is evident in Malaysia, the Philippines and Singapore. Similarly, the state is the key player in shaping the destiny of agriculture in the India and the Republic of Korea, although their strategies differ. Australia and New Zealand are the key players in the Pacific region with world-class capacity in biotechnology.

Crops

Resistance to genetically modified (GM) crops in the Asia-Pacific region is weak and is confined to only India and the Philippines. Many countries in the region import GM crops for feed and for industrial purpose, including countries, such as Japan, in which there is no commercial cultivation of GM crops. Many countries permit domestic consumption and trade in GM crops, but limit their commercial cultivation.

Countries have adopted a wide variety of low-, medium- and high-technology applications in crop biotechnology, and newer applications and technologies are pursued with interest. However, in spite of the capacity and need, genetic modification in agriculture is limited to a few crops and a few traits. GM cotton is widely grown across the region, with adoption rates as high as 97 percent in some countries. Although work has been done on developing GM rice, it is yet to be commercialized. Other GM crops are under development but whether many of them will be commercialized is questionable.

More and more countries in the region are adopting high-technology applications. For example, at least six countries are using genome editing and genome mapping, and 15 countries are using marker-assisted selection. Fifteen countries have successfully adopted tissue culture, but its potential is to be yet fully harnessed.

Countries vary widely in terms of capacity to adopt agricultural biotechnologies in the crop sector. Some have exceptionally good capacities while others have low to very low capacities. Australia, China and India have very good or excellent capacity as a result of good availability of human resources, strong public sectors, well-endowed educational systems and strong national innovation systems in agriculture. However, most LDCs and island states have insufficient current capacity to make full use of crop biotechnology. International/regional collaborations can play a key role in enhancing their capacity.

The overall enabling environment is positive, as many countries have policies, regulations and laws favouring development of crop biotechnology. Eleven countries (Australia, Bangladesh, China, India, Iran, Malaysia, Nepal, the Philippines, Republic of Korea, Sri Lanka and Thailand) have specific policies or strategies relating to crop biotechnology. In many others, crop biotechnology is integrated in agricultural development plans, and is actively promoted. However, most of the LDCs do not have a strong enabling environment for crop biotechnology. Most of the countries have biosafety policies or regulations. Incentives and intellectual property protection in many countries, particularly members of the Association of Southeast Asian Nations (ASEAN), also play a vital role in creating a favourable enabling environment.

Livestock

In the livestock sector, major applications of advances in agricultural biotechnologies in the region include exploitation of the genetic association between single nucleotide polymorphisms (SNPs) and meat quality traits; development of effective methods for conservation of avian genetic resources using germ cells; development of an effective method of genome editing in chicken; and functional gene analysis of sexual differentiation of avian species. Australia, China, India, Iran (Islamic Republic of) and Japan have all employed one or more of these in livestock. China has used knowledge of molecular mechanisms underlying muscle development and intramuscular fat deposition in chickens and protein expression profiles to create new meat-type chicken breeds with quality meat, disease resistance and good feed conversion characteristics. China has sequenced the entire mitochondrial genome of the Datong Yak and has used the CRISPR-Cas9 system to develop transgenic sheep, goats and pigs with traits of interest, including disease tolerance. Australia, China, India, Iran (Islamic

Republic of), Japan, New Zealand and the Republic of Korea are all conducting fundamental research in animal biotechnology. Development of diagnostics and vaccines has enabled the livestock sector meet challenges in animal health, particularly in the case of epidemic diseases.

Countries in the region are diverging in terms of capacity and enabling environment. Most LDCs and island states have low or very low capacities and weak enabling environments. In contrast, some countries, such as Australia, China, Japan and the Republic of Korea, have exceptionally good capacity and very favourable enabling environments. International collaborations and capacity-building initiatives can play a key role in enhancing capacity and contributing to a positive enabling environment. Although not all countries in the region need to be at the forefront of livestock biotechnology, it is important that they at least have some capacities and an adequate enabling environment to allow them to harness livestock biotechnology to address developmental needs and to utilize their animal genetic resources. There is thus a need to address the gaps in capacities and enabling environments between countries in the region.

Forestry

The adoption of biotechnologies in the Asia-Pacific forestry sector is limited, both in terms of the technologies used and the countries using them. Fewer than 15 countries are actively using biotechnologies in the forestry sector. Tissue culture and biopesticides are the most-widely adopted applications. Genetic modification of trees in the Asia-Pacific region is confined to research and development (R&D); there has been only one approval for cultivation of GM trees in the region (*Populus* in China). A few countries are conducting R&D in emerging technologies such as gene editing.

Capacity in research and training in forest biotechnology needs to be enhanced to leverage the full potential of forest biotechnologies in the region. Private-sector involvement also needs to be enhanced. Capacity-building programmes and international collaboration in forestry biotechnology are enabling several countries, including Sri Lanka, Vanuatu and Viet Nam, to harness forestry biotechnology, but such collaborations need to be strengthened and expanded.

Because few countries are engaged in forestry biotechnology, forestry policies generally do not create a positive milieu for forestry biotechnology. The public sector and governments have a key role to play in creating an enabling environment, but only a few countries – e.g. Australia, China, Japan, Republic of Korea and Malaysia – are giving this due consideration.

Fisheries/aquaculture

The fisheries and aquaculture sector in the Asia-Pacific region needs breeding-support and diagnostic tools and vaccines that could be developed using biotechnology, but few countries have the R&D capacity to develop them or the capacity to adopt them. Only eight countries have the capability to undertake R&D and to adopt sophisticated applications such as genome mapping and genome editing. Many others are unable to adopt even low-level technologies,

despite an urgent need to do so. The gap between countries in terms of adoption of applications is a cause for concern.

Most of the LDCs lack the capacity to apply even medium-level technologies and have confined themselves to limited use of low-level technologies. Despite their lack of home-grown capacity, countries can benefit from collaborations and regional capacity-building programmes.

Way forward

It is clear that capacity to develop and apply biotechnology in any one sector, e.g. fisheries, cannot be enhanced substantially unless overall capacity in biotechnology is enhanced. This highlights the need for long-term strategies in capacity building. The enabling environment in the region also needs improvement, although it is very good in some countries. In most of the others, the policy thrust is lacking or is found wanting. International collaborations are essential but they are not a substitute for an enabling policy framework, which can create a positive milieu.

2 Introduction

This report presents the findings of a study commissioned by the Food and Agriculture Organization of the United Nations (FAO) to assess the status of applications, capacities and the enabling environment for biotechnologies in the Asia-Pacific region.

2.1 Food and agriculture in the Asia-Pacific region

The world is facing a huge challenge – how to feed a rapidly increasing population that is forecast to reach 10 billion by 2050. To achieve this, food production will need to increase by 50 percent globally. Sustainable Development Goal 2 – End hunger, achieve food security and improved nutrition and promote sustainable agriculture – and the United Nations Decade of Action on Nutrition 2016–2025 highlights the international community's dedication to addressing this issue.

However, despite the fact that there is more than enough food produced in the world to feed everyone, 815 million people worldwide were suffering from hunger in 2016 (FAO *et al.*, 2017) – more than the combined population of the European Union (EU), Japan and Russia.

The Asia-Pacific region occupies a unique position in global agriculture. With 40 percent of the world's land area and 60 percent of the global population, it produces about 50 percent of the world's cereals and fruits and 70 percent of its vegetables. Half a century ago, most nations in the Asia-Pacific region were largely agrarian economies. Now, however, the share of agriculture in their GDP is much lower, ranging from a low of 0.035 percent in Singapore to a high of nearly 30 percent in Nepal (Table 1.1, in annexure), and their growth is mostly driven by industry and services. Nevertheless, agriculture is still important in terms of employment, ranging from 2.6 percent in Australia to nearly 67 percent in Nepal.

Agriculture in the region both contributes to climate change and will be affected by it. Livestock (enteric fermentation) and paddy rice, for example, are major sources of methane, a potent greenhouse gas. According to FAO (2016), potential impacts of climate change on agriculture in the region include the following:

- Agricultural zones will shift northwards as fresh-water availability declines in South, East and Southeast Asia.
- Higher temperatures during critical growth stages will cause a decline in rice yields over a large portion of Asia.
- Demand for irrigation water will increase substantially in arid and semi-arid areas.
- Heat stress will limit the expansion of livestock numbers.
- In New Zealand, wheat yields will rise slightly but animal production will decline by the 2030s.
- In Australia, soil degradation, water scarcity and weeds will reduce pasture productivity.
- In the Pacific islands, farmers will face longer droughts and also heavier rains.

The impacts of climate change are not limited to crops and livestock, but will also affect fishery and forestry sectors.

Thus, the agricultural sector must both contribute to mitigation of climate change and adapt and increase its resiliency to the effects of climate change.

Biotechnology has a key role to play in this, and in meeting the challenges in food and nutrition, but will only be able to do so if current capacities and enabling environments in the region are strengthened and made resilient. There are many examples in the region of successful adoption of biotechnology (Kadiresan, 2017). The challenge now lies in better harnessing agricultural biotechnologies in the region.

2.2 Scope

The scope of the background study is as follows.

a) ***Countries:***

Asia: Afghanistan, Bangladesh, Bhutan, Brunei Darussalam, Cambodia, China, Democratic People's Republic of Korea, India, Indonesia, Iran (Islamic Republic of), Japan, Kazakhstan, the Lao People's Democratic Republic, Malaysia, Maldives, Mongolia, Myanmar, Nepal, Pakistan, the Philippines, the Republic of Korea, Singapore, Sri Lanka, Thailand, Timor-Leste, Uzbekistan and Viet Nam

Pacific: Australia, Cook Islands, Fiji, Kiribati, the Marshall Islands, Micronesia (Federated States of), Nauru, New Zealand, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu

b) ***Sectors:*** Crop, livestock, forestry and fisheries/aquaculture
c) ***Time frame***: As up-to-date as possible (2017)
d) ***Agricultural biotechnologies***: These are described in Section 2.3
e) ***Broad definition of applications, capacities and enabling environments***

   i. *Applications* – Specific technologies that have been tested or adopted and are permitted in commercial use or are close to approval or commercialization
   ii. *Capacities* – Availability of human resources, R&D and educational infrastructure, capacity of public and private sectors to develop, test and deploy technologies and their R&D capacity, including capacity to absorb technology
   iii. *Enabling environment* – Policies, legislation, regulations, becoming party to relevant international treaties or conventions, promotional measures, incentives to innovation and overall milieu for growth of agricultural biotechnology sector

These are explained in detail in each chapter in the context of each sector.

2.3 Agricultural biotechnologies

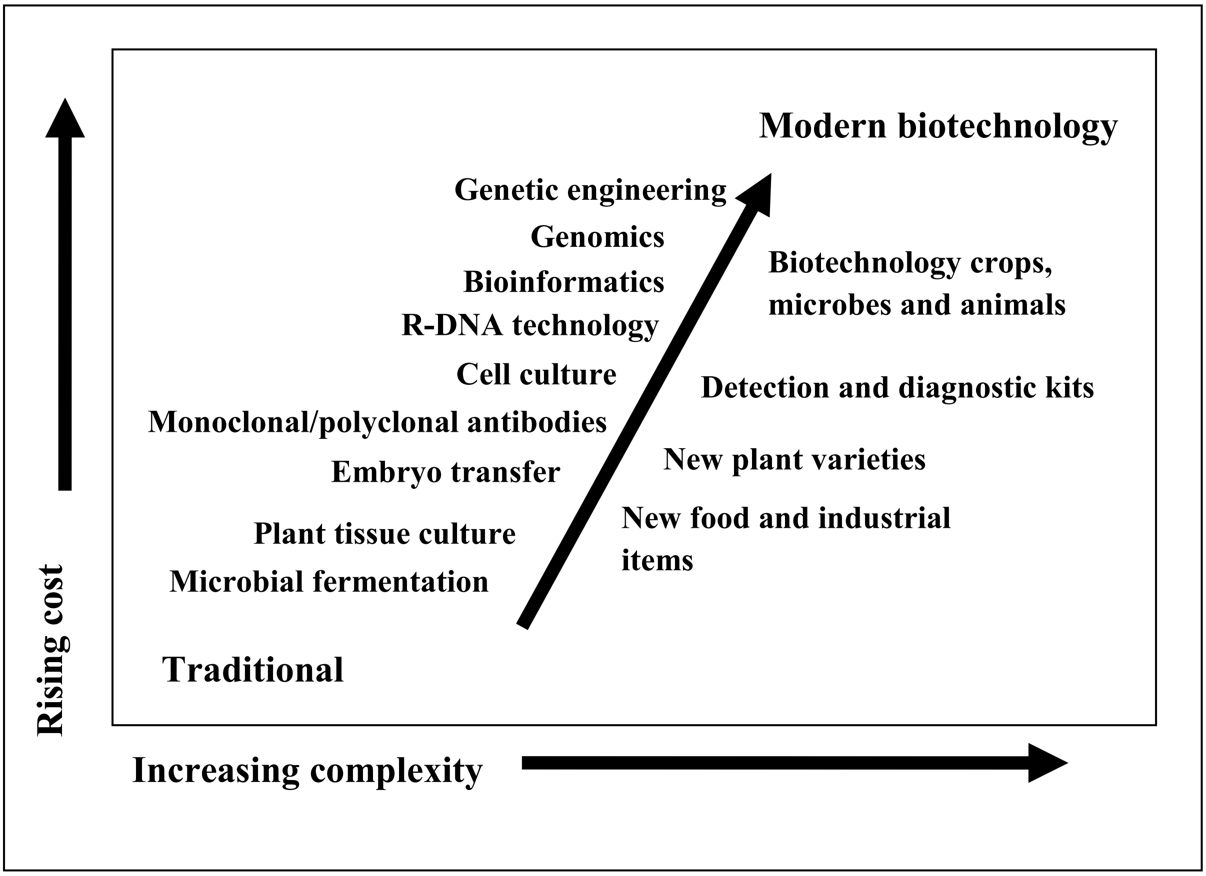
Agricultural biotechnologies can be defined in a variety of ways.

Article 2 of the Convention on Biological Diversity (UN, 1992) defines biotechnology as "any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use." However, this definition is not precise; it can be interpreted to include everything from biofertilizers to genome editing and cloning.

According to the United States Department of Agriculture (USDA), "Agricultural biotechnology is a range of tools, including traditional breeding techniques, that alter living organisms, or parts of organisms, to make or modify products; improve plants or animals; or develop microorganisms for specific agricultural uses. Modern biotechnology today includes the tools of genetic engineering" (USDA, 2017). This definition includes traditional breeding techniques, although the term biotechnology is more commonly applied to techniques that modify the animal's or plant's DNA directly rather than traditional breeding techniques. These new breeding techniques include genome editing and cisgensis. According to the United Kingdom's Parliamentary Office of Science and Technology (POST, 2017), "New breeding techniques [NBTs] have created additional options to conventional breeding and transgenic technology. Collectively NBTs allow researchers to insert or remove whole genes, make small changes to the DNA, or change the activity of genes without modifying their sequence … They give researchers more precise tools for increasing variation in specific genes." NBTs can be considered as the next-generation technologies in plant and animal breeding, but in future may be supplanted by newer and more complex techniques that offer other benefits. Hence, evolution of biotechnologies can be one way in defining and understanding them.

Another way to define and understand biotechnology is to understand gradients in technology, and understand biotechnologies as a set of technologies ranging from simple technologies and applications to sophisticated or complex technologies that enable manipulation at the genetic level (see Figure 2.1).

Figure 2.1. Technology gradients in biotechnology



Source: Teng (2015: 306)

In this portrayal, technological complexity is associated with higher cost. However, this need not be so and not all complex technologies will remain expensive forever. For example, the cost of genome sequencing has come down rapidly in recent years.

Categorizing agricultural biotechnologies in this manner enables us to understand other considerations that are important in developing and applying them. For example, a limited or basic capacity is sufficient to develop and apply simple biotechnologies such as microbial fermentation and plant tissue culture, whereas genome mapping and editing require much higher capacity to innovate, apply and regulate. Taking the example of plant breeding, using and applying NBTs require higher capacity than application of traditional plant breeding techniques.

This study has categorized agricultural technologies into three broad categories:

- 'low tech', such as development and use of biofertilizers or biopesticides in crops/trees; artificial insemination in livestock; use of polyploidy in farmed fish; development and use of probiotics in livestock or fish feed; fermentation and use of bioreactors in food processing

- ‘medium tech’, such as use of polymerase chain reaction (PCR)-based disease diagnostic tools or marker-assisted selection; embryo transfer in livestock; use of tissue culture-based techniques in crops/trees
- ‘high tech’, such as gene-editing techniques; genome sequencing; genetic engineering; cloning of livestock.

The present study uses a limited range of biotechnologies to represent and indicate spread and use of low-, medium- and high-tech biotechnologies in the Asia-Pacific region, and excludes conventional breeding (Table 2.1). Some applications, such as biofertilizers and genetic modification, are applicable to the crop and forestry sectors, while genetic modification techniques are applied to all four sectors.

The report uses broad terms, such as ‘tissue culture’ and ‘genetically modified crops’, rather than specific techniques. Similarly, definitions and explanations have been limited to terms such as ‘genome editing’ and ‘tissue culture’ for the sake of brevity and clarity.

Some definitions given as examples are as follows:

- ***Biotechnology***: “any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use.” The term ‘agricultural biotechnology’ (or ‘agricultural biotechnologies’), therefore covers a broad range of technologies used in food and agriculture (FAO, 2010).
- ***Biofertilizer***: a microorganism that either mobilizes a soil-borne chemically bound plant nutrient/mineral (i.e. makes the nutrient/mineral bio-available to plant roots) or itself produces a plant nutrient (e.g. nitrate from the nitrogen in atmosphere) (Nill, 2016).
- ***Biopesticide***: a crop protection agent based on living microorganisms or natural products (often an insect) that can be used as a pest control device through its predation of pests or problem plants (AHDB Cereals and Oilseeds, 2017).
- ***Tissue culture***: growth and maintenance of cells from higher organisms *in vitro*, that is, in a sterile environment (e.g. test tube, Petri dish, etc.) that contains nutrients and substrate/structure necessary for cell growth. One use of tissue culture is to produce disease-free offspring from plants (Nill, 2016).
- ***Marker-assisted selection***: use of DNA sequence markers (molecular markers) to select individuals plants or animals that possess gene(s) for a particular trait (e.g. rapid growth, high yield, disease resistance) (Nill, 2016).
- ***Genetic modification***: manipulation and alteration of the genetic material of an organism in such a way as to allow it to produce endogenous proteins with properties different from those of the traditional (historic/typical) organism or to produce entirely different (foreign) proteins (Nill, 2016).
- ***Gene editing***: techniques utilized by scientists to correct or to introduce specific mutations at a particular site (locus) within the DNA of an organism. The techniques used to accomplish these site-specific corrections or directed mutations (base substitution, addition or deletion) include CRISPR-Cas9 gene editing and transcription activator-like effector nucleases (TALENs) (Nill, 2016).

The use of the terms 'low', medium' and 'high' is not indicative of the relevance of the biotechnologies or to suggest that high-level technologies are always preferable to low- or medium-level technologies. The categorization is based on the gradient in technology and not on the scope or relevance of those technologies. The study did not attempt any technology assessment *per se*.

Table 2.1. Technologies covered in the survey

Sector	Low-level technologies	Medium-level technologies	High-level technologies
Crops	Biofertilizers	Tissue culture	Genetic modification
	Biopesticides	Marker-assisted selection	Gene-editing techniques
Livestock	Artificial insemination	Embryo transfer	Cloning
	Pregnancy diagnosis	*In vitro* fertilization	Gene-editing techniques
	Probiotics		
Forestry	Biofertilizers	Tissue culture	Genetic modification
	Biopesticides	Marker-assisted selection	Gene-editing techniques
Fisheries/aquaculture	Polyploidy	Marker-assisted selection	Genetic modification
	Probiotics	Sex reversal	

2.4 Methodology

In preparing this report, RIS drew upon its own resources, including connections and contacts in the region and elsewhere. To ensure that the report is based on verifiable, credible data, the study drew as much as possible on credible sources such as publications of the Organisation for Economic Co-operation and Development (OECD), FAO (including the *State of the World's Plant Genetic Resources*, the *State of the World's Animal Genetic Resources* and the *State of the World's Forest Genetic Resources*), the Asian Development Bank, information from departments and ministries of the countries studied and refereed publications, including scientific books and journals, and databases. Since the report covers the region as a whole, the authors used publications and data from the World Bank, the International Monetary Fund (IMF), the Asian Development Bank (ADB), the United Nations Economic and Social Commission for Asia (UNESCAP) and similar agencies related to agriculture, macroeconomic aspects and environment. Country-level data were obtained from official and other reliable sources.

Reports on the use of biotechnology applications, capacity and enabling environment were prepared for each of the sectors (crops, fisheries/aquaculture, livestock and forestry) for each of the 43 countries. These were reviewed by RIS and also by external experts. Summary reports, structured identically, were prepared for each of the countries. Relevant data and main points regarding use of biotechnology applications, capacity and enabling environment were summarized. The country reports and the summaries were used to assess and categorize the

countries' use of biotechnologies and their capacities and enabling environments. The Tables and data in this report were primarily drawn from country reports and summaries. Data from a survey conducted by FAO were also used.

This report has benefited immensely from the comments received from the expert reviewers and from the team at FAO.

2.5 Classification frameworks

General frameworks were developed to classify countries according to their use of applications, their capacities and their enabling environment in each sector (crops, livestock, forestry and fisheries/aquaculture) (Tables 2.2–2.4).

Table 2.2. Classification framework of countries on the basis of use of biotechnology applications

Very low	Low/limited research and field application of low-level technologies. Current status does not provide scope for application of medium-level technology
Low	Moderate application of low-level technologies and limited or very little R&D, and mostly on low-level technologies
Medium	Significant/extensive application of low-level technologies; moderate level of R&D on low-level technologies; limited application of and R&D on medium-level technologies
High	Extensive application of low-level technologies; good use of medium-level technologies with R&D capacity; some application of high-level technologies, with moderate R&D capacity
Very high	High level of application of and R&D on low-, medium- and high-level technologies

Table 2.3. Classification framework of countries on the basis of capacities for biotechnologies

Capacity category	**Human resources and training**	**Educational and R&D infrastructure**	**Public-sector and private-sector engagement**	**Collaboration, R&D networks* and regional/international cooperation**
Very low	Very low numbers and low capacity in training	Very limited	Limited or poor	Hardly any or limited to a few
Low	Low numbers and training levels	Some basic facilities; few institutions and little R&D capacity	Limited and confined to a few applications/low-technology deployment	Limited; R&D activity is not systematically organized
Medium	Human resource capacity is improving and has potential to improve in terms of number and capacity, training and capacity building	Reasonably good infrastructure in at least a few institutions; R&D facilities with moderate capacity	Both are present with R&D capacity and capacity to absorb and deploy technologies	Collaboration and R&D networks are present but not very strong or with limited capacity
High	Availability of human resources for R&D and adoption of low/medium tech; R&D in selected high-level applications; capacity in human resources development	Infrastructure is good and is improving; educational institutions/ universities with thrust in biotechnologies are functional	Both are present with R&D capacity to innovate; availability of other resources	Good number of collaborations and networks; involvement of international networks/institutions
Very high	Human resource capacity across technologies is excellent and growing; training in high-level technologies	Very well equipped labs; R&D facilities for high-level technology	Public and private sectors have excellent capacity in R&D; financial resources	Extensive and dynamic R&D networks; linkages with global R&D programmes; home-grown capacity to collaborate and extend support in capacity building

* R&D networks include those that conduct research (basic/applied) and those that facilitate adoption and absorption of technology and exchange of human resources

Table 2.4. Classification framework of countries on the basis of enabling environment for biotechnologies

Enabling environment category	**Biotech policy or programmes for agri-biotech**	**Implementation**	**Biosafety regulation**	**Party to international conventions/ treaties and role in them**	**Other factors***
Very weak	No policy or specific programmes	Weak or none	Rules in place; infrastructure lacking	Party but not playing any role	Very low or non-existent
Weak	Policy/ programme exists	Low	Rules in place; little infrastructure	Party but not active in international negotiation; low capacity to intervene or negotiate	Not available or not conducive
Medium	Policy with goals/specific focus	Good	Rules in place; infrastructure and implementation good	Party; has capacity to negotiate or intervene	Positive/ conducive
Strong	Strong policy	Better	Rules in place; put into practice in many institutions	Party; capacity to negotiate; benefits from negotiations	Positive and enabling growth
Very strong	Strong policy with focus on three or four sectors	Very good	Excellent infrastructure; regulatory capacity very good	Active player; capacity to build/join alliances; benefits from negotiations	Very positive and stimulating growth

* This includes factors such as the strength of the national agricultural research system, incentives for innovation, availability of intellectual property protection and its implementation, and policies to attract foreign direct investment in biotechnology

3 State of application of agricultural biotechnologies

3.1 Crops

3.1.1 Introduction

A diverse range of biotechnological applications are in use or under development in the crop sector in the Asia-Pacific region. They range from less-advanced applications such as biopesticides, biofertilizers and tissue-culture techniques to technically advanced applications such as genome editing of crops. There are numerous examples of biotechnologies, many non-GM, that meet the needs of smallholders in the region (Ruane *et al.,* 2013). High-level applications are also increasingly used, including genome mapping to assist in developing improved varieties of pulses and molecular breeding for improved wheat quality and for developing maize varieties resistant to head smut (*Sphacelotheca reiliana*) (Varshney, 2017a; Li, 2017a). Medium-level applications, such as tissue culture, have also been widely used and have been successful in many countries, including India and Sri Lanka (John, 2017).

3.1.2 Biofertilizers and biopesticides

Biofertilizers

Nill (2016) defined a 'biofertilizer' as "a microorganism that either mobilizes a soil-borne chemically bound plant nutrient/mineral (i.e. makes the nutrient/mineral bio-available to crop plant roots) or itself produces (e.g. nitrate from the nitrogen in the atmosphere) a plant nutrient."

The most commonly exploited microorganisms that meet this definition are those that help fix atmospheric nitrogen for plant uptake or solubilize or mobilize soil nutrients such as unavailable phosphorus into plant available forms (FAO, 2011).

An overview of applications of biofertilizers in the region is given in Table 3.1 in annexure. Biofertilizers are considered suitable for small-scale farmers as they are often cheaper than alternative commercial fertilizers or soil amendments and are easy to use. They are currently used in 19 countries in the region in both conventional and organic agriculture. However, data on use and application of biofertilizers are commonly not available.

The most common applications are for nitrogen fixation and yield increase. For example, in Bangladesh, *Trichoderma harzianum* is used in crops such as sugar cane and soybean to promote nitrogen fixation, while in China, *Rhizobium* is extensively used in many crops, including rice and wheat. In India, S*treptomyces* spp., *Azotobacter* spp., *Rhizobium* spp. and *Azospirillum* spp. are used on many crops, including rice, and have resulted in yield increases of 20–40 percent in rice, cotton and other crops. In Kazakhstan, *Pseudomonas* spp*., Rhizobium* spp. and *Azotobacter* spp. are used on leguminous crops for nitrogen fixation. In the Republic of Korea, plant-growth-promoting rhizobacteria and nitrogen-fixing microbes are used to boost growth of lettuce and to reduce risk of tomato wilt disease. In Viet Nam, *Burkholderia vietnamiensis* TVV75 and *Pseudomonas aeruginosa* are used on rice and watermelon. In some

countries, such as New Zealand and Sri Lanka, biofertilizers are solely naturally occurring organisms.

Recent literature suggests that the potential of biofertilizers is not fully used, and there are issues relating to their regulation and technology (Chandler *et.al,* 2011; Glare *et al.,* 2011; Koul, 2011; Sahayaraj, 2014; Kourti, Swevers and Kontogiannatos, 2016).

Although biofertilizers have been used in many countries for decades, there is little indication of technological development, i.e. there has been little more than selection of superior strains from among wild populations.

Uptake of biofertilizers in Asia faces issues ranging from lack of awareness among farmers to regulatory issues (Singh, Sarma and Keswani, 2016). This has limited their uptake. For example, in 2012–13, India produced only 0.5 million tonnes of biofertilizers, compared with a potential market of 2.5 million tonnes (Hegde 2016). In China, annual output is only about 130 000 tonnes (Li, 2017a).

This suggests that countries adopt biofertilizers only when the need arises.

Biopesticides

'Biopesticides' are "mass-produced, biologically-based agents used for the control of plant pests. They can be living organisms such as microorganisms or naturally occurring substances such as plant extracts or insect pheromones" (FAO, 2010).

The global biopesticide market is projected to grow by 18.8 percent from 2015 to 2020 and reach US$6.6 billion by 2020. In 2013, the Asia-Pacific region consumed 27.7 percent of global bioinsecticides by volume and 38 percent by value. The biopesticide market in the region is projected to grow 17.8 percent a year between 2015 and 2020 (Mordor Intelligence, 2017), with the market in India forecast to show an even higher growth rate of 19 percent a year over the same period (Ken Research, 2016).

Twelve countries in the region have adopted biopesticides, with biopesticides based on *Bacillus thuringiensis* (*Bt*) being most-widely used (Table 3.2, in annexure). China is the largest biopesticide market in the Asia-Pacific region, accounting for 35 percent of the overall market, followed by India (Atieno, 2015). The market in China is also expected to be the fastest growing in the region because of increasing acceptance of biopesticide as an alternative to existing chemical pesticides.

Biopesticides face similar challenges to biofertilizers and much of the potential remains underutilized (Singh, Sarma and Keswani, 2016). Despite positive developments in the technologies, significant uptake is still lacking (Glare *et al.,* 2011). In many countries in the region, they are the only biotechnology applications used in crops. Only Australia, China and India are able to leverage them with advanced applications.

Future developments in biofertilizers and biopesticides in the Asia-Pacific region

There are considerable difference across the region in terms of utilization of biofertilizers and biopesticides in crop production. Their use is more widespread in Southeast Asia than in the Pacific island countries. In South Asia, Bangladesh, India, Nepal and Sri Lanka are extensive users, and in Central Asia Iran (Islamic Republic of) has shown much progress. However, overall the current situation is not very conducive to further development and utilization of these technologies.

Options for enhancing use of biofertilizers and biopesticides include:

- Promote their use through technological and policy interventions;
- Invest more in basic research on biopesticides and biofertilizers to develop improved applications that meet the needs of small-scale farmers and that have commercial potential;
- Build capacity in LDCs to effectively utilize biofertilizers and biopesticides.

3.1.3 Tissue culture

'Tissue culture' is "the *in vitro* culture of plant cells, tissues or organs in a nutrient medium under sterile conditions" (FAO, 2010).

The scope for tissue culture is enormous: it can be used for conservation (including *in vitro* regeneration), propagation, in genetic engineering, and for selecting plants for specific characteristics such as insect resistance (Anis and Ahmad, 2016). Tissue culture has been widely used to produce uniform (clonal) crops such as in some horticultural crops, banana and sugar cane.

In India, tissue culture has been used mostly in horticultural, aromatic, medicinal and forestry crops (Hegde, 2016). The country has had some successes in producing banana plants *in vitro*, benefiting small farmers, but has not been successful in using the technique with spices; research is ongoing to introduce it in saffron (John, 2017). According to Anis and Ahmad (2016), "In recent years, there has been an explosion in the number of commercial plant tissue culture units in India. Till date, 95 commercial tissue-culture production units have been recognized by the Department of Biotechnology, Government of India, under the National Certification System for Tissue Culture Raised Plants (NCS-TCP, 2016). The potential for the domestic market is enormous, and by conservative estimates, it is around Rs 2 billion with an annual growth rate of 20 %. The production capacity of commercial tissue-culture units ranges between 0.5 million and 10 million plants per annum with an aggregate production capacity of about 200 million plantlets per year."

In Sri Lanka, tissue culture is a success story, and it is the most-widely used application of agricultural biotechnologies, accounting for 60 percent of their use in the country.

Use of tissue culture in the Asia-Pacific region has been hampered because of the technical difficulties in transfer of the technology from the laboratory to the farmer and because of a lack of extension services to train farmers in handling tissue-cultured plantlets.

3.1.4 Marker-assisted selection

'Marker-assisted selection' (MAS) is the use of DNA sequence markers (molecular markers) to select individual plants or animals that possess gene(s) for a particular performance trait (e.g. rapid growth, high yield, disease resistance) (Nill, 2016).

MAS is made possible by the development of molecular-marker maps, where many markers of known location are scattered at relatively short intervals throughout the genome and statistical associations have been determined between markers and traits of interest. The presence of a marker suggests the presence of the associated gene (FAO, 2010).

MAS is widely used in plant breeding in the Asia-Pacific region (Table 3.3, in annexure). According to some reviewers, it is an alternative to genetic engineering to produce new crops and for inclusive innovation in agriculture (Haribabu, 2009; Greenpeace, 2014). At least seven countries have at least one project or research initiative in MAS, while India and China have used it extensively (Table 3.4).

Despite progress, its full potential is yet to be fully harnessed in the region, largely because of a combination of lack of capacity and the cost of applying the technology.

3.1.5 Molecular breeding

'Molecular breeding' has been defined as "the utilization of molecular genetics and/or MAS in a breeding programme (e.g. within a seed company or within a university) to select the organisms (e.g. crop varieties) that possess gene(s) for a particular trait (e.g. higher yield, disease resistance)" (Nill, 2016).

Molecular breeding has the potential to enhance breeding for such traits as increased yield and disease resistance, and is relevant for the Asia-Pacific region (Hu, Xiao and He, 2016). Its application has picked up in the region but there are considerable gaps between research and its outcomes; collaborations could play an important role in bridging these gaps (Schafleitner and Karihaloo, 2013).

Table 3.4. Use of marker-assisted selection to develop varieties with different traits in different crops in India and China

Crop	Trait	India	China
Bean	Disease resistance	1	-
Chilli	Disease resistance	1	-
Maize	Quality protein maize	1	-
Pearl Millet	Disease resistance	1	-
Tomato	Disease resistance	2	-
Rice	Cooking quality		1
	Disease resistance	10	17
	Drought tolerance	3	-
	High yield	-	1
	Flood tolerance	3	-

Source: Varshney (2017b)

3.1.6 Genome mapping

At least six countries in the Asia-Pacific region have initiated projects to map genomes of important crops and to identify genes that confer desirable traits. For example, China has completed whole-genome sequencing in major crops, including rice, wheat, cotton, cucumber and tomato (Li, 2017b). The CGIAR centres, such as the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), are engaged in genome mapping. ICRISAT and its partners have conducted genome mapping in pigeon pea, chickpea, groundnut, longan (*Dimocarpus longan*), adzuki bean, mung bean, pearl millet and sesame (Varshney, 2017b).

The United Nations agencies have an important role in supporting the use of genome mapping, especially through capacity-building and sharing of research outcomes, including data.

3.1.7 Genetically modified crops

According to FAO (2011), "A genetically modified organism (GMO) is an organism in which one or more genes (called transgenes) have been introduced into its genetic material from another organism. The genes may be from a different kingdom (e.g. a bacterial gene introduced into plant genetic material), a different species within the same kingdom or even from the same species. For example, so-called 'Bt crops' are crops containing genes derived from the soil bacterium *Bacillus thuringiensis* coding for proteins that are toxic to insect pests that feed on the crops." (FAO, 2010)

GM crops are perhaps the most-widely adopted and also most controversial application of agricultural biotechnologies. They are being cultivated in eight countries in the region – Australia, Bangladesh, China, India, Myanmar, Pakistan, the Philippines and Viet Nam.

Maize, soybean and cotton are the most-widely grown and tested GM crops. Rice has been tested in five countries but has not yet been approved for commercial cultivation in any country in the region. The current situation on GM crops in the Asia-Pacific region is summarized in Tables 3.5, and 3.6, and in Figures 3.1 and 3.2).

Table 3.5. Cultivation of genetically modified crops in selected countries in the Asia-Pacific region in 2015/2016

Country	GM crops	Area (million hectares)	Quantity	Value (US$)
Australia	Cotton	0.852 (2016)	Cotton: 4.2 million bales (2016)	73 million (2015)
	Canola	N/A	Canola: not available	N/A
Bangladesh	Brinjal (aubergine)	0.0007 (2016)	N/A	N/A
China	Cotton, papaya, poplar	2.8	N/A	1.0 billion (2015)
India	Cotton	11.2 (2016) (96% of area under cotton cultivation)	35 million bales (2016)	1.3 billion (2015)
Myanmar	Cotton	0.30 (93% of area under cotton cultivation)	N/A	N/A
Pakistan	Cotton	2.9 (2016)	N/A	398 million (2015)
Philippines	Maize	0.812	N/A	82 million (2015)
Viet Nam	Maize	0.035	N/A	N/A

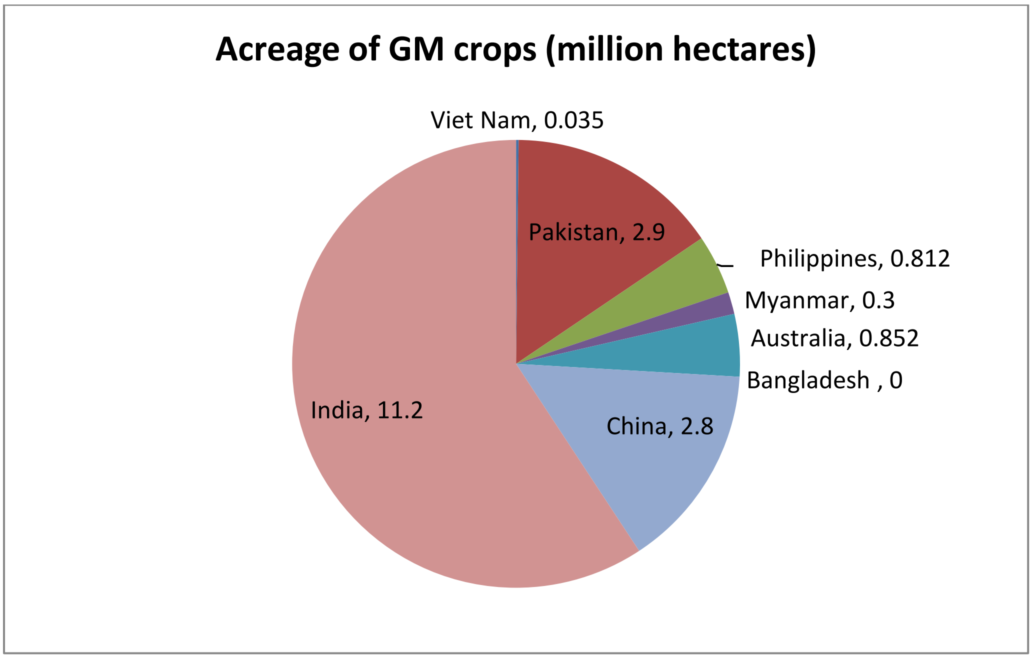
N/A – not available.
Source: ISAAA (2016), GAIN (2016a, 2016b, 2016c), Cotton Australia (2016).

Table 3.6. Status of regulatory approvals and trials of genetically modified crops in selected countries in the Asia-Pacific region

Crop	Australia	China	Bangladesh	Pakistan	Philippines	New Zealand	Republic of Korea	Japan	Thailand	Indonesia	Iran (Islamic Republic of)	India	Malaysia	Viet Nam
Alfalfa	*				*			*						
Canola	*#	*			*		*	*						
Cotton	*#	*#		*#	*		*	*				*#		
Brinjal			*#											
Maize	*	*		*	*#		*	*	*	*			*	*#
Papaya		*#						*						
Potato	*				*		*	*						
Rice	*	*			*			*			*			
Soybean	*	*			*		*	*	*	*			*	*
Sugar beet	*	*			*		*	*						
Sugar cane	*									*				
Capsicum		*												
Tomato		*						*						

*Crop has been genetically modified and a specific trait has been given an environmental and/or food and/or feed approval.
*# the approved crop is under commercial production at present.
Source: ISAAA (2016), GAIN (2016a, 2016b, 2016c)
(See also Table 3.7 in annexure)

Figure 3.1. Area of genetically modified crops grown in selected countries in the Asia-Pacific region



Source: Authors' compilation from various sources

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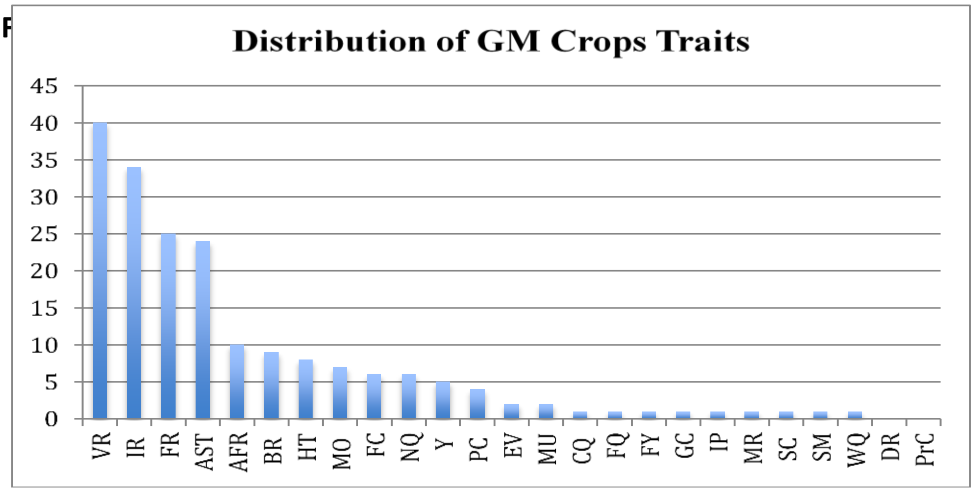


Notes: AFR: Altered fruit ripening; AST: Abiotic stress tolerance; BR: Bacterial resistance; CQ: Cooking quality; DR: Disease resistance;
EV: Edible vaccine; FR: Fungal resistance; FQ: Fibre quality; HT: Herbicide tolerance; GC: Growth control; IP Industrial product; FC: Food composition for human and animal nutrition, MU: Micronutrient uptake; SM: Sugar metabolism; FY: Fibre yield
IR: Insect resistance; MO: Modified oil composition; MR: Multiple resistance; NQ: Nutrition quality; PC: Pollination control; PrC: Protein content; SC: Starch composition; VR: Virus resistance; WQ: Wood quality; Y: Yield.

Source: Authors' compilation from various sources

Genome editing is emerging as tool to develop crops with novel traits and is an alternative to genetic modification. However, whether genome editing would be a preferable option for use on food crops depends on public acceptance of genome-edited crops.

The current survey found that, although some countries have conducted R&D on GM crops for meeting climate-change challenges, few GM varieties are available to farmers and these are yet to be widely deployed.

Several countries in the region that, until recently confined biotechnological applications to biofertilizers, biopesticides and the like, are showing increasing interest in GM crops. For example, numerous trials have been conducted on a range of crops in Viet Nam, including soybean, maize, cotton, canola, sugar beet and alfalfa, and insect-resistant and herbicide-tolerant GM maize is in commercial production. GM soybean has been approved for use as a food and as a feed. If the other crops tested are approved and commercialized, Viet Nam will be catching up with Australia in terms of the range of GM crops commercialized.

Myanmar has developed and released *Bt* cotton, and this has been adopted by smallholder farmers.

Bangladesh has developed *Bt* brinjal and this is now in commercial production. Although adoption is currently very low, the country is going ahead with ambitious plans on GM agriculture and new varieties are expected to be developed, include of cotton, tomato and rice.

Both Thailand and the Philippines have been investing in R&D in agricultural biotechnology since the 1990s and have adopted regulatory regimes. However, despite many trials, GM crops have not been commercialized in Thailand, although they have been in the Philippines (Larsson, 2016).

Several countries, including Indonesia, Malaysia, New Zealand and the Republic of Korea have approved GM of crops, but have yet to start growing GM varieties commercially.

Many countries of the region have approved GM crops for different uses – food, feed and industrial. Thus, even if a country is not growing GM crops commercially, it does not mean that it is not using GM food or GM feed.

3.1.8 Genome editing

According to Genetics Home Reference (2017), “Genome editing (also called gene editing) is a group of technologies that give scientists the ability to change an organism's DNA. These technologies allow genetic material to be added, removed, or altered at particular locations in the genome.” A very important issue with genome editing is whether plants developed using genome editing should be treated as GM crops or similarly to crops developed using conventional plant breeding (Wolt, Kan Wang and Yang, 2016; Eriksson and Ammann, 2017).

Twelve countries in the Asia-Pacific region have started using this technology, although many are at the experimental stage (Table 3.8, in annexure). Current projects and initiatives include research on commercially and nutritionally important crops such as rice and cassava (ISAAA,

2017). CRISPR-Cas9 (clustered regularly interspaced short palindromic repeats [CRISPR]-CRISPR-associated protein 9) is the most-widely used technology in the region.

One purpose for which genome editing could be used is to develop insect-resistant and herbicide-tolerant plants (Lombardo, Coppola and Zelasco, 2015). However, no products based on genome editing have reached the market in the Asia-Pacific region, and hence it is too early to assess the commercial impact of this technology.

3.1.9 Categorization of countries in terms of use of biotechnology applications in the crop sector

The classification of countries according to their use of biotechnology applications in the crop sector is shown in Table 3.9.

Among the 'Very low use' category, most countries have not adopted even simple applications such as biofertilizers and biopesticides.

Among the 'Low use' countries, adoption of biotechnologies is very limited. However, this does not mean that they have no potential for expanded adoption. For example, although adoption of biotechnologies in Cambodia is currently very low, MAS in rice has a good potential, and the country has benefited from a regional development programme in MAS for rice. However, to adopt such applications, these countries needs greater capacities, better policies and a more enabling environment.

Countries in the 'Medium use' category show good potential for adoption and application of agricultural biotechnologies. For example, although Sri Lanka has not adopted GM crops, it does have the potential to apply the technology, is making appropriate use of tissue culture and has adopted MAS. Similarly, Myanmar has increasingly adopted agricultural biotechnologies, and has approved growing of GM crops. Nepal has adopted many applications, and has potential to adopt GM crops.

Countries in the 'High use' category have adopted a wide range of applications and some of them have approved GM crops for cultivation or have allowed field trials with GM crops (e.g. Bangladesh and Pakistan). For example, Malaysia has adopted crop biotechnologies, has the potential to commercialize GM technology and has approved its adoption. Viet Nam has approved growing of GM crops and is also implementing MAS. Iran (Islamic Republic of) has adopted many applications, including genetic modification of crops and is working on genome editing, as is Pakistan.

'Very high use' category countries have the capacity to engage in R&D of high-level technologies and to apply them. In general, they have excellent capacity in biosciences and life sciences. For example, China has adopted low-, medium- and high-level technologies, while Australia, India, Japan, and the Republic of Korea have all adopted high-level technologies and are involved in R&D of emerging applications like genome editing. Singapore has adopted genome editing and, in general, has an excellent capacity in biotechnologies although, as an island state, it has little crop cultivation.

Table 3.9. Categorization of countries in the Asia-Pacific region in terms of application of biotechnologies in the crop sector

Category	Countries
Very low use	Afghanistan, Brunei Darussalam, Cook Islands, Kiribati, Democratic People's Republic of Korea, Maldives, Mongolia, Marshall Islands, Micronesia (Federated States of), Nauru, Niue, Palau, Samoa, Solomon Islands, Timor-Leste, Tonga, Tuvalu, Vanuatu
Low use	Bhutan, Cambodia, Lao People's Democratic Republic, Uzbekistan
Medium use	Fiji, Indonesia, Kazakhstan, Myanmar, Nepal, Sri Lanka
High use	Bangladesh, Indonesia, Iran (Islamic Republic of), Malaysia, Pakistan, Philippines, Thailand, Viet Nam
Very high use	Australia, China, India, Japan, Republic of Korea, New Zealand, Singapore

3.2 Livestock

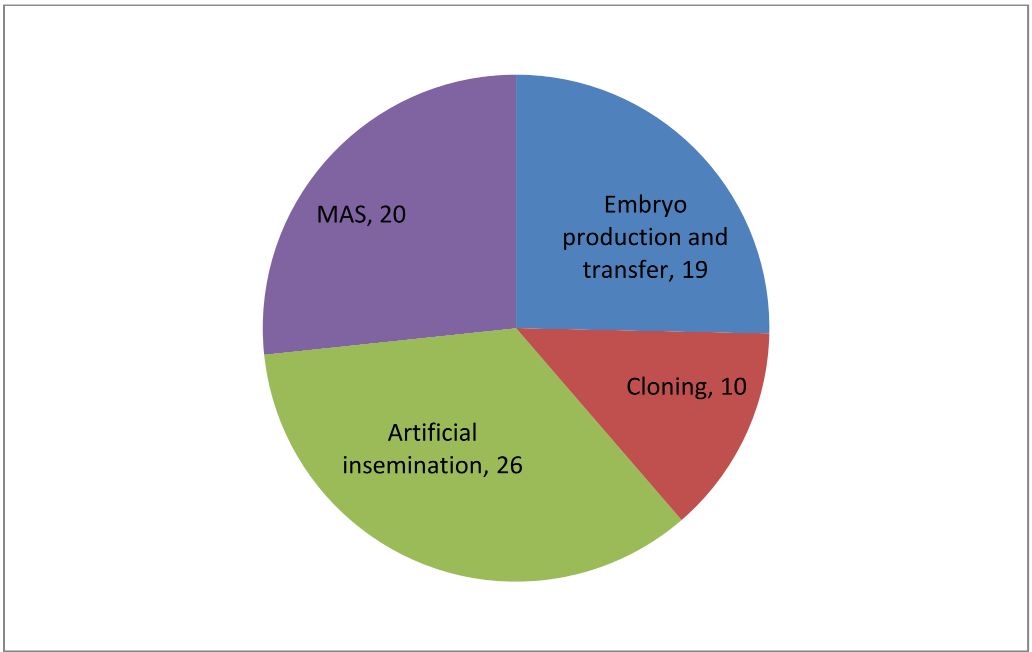
3.2.1 Introduction

Examples of livestock biotechnology applications used in various countries in the Asia-Pacific region are given in Table 3.10 in the annexure.

Many countries in the Asia-Pacific region have a wide range livestock genetic resources in terms of both number of species and their diversity and have used various biotechnology tools and techniques to characterize and catalogue them for the purpose of conservation. Several have also used marker-assisted breeding techniques for introgression of desirable genes from identified genetic sources into productive breeds. Other tools such as cloning, embryo transfer, disease diagnostic kits and vaccines for prophylaxis of diseases have been progressively integrated into livestock production in the region (Figure 3.3).

China, for example, is using biotechnology applications in breeding chickens with high-quality meat, disease resistance and improved feed efficiency. It has also sequenced the mitochondrial genome of the Datong Yak and used the CRISPR-Cas9 system to produce transgenic sheep, goats and pigs with novel traits, including disease tolerance. Other countries in the region conducting such fundamental research in animal biotechnology include Australia, India, Iran (Islamic Republic of), Japan, the Republic of Korea and New Zealand.

Figure 3.3. Number of countries in the Asia-Pacific region using various biotechnologies



Source: Authors' compilation from various sources

3.2.2 General applications

PCR-based tools developed in the region have been used to differentiate between cow and buffalo milk and between A1 and A2 milk (NDRI, 2017). These are widely used by food safety and standards management agencies in the region.

Australia, China, India, Iran (Islamic Republic of), Japan and the Republic of Korea have developed and applied a number of animal biotechnologies, including genetic manipulations for improvement of meat quality, muscle mass and shelf life.

3.2.3 Major applications

Countries in the Asia-Pacific region use a wide range of biotechnological interventions in livestock research, including artificial insemination (AI), probiotics, sperm sexing, embryo transfer, cloning, vaccines and diagnostics to monitor diseases. However, adoption of such techniques is not geographically uniform and is at a much lower level than in the crop sector. The Democratic People's Republic of Korea, Fiji, Kazakhstan, Maldives, Mongolia, Myanmar and Timor-Leste have all improved livestock using low-level technologies such as AI. Several Pacific island nations, including Cook Islands, Kiribati, the Marshal Islands, Micronesia (Federated States of), Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu, have recently initiated agricultural development plans that include a focus on improvement of livestock.

All countries in the region that include milk in their food basket use AI in their dairy breeding programmes. In India, particularly in Punjab, AI has been extensively used in buffalo

improvement. In Bangladesh, community-based AI campaigns are being used to improve cattle kept by smallholder farmers (Bhuiyan, Islam and Shamsuddin, 2013).

3.2.4 Marker-assisted selection

All the major livestock-producing countries in the region, including Australia, Bangladesh, China, India, Iran (Islamic Republic of), Kazakhstan, Malaysia, and New Zealand, use marker-assisted pedigree development for their economically important livestock species. For example, MAS has been used in India to introgress the FecB gene from the Garole sheep breed into the local breed on the Deccan Plateau to increase productivity. Common goals include improvement and maintenance of high-yielding disease-resistant breeds for both meat and milk production. MAS is used for pedigree analysis in Mongolia, New Zealand and the Philippines, and in breeding for increased milk yield in Bangladesh, India and many other countries. Japan and Pakistan focus more on meat production. Australia and the Lao People's Democratic Republic use MAS in breeding for disease resistance. India is using genomics and proteomics techniques as diagnostic tools for detecting genetic disorders in breeding bulls.

However, some countries lag behind in the application of such technologies, including Uzbekistan in Central Asia, South Asian countries such as Brunei Darussalam, Indonesia and Thailand, and littoral nations of the Pacific.

3.2.5 Embryo transfer

Embryo transfer techniques are extensively used in China, India, Iran (Islamic Republic of), Japan, the Republic of Korea and Viet Nam. India uses embryo transfer in Gir and Kankrej cattle breeds and Jaffarabadi, Mehsani, Surti and Banni buffalo breeds. In Pakistan, embryo transfer is used to maintain and multiply native cattle and goat breeds. Countries that have recently started using embryo transfer, such as Bangladesh, Bhutan, Indonesia, Malaysia and Nepal, have progressed through various international collaborations.

3.2.6 Cloning

China, India, Japan and the Republic of Korea have used cloning to maintain genetic purity of buffalo breeds, and the Republic of Korea has extended this technology to other animal species, including the Korean native pig (Hwang *et al.*, 2015). At the time of writing, Japan had produced 625 cows by fertilized egg-cell cloning and 415 cows, 638 swine and 5 goats by somatic nuclear transfer, all in public research institutions.

3.2.7 Animal health management

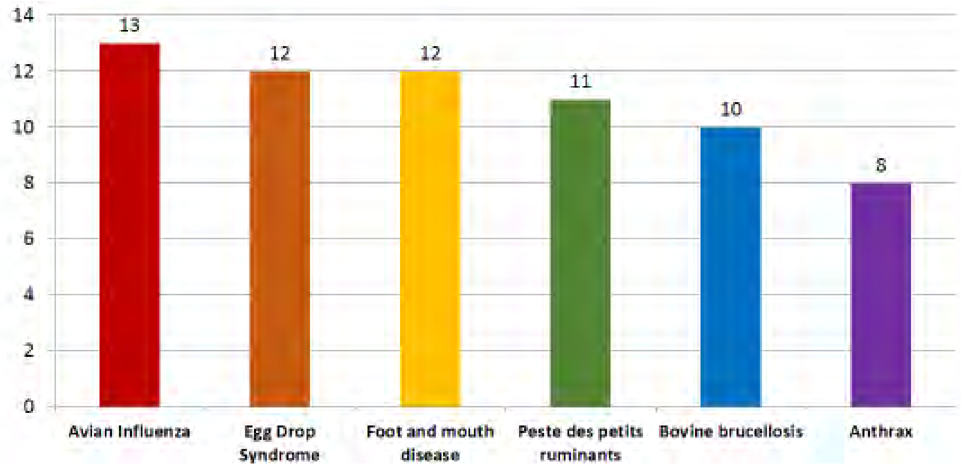
Figure 3.4 shows the number of countries in the region in which major livestock diseases occur.

There is a growing demand for modern techniques to improve disease management through monitoring with diagnostic kits and prophylaxis with vaccination of animals. Farmers are

benefiting from various products and knowledge generated from research in these fields in the region.

Participatory programmes for international surveillance of foot and mouth disease and other invasive alien pathogens/diseases are undertaken in most of the countries in the region (ACIAR, 2017).

Figure 3.4. Occurrence of major livestock diseases in Asia-Pacific countries



Source: Authors' compilation from various sources

Australia, China, India, Iran (Islamic Republic of), Malaysia, the Republic of Korea, Sri Lanka and Viet Nam employ diagnostic and vaccine biotechnologies. Australia, Bangladesh, China, India, Indonesia, Iran (Islamic Republic of), Japan, Malaysia, New Zealand, Pakistan, the Republic of Korea, Singapore and Viet Nam produce robust animal health diagnostic tools and techniques for common livestock diseases and have standardized their vaccine research and production facilities. They currently produce animal vaccines for anthrax, bovine tuberculosis, bovine herpesvirus, mastitis, theileriosis, leptospirosis, canine parvovirus, canine distemper, canine coronavirus, canine adenovirus, salmonellosis, Newcastle disease and infectious bursal disease, among others.

China, India, Kazakhstan, Mongolia and Thailand all have official control programmes for foot and mouth (OIE, 2018). Various pen-side tests for the virus have been developed, including lateral flow, reverse transcription loop-mediated isothermal amplification (RT-LAMP) and immunostrip tests (Longjam *et al*. 2011).

Research in the fields of recombinant DNA, stem cells and cell lines has found practical application in management of animal health in the region. Stable cell lines are used in carcinoma research, drug discovery, development of vaccines/diagnostic kits against viral diseases and several such high-level animal studies in Australia, China, India, Iran (Islamic Republic of), Japan and the Republic of Korea. Applications developed in these countries are becoming available in other countries in the region, such as Afghanistan, Bhutan, Brunei Darussalam, Kazakhstan, Uzbekistan and Pacific Rim countries.

Cures and therapies for recalcitrant ailments developed using cell lines have taken deep root in Asia-Pacific countries. Genomic research on animal pathogens in Australia, China, India, Iran (Islamic Republic of), Japan and the Republic of Korea is contributing to the development of animal health tools such as diagnostics and vaccines.

3.2.8 Categorization of countries in terms of use of biotechnology applications in the livestock sector

The classification of countries according to their use of biotechnology applications in the livestock sector is shown in Table 3.11.

Table 3.11. Categorization of countries in the Asia-Pacific region in terms of extent of biotechnology application in the livestock sector

Category	Countries
Very low	Cook Islands, Fiji, Kiribati, Democratic People's Republic of Korea, Maldives, Marshal Islands, Micronesia (Federated States of), Mongolia, Myanmar, Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Timor-Leste, Tonga, Tuvalu, Uzbekistan, Vanuatu
Low use	Afghanistan, Brunei Darussalam, Bhutan, Cambodia, Kazakhstan, Lao People's Democratic Republic, Philippines
Medium use	Indonesia, Nepal, Singapore, Sri Lanka
High use	Bangladesh, Iran (Islamic Republic of), Malaysia, Pakistan, Thailand, Viet Nam
Very high use	Australia, China, India, Japan, Republic of Korea, New Zealand

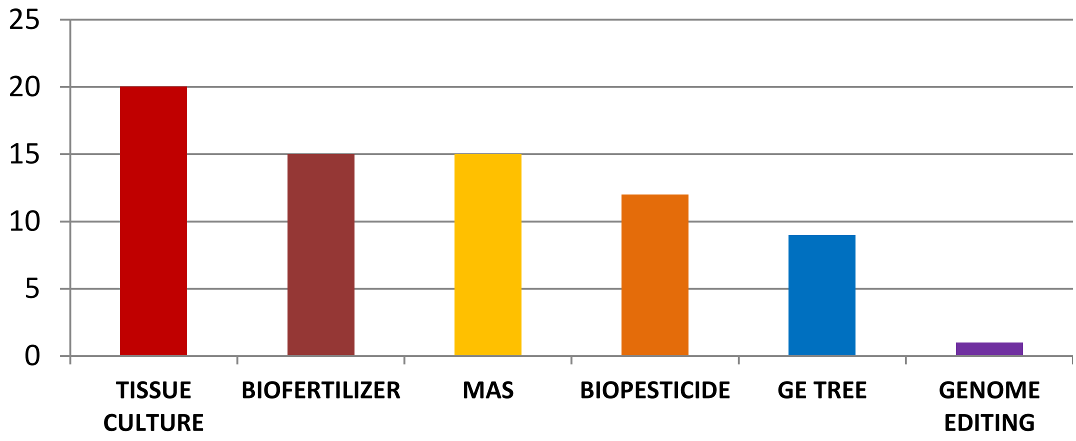
The 20 countries in the 'Very low' category – most of which are LDCs or Pacific island states – do not use any biotechnology application in the livestock sector. The seven countries in the 'Low use' category have developed their interest in the application of biotechnology in need-based areas through regional collaborations. Indonesia, Nepal, Singapore and Sri Lanka have used high-level technologies in the livestock sector and have the capacity to use these more extensively. The countries in the 'Very high' category are at the forefront of both use of livestock biotechnology applications and biotechnology R&D in the region.

3.3 Forestry

3.3.1 Introduction

The current state of application of biotechnologies in the forestry sector in the Asia-Pacific region is given in Table 3.12 (in annexure) and Figure 3.5.

Figure 3.5. Number of countries in the Asia-Pacific region using various biotechnologies in the forestry sector



Source: Authors' analysis based on survey results

The forestry sector poses unique opportunities for biotechnology applications, particularly in relation to multiplication and breeding, because conventional methods are slow and not as effective as biotechnological interventions in addressing the challenge of diseases or enhancing productivity. Biotechnology applications are used in the Asia-Pacific forestry sector in both planted and naturally regenerated forests.

For the management of naturally regenerated forests, the most commonly used tool is molecular markers, which are available for a growing number of tropical species. These and genomics are providing important knowledge about naturally regenerated tropical forests and important insights into the nature of entire tropical forest ecosystems, which can inform the strategies employed for managing tropical forests (FAO, 2010).

The biotechnologies used in the context of planted forests are quite different from those used in the management of naturally regenerated forests. The applications used depend on the type of management system (e.g. intensive, semi-intensive) and the genetic material planted (e.g. wild material, genetically improved trees).

The current study found that the biotechnologies used in the forestry sector in the Asia-Pacific region range from low-level technologies, such as biofertilizers and biopesticides, to high-level technologies, such as genetic engineering and gene editing.

3.3.2 Biofertilizers and biopesticides

Biofertilizers

The use of biofertilizers has yielded positive results for many forest species. Biofertilizers such as azolla, mycorrhizal fungi and nitrogen-fixing bacteria have been extensively used

with forest trees in China (Shen *et al*. 2016), India (Sivakumar, 2014), Indonesia, Malaysia (Rahim, 2002), the Philippines (UoPLB, 2017) and Thailand (Thamsurakul and Charoensook, 2006).

Biopesticides

Biopesticides are have been used to protect many forest tree species from serious insect and pest attacks. In India, a *Hyblaea purea* nuclear polyhedrosis virus (HyNPV), isolated from natural populations of the insect larvae, has been used to control teak defoliator, a serious insect pest of teak (FAO, 2010). Biopesticides have also been applied to various forest tree species in Australia, Cambodia (control of citrus root rot; Kean, Soytong and To-anun, 2010), China, Fiji, India, Iran (Islamic Republic of), the Republic of Korea and Malaysia.

3.3.3 Tissue culture

Tissue culture has been used to multiply many tree plantation species in the Asia-Pacific region (Table 3.13). It is a useful technique for species that produce few or recalcitrant seeds or seedlings and also for quickly multiplying selected genotypes (FAO, 2010). Tissue culture is used extensively in the forestry sector in Australia, Bangladesh (BFRI, 2017), India (Hong, Bhatnagar and Chandrasekharan, 2016), Indonesia, Malaysia, the Republic of Korea (Monteuuis, 2016) and Thailand. India has about 8.9 million ha of teak forest, much of which is propagated by only tissue culture (Tiwari, Tiwari and Siril, 2002). Teak systems, using selected clonal planting materials, allow farmers to diversify farm production with mixed crops, which reduces risk of crop failure, supports food security and generates income. Application of biotechnologies has created planting materials with selected qualities – shorter rotation, improved wood quality and yield and reduced losses – for smallholder plantations and has led to significant increases in rural livelihood in Indonesia and Malaysia (Goh, 2017).

Somatic embryogenesis has been widely applied in sandalwood (*Santalum album* L.) in Indonesia, where it is an important tree crop (Herawan *et al.*, 2016) and in some Pacific countries (SPC, 2017).

Tissue culture is also widely used in bamboo, which is a very important forest crop used by rural communities in Asia and the Pacific (Chang and Ho, 1997).

Table 3.13. Forest tree species that have been multiplied using tissue-culture applications in selected countries in the Asia-Pacific region

Country	Forest tree species
India	*Tectona grandis*
	Anogeissus latifoglia
	Bamboo species
	Eucalyptus spp.
Indonesia	*Acacia mangium*

Country	Forest tree species
	Acacia mangium × *Acacia auriculiformis* hybrids
	Santalum album
	Tectona grandis
Malaysia	*Acacia mangium*
	Acacia mangium × *Acacia auriculiformis* hybrids
	Tectona grandis
Viet Nam	*Acacia mangium*
	Acacia mangium × *Acacia auriculiformis* hybrids
	Eucalyptus spp.
Thailand	*Tectona grandis*

Source: FAO (2011)

3.3.4 Marker-assisted selection

Marker-assisted selection has been extensively used in forest species, including rubber, teak, pine, *Picea asperata* Mast., acacia and eucalyptus, in Australia (Joseph *et al.*, 2013), China (Fu *et al.*, 2016; Xia *et al,* 2017), India (Kumar *et al.*, 2015; ICFRE, 2017), Indonesia (Kurokochi *et al.*, 2015), Malaysia (Liew *et al.*, 2015; Shi, 2011), Pakistan (Razaq *et al.,* 2016), Thailand (Tangphatsornruang *et al.*, 2011) and Viet Nam (Quang, 2010).

Molecular markers have also been used in Myanmar to identify teak populations to be given highest priority for *in situ* conservation (Thwe-Thwe-Win, Watanabe and Goto, 2015).

3.3.5 Genetic engineering

The potential of genetic engineering (GE) for forestry is huge and is expected to increase in future (Sonnino, 2016). Planted forests account only 7 percent of the global forest area (FAO, 2017) but approximately 20 percent in the Asia-Pacific region. However, within the Asia-Pacific region, only seven Asian countries (China, India, Indonesia, Japan, the Republic of Korea, Malaysia and Thailand) and two Pacific countries (Australia and New Zealand) use GE in the forestry sector, and GE application is largely limited to research rather than commercial deployment (Table 3.14).

Table 3.14. Genetic engineering research and development on forest tree species by country in the Asia-Pacific region

Country	Forest tree species
Australia	*Eucalyptus globulus*
China	*Populus nigra* and *Populus* hybrid (Commercial)
	Eucalyptus globulus
	Hevea brasiliensis
India	*Hevea brasiliensis*
Indonesia	*Acacia mangium*
	Paraserianthes falcataria
Japan	*Eucalyptus globulus*
	Cryptomeria spp.
	Populus spp.
	Acacia mangium
	Paraserianthes falcataria
	Pinus spp.
Republic of Korea	*Populus* spp.
	Tectona grandis
	Cedrus spp.
New Zealand	*Pinus radiata*
	Picea abies
	Eucalyptus spp.
Thailand	*Hevea brasiliensis*
	Tectona grandis

Source: Based on various sources including WRM (2014) and FAO country reports

In India, transgenic technology has been used in rubber tress at the research level. In China, genetic improvements have been achieved in dozens of plantation tree species, including *Populus* spp., *Cunninghamia lanceolata, Larix dahurica, Pinus massoniana,* Paulownia, eucalyptus, *Acacia* spp., *Hippophae rhamnoides, Juglans* spp. and *Camellia oleifera*. However, to date, the only transgenic forest trees approved for commercial use in China are insect-resistant poplars (e.g. cultivars 12, 153 and 192) (Sonnino, 2016).

Japan has used GE to develop 260 cultivars of *Pinus* spp. that are resistant to pine wilt nematode and 45 that are resistant to snow pressure, and cypress, cedar and pine cultivars with superior growth and wood quality (FFPRI, 2017).

In New Zealand, Scion (New Zealand Forest Research Institute Ltd) is actively involved in research and applying high-level biotechnologies, such as GM, in radiata pine, Norway spruce and eucalyptus (Scion, 2017).

3.3.6 Gene editing

Research on gene editing in forest species is still in the nascent stage in the Asia-Pacific region, with only China working on poplar using CRISPR-Cas9 (Fan *et al.*, 2015).

3.3.7 Categorization of countries in terms of applications

The classification of countries according to their use of biotechnology applications in the forestry sector is shown in Table 3.15.

Many Pacific island states, such as Cook Islands, the Marshall Islands, Nauru, Niue and Samoa, and some of the Asian countries, such as Afghanistan, Bhutan and Uzbekistan, fall into the category of 'Very low use' because there is little or no evidence of application of even low-level biotechnologies in their forestry sectors.

Countries in the 'Low use' category are applying low-level biotechnologies such as biofertilizers and biopesticides in their forestry sector, whereas those in the 'Medium use' category are using medium-level biotechnologies such as micropropagation/tissue culture and PCR/MAS.

Countries in the 'High use' category – Australia, India, Indonesia, the Republic of Korea, Malaysia, New Zealand and Thailand – are employing high-level biotechnologies such as GE in their forestry sector, while those in the 'Very high use' category – only China and Japan – are both employing high-level biotechnologies in their forestry sectors and have extensive R&D programmes in technologies such as gene editing in forestry species.

Table 3.15. Categorization of countries in the Asia-Pacific region in terms of state of application of agricultural biotechnology in the forestry sector

Category	Countries
Very low	Afghanistan, Cook Islands, Bhutan, Maldives, Marshall Islands, Micronesia (Federated States of), Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Timor-Leste, Tonga, Tuvalu, Uzbekistan, Vanuatu
Low use	Brunei Darussalam, Cambodia, Kiribati, Lao People's Democratic Republic, Mongolia
Medium use	Bangladesh, Fiji, Iran (Islamic Republic of), Kazakhstan, Myanmar, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Viet Nam
High use	Australia, India, Indonesia, Republic of Korea, Malaysia, New Zealand, Thailand
Very high use	China, Japan

3.4 Fisheries/aquaculture

3.4.1 Introduction

The current state of application of biotechnologies in the fisheries/aquaculture sector in the Asia-Pacific region is given in Table 3.16 (in annexure). Biotechnologies used include probiotic-containing feed (FAO, 2010; FAO, 2016), MAS of aquaculture animals from wild populations, genomics and proteomics, diagnostics and vaccines.

Examples of the application of biotechnology in fisheries/aquaculture include: using probiotics to improve shrimp production in China (Xinhua, 2013); breeding hybrid catfish in Thailand

using AI (Na-Nakorn, 2013); genetic improvement of carp species in China using gynogenesis (Dong, 2013); cryopreservation in Malaysian aquaculture (Chew, Rashid and Hassan, 2010); and rapid detection of viral diseases in shrimp in India (Thakur *et al.*, 2013). Countries that are able to provide farmers with institutional support for such products include Australia, China, India, Iran (Islamic Republic of), Malaysia, New Zealand, the Philippines, Sri Lanka, Thailand, and Viet Nam.

3.4.2 Biotechnologies for breeding

Bangladesh, Indonesia, Nepal and Sri Lanka are using induced fish breeding and polyploidy in breeding programmes. Iran (Islamic Republic of) has capability to identify quantitative trait loci (QTLs) to breed various animals for aquaculture. Malaysia, Thailand and Viet Nam in Asia and New Zealand in the Pacific have expanded the use of biotechnology in various aquaculture organisms to build up stocks and enhance their breeding (FAO, 2010).

Several countries in the region are developing breeding techniques for induction of monosex in fin fishes, such as tilapia and silver carp. For example, Bangladesh is using induced breeding techniques in carp, Pabda catfish, koi and other species to produce fry for distribution to farmers. The Philippines is using similar techniques with giant trevally (*Caranx ignobilis*). Researchers in China have used MAS to produce all-male lines of Nile and blue tilapia and have developed gene-knockout lines for genes critical to sex determination (Chen *et al.*, 2018).

Bangladesh has used microsatellite DNA markers to detect introgressed hybrids in carp in hatcheries and allozyme and DNA-restriction fragment length polymorphism (RFLP) markers discriminate among *Tenualosa ilisha*. Australia, Indonesia and Sri Lanka use SNP markers to select breeding stock of fin fishes. Iran (Islamic Republic of) has utilized the genes associated with quantitative traits in cellular organelles and tissues for use in breeding.

Afghanistan, Bangladesh, Cambodia, Indonesia, Iran (Islamic Republic of), Malaysia, New Zealand, Pakistan, Sri Lanka, Thailand and Viet Nam are all using MAS to select for desirable traits within wild fish, crustacean and mollusc populations and are using molecular tools for biodiversity assessment, enabling their conservation. Markers from microsatellite DNA and mitochondrial DNA are utilized. Examples include: development and characterization of microsatellite markers in *Schizothorax richardsonii* and implementation of marker-assisted selection in Afghanistan; and MAS of indigenous and exotic carp, catfish, *Anabas testudineus*, koi and other species in Bangladesh, black tiger shrimp in Brunei Darussalam (Black tiger shrimp), *Clarias batrachus* in Cambodia, carp and pearl oyster in China, tilapia and catfish in India, shrimps in Malaysia, clown fish in the Maldives, catla (*Gibelion catla*), rohu (*Labeo rohita*) and moraki (*Cirrhinus mrigala*) in Pakistan, mud crab, oysters, abalone, blue swimming crab, Asian sea bass and fresh water mussels in Thailand and cat fish, spiny lobster and carp in Viet Nam. Japan is using CRISPR-Cas9 gene editing to breed tuna that are better suited for aquaculture. Advances in such breeding techniques using current biotechnologies could enable breeding of stocks with improved traits for commercial production.

3.4.3 Biodiversity analysis and conservation

Genetic markers are used for biodiversity analysis and selection in Afghanistan, Brunei Darussalam, Cambodia, Fiji, Indonesia, Maldives, the Philippines, Singapore and Thailand. For example, Thailand has initiated research programmes to study the genetic diversity and species identity markers of economically important aquatic species including mud crabs (*Scylla serrata, S. oceanica* and *S. tranquebarica*), oysters (*Crassostrea belcheri, C. iredalei, Saccostrea cucullata, S. forskali* and *Striostrea mytiloides*), abalone (*Haliotis asinina, H. ovina* and *H. varia*) and blue swimming crab (*Portunus pelagicus*) and to develop suitable applications.

DNA barcoding techniques are used for diversity analysis in Australia, China, Fiji, India, Iran (Islamic Republic of), Malaysia, New Zealand, the Philippines and Thailand. Indonesia uses DNA-based barcoding for species identification in both aquaculture and trade (Abdullah and Rehbein, 2017).

3.4.4 Disease detection and diagnostics

Australia, China, India, Japan, Malaysia, the Republic of Korea and other countries in the region use PCR-based diagnostic kits for detecting diseases in fish. Many other countries in the region have developed the technical competences needed to develop disease diagnostic kits, including Bangladesh, Cambodia, Indonesia, Iran (Islamic Republic of), Thailand (AMGBL, 2017) and Viet Nam. For example, Thailand uses PCR-based disease diagnostics to screen brood stock and shrimp larvae for acute hepato-pancreatic necrosis disease and to monitor the occurrence of the disease during the grow-out period (Virapat, 2017). Countries such as Afghanistan, Kazakhstan, Myanmar, Nepal and the Philippines are utilizing such kits but do not have the requisite competences to develop them.

Spot agglutination kits and dot enzyme-linked immunosorbent assay (ELISA) kits for diagnosis of Edwardsiellosis, aeromoniasis and bacterial gill disease of carp are available in South Asia at reasonable cost and are extensively used in many carp-producing countries. Diagnostic kits based on the nested reverse transcription-PCR method are widely used to detect carriers and early or latent infection with white-tail disease in shrimps and prawns. Brood stock and seed screening with PCR have become very common in all countries that sustain aquaculture. The Republic of Korea uses PCR-based diagnostics to detect disease caused by *Kudoa iwatai*.

DNA-based diagnostic kits for disease detection and monitoring have been advocated for about two decades (FAO, 2000) and are currently used extensively in Asian countries. DNA diagnostic kits for detection of shrimp white spot virus are used in Thailand for brood stock sanitation. Similarly, Bangladesh, China, India, Indonesia, Iran (Islamic Republic of), Japan, Malaysia, Pakistan, the Philippines, the Republic of Korea, Sri Lanka, Thailand, Viet Nam and others have deployed molecular disease diagnostic kits for surveillance and detection of diseases in fisheries/aquaculture enterprises.

3.4.5 Genomics and bioinformatics

Australia, China, India, Japan, and the Republic of Korea are using genomics, gene editing and bioinformatics in the fisheries sector to develop applications, including vaccines. Farmers in the Philippines are being encouraged to raise heat-stress-tolerant mud crab populations developed through biotechnology (Lagman, 2017).

Genome sequence studies are being conducted in locally important fish in various countries in the region. For example, China is conducting genome analysis of snubnose pompano (*Trachinotus blochii*) and golden pompano (*T. ovatus*) in support of breeding efforts; India is sequencing genes in rohu (*Labeo rohita*) and walking catfish (*Clarius batrachus*) and Indonesia is conducting similar work in snakehead mackerel (*Gempylus serpens*); Malaysia is sequencing the whole genome of the commercially important and endangered fish, Asian Arowna (*Scleropages formosus*) (Austin *et al*., 2015) and conducting genomic analysis hapuku (*Polyprion oxygeneios*), kingfish and abalone (*Haliotis discus hannai*) brood stock (Nam *et al.*, 2017).

Advances in genomics of fish pathogens in Australia, China, India, Japan and the Republic of Korea have contributed to understanding the genomic make up of several bacterial and viral fish pathogens (Liu, 2017). This has in turn contributed to designing PCR-based diagnostic kits, especially in cold-water fisheries.

3.4.6 Vaccines

A vaccine against streptococcal infections in olive flounder (*Paralichthys olivaceus*) (Park *et. al*, 2016) is used in the Republic of Korea, and the Department of Fisheries, Malaysia, has developed of vaccine, StrepToVax, for streptococcosis disease in tilapia (Daily Express, 2014; FRI, 2017). R&D on development of vaccines against bacterial and viral disease in aquaculture is in progress in China, India and some other countries. For example, researchers in China have developed a vaccine for grass carp haemorrhagic disease (Gao *et al.*, 2018).

3.4.7 Categorization of countries in terms of applications

The classification of countries according to their use of biotechnology applications in the fisheries/aquaculture sector is shown in Table 3.17.

Table 3.17. Categorization of countries in the Asia-Pacific region based on status of application of agricultural biotechnology in the fisheries/aquaculture sector

Category	Countries
Very low use	Bhutan, Brunei Darussalam, Cook Islands, Kazakhstan, Kiribati, Democratic People's Republic of Korea, Lao People's Democratic Republic, Marshal Islands, Maldives, Micronesia (Federated States of), Mongolia, Myanmar, Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Timor-Leste, Tonga, Tuvalu, Uzbekistan, Vanuatu
Low use	Afghanistan, Fiji
Medium use	Bangladesh, Cambodia, Indonesia, Iran (Islamic Republic of), Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Thailand
High use	Malaysia, New Zealand, Viet Nam
Very high use	Australia, China, India, Japan, Republic of Korea

In 23 countries the level of application is very low; these countries have adopted either no applications or only one low-level application. Afghanistan and Fiji are doing slightly better than this and hence have been placed in the 'Low use' category. Countries in the 'Medium use' category have extensively adopted low- and medium-level technologies and have adopted at least one high-level technology or have R&D capacity to work on them. Countries in 'High use' category have extensively adopted low-, medium- and high-level technology applications. Among these, New Zealand has the potential to move to the 'Very high use' category. Countries in the 'Very high use' category have adopted a significant number of medium- and high-level technologies and have excellent R&D capacity to develop vaccines, etc.

3.5 Synthesis

Low-level biotechnology applications are the most-widely used across countries, and the only such applications in use in many countries. In crops and forestry, biofertilizers and biopesticides are the most-widely used low-level applications. Low-level applications are the most-widely used in the livestock and fisheries/aquaculture sectors, including AI in livestock and polyploidy in fish. However, although adoption of low-level applications in these four sectors is widespread in the region, not all countries use them in all the sectors.

Medium-level biotechnology applications are less widely used than low-level applications. MAS is widely used in the crops and forestry sectors, as is tissue culture, but the latter's full potential is yet to be realized. Embryo transfer and diagnostics are the most widely used medium-level applications in livestock and fisheries sectors.

Countries that use high-level biotechnology applications in one sector commonly use them in other sectors also. Here the applications are based on higher capacity to innovate and adopt them.

3.6 Main gaps identified

1) Uneven adoption of technologies across countries and across sectors. This is a cause for concern as this indicates that the technologies might not have been adopted by those who need them most.
2) Underutilization of the potential in some technologies such as tissue culture and MAS indicates that issues such as technical difficulties, lack of extension and lack of capacity have to be addressed. In livestock, fisheries and aquaculture a major gap is lack of capacity to adopt medium- and high-level technologies. An important issue is whether the public sector and extension services are well-enough equipped to harness the potential of technologies.
3) Lack of collaborations and issues in technology absorption appear to be important gaps, although these aspects were not studied in detail.

4 State of capacities for developing and applying agricultural biotechnologies

4.1 Crops

4.1.1 Introduction

Capacity for developing and applying agricultural biotechnologies is a key factor in realizing their potential in the crop sector. Capacity includes the capacity to develop applications, capacity to develop human resources, capacity to absorb technologies obtained/transferred from external sources, and capacity for successful commercialization. Even applying a low-level biotechnology requires some capacity.

Among the different components of capacity, the capacity to innovate is very important. Countries that have the capacity to innovate across a range of technologies are able to deploy them in appropriate context and to create a synergy, whereas a country that has limited capacity to innovate can only acquire ready-made technology and deploy it.

Whether a country is able to apply agricultural biotechnologies to meet needs of smallholder farmers depends, *inter alia*, on its capacity to innovate and adopt technologies to meet needs. Since the mid-1990s or so, when the biotechnology revolution in agriculture was taking shape, there has been debate on capacity and capacity building in agricultural biotechnologies, particularly on capacity to develop pro-poor biotechnology (Falconi, 1999; Byerlee and Fischer, 2000; FAO, 2004; Hall and Dijkman, 2006).

Traditional biotechnological applications, such as microbial fermentation, do not require much capacity. However, adoption of a complex set of biotechnologies requires competence in a wide range or areas, including bioinformatics, genomics and GE. For applications such as GM crops, investments in infrastructure, human resources and R&D become essential.

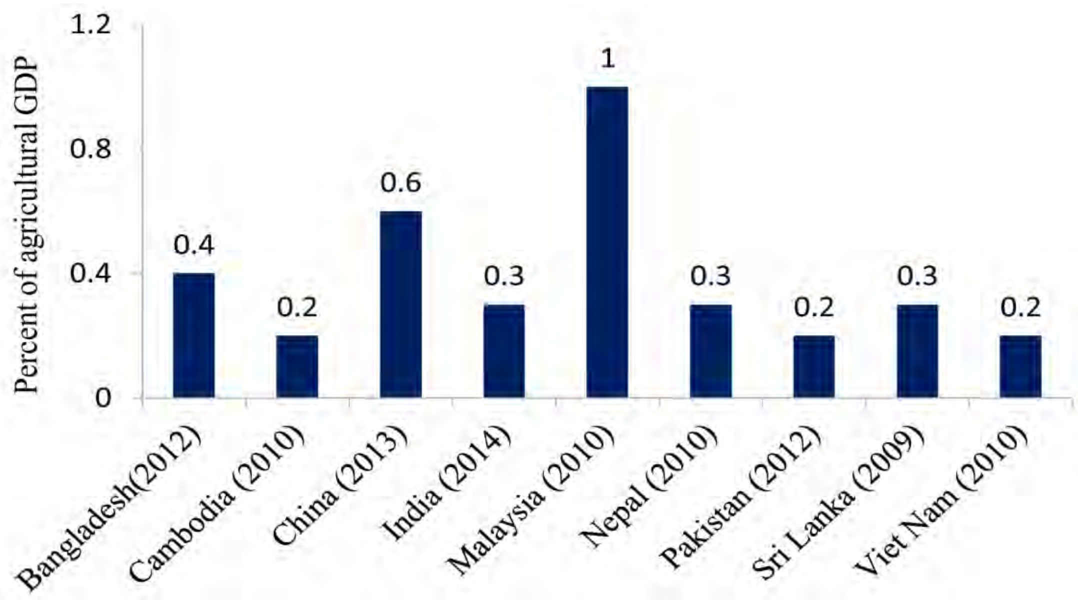
Spending on agricultural research have fluctuated in recent years and has shown marked declines in some countries (e.g. Lao People’s Democratic Republic (Table 4.1). Malaysia allocates the largest share of investment to agricultural biotechnologies as a percentage of gross domestic product (Figure 4.1).

Table 4.1. Agricultural research spending by country in the Asia-Pacific region (excluding private for-profit sector), 2000–2014

	Total spending (million 2011 PPP dollars)						
Country	***2000***	***2005***	***2010***	***2011***	***2012***	***2013***	***2014***
Bangladesh	200.4	158	239	256.4	250.6	N/A	N/A
Cambodia	17.7	19.8	22.4	N/A	N/A	N/A	N/A
China	2614.9	3769.8	7887.5	7768.2	8918.9	9366.2	N/A
India	1927.9	2269.6	2880.5	3194.6	3473.2	3279.4	3360.3
Indonesia	579.6	914.7	1067.7	1182	1282	1585.2	1352.7
Lao People's Democratic Republic	37.2	21.4	16.2	14.5	12.8	8.8	8.8
Malaysia	91	117	101.6	78.6	83.7	87.9	86.5
Nepal	39.2	29.8	36.5	49.9	53.4	47.9	N/A
Pakistan	235.6	305	291.5	291	332.5	N/A	N/A
Sri Lanka	90.4	59.4	49.2	51.2	46.4	N/A	N/A
Thailand	327	278	439.5	354.4	390	423.6	N/A
Viet Nam	61.6	108.9	136	N/A	N/A	N/A	N/A

PPP – purchasing power parity
Source: Stads, Gert-Jan. 2016

Figure 4.1. Public spending on agricultural biotechnology research and development as a share of agricultural GDP in selected countries in the Asia-Pacific region (percent)



Source: Agricultural Science and Technology Indicators (ASTI) Database, 2016

4.1.2 Genetically modified crops

Thirteen of the 43 countries in the region (Australia, China, India, Iran (Islamic Republic of), Japan, Malaysia, Myanmar, New Zealand, Pakistan, the Philippines, the Republic of Korea, Singapore and Thailand) have the capacity to develop GM crops, but the number is likely to increase because countries such as Indonesia, Nepal and Sri Lanka are expected to start permitting or promoting GM crop cultivation in the next few years. On the other hand, the capacity to develop GM crops may be beyond the reach of many LDCs and island states in the region, except perhaps Fiji.

A survey on capacity to develop GM crops has shown that although the private sector is playing the dominant role, the public sector is also crucial. Monsanto and Syngenta and/or their associates are the dominant private-sector players in the region. Among the public-sector players, the Chinese Academy of Sciences (CAS), the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and universities and public institutions are key players.

Australia, China, India, Japan, Malaysia and the Republic of Korea have the greatest capacity to innovate in crop biotechnology, followed by Bangladesh, Iran (Islamic Republic of) and Pakistan, while Myanmar is making strides in crop biotechnology.

In large countries such as Australia, China and India, capacity to develop GM crops is distributed across public-sector institutions and in the private sector. However, in terms of crops and traits, Monsanto and Syngenta are the major players.

In China, the public sector developed *Bacillus thuringiensis* (*Bt*) cotton technology, and was able to compete with Monsanto because of regulations that initially favoured the public sector. However, Monsanto has since emerged as a key player (Linton and Torsekar, 2009). In contrast, in India, Monsanto had the monopoly on *Bt* cotton, although *Bt* cotton developed using technology from the Indian Institute of Technology, Khargapur, was also authorized for release. However, because the Indian Council of Agricultural Research (ICAR) was not able to develop and commercialize *Bt* cotton, and in the absence of an effective competition, Monsanto became the *de facto* lead player in *Bt* cotton commercialization. Indian public-sector bodies have since developed GM mustard and GM chickpea, although the former is yet to be approved for commercial cultivation. The involvement of different agencies such as the ICAR Department of Biotechnology (DBT) and many agricultural universities has created GM capacity in the public sector in India but the public sector has not been able to take advantage of this because of the strength of the private sector in the seed and crop sector.

Iran (Islamic Republic of) has built significant capacity to develop GM crops, with 46 research institutes (Table 4.2) and 42 universities active in biotechnology. Iran (Islamic Republic of) is also one of the few countries engaged in GM rice research.

Table 4.2. Number of academic and non-academic centres of biotechnology in Iran (Islamic Republic of)

Field	Academic	Non-academic	Total
Agriculture and natural resources	11	8	19
Medicine	9	3	12
Pure science	6	2	8
Industry and environment	3	4	7
Total	29	17	46

Source: Authors' compilation based on country survey

Pakistan has more than 10 public-sector institutions involved in crop biotechnology R&D. In 2014, investment in biotechnology R&D was about $40 million.

In Myanmar, the public sector plays the lead role in developing GM crops. The country has only one agricultural university (Yezin Agricultural University), which is the key centre for biotechnology in the country and has developed two *Bt* cotton varieties that have been registered with the National Seed Committee (OECD, 2014). Although the private sector does not seem to be involved directly in crop development in Myanmar at present, collaborations with the private sector are being developed (ISAAA, 2016).

However, capacity does not translate directly into commercialization of products, particularly GM crops. For example, despite considerable capacity for R&D of GM rice in the region and the progress made in developing GM cultivars, GM rice is nowhere near commercialization on account of factors such as hold-ups in regulatory approval and opposition from civil society.

To sum up, 13 countries in the region have the capacity to develop GM crops, and more are developing the capacity. The private sector is the key player in GM crop development, but the public sector is also significant.

4.1.3 Biofertilizers, biopesticides and tissue culture

Capacity in these three applications is more widespread in the Asia-Pacific than that is that for development of GM crops, as these are relatively low-level technologies. However, lack of capacity is still the major constraint in applying these biotechnologies. While public-sector capacity is well developed in larger countries such as Australia, China and India, and Nepal and Sri Lanka have universities and research centres that have some capacity, the limited market potential of these low-level technologies in many countries may not attract larger players in the private sector to invest or introduce better products. The unevenness in public-sector capacity across the region is also a matter of concern.

4.1.4 Genome mapping and editing

Seven countries in the Asia-Pacific region have the capacity to harness genome editing and genome mapping – Australia, China, India, Japan, New Zealand, Republic of Korea and Singapore. China (through CAS) is one of a few countries in the world to hold patents for this technology. The capacity for these technologies in China has been facilitated by investments in institutes such as the Beijing Genomics Institute and the expertise gained in sequencing genomes. The cost of genome sequencing in China is considerably less than in the United States, and this enables China to use genomics in health and other biotechnology applications. India, Japan, Malaysia and the Republic of Korea also have capacity in these applications. Capacity in genome editing is not the same as that in genome mapping; many countries have capacity in both.

At present, most capacity seems to be in conduct of experimental studies and selected applications in various crops. As no product has been commercialized, it is difficult to assess potential and limitations of current capacity. Another issue is that as genome editing employs a wide range of technologies, capacity to apply one of the technologies does not ensure that the capacity to use all of them is available. There are also legal and ethical barriers to the use of genome editing, although they do not apply to crop-related experimentation or R&D.

To conclude, genome mapping and editing are yet to be established fully as reliable technologies that can deliver exceptional outcomes in crop biotechnology. The potential seems to be immense but so are the uncertainties and other issues such as regulation. Thus, it is reasonable to assume that capacity now available may be constrained by other factors in terms of delivery of applications. Given the ‘patent wars’ in this technology, as exemplified by claims and counterclaims regarding CRISPR by the University of California, the Broad Institute and others (see, for example, Servick, 2018), it is still not clear to what extent intellectual property rights will be a factor in the application of these technologies.

4.1.5 Marker-assisted selection and molecular breeding

The capacity to apply marker-assisted selection (MAS) across crops is available in many countries, and it is more widespread than the capacity for GM crops or genome editing. Because this is a technology that is non-controversial and can supplement traditional plant breeding, it is an ideal application for countries having strong capacity in plant breeding and in genomics. Nevertheless, the potential of the technology is not used fully in the region. One suggestion is that countries should collaborate in MAS and form crop-specific collaborative projects (Schalfleitner and Karihaloo, 2013).

4.1.5 Publications, impact factor, patents and research collaboration

Publications, patents and research collaborations are indicators of capacity. Table 4.3 gives an overview of the share of the region in global publications and research collaborations related to agricultural biotechnologies.

Table 4.3. Publications related to agricultural biotechnologies by country in the Asia-Pacific region

Country	Peer-reviewed publication output	CAGR (publication output)	Percentage of publications from international collaboration
Asia			
Afghanistan	9	N/A	100
Bangladesh	629	13%	87
Bhutan	10	N/A	100
Brunei Darussalam	16	16%	100
Cambodia	128	14%	98
China	78 263	20%	28
India	24 081	13%	22
Indonesia	629	9%	91
Iran (Islamic Republic of)	6 015	25%	25
Japan*	N/A	N/A	N/A
Kazakhstan	98	30%	91
Democratic People's Republic of Korea	12	N/A	92
Republic of Korea*	N/A	N/A	N/A
Lao People's Democratic Republic	41	10%	93
Malaysia	2 645	21%	45
Maldives	3	0%	100
Mongolia	58	27%	100
Myanmar	32	0%	94
Nepal	210	11%	93
Pakistan	2 968	22%	37
Philippines	609	11%	81
Singapore*	N/A	N/A	N/A
Sri Lanka	160	10%	74
Thailand	3 802	10%	60
Timor-Leste	N/A	N/A	N/A
Uzbekistan	71	12%	75
Viet Nam	729	13%	92

Country	Peer-reviewed publication output	CAGR (publication output)	Percentage of publications from international collaboration
Pacific			
Australia*	N/A	N/A	N/A
Cook Islands	N/A	N/A	N/A
Fiji	20	N/A	100
Kiribati	N/A	N/A	N/A
Marshall Islands	N/A	N/A	N/A
Micronesia (Federated States of)	2	N/A	100
Nauru	N/A	N/A	N/A
New Zealand*	N/A	N/A	N/A
Niue	N/A	N/A	N/A
Palau	2	0	100
Papua New Guinea	116	12%	97
Samoa	5	N/A	100
Solomon Islands	1	N/A	100
Tonga	N/A	N/A	N/A
Tuvalu	N/A	N/A	N/A
Vanuatu	5	N/A	80

CAGR – compound annual growth rate
N/A – not available
* These countries were not covered as the study was restricted to developing countries
Source: CAS-TWAS and Clarivate Analytics (2016)

Although these do not relate to crop biotechnology *per se*, they indicate that the region has significant capacity in the sector, although this is concentrated in only a few countries. Most large-scale science projects are now exercises in collaboration.

Many countries in the region are stepping up their spending in science and technology. For example, Uzbekistan is boosting investments in science and technology, and has ambitious plans to transform itself into an innovation economy. These developments will need to be closely monitored to determine their impact on capacity in biotechnology.

4.1.6 Human resources

Table 4.4 provides estimates of numbers of people involved in the agricultural biotechnology sector in the Asia-Pacific region, compiled from a number of data sources. However, these data

come with several caveats. Even OECD does not have recent data on human resources engaged in the biotechnology sector. The data on students and faculty in institutions are often incomplete or not properly segregated. For countries not listed the data available are old or are not from credible sources or have issues with quality.

4.1.7 Issues regarding capacity in crop biotechnology

The response to the questionnaire from FAO identifies lack of funds and lack of infrastructure as the major constraints in the capacity to develop and apply crop biotechnology in most countries surveyed. However, there are other emerging issues that require attention include:

1) the widening gap between countries and regions and across technologies;
2) underutilization of capacity in technologies such as biofertilizers and GM crops because of regulatory constraints and policies;
3) the inability to leverage public-sector capacity to develop and commercialize products; and
4) the overall capacity to apply and benefit from S&T.

These need to be examined on a country-by-country basis to determine what action is required to build the region's capacity in biotechnology and how FAO can best contribute.

4.1.8 Categorization of countries in terms of capacity

The classification of countries in terms of their capacity to develop and utilize biotechnology applications in the crops sector is shown in Table 4.5.

Table 4.4. Human resources in biotechnology by country

Country	Employment	Education/R&D
Australia	14664 as of January 2017	
Brunei Darussalam	N/A	More than 200 (2015)
China	N/A	More than 1.5 million (2010)
India	N/A	Nearly 71 universities imparting biotech related courses*
Indonesia		Masters 1347 LS, 25 A&V† PhD 410†
Democratic People's Republic of Korea	N/A	N/A
Republic of Korea	N/A	Masters 2002 LS, 977 A&V† PhD 902 LS, 299 A&V†
New Zealand		In 2011, 474 organizations were involved in biotechnology in some way. The industry employed 1 900 people in 2011, with 57 percent having a bachelor's degree or higher
Pakistan	N/A	More than 15 institutions involved in Biotechnology, with approximately 3500 students enrolled in PhD and MSc/MTech courses (2014)
Sri Lanka	As of 2014: Total: 576 Universities: 221 Research: 61 Other: 294	
Thailand	N/A	24 universities across the country have the combined capacity to train approximately 7 000 students in biotechnology-related subjects (2015)

LS – Life sciences; A&V – Agriculture and veterinary.

Sources: From various sources including * DBT (2018), † OECD and data compiled for country reports

Table 4.5. Categorization of countries in the Asia-Pacific region in terms of capacity to develop and apply biotechnology in the crop sector

Category	Countries
Very low capacity	Afghanistan, Brunei Darussalam, Cook Islands, Kiribati, Democratic People's Republic of Korea, Maldives. Mongolia, Marshall Islands, Micronesia (Federated States of), Nauru, Niue, Palau, Samoa, Solomon Islands, Timor-Leste, Tonga, Tuvalu, Vanuatu
Low capacity	Bhutan, Cambodia, Lao People's Democratic Republic, Uzbekistan
Medium capacity	Fiji, Indonesia, Kazakhstan, Myanmar, Nepal, Sri Lanka
High capacity	Bangladesh, Indonesia, Iran (Islamic Republic of), Malaysia, Pakistan, Philippines, Thailand, Viet Nam
Very high capacity	Australia, China, India, Japan, Republic of Korea, New Zealand, Singapore

Countries in the 'Very low capacity' category lack human resource, have weak educational and R&D infrastructure and have very limited public-sector involvement in crop biotechnology. Although some work with regional institutions and participate in collaboration, their scope is limited because they do not have a strong national research and innovation system in agriculture and they have been users/adopters of technologies rather than innovators. Moreover, capacity in agricultural training is limited.

Countries in the 'Low capacity' category also lack adequate human resources, do not have strong public-sector engagement in crop biotechnology and have little or no involvement of the private sector in crop biotechnology. They do benefit from international collaboration and networks but their engagement in them is more as recipients than contributors to the scientific research.

Countries in the 'Medium capacity' category have reasonably good capacity in terms of human resources, have a strong public-sector capacity in crop biotechnology, actively participate in regional networks and collaborate with institutes such as the CGIAR centres. They also have a vibrant private sector active in crop technologies or applications such as tissue culture and biofertilizers. Their national innovation system in agriculture has a good capacity in biotechnology.

Countries in the 'High capacity' category have good capacity in terms of human resources and have public and private sectors active in crop technologies, ranging from developing new varieties to R&D in crop biotechnology, backed by favourable policies. These countries have benefited from international collaboration, and are active in international research projects. Some of them benefit from being members of regional groups, such as ASEAN, that promote biotechnology.

Countries in the 'Very high capacity' category have excellent capacity in terms of educational institutions, giving training and conducting R&D, and have a strong national innovation system in agriculture with significant capacity in crop biotechnology. Their public and private sectors

are strong in R&D, with capability to turn outcomes of R&D into products and services for wider adoption. They benefit from international collaboration and are contributors to global research networks. They are leaders in agricultural biotechnology in the region, with continuing emphasis on enhancement of their capacity.

4.2 Livestock

4.2.1 Introduction

Table 4.6 (in annexure) provides examples that highlight the range and extent of livestock biotechnology capacity in the region.

Capacity in biotechnology in this sector has been built up largely by the public sector. A strong foundation of public institutions providing training and engaging in R&D has enabled countries such as China, India and the Republic of Korea to develop livestock biotechnology applications. Capacity building in the region through collaboration and cooperation in basic research and R&D has enabled many countries to develop their capacity for biotechnology in the livestock sector, but this alone is not sufficient for harnessing the potential of the technology. Many LDCs have very limited capacity or are in the preliminary stages of developing capacity.

4.2.2 Institutional strength and infrastructure support

Public investment in research and educational institutions has helped mobilize the human resources and scientific capacity needed to deploy livestock biotechnology successfully in several countries. Regional cooperation has also played a role in mitigating pandemic outbreaks and in establishing steps to manage the health of livestock in the region.

Only a few countries in the region have the capacity to do basic research and R&D to develop livestock biotechnology products. These include Australia, Bangladesh, China, India and Thailand.

In Australia, livestock biotechnology research is carried out at several universities, by CSIRO and at Co-operative Research Centres (CRCs) working on livestock (e.g. the CRC for Beef Genetic Technologies). Bangladesh, under the 2012 Action Plan of the National Biotechnology Policy, is supporting research in livestock biotechnology at selected institutions including the Bangladesh Livestock Research Institute. These institutes have capacity in GE, molecular markers and genetic transformation and are undertaking research in them (Shakera, 2015).

China has supported research in GE of livestock such as cattle, pigs and sheep since 2008 through the Key Scientific and Technological Grant of China for Breeding New Biotech Varieties. The National GE Animal Technology Research Center at Inner Mongolia University was set up in September 2012 with the key objective to improve new livestock variety development and animal breeding in China (GAIN, 2016). The Institute of Animal Sciences, under the Chinese Academy of Agricultural Sciences, has set up specialized institutes in

Animal Biotechnology and Reproduction, Animal Germplasm Resources and Production (CAAS, 2017).

Indian livestock R&D institutions have attained levels of excellence in developing precision diagnostic kits and vaccines for prophylaxis of key animal diseases (DBT, 2017).

In Thailand, universities such as Chulalongkorn University, Kasetsart University and Suranaree University of Technology have intensified R&D in livestock biotechnology, including cloning. The Thailand Science Park, the country's technology and innovation hub, is a key centre for facilitating R&D, allowing access to trained human resources including holders of master's degrees and PhDs. In addition to these initiatives, livestock biotechnology research capacity has been enhanced in Thailand by involving the private sector.

Many other countries in the region rely on these stronger nations and/or international agencies and collaborations for animal health products.

In some countries, such as India and Singapore, the private sector is increasingly investing in R&D on livestock biotechnology and is working closely with academic institutions.

Thus, capacity in livestock biotechnology across the region is increasing, but not uniformly across all countries.

Although many institutes in the region provide training in livestock, coverage of animal biotechnology may be lacking. Agricultural Science and Technology Indicators (ASTI) data available for selected countries indicates that in terms of full-time equivalents (FTEs), capacity in livestock R&D is low and perhaps not sufficient to harness the potential of the livestock biotechnology (Table 4.7), despite recent increases in focus on livestock health in India (ASTI, 2016). The International Livestock Research Institute (ILRI) found that postgraduate training in livestock biotechnology and related themes needed improvement in coverage in South Asia.

This indicates a need for efforts to increase the availability of human resources in livestock biotechnology. This is being addressed by organizations such as ASEAN, and CGIAR institutions such as ILRI are actively promoting collaboration and capacity building in livestock biotechnology in the region. For example, recently ILRI and the Viet Nam Institute of Animal Science announced that they would collaborate in areas including animal genetic resources. In 2017, ASEAN and India conducted a training workshop at the ICAR-Central Institute for Research on Buffaloes, Hisar, on 'Buffalo production using reproductive biotechnology' for delegates from ASEAN countries (ICAR-CIRB, 2017).

Table 4.7. Total number of researchers engaged in the livestock sector in selected countries

Country	Number of researchers (full-time equivalents)	Year
Bangladesh	181.1	2012
Cambodia	11.0	2010
India	2 038.2	2014
Lao People's Democratic Republic	36.3	2010
Malaysia	211.4	2010
Nepal	71.1	2012
Pakistan	566.2	2012
Viet Nam	586.6	2010

Source: ASTI https://www.asti.cgiar.org/data

Such collaborations are valuable, but cannot substitute entirely for home-grown efforts to develop capacity in livestock biotechnology.

4.2.3 Categorization of countries in terms of capacity

The classification of countries in terms of their capacity to develop and utilize biotechnology applications in the livestock sector is shown in Table 4.8.

The countries in the 'Very low capacity' category are mostly LDCs or island states. Their overall capacity in biotechnology is low, and hence it is not surprising that they lack capacity in livestock biotechnology.

Countries in the 'Low capacity' category current do not have sufficient capacity to adopt medium-level technologies; these countries are users of products developed by other countries. Their home-grown capacity should be developed further, particularly in terms of human resources and the capacity to harness low- and medium-level applications.

Countries in 'Medium capacity' category have good capacity but not sufficient to propel them to the next level. A redeeming feature is that these countries have a conducive milieu for capacity enhancement and to support livestock biotechnology. Moreover, the presence of public-sector institutions working in this sector will enable them to move ahead, although this would benefit from regional cooperation.

Table 4.8. Categorization of countries in the Asia-Pacific region in terms of capacity to develop and apply biotechnology in the livestock sector

Category	Countries
Very low capacity	Cook Islands, Kiribati, Democratic People's Republic of Korea, Maldives, Mongolia, Myanmar, Timor-Leste, Marshal Islands, Micronesia (Federated States of), Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu
Low capacity	Afghanistan, Bhutan, Brunei Darussalam, Cambodia, Fiji, Kazakhstan, Lao People's Democratic Republic, Philippines, Uzbekistan
Medium capacity	Bangladesh, Indonesia, Iran (Islamic Republic of), Nepal, Pakistan, Singapore, Sri Lanka, Thailand
High capacity	Malaysia, New Zealand, Viet Nam
Very high capacity	Australia, China, India, Japan, Republic of Korea

Countries in the 'High capacity' and 'Very high capacity' categories are well aware of their current capacity, and as they have national plans/strategies or have given considerable attention to livestock biotechnology, capacity enhancement for them will be easy. With strong presence of both the public and the private sector, they are in a position to increase the use of biotechnologies in the livestock sector. As they are also suppliers of vaccines and diagnostic kits, their capacity enhancement in these will benefit other countries directly.

4.3 Forestry

Capacities for developing and applying agricultural biotechnologies in the forestry sector range from very low to very high among the countries of the Asia-Pacific region. Some countries were found to have very limited or no capacity to either develop or apply agricultural biotechnologies in their forestry sector, whereas in some countries such capacities were found to be quite adequate.

4.3.1 Capacity in terms of institutions and collaborations

Capacity in forest biotechnology in the region rests primarily with academic/research institutions (Table 4.9, in annexure) and the private sector. There are large differences among countries in the number of researchers working in the forestry sector (Table 4.10).

Table 4.10. Number of full-time equivalent biotechnology researchers in the forestry sector in selected countries in the Asia-Pacific region

Country	No. of full-time equivalent researchers in forestry sector	Year
Bangladesh	75.3	2012
Cambodia	21.1	2010
India	492.8	2014
Lao People's Democratic Republic	15.9	2010
Malaysia	119.5	2010
Nepal	9.3	2012
Pakistan	89.1	2012

Source: ASTI (2017)

Not all countries engaged in forestry have research programmes or academic institutions working in the sector, and thus are dependent on international collaboration. For example, Vanuatu does not have any academic/research institution for teaching and training solely in forest biotechnology, but the Department of Forests of the Government of Vanuatu works on some research projects in collaboration with the Vanuatu Agricultural Research and Technical Centre and international agencies (Department of Forests, Government of Vanuatu, 2017).

Among the Pacific countries, only Australia and New Zealand have sufficient capacity in forest biotechnology. Fiji has only one prominent academic/research institution, Fiji National University, which offers bachelors, diploma and certificate courses in forestry (Fiji National University, 2017). Papua New Guinea has only one forest research institution, Papua New Guinea Forest Research Institute (ACP Forenet, 2017). None of the other Pacific countries has even a single research/academic institution offering training and teaching in forest biotechnology. However, the University of the South Pacific (USP) and the Pacific Community (SPC) do some research and training on medium-level forest biotechnology such as tissue culture and PCR.

Bangladesh, Iran (Islamic Republic of), Lao People's Democratic Republic, Myanmar, Pakistan, the Philippines, Sri Lanka and Viet Nam have academic/research institutions active in forestry biotechnology research. For example, Bangladesh has the national-level Bangladesh Forest Research Institute (BFRI) with research programmes on forest biotechnology (BFRI, 2017) and the Bangladesh Forest Industries Development Corporation for promotion of forest-based industry. It also has university departments for forest research such as the Institute of Forestry at Chittagong University. In Sri Lanka, the Sri Lanka Forestry Institute conducts research and training in forestry and environment, including forest biotechnology, mainly to strengthen capabilities of the technical staff of the Forest Department.

China, India, Indonesia, Japan, Malaysia, the Republic of Korea and Thailand in Asia and Australia and New Zealand in the Pacific have good capacity built up over the years. In India

and Malaysia, the British gave importance to training and research in forestry, and this resulted in these countries having institutions engaged in forestry education, research and training. In both, the private sector also has R&D capacity. In Thailand, there are several universities offering bachelor's and master's degree courses related to forest and natural resources (FAO, 2009). Generally, most institutions in forestry R&D and training in these countries are in the public sector.

In India, the nodal ministry for the forestry sector, the Ministry of Environment, Forests and Climate Change, has established an autonomous body, the Indian Council of Forestry Research and Education, which has 12 research institutions located across the country with facilities for teaching, training and conducting forest R&D (ICFRE, 2017). These institutes have forestry R&D projects and programmes in the domain of biotechnology, covering various applications. Some offer PhD programmes in forestry biotechnology. The ICAR Department of Biotechnology (DBT) in India has also supported some studies on forestry, focusing on the genetic improvement of eucalyptus through mapping and tagging of QTL genes for two industrially important traits – adventitious rooting capacity and wood property (DBT, 2017). In India, emphasis is placed on capacity in conservation and utilization of forest genetic resources, in which biotechnology applications play a crucial role. The Indian State Forest Development Corporations are engaged in deploying applications but do not have good capacity for R&D. For example, the Forest Development Corporation of Maharashtra procured clonal seedlings of 42 tested and genetically superior clones of eucalyptus from the ITC Limited Bhadrachalam for propagation. Recently it has initiated clonal propagation of *Casuarina*, Indian rosewood (*Dalbergia sissoo*) and tamarind (FDCM, 2016). The Kerala Forest Research Institute has worked on tropical forests and forestry using forest genetics and biotechnology, and is also involved in extension services (KFRI, 2017).

In China, the Chinese Academy of Forestry, with about 15 committed research institutes, is active in research on forest biotechnology, and has a large number of programmes on forest R&D. The Research Institute of Forestry of the Chinese Academy of Forestry has many research and training projects in cutting-edge forest biotechnologies (CAF, 2017)

Australia has many academic programmes in forest R&D at several universities, and CSIRO has a special division on forestry and forest products, with projects on forest biotechnologies. There is also an active presence of the private sector.

In the Republic of Korea, the Korea Forest Service is involved in conducting high-end research in forest biotechnology as well as in training local human resources (KFS, 2017).

Malaysia's high capacity in forest biotechnology is attributed to the presence of very strong industry infrastructure aimed at promoting bioeconomy-based national development (Bioeconomy Corporation, 2017).

There are numerous private-sector players in the forest biotechnology sector in the region. For example, the APRIL Group, based in Indonesia, is one of the largest and most-efficient makers of pulp and paper products in the world. It is engaged in R&D on the use of biotechnologies to

breed trees with higher pulp yield and better pulping properties and greater pest and disease resistance (APRIL, 2018).

4.3.2 Categorization of countries in terms of capacity

The classification of countries in terms of their capacity to develop and utilize biotechnology applications in the forestry sector is shown in Table 4.11.

Many of Pacific countries and some Asian countries fall into the category of 'Very low or no capacity' as there are no academic/research institutions or private-sector facilities engaged in research or application of biotechnologies in the forestry sector.

Table 4.11. Categorization of countries in the Asia-Pacific region in terms of capacity to develop and apply biotechnology in the forestry sector

Category	Countries
No capacity	Afghanistan, Cook Islands, Marshall Islands, Micronesia (Federated States of), Nauru, Niue, Palau, Samoa, Tonga, Tuvalu, Uzbekistan
Low capacity	Bhutan, Brunei Darussalam, Cambodia, Fiji, Kazakhstan, Kiribati, Lao People's Democratic Republic, Maldives, Mongolia, Nepal, Papua New Guinea, Solomon Islands, Timor-Leste, Vanuatu
Medium capacity	Bangladesh, Iran (Islamic Republic of), Myanmar, Pakistan, Philippines, Singapore Sri Lanka, Viet Nam
High capacity	Indonesia, Republic of Korea, Malaysia, New Zealand, Thailand
Very high capacity	Australia, China, India, Japan

Countries in the 'Low capacity' category have only a few local academic/research institutions engaged in forest R&D and limited private-sector engagement, whereas those in the 'Medium capacity' category have some academic/research institutions and private-sector activity in biotechnologies for forestry.

Countries in the 'High capacity' category – Indonesia, Malaysia, New Zealand, the Republic of Korea and Thailand – have many academic/research institutions engaged in forest biotechnology R&D and there is also a strong private-sector engagement.

Only four countries – Australia, China, India and Japan – fall into the category of 'Very high' capacities; these countries have many specialized academic/research institutions engaged in forest biotechnology R&D and also very strong private-sector engagement in the sector.

4.4 Fisheries/aquaculture

4.4.1 Institutions and collaborations

Thirty countries in the region have infrastructure for research in fisheries/aquaculture technologies (Table 4.12, in annexure), mostly with public funding. The educational

institutions offer various programmes, including PhD programmes. However, only some countries have adequate capacity to harness biotechnology fully in this sector.

Recent ASTI data (Table 4.13) indicates that a relatively small proportion (3.2–18%) of agricultural researchers are working in the fisheries/aquaculture sector in Asia, and the share of those working in biotechnology is likely to be much less. This indicates inadequate capacity in fisheries to harness the full potential of biotechnology in this sector.

Table 4.13. Number of researchers working in the fisheries/aquaculture sector in Asia

Country	**Bangladesh**	**Cambodia**	**China**	**India**	**Lao People's Democratic Republic**	**Malaysia**	**Nepal**	**Pakistan**	**Sri Lanka**	**Viet Nam**
Year	**2012**	**2010**	**2013**	**2014**	**2010**	**2010**	**2012**	**2012**	**2009**	**2010**
Researchers (FTEs)*	128.6	26.1	-	614	40.9	133.6	47.2	105.9	-	436
Researchers (share of total, FTEs, %)	6.0	9.2	-	4.8	18	8.3	11.7	3.2	-	11.6

* FTE – full-time equivalent
Source: ASTI, 2017

Many countries have to rely on regional-level programmes for assistance in building capacities in fisheries/aquaculture biotechnology. China, for example, participates in regional activities of FAO, the United Nations Environment Programme (UNEP), the EU Framework Programme for Research, the Asia-Europe Meeting on Aquaculture, the World Aquaculture Society, the International Marine Biotechnology Association and others (Xiang, 2015). Other examples include the ASEAN-SEAFDEC Aquaculture Department project entitled "Promotion of sustainable aquaculture and resource enhancement in Southeast Asia", under the ASEAN-SEAFDEC Fisheries Consultative Group Program (SEAFDEC/AQD, 2017). This focuses on development and extension of rapid and effective fish and shrimp health management; enhancement of vaccine efficacy for the prevention of viral nervous necrosis in high value marine fish; application of adjuvants, carriers and RNAi technology to enhance the antiviral immune response of shrimp to white spot syndrome virus; establishment of protective measures against persistent and emerging parasitic diseases of tropical fish; epidemiology of the early mortality syndrome/acute hepatopancreatic necrosis disease in *Penaeus monodon*; and technology extension and demonstration. Organizations such as ASEAN, the Indian Ocean Rim Association, the Pacific Community and others have taken up cooperation and collaboration to ensure biosecurity, with considerable support from FAO and the World Health Organization (WHO) in the region. These agencies have all taken measures to enhance nations' capacity to deploy appropriate interventions in case of eventualities of disease outbreak. However, many countries also have national-level initiatives on fisheries biotechnology, often launched as part of a national biotechnology plan or strategy.

Table 4.14 lists educational institutes offering courses in fisheries/aquaculture biotechnology in selected countries in the Asia-Pacific region.

Table 4.14. Selected educational institutions in the Asia-Pacific region offering courses in fisheries/aquaculture biotechnology

Country	Institutes/Universities	Courses offered
Australia	Australian Institute of Marine Science to stimulate research in marine science. Other such institutions are: Western Australian Marine Sciences Institution Flinders University Centre for Marine Bioproducts Development James Cook University School of Tropical and Marine Biology South Australian Research and Development Institute	Bachelors, Masters and PhD courses in Marine biology, Aquatic animal health management, Marine Biotechnology and others
China	Lanzhou Veterinary Research institute, Zheijiang University College of Ocean and Earth Sciences, Xiamen University Shanghai Ocean University	Bachelors and MSc/MTech in marine biotechnology, marine biological resources and utilization, mariculture, aquatic animal nutrition, basic immunology of aquatic animals, comprehensive disease prevention
India	ICAR-Central Institute of Fisheries Education Tamil Nadu Veterinary and Animal Sciences University, Chennai Cochin University of Science and Technology Central Salt and Marine Chemicals Research Institute at Bhavnagar	Most of these Institutions offer courses in biotechnology, with focus on fisheries health management, reproductive technologies and others. BSc/BTech, MSc/MTech, PhDs have been offered in these institutions
Japan	Japan Fisheries Research and Education agency Hokkaido National Fisheries Research Institute Tohoku National Fisheries Research Institute Japan Marine Fishery Resources Research Centre National Research Institute of Fisheries Engineering	Courses on marine resources and the oceanic environment management, marine biotechnology, disease management in aquatic animals, Fisheries health, etc.
Republic of Korea	Korean Institute for Ocean and Technology Cheju National University - College of Ocean Sciences Department of Marine Production Systems, Department of Aquaculture, Department of Marine	Graduate and master's degree courses on marine ecosystem management, marine biotechnology, aquatic animal nutrition and health management and others

Country	Institutes/Universities	Courses offered
	Biotechnology, Shellfish Research and Aquaculture Laboratory	
	Pusan National University	
	Korea Maritime Institute	

In Indonesia, for example, some universities have working groups in marine biodiscovery and biotechnology, including Diponegoro Univesity, Gadjah Mada University, Sam Ratulangi University and Bogor Agricultural Institute; the Marine Fisheries Agency’s Ekowati Chasanah Research Centre for Marine and Fisheries Product Processing and Biotechnology also has such programmes. Australia also has many centres that work on biotechnology in fisheries, some of which also conduct research on biodiscovery, including the Western Australian Marine Sciences Institution and the South Australian Research and Development Institute (SARDI). In New Zealand, the Cawthron Institute, the country’s largest independent science research organization, has an aquatic biotechnology department involved in aquaculture and seafood safety. In Japan, the Marine Biotechnology Institute, established in 1990, is a major research centre. Similarly, various Universities in the Republic of Korea are involved in marine biotechnology research and supporting activities. The Division of Marine Environment and Bioscience, Korea Maritime University, offers a major in marine biotechnology, while the College of Ocean Science and Technology, Kunsan National University, has a department of Marine Biotechnology working on mariculture.

The Viet Nam Academy of Science and Technology has many institutes working in marine biotechnology. The Nhatrang Institute of Technology Research and Application, for example, works on genetic resources and cultivation, including aquaculture development. The Institute of Biotechnology at the National Centre of Natural Science and Technology conducts research on basic biotechnology. Several universities in Viet Nam are involved in marine biotechnology and fisheries biotechnology is a part of it. Ho Chi Minh City Biotechnology Center is an important research centre working in this sector.

4.4.2 Categorization of countries in terms of capacity

The classification of countries in terms of their capacity to develop and utilize biotechnology applications in the fisheries/aquaculture sector is shown in Table 4.15.

Table 4.15. Categorization of countries in the Asia-Pacific region in terms of biotechnology capacities in the fisheries/aquaculture sector

Category	Countries
Very low	Bhutan, Brunei Darussalam, Cook Islands, Kazakhstan, Kiribati, Democratic People’s Republic of Korea, Lao People’s Democratic Republic, Maldives, Marshal Islands, Micronesia (Federated States of), Mongolia, Myanmar, Nauru, Niue, Palau, Papua New Guinea, Samoa, Singapore, Solomon Islands, Tonga, Timor-Leste, Tuvalu, Uzbekistan, Vanuatu
Low	Afghanistan, Cambodia, Fiji, Nepal

Category	Countries
Medium	Bangladesh, Indonesia, Iran (Islamic Republic of), Pakistan, Philippines, Sri Lanka, Thailand
High	Malaysia, New Zealand, Viet Nam
Very high	Australia, China, India, Japan, Republic of Korea

The categorization takes into account the countries' capacities in terms of educational/research institutions, human resources and collaborations. Of the 43 countries, only 19 have meaningful capacity in biotechnology in fisheries. The other 24 have very low capacity. Although many of these countries are involved in regional or international capacity-building programmes, their capacity is very low because their domestic capacity is weak. Countries in the 'Low' category have some domestic capacity, which is supplemented with collaborations. Countries in the 'Medium' category have good capacity in biotechnology and in application of biotechnology to the fisheries sector, supplemented by collaboration. Countries in the 'High' category have very good capacity in terms of R&D and training capacity that is complemented by international collaboration. Countries in the 'Very high' category have excellent capacity in R&D, training and capacity building and are active in international collaboration.

4.5 Synthesis

There is a wide variance among the countries in terms of their capacities to develop and utilize biotechnology applications in the different sectors. Most countries have low or very low capacities in all sectors. Thus, capacity development is key to ensuring the countries have sufficient capacity to take advantage of biotechnology. For many LDCs and island states, cooperation and collaboration are important sources of capacity enhancement. However, unless domestic capacity is also strengthened, this alone will not make a difference in the long run. Lack of human resources and lack of institutional capacities are obviously the major constraints. The state of national agricultural innovation systems is a key factor in the overall capacity in biotechnologies. Our survey shows that investments in agricultural R&D in the region have generally increased, although further investment and strengthening are needed. Sector-specific capacity-building programmes can be undertaken to address weaknesses in particular national agricultural innovation systems.

4.6 Main gaps identified

1) Lack of institutional capacity and lack of human resources in terms of both numbers and expertise and skills are the major gaps that constrain overall capacity in biotechnologies in the region.
2) Although there are international collaborative programmes in the region, they alone are not sufficient to address all weaknesses in capacity in the region and have to be expanded in scope and coverage.

3) Capacity is lacking in both the public sector and the private sector. Public-sector capacity has to be enhanced through public investment, while development of the private sector's capacity can be encouraged through policy interventions.

5 State of the enabling environment for developing and applying agricultural biotechnologies

The term 'enabling environment' in the context of this report means a milieu that is conducive to the functioning and growth of biotechnology-related institutions, firms, investors and other players. The enabling environment is influenced by policies, regulations, actions of different players and developments in technology. It is thus affected by developments across time and space.

It is important that countries embarking on agricultural biotechnology programmes adhere to norms of World Trade Organization (WTO) agreements in trade, particularly in intellectual property rights, the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement) and the Agreement on Technical Barriers to Trade (TBT Agreement) and commitments under the Cartagena Protocol on Biosafety to the Convention on Biological Diversity. They must also be sensitive towards norms and demands in larger markets such as the European Union. Thus, the enabling environment has to balance competing interests, multiple objectives and emerging issues in trade in agriculture. Concerns about biosafety can stem from environmental, trade and scientific perspectives. Technological developments demand revising laws and regulations, often resulting in enactment of new laws. Thus, adhering to biosafety regulations and developing a biosafety regime is not a one-time effort.

The current enabling environments in the region have undergone transformations since the 1990s, and are likely to be modified further as new technological options emerge. For example, regulating gene drives, plants developed using new plant breeding technologies and genome editing is not the concern only of countries that have the capacity to handle or use them but to all countries, given trade and environmental dimensions.

The following sections discuss enabling environment in terms of specific applications as well as in terms of policies, regulations, incentives, intellectual property protection and membership of treaties/conventions affecting the different agricultural sectors.

5.1. Crops

5.1.1 GM crops

The enabling environment for GM crops is positive across the region, and in recent years has become attractive. Bangladesh, Myanmar and Viet Nam have seen particular improvements in their enabling environments. Countries like Thailand that have not permitted commercial cultivation of GM crops have created an environment that enables trade and consumption of GM crops. Many countries in the region have been able overcome the issue of trade and standards emerging as a barrier to trade in GM food, although the global situation is complex.

Resistance or objections to cultivation of GM crops has been vociferous in some countries, resulting in moratoriums and similar measures, such as delaying permission to cultivate GM crops, but these have not deterred R&D or plans to promote GM crops. Private-sector

investment in GM crops is significant across the region except in a few countries, such as Iran (Islamic Republic of). The fact that multinational corporations are willing to become visible in the region through joint ventures, licensing agreements and undertaking R&D is proof that the enabling environment is conducive. However, issues such as low yield in GM crops, lack of access to seeds and concerns about safety of GM food may impact negatively on the enabling environment.

One way to assess the enabling environment is to examine whether R&D and commercialization of GM crops is established or increasing. Tables 3.1 to 3.8 (Tables 3.2, 3.3 and 3.7 in annexure) show an increasing number of trials, crops and traits in many countries in the region, indicating a conducive enabling environment, although not all the trials result in approval for cultivation. Given the huge investments in the R&D and infrastructure, it is likely that the enabling environment that has been created will continue to flourish unless there is a disruption such as a major backlash against GM crops or abrupt changes in policies.

Despite a favourable enabling environment, the region has not produced many GM varieties of crops that meet the specific needs of smallholders and that are suitable for climate-change mitigation/adoption. Developing such varieties may need an initiative similar to the Water Efficient Maize for Africa initiative (see https://wema.aatf-africa.org/). However, given the diversity in needs, including country-specific needs, a better solution might be to replicate the Green Revolution model in a mission mode wherein CGIAR institutes work with national-level institutions and state-level institutions such as state agricultural universities.

Such initiatives would create a more favourable response to GM crops from smallholders, the key stakeholder of the agriculture in the region.

5.1.2 Biofertilizers, biopesticides and tissue culture

The enabling environment for biofertilizers, biopesticides and tissue culture is broadly positive. The issue here is more of capacity and regulation than of policies as such.

Regulations in some countries are not conducive for the development of biopesticides, while in the case of biofertilizers the primary constraint is underutilization of capacity because of lack of adequate attention in policy. Thus, the current enabling environment for these needs to be examined and adjusted to be more conducive to innovation to make these applications more suitable for smallholders.

5.1.3 Marker-assisted breeding and molecular breeding

The enabling environment for both marker-assisted breeding and molecular breeding is positive and improving as more countries adopt these applications. Here the issue is more a matter of lack of capacity and the need to identify the right solution rather than policy *per se*. Collaboration, particularly at the regional level, could strengthen the current enabling environment.

5.1.4 Genome editing and genome mapping

Genome editing and genome mapping are emerging technologies and not all countries have competence in them. The enabling environment is positive in those countries that do have competence. However, these technologies have raised many ethical and moral issues, such as such as whether to regulate their products as GMOs or as non-GMOs. As such, maintaining a positive enabling environment requires that these issues be addressed, particularly the ethical and regulatory concerns.

For example, if Europe decides to treat genome-edited cultivars as GMOs and the United States opts to treat them as non-GMOs, this will affect trade and cultivation and hence the enabling environment in the region. In the case of genome mapping in crops and plant genetic resources, the enabling environment is positive but the Nagoya Protocol on Access and Benefit Sharing must be taken into account if the mapping involves access and benefit-sharing.

Labelling of GM foods and products has not been a major issue in the region, and most countries do not have norms mandating labelling and/or segregation of GM and non-GM produce and processed food. Although there have been a few instances of mixing of GM and non-GM produce/food, these have not disrupted overall trade and consumption.

Despite the positive enabling environment, there seem to be no plans at present in the region to use these technologies for developing varieties to benefit smallholders; even applications regarding climate change do not appear to be a priority.

5.1.5 Biosafety regulation in crop biotechnology

Most countries in the region are Parties to the Cartagena Protocol on Biosafety to the Convention on Biological Diversity, the major international convention relevant for crop biotechnology. As a result of efforts of the United Nations Development Programme (UNDP) and the UNEP Global Environment Facility (GEF) in capacity-building programmes and regional programmes on biosafety, most countries in the region have biosafety guidelines, rules and regulations, even in the absence of any biotechnology activity. OECD guidelines and documents have also played an important role in shaping the biosafety regulatory framework in the region, as have the United Nations Industrial Development Organization (UNIDO), FAO, UNEP and others, such as the International Centre for Genetic Engineering and Biotechnology. This has ensured that frameworks are compatible with global norms.

Some countries have comprehensive legislations while many have guidelines and rules. As most of the countries are Parties to the WTO Agreements, the TBT/SPS Agreements are binding. This means that countries cannot arbitrarily use national standards. Thus, biosafety regimes are part of the enabling environment in the region and they add credibility and acceptability to biotechnology policies.

Most countries in the Asia-Pacific region have functional regulatory frameworks for crop biotechnologies, and have specific laws and rules covering field trials, commercialization and

post-approval follow ups (Table 5.1). These laws and frameworks have been devised taking into account specific needs and technological developments.

There have been criticisms about regulatory regimes in a few countries. In future, the challenges could come from new technologies, such as gene drives and genome-edited crops. In many countries, regulation is entrusted to an agency or ministry. Current capacity seems to be adequate for GM crops in the pipeline, as they are based on genetic modification technology.

5.1.6 Intellectual property rights and incentives for innovation

There is no uniformity in intellectual property protection for plant varieties, even among members of ASEAN (Table 5.2).

In crop biotechnology, the most relevant intellectual property protection modes are patents and plant variety protection. However, not all countries in the region provide for both patents and plant variety protection.

As most countries in the region are members of the WTO, implementation of the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) is mandatory. Some countries have opted for TRIPS Plus norms on account of bilateral trade agreements and other factors.

With the exception of India, all major countries in the region with high capacity for R&D in crop biotechnology (Australia, China, Japan, New Zealand, the Republic of Korea, Singapore and Viet Nam) are also members of the International Union for the Protection of New Varieties of Plants (UPOV) (UPOV, 2017). Some members of UPOV offer both patent and plant variety protection but countries that are party to the 1978 Act of UPOV need not.

Table 5.1. Overview of biotechnology regulation in the Asia-Pacific region

Country	CPB member	Regulation	Labelling	Biosafety rules and institution(s)
Australia	Non-party	Process-based	Mandatory labelling based on product content (1% threshold)	Office of the Gene Technology Regulator
China	Party (2005)	Process-based	Mandatory for 17 products from corn, soybean, cotton, canola and tomato	National Biosafety Committee of China
India	Party (2003)	Process-based	No mandatory labelling	Genetic Engineering Appraisal Committee
Indonesia	Party (2005)	Process-based	Mandatory for packaged foods; introduced but not implemented (5% threshold)	National Biosafety Commission on Genetically Engineered Products
Japan	Party (2004)	Process-based	Mandatory labelling based on product content (5% threshold)	Ministry of Agriculture, Forestry and Fishery and Ministry of Environment
Republic of Korea	Party (2008)	Process-based	Mandatory labelling based on product content (3% threshold)	Korea Biosafety Clearing House
Malaysia	Party (2003)	Process-based	Mandatory labelling based on product content (3% threshold)	National Biosafety Board
New Zealand	Party (2005)	Process-based	Mandatory labelling based on product content (1% threshold)	Environmental Protection Agency
Pakistan	Party (2009)	Process-based	No legislation on labelling	National Biosafety Committee of Pakistan
Philippines	Party (2007)	Product-based	No labelling policy in place	National Committee on Biosafety of the Philippines
Singapore	Non-party	Process-based	No labelling policy in place	Genetic Modification Advisory Committee
Thailand	Party (2006)	Process-based	Mandatory labelling for corn and soybean products based on product content (5% threshold)	National Biosafety Committee
Viet Nam	Party (2004)	Process-based	Mandatory; introduced but not implemented (5% threshold)	Ministry of Natural Resources and Environment

CPB – Cartagena Protocol on Biosafety
Source: Gain (2016a, 2016b, 2016c), APCTT (2011), Biosafety clearing house (2016) and country papers prepared for this review

Table 5.2. Law governing intellectual property rights in ASEAN countries

Country	Year Joined WIPO	Year Joined WTO-TRIPs	Latest version of IPR laws			
			Patent	*Copyright*	*Trademark*	*Plant variety protection*
Cambodia	1995	2004	2003	2003	2002	-
Indonesia	1979	1995	2001	2014	2001	2000
Lao People's Democratic Republic	1995	2013	2011	2011	2011	-
Malaysia	1989	1995	2006	2006	2002	2004
Myanmar	2001	1995	1946	1911	1989	-
Philippines	1980	1995	1998	2013	1998	2002
Thailand	1989	1995	1999	2015	2000	1999
Viet Nam	1976	2007	2009	2009	2009	2004

ASEAN – Association of Southeast Asian Nations
IPR – intellectual property rights
WIPO – World Intellectual Property Organization
WTO-TRIPS – World Trade Organization, Agreement on Trade-Related Aspects of Intellectual Property Rights
Source: OECD (2017)

Many other countries, including India, Indonesia, Malaysia and Thailand, are not the members of the UPOV. They do, however, have plant variety protection laws and regulate seed trade. Although many have not joined UPOV, as Parties to TRIPS countries have to provide for IP protection for plant varieties. India, for example, opted for a *sui generis* system for plant variety protection and farmers' rights (Kanniah and Antons, 2017). Eleven countries are discussing with UPOV the development of national laws based on the UPOV convention or have initiated the process of acceding to the UPOV convention (UPOV, 2017). However, this does not mean that they will join UPOV or change their laws to adhere to the UPOV.

For countries with little innovative capacity, joining UPOV is more a symbolic gesture, indicating their willingness to provide plant variety protection similar to that offered in developed countries. For example, Myanmar and Viet Nam have revamped their national laws on the plant variety protection and seeds. Such changes are gradually transforming intellectual property (IP) landscape in the region.

Given that many countries have legislation that protects plant varieties, the intellectual property rights scenario is positive and contributes to enhancing the enabling environment. In some jurisdictions (e.g. India), patenting of plant varieties, seeds and life forms *per se* is prohibited, explicitly or otherwise. However, for genetically modified microorganisms, which are used in biotechnology applications, patent protection is available in many countries, including China, India and Japan. This is an important incentive for production of biopesticides and biofertilizers.

Translating R&D to a commercial product is fraught with risks such as failure to get clearance for cultivation/commercialization and obsolescence. Since IP rights are incentives for innovation, many multinational corporations consider the status of such rights in their decision-

making. Given the shift from the public sector to the private sector in crop biotechnology, IP rights have a crucial role in ensuring that the enabling environment is conducive for R&D and commercialization. However, some people claim that strong IP rights create constraints to access and make seeds of GM crops unaffordable. Despite such controversies, governments have continued to support the development of agricultural biotechnologies.

What is remarkable is that many countries have started considering incentivizing innovation in addition to providing for IP protection. These incentives are provided in many ways, ranging from tax concessions, incentives to commercialize products and special schemes to promote start-ups, to schemes to encourage techno-entrepreneurship, acquisition of technology and incentives to commercialize/scale up (OECD, 2017). Although the OECD publication lists only developments in Southeast Asia, the proliferation of incentives to innovate is found across the region. Some countries have set up agencies to promote innovations in biotechnology, such as the Biotechnology Industry Research Assistance Council in India.

To sum up, the availability of IP protection and incentives in many countries in the region has contributed to developing a positive enabling environment for crop biotechnology.

5.1.7 Policy and strategy in developing the enabling environment

Eleven countries in the Asia-Pacific region have explicit policies or strategies on biotechnology, but in many countries, agricultural biotechnology is a part of the national developmental strategies in agriculture, and many countries in the region have policies with specific objectives in agriculture (OECD, 2017).While China promotes biotechnology through special programmes, India offers a range of programmes and policies ranging from incentives to R&D to support for start-ups through the Department of Biotechnology and institutions/entities promoted by it. Malaysia promotes biotechnology through the Malaysian Biotechnology Corporation, which was set up by the government, and many programmes. Singapore's focus on life sciences and health technology has created a policy environment to attract investment, human resources and research. Thailand has a national strategy on biotechnology that identifies sectors that need focus, and the Republic of Korea is promoting biotechnology through policies and strategies.

Small countries cannot afford such grand-scale initiatives and have used traditional tools of policymaking and promotional strategies. The rapid growth of agricultural biotechnologies in the region is proof that these policies and strategies have worked, but the performance has been uneven.

To develop workable strategies and execute a plan requires capacity and investment. While there are lessons that can be learned from case studies of successes in policy and strategy, the diversity in size of economies, capacities and needs demands diversity in policy frameworks and strategies. Supporting this will require an in-depth analysis of existing policies and their performance.

To sum up, countries in the region have adopted various approaches to promoting biotechnology, and the enabling environment is largely positive. However, it is less so in most

LDCs because either they lack policies or their underdeveloped national innovation systems act as a constraint.

5.1.8 Collaborations and capacity building

Collaborations and capacity building have an important role in creating an enabling environment, particularly in small countries where capacity is limited. This study shows that collaborations are crucial for several countries but there are few collaborations or crop-specific projects across countries or the regions. Moreover, there are few examples of the private sector actively partnering with the public sector to meet the needs of the small-scale farmers. However, precise information on collaborations and cooperation across institutions is difficult to access.

Capacity-building initiatives have worked well in biosafety and in regulatory capacity, but many of these were part of projects that ended a long time ago. In the absence of further capacity building, many guidelines and regulations are old. In addition, capacity building in biosafety has not been of much benefit in countries that do not have any significant capacity in biotechnology or R&D. Nevertheless, collaborations and capacity building in the region will continue to be important for an effective enabling environment.

5.1.9. Categorization of countries in terms of enabling environment

The classification of countries in terms of their enabling environment for development and utilization of biotechnology applications in the crops sector is shown in Table 5.3.

Table 5.3. Categorization of countries in the Asia-Pacific region in terms of enabling environment for developing and applying agricultural biotechnologies in the crop sector

Category	Countries	Remarks
Low	Afghanistan, Brunei Darussalam, Cook Islands, Kiribati, Democratic People's Republic of Korea, Maldives. Marshall Islands, Micronesia (Federated States of), Mongolia, Nauru, Niue, Palau, Samoa, Solomon Islands, Timor-Leste, Tonga, Tuvalu, Vanuatu	Mostly LDCs/island states in the Pacific. Little or no activity in crop biotechnology.
Very low	Bhutan, Cambodia, Kazakhstan, Lao People's Democratic Republic, Uzbekistan	Need to develop and enhance enabling environments to harness crop biotechnology.
Medium	Fiji, Indonesia, Myanmar, Nepal, Sri Lanka	Potential to move to next category if enabling environment is enhanced, but constraints such as lack of funding may limit progress.
High	Bangladesh, Indonesia, Iran (Islamic Republic of), Malaysia, Pakistan, Philippines, Thailand, Viet Nam	Have potential and have invested in enabling environment and made changes in policies. Should aim at identifying gaps in enabling environment to move to the 'Very high' category.
Very high	Australia, China, India, Japan, Republic of Korea, New Zealand, Singapore	Have excellent enabling environments backed by policies but will have to support the enabling environments on a sustained basis and make them more attractive to remain in the same position and to move ahead.

5.2 Livestock

5.2.1 Policies and initiatives in cooperation

Table 5.4 (in annexure) provides illustrative examples of livestock-related policies, legislation and international collaborations in the Asia-Pacific region. Few countries have specific policies relating to livestock biotechnology and, in general, sector-oriented laws and regulations are applied in conjunction with other relevant laws and regulations. International and regional collaborations have played an important role in creating the enabling environment. The following section highlights some of the national-level policies/strategies to illustrate the scope and coverage of policies in this sector.

In India, the National Livestock Policy 2013 categorically states that newer breeding and reproductive technologies, including those involving biotechnology and genetic

engineering/genetic marker technology, will be adopted for use in breed improvement programmes and for increasing production. The Indian National Biotechnology Development Strategy 2015–2020 refers to the use of biotechnology in the livestock sector. According to the strategy, research in breeding, reproduction technologies, nutrition and health care is being carried out and will continue to be supported to enhance animal health and productivity through a multipronged approach. The strategy encourages the use of genomics and genetic characterization in livestock and poultry through application of genome-wide MAS for enhancement of production, feed conversion ratio and disease resistance in indigenous breeds of cattle, chicken, buffalo, sheep and pigs. In the area of animal reproduction and transgenics, the strategy calls for application of techniques such as: sperm sexing; biopharming for therapeutic proteins specifically in purification of recombinant proteins; production of biologicals for embryo transfer technology; generation of transgenic animal models for disease/disease resistance; and development of new tools for detection of silent heat and pregnancy in cattle; and for the launch of a major multi-centric programme on generating transgenic livestock (DBT, 2017).

Australian Biotechnology: A National Strategy (Commonwealth of Australia, 2000) states that one of its objectives is to promote responsible uptake of biotechnology for product and process development in industry. The Australian Centre for International Agricultural Research (ACIAR) encourages research for the purpose of identifying, or finding solutions to, agricultural problems of developing countries including that in livestock sector (ACIAR, 2018). ACIAR also provides fellowships and scholarships for researchers from developing countries to pursue research in livestock sector.

In Japan, the 2011 Basic Policy and Action Plan for Revitalization of Japan's Food, Agriculture, Livestock and Fisheries (GoJ, 2011) focuses on the promotion of development, practical application and dissemination of advanced technologies. The *Bioeconomy Vision of Japan for 2030* (JABEX, 2016) also advocates for biotechnology-based innovative solutions in the livestock sector.

In Bangladesh, the National Biotechnology Policy (GoB, 2005) states that livestock is an opportunity area of application of biotechnology and categorizes the sector as an area of national interest for Bangladesh. The policy calls for the creation of centre(s) of excellence in selected areas, such as livestock biotechnology, to be housed in places where advanced research of international repute is being conducted. Sri Lanka's National Biotechnology Policy (GoSL, 2009) states that livestock is a key area in which biotechnology applications can be expected to make a substantial contribution and refers to developing the livestock sector through application of biotechnology.

At the regional level, the Animal Production and Health Commission for Asia and the Pacific, in collaboration with other units in FAO and international partners such as the World Organization for Animal Health (OIE) and WHO, continues to carry out a number of initiatives in the region, including providing technological support in biotechnology.

The Secretariat of the Pacific Community (SPC), through its Animal Health and Production Service, currently works to support the development of animal health and production capacity in the region and the strengthening of animal disease surveillance and emergency response preparedness. It has also entered into an agreement with FAO and OIE to collaborate in the implementation of the Global Framework for the Progressive Control of Transboundary Animal Diseases. The Department of Livestock Development in Thailand has collaborated with NARO Bio-oriented Research Advancement Institution, Japan, for avian influenza and swine influenza. Similarly, the Viet Nam Institute of Animal Science has collaboration with ILRI for advancing livestock research.

ILRI has been quite active in undertaking capacity building and collaborative projects on livestock biotechnology research in some Asian countries. For example, use of artificial insemination for swine reproduction was launched in the state of Nagaland (India) for the first time in October 2017, benefiting swine producers and enhancing the quality of swine. The facility was a result of joint efforts and collaboration between the Department of Animal Husbandry and Veterinary Services, ILRI and the National Research Centre on Pigs (ILRI, 2017). Similarly, ILRI has collaborated with National Institute of Animal Science in Viet Nam to conduct a capacity-building programme on research for safer pork products (ILRI Asia, 2017).

5.2.2 Categorization of countries in terms of enabling environment

The classification of countries in terms of their enabling environment for development and utilization of biotechnology applications in the livestock sector is shown in Table 5.5.

Most of the countries are in the ‘Very low’ or ‘Low’ category, which indicates that there is a need to assess the applications that are necessary for them vis-à-vis the capacity and enabling environment in the respective countries. Countries in the ‘Very low’ and ‘Low’ category can benefit from international collaboration and cooperation but that alone will not create a very favourable enabling environment as these would be limited to a few institutions. There is a clear need for the right policy mix, including incentives, target-oriented or mission-mode approaches, and sector-specific policies to promote biotechnology and enhance domestic capacity. In the case of countries in the ‘Medium’ category, the overall enabling environment for biotechnology is positive and hence sector-specific initiatives to enhance the enabling environment can make a difference.

Table 5.5. Categorization of countries in the Asia-Pacific region in terms of on enabling environment for developing and applying agricultural biotechnologies in the livestock sector

Category	Countries
Very low	Cook Islands, Kiribati, Democratic People’s Republic of Korea, Maldives, Marshal Islands, Micronesia (Federated States of), Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Timor-Leste, Tonga, Tuvalu, Vanuatu
Low	Afghanistan, Bhutan, Brunei Darussalam, Cambodia, Fiji, Lao People’s Democratic Republic, Mongolia, Myanmar, Kazakhstan, Singapore, Uzbekistan

Category	Countries
Medium	Bangladesh, Indonesia, Iran (Islamic Republic of), Nepal, Philippines, Singapore, Thailand
High	Malaysia, New Zealand, Viet Nam
Very high	Australia, China, India, Japan, Republic of Korea

5.3 Forestry

5.3.1 Policies, collaborations and initiatives

Table 5.6 (in annexure) gives an overview of laws, policies and collaborations in the forestry sector in the Asia-Pacific region.

Australia, in its policy document *Australian Biotechnology: A National Strategy* (Commonwealth of Australia, 2000), has categorically stated that one of its objectives is to promote responsible uptake of biotechnology for product and process development in industry, including forestry.

ACIAR has been encouraging research for the purpose of identifying and finding solutions to agricultural problems in developing countries, including of forestry sector. For example, ACIAR, along with CSIRO, has undertaken a project for maximizing productivity of eucalyptus and acacia plantations for growers in Indonesia and Viet Nam (ACIAR, 2017) and the Lao People's Democratic Republic (ACIAR, 2014). ACIAR also provides fellowships and scholarships for researchers from developing countries to pursue research in the forestry sector.

In Japan, there has been a significant focus on promoting advanced technologies in forestry sector because of the importance of wood for housing. The Basic Policy and Action Plan for Revitalization of Japan's Food, Agriculture, Forestry and Fisheries (GoJ, 2011) states that promotion of development, practical application and dissemination of advanced technologies is its strategy for enhancing competitiveness in light of the sixth industrialization of Japanese agriculture. The *Bioeconomy Vision of Japan for 2030* (JABEX, 2016) also advocates biotechnology-based innovative solutions in the forestry sector to generate new business.

Japan has implemented bilateral assistance in forestry in the form of transfer of technical cooperation and provision of grants and loans mainly through the Japan International Cooperation Agency (JICA). The Government of Japan has also given financial support to the International Tropical Timber Organization, headquartered in Yokohama, Japan (Forestry Agency, Japan, 2016).

The National Biotechnology Policy 2005 of Bangladesh states that forestry is prime area for application of biotechnology and categorizes forestry as an area of national interest for Bangladesh. Opportunity areas mentioned in the forestry sector include: forest resource management, agroforestry, *in situ* and *ex situ* conservation of forest resources and improvement of economic forest plants by application of modern biotechnology. The policy also calls for

creation of centre(s) of excellence in selected areas of national interest such as forestry, to be located in places where advanced research of international standard is being conducted. The policy also identified generation of transgenic agroforestry plants with improved traits as a priority area of biotechnology R&D in Bangladesh (GoB, 2005).

The Indian National Biotechnology Development Strategy 2015–2020 (GoI, 2015) proposes use of biotechnology for prospecting and product development of non-timber forest products such as gums, resins, tannins and mucilages. The Sri Lanka National Biotechnology Policy 2009 (GoSL, 2009) states that forestry is a key area in which biotechnology applications can make substantial contributions and emphasizes development of the forestry sector through application of biotechnology.

In those countries that have weaker enabling environments, international collaboration and networks can play a significant role in building and strengthening local capabilities in the field of forest research and management, and thereby create a favourable enabling environment.

For example, in Vanuatu numerous foreign agencies, such as AusAID, ACIAR, GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit), EU, IRD (Institut de recherche pour le développement, France), New Zealand, FAO, Coherence in Information for Agricultural Research for Development and the New York Botanical Garden, are active in funding forest research projects (Department of Forests, Government of Vanuatu, 2017). Australia has forged associations with most Pacific countries through CSIRO- and ACIAR-funded research in the forest sector, particularly in the field of tissue culture and PCR application. However, not all capacity-building programmes in forestry contribute to creating capacity in agricultural biotechnologies related to forestry.

Many of the Asian countries that fall in the 'Medium' enabling environment category have forest policies or forest legislations that do not specifically mention the role and application of biotechnology in forest management. Their primary focus is on application of science to increase their forest cover and to utilize forest products for economic and social benefits. These countries have forged international collaboration with research organizations to implement forest R&D projects in their territory, supported by international funding. For example, Viet Nam has collaboration with the Center for International Forestry Research, Sweden, UNDP, the International Union for Conservation of Nature (IUCN) and ACIAR for forestry-related R&D. Many donor agencies, such as ADB, AusAID, Danida, FAO, the Finnish International Development Agency (FINNIDA), GIZ, the International Fund for Agricultural Development (IFAD), JICA, UNDP, the United States Agency for International Development (USAID), the World Bank (WB) and World Wide Fund for Nature, support forest R&D projects in Nepal. Sri Lanka also has a Forest Sector Development Project co-financed by FAO, FINNIDA, UNDP and WB.

However, these collaborations or joint projects may have little to do with forestry biotechnology. In Malaysia, the thrust for promoting application of high-level biotechnologies has come from the private sector, led by Bioeconomy Corporation (formerly Malaysian

Biotechnology Corporation), which is responsible for executing the objectives of the National Biotechnology Policy of Malaysia and identifies value propositions in R&D and commerce.

There are also some intergovernmental arrangements among the countries, particularly involving many Pacific countries, which are active in promoting forest R&D, including medium-level biotechnologies. One such example is the University of the South Pacific (USP), a premier institution for higher learning in the Pacific region, which is owned by 12 Pacific countries. USP has established collaborations with Australia and other countries for acquisition of funding and expertise in the field of forest R&D. Similarly, various domestic forest research institutions of the countries of the Pacific region collaborate with the United States-based Center for Tropical Forest Science to carry out forest research and management.

At the regional level, the Asia Pacific Association of Forestry Research Institutions (APAFRI) and the Asia-Pacific chapter of the International Union of Forest Research Organizations (IUFRO) aim to enhance research and technology development capabilities in support of conservation and management of forest resources in the Asia-Pacific region. Many forestry research institutions from the region are members.

Similarly, the Asia-Pacific Forest Genetic Resources Programme (http://www.apforgen.org/) works to enhance conservation and sustainable use of tree species and their genetic diversity in Asia and the Pacific. It collaborates with FAO to implement the Global Plan of Action for Forest Genetic Resources in the Asia-Pacific region, and advocates for biotechnology innovation for sustainable use of forest genetic resources and for adding value through regional cooperation (Zheng, 2017).

5.3.2 Categorization of countries in terms of enabling environment

The classification of countries in terms of their enabling environment for development and utilization of biotechnology applications in the forestry sector is shown in Table 5.7.

Table 5.7. Categorization of countries in the Asia-Pacific region in terms of enabling environment for developing and applying agricultural biotechnologies in the forestry sector

Category	Countries
Very low	Nauru, Tonga, Tuvalu
Low	Afghanistan, Bhutan, Brunei Darussalam, Cook Islands, Kazakhstan, Kiribati, Maldives, Marshall Islands, Micronesia (Federated States of), Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Timor-Leste, Uzbekistan, Vanuatu
Medium	Bangladesh, Cambodia, Fiji, Iran (Islamic Republic of), Lao People’s Democratic Republic, Mongolia, Myanmar, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Viet Nam
High	China, India, Indonesia, Republic of Korea, Malaysia, New Zealand, Thailand
Very high	Australia, Japan

Only Nauru, Tonga and Tuvalu have no policy at all for biotechnology. These countries fall into the category of 'Very low' enabling environment. Many more have no specific policy for forestry biotechnology, and fall into the 'Low' category.

Countries in the 'Medium' category have forest policies or Acts that give importance to applying biotechnology in forestry. These countries also benefit from collaboration/cooperation in forestry.

In the 'High' enabling environment category, countries such as China, India, Indonesia, Malaysia, New Zealand, the Republic of Korea and Thailand have forest policies or Acts that refer to forest research and development, including R&D of high-level biotechnologies. These countries have international collaborations in the forestry sector and also have private-sector involvement in forestry R&D.

Only Australia and Japan belong to the 'Very high' enabling environment category. Their policy framework is conducive to the development and application of forest biotechnologies, and the private sector is active in deploying biotechnology in forestry.

5.4 Fisheries/aquaculture

5.4.1 Policies and collaborations

The enabling environment for the fisheries/aquaculture sector in the Asia-Pacific region includes the availability and inclusivity of biotechnology-promoting policies, laws, rules and regulations and collaborations/cooperation with external agencies or among institutions within and outside a country. Applying biotechnology in this sector has had a positive impact in terms of diversification, investment and international technology exchange (FAO, 2010).

Most countries in the region have specific policies, laws and regulations in the fisheries sector, including on biotechnology (Table 5.8, in annexure). Biosafety regulations cover application of biotechnology in the sector. Similarly, laws on food safety and standards are applicable to products of fisheries and aquaculture.

However, even countries that have ambitious policies that promote biotechnology do not give much importance to fisheries biotechnology. For example, Thailand's biotechnology policy emphasizes sectors such as health and agriculture, but not fisheries. Similarly, Cambodia's Strategic Planning Framework 2010–2019 for Fisheries does not identify application of biotechnology as part of the strategy (Fisheries Administration, Cambodia, 2010).

China has given importance to applying genomics technologies in the fisheries sector and has sequenced the entire genome of several fish species (Xiang, 2015). In Indonesia, although fisheries science and technology received 16.5 percent of the budget of the Ministry of Marine Affairs and Fisheries, product competitiveness and biotechnology received less than 2 percent (CEA, 2016). This reflects the fact that there is no marine biotechnology strategy in Indonesia.

In Australia, marine biotechnology has been accorded priority by the federal government and by state governments. Consequently, biotechnology has been considered one of the crucial

aspects of fisheries and aquaculture. The private sector is also active in this domain. In terms of R&D capacity, various universities, CSIRO and SARDI are the major players.

New Zealand's Aquaculture Strategy of 2012 supports innovation and has set an ambitious target of turnover of NZ$1 billion per annum for aquaculture. Similarly, the Five-Year Action Plan for the Aquaculture Industry identifies increasing value through R&D as a core objective.

In the Republic of Korea, marine biotechnology was included in the 2002 BioStrategy Guidelines while Blue-Bio 2016 has a specific strategic plan for marine biotechnology. A Master Plan for Marine Biotechnology has been developed, based on the Biotechnology Promotion Act of 1983, Biotech 2000, Bio-Vision 2016 and Blue-Bio 2016. The Marine Bioresources Management Law was introduced in 2012.

Viet Nam has no national strategy for marine biotechnology. However, the Viet Nam Academy of Science and Technology is engaged in supporting R&D in this sector.

There are many collaboration/cooperation programmes in the fisheries/aquaculture sector (Table 5.9). These programmes range from regional to continental in nature. In the case of island nations, few have good capacity or policies for effective utilization of their resources and biodiversity, and these collaborations are the major factor creating a positive enabling environment.

Table 5.9. Enabling environment for developing and applying agricultural biotechnologies in the fisheries/aquaculture sector in the Asia-Pacific region

Country	**International/regional collaborations**
Asia	
Afghanistan	USAID supported aquaculture of fin fishes in the Kabul River at Jalalabad and in Helmand river in southern Afghanistan
Brunei Darussalam	Southeast Asian Regional Center for Graduate Study and Research
Cambodia	Culture-based fisheries development in Cambodia funded by ACIAR
China	FAO
	Commonwealth Scientific and Industrial Research Organization
India	Indo-Norwegian platform on fish and shellfish vaccine development
	Central Institute of Brackish water Aquaculture and Central Institute of Freshwater Aquaculture are working with Nofima (the Norwegian Institute of Food, Fisheries and Aquaculture Research) to sequence the transcriptome and genome of the tiger shrimp.
Indonesia	ASEAN
Japan	Regional Centre for Biotechnology (India) and National Institute of Advanced Industrial Science & Technology (Japan) Agreement for Joint Research Training and Capacity Building in Bio-imaging and Biotechnology
Republic of Korea	The Republic of Korea, along with UN's FAO, is planning to help develop fish farms in the Democratic People's Republic of Korea

Country	International/regional collaborations
Lao People's Democratic Republic	Culture-based fisheries development in Laos funded by ACIAR
Malaysia	ASEAN
Maldives	Indian Ocean Rim Association
Mongolia	Food and Agriculture Organization (FAO) called 'Developing aquaculture for improved fish supply in Mongolia'
Singapore	Asia-Pacific Economic Cooperation
Sri Lanka	National Aquaculture Research Development Agency
Thailand	Network of Aquaculture Centres in Asia and the Pacific Scientific collaboration between Animal, Plant and Fisheries Quarantine And Inspection Agency, Korea BIOTEC has collaboration with the following institutions along with major Thailand research institutions. Columbia Genome Center, Columbia University, New York, USA. National Research Institute of Aquaculture, Fisheries Research Agency, Japan. Department of Comparative Physiology, Uppsala University, Uppsala, Sweden
Pacific	
Australia	Pacific Ocean Community The Australian Centre for International Agricultural Research (ACIAR)
Cook Islands	Pacific Ocean Community ACIAR
Fiji	Pacific Ocean Community Use of molecular markers to study marine diversity is being carried out in University of South Pacific through collaboration with University of Queensland.
Kiribati	Pacific Ocean Community ACIAR
Marshall Islands	Pacific Ocean Community ACIAR
Micronesia (Federated States of)	Pacific Ocean Community ACIAR Western SARE (Sustainable Agriculture Research and Education) issues grants and education towards sustainable development of agriculture. It has several projects in Federated States of Micronesia.
Nauru	Pacific Ocean Community ACIAR

Country	International/regional collaborations
New Zealand	Pacific Ocean Community
Niue	Pacific Ocean Community ACIAR
Palau	Pacific Ocean Community
Papua New Guinea	Pacific Ocean Community
Samoa	Pacific Ocean Community ACIAR
Solomon Islands	Pacific Ocean Community
Tonga	Pacific Ocean Community
Tuvalu	Pacific Ocean Community
Vanuatu	Pacific Ocean Community ACIAR collaborates with home-grown organizations in Vanuatu, developing sustainable strategies to enhance production of sustenance farming and cash crops as well as large-scale developments in the agriculture, fisheries and forestry industries.

To conclude, the enabling environment is by and large encouraging, although a lot needs to be done to make it more conducive.

5.4.2 Categorization of countries in terms of enabling environment

The classification of countries in terms of their enabling environment for development and utilization of biotechnology applications in the fisheries/aquaculture sector is shown in Table 5.10.

The enabling environment ranges from very positive to lack of any policy on biotechnology in fisheries. The word ‘biotechnology’ is often missing in policy documents, although that does not mean that there are no biotechnology-oriented programmes in this sector. Lots of activities are happening through collaboration and cooperation.

The categorization is mostly based on the two parameters: national milieu and collaborations. The countries in the ‘Very low’ category have hardly any enabling environment except a few collaborations. Countries in the ‘Low’ category have a weak national-level milieu, have no policy or strategy and rely on international collaboration to create a positive enabling environment. Countries in the ‘Medium’ category have supportive policies and more extensive collaborations and cooperation programmes. Countries in the ‘High’ category have a positive enabling environment and are active in international collaborations. Countries in the ‘Very high’ category have policies that actively promote biotechnology in the fisheries/aquaculture sector and are actively engaged in collaborations.

Table 5.10. Categorization of countries in the Asia-Pacific region in terms of enabling environment for developing and applying agricultural biotechnologies in the fisheries/aquaculture sector

Category	Countries
Very low	Democratic People's Republic of Korea, Lao People's Democratic Republic, Myanmar Timor-Leste
Low	Afghanistan, Bhutan, Brunei Darussalam, Cook Islands, Cambodia, Fiji, Kazakhstan, Kiribati, Maldives, Mongolia, Marshal Islands, Micronesia (Federated States of), Nauru, Nepal, New Guinea, Niue, Palau, Papua, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu, Uzbekistan
Medium	Bangladesh, Indonesia, Iran (Islamic Republic of), Malaysia, Pakistan, Philippines, Singapore, Sri Lanka, Thailand
High	New Zealand, Viet Nam
Very high	Australia, China, India, Japan, Republic of Korea

5.5 Synthesis

The overall enabling environment for developing and applying agricultural biotechnologies in the Asia-Pacific region is positive and there is good scope to improve it. By and large, policy measures and regulations are positive. While some countries have an excellent enabling environment, in most countries it could be improved through a focused approach to identify what factors constrain the enabling environment to foster growth of biotechnology. In many LDCs and island states, the enabling environment for biotechnologies will improve only if policies in agriculture, forestry, livestock, and fisheries and aquaculture include programmes to promote biotechnologies. Collaborations can make a positive impact on the overall milieu for biotechnology but they themselves cannot sustain the enabling environment. Biosafety regulations have helped to create an enabling environment for biotechnologies but may need revision in light of technological developments. Providing incentives to innovate and giving importance to IP protection can play an important role in making the enabling environment more conducive for innovation and investment.

5.6 Main gaps identified

1) Lack of policy measures to promote biotechnology in different sectors
2) Lack of sector-specific strategies.
3) Insufficient human resources and other core capacities
4) Reliance on collaborations to compensate for lack of internal capacities.

6 Conclusions

Key points from the survey

- Agricultural biotechnologies in the region are performing well and can take a leap forward.
- Low-, medium- and high-technology applications have been widely adopted in the region and new technologies such as genome editing are gaining attention.
- The divergence among the countries and within the subregions in application, capacity and enabling environments is growing.
- The new dynamism towards application of biotechnologies in countries like Myanmar, Uzbekistan and Viet Nam is a positive development.
- The state plays a key role in promoting agricultural biotechnologies in many countries, with the public sector leading in agricultural R&D. The private sector is a key player in some countries where market forces are very active.
- Capacity building and collaboration are necessary for many LDCs and island states so that they are able to harness agricultural biotechnologies.
- The regulatory regime is functioning well, by and large, but will need to evolve to meet the emerging challenges in the agricultural biotechnology sector, such as new technologies.
- Numbers of patents and publications relating to biotechnology indicate the technological strength in the region, although in some countries most publications arise from collaborative programmes.
- Technology needs assessment is necessary to enable countries to realize the potential of biotechnology in agriculture.
- FAO and other agencies can make a positive difference in many ways, including initiatives in capacity building.

Crops

- A wide range of technologies are in use, but many countries have adopted only low- or medium-level technologies such as tissue culture and biopesticides.
- GM crops are a successful application; eight countries have permitted commercial cultivation, with *Bt* cotton being the most-widely grown GM crop.
- GM cultivars in the pipeline include crops such as rice, novel traits suited to meet climate change and stacking of genes.
- Genome editing is getting established and other high-level technologies have been put into practice by at least six countries.
- Capacity in crop biotechnology is increasing but many countries lag behind.
- The enabling environment in crop biotechnology is by and large conducive and positive and there is ample scope for improving it.
- Capacity building is necessary for most of the LDCs.
- This variance between countries in applications, capacity and enabling environment is increasing and has to be addressed.

Livestock

- Infrastructure and capacity in R&D enables some countries to excel in livestock biotechnology but many countries lag behind considerably.
- Vaccines and diagnostic kits are two applications that are widely needed in the region but capacity to produce them or to conduct R&D is limited to about eight countries.
- Capacity building is a must for countries with a vibrant livestock economy but are unable to benefit from agricultural biotechnologies on account of lack of capacity, lack of funding and institutions. FAO and other similar organizations can play a key role in this.

Forestry

- Forestry biotechnology applications have been adopted in only about ten countries.
- Lack of capacity is a major issue for countries in the region.
- International collaborations can make a difference in capacity building.
- Technologies such as clonal propagation have excellent scope but are not fully utilized.
- The full potential in forestry biotechnology in the region can be realized if capacities are built up and a more positive enabling environment is created.

Fisheries/aquaculture

- A range of applications have been adopted, with many countries using low- and medium-level technologies only. Genomics-based applications are gaining importance.
- Institutional capacity is excellent in some countries but in many others factors such as lack of funding and lack of human resources constrain full utilization of technology and resources.
- International collaborations and regional-level initiatives are important and should be expanded. However, they alone cannot build sufficient capacity or create a positive enabling environment that can be sustainable in the long run.

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Annexure

Table 1.1. FAO indicators for the Asia-Pacific region, 2014

Country	***Employment indicator: share of agriculture in total employment (%)***	***Economic indicator: share of agriculture in total GDP (%)***	***Economic indicator: avg annual percentage change in net agri-production (%)***	***Economic indicator: gross fixed capital formation in agriculture as a share of agricultural GDP (%)***	***Environmental indicator: emissions from crops and livestock production as a share of total emission (%)***	***Environmental indicator: emissions from land use as a share of total emissions (%)***
Asia						
Afghanistan	N/A	N/A	N/A	N/A	N/A	N/A
Bangladesh	N/A	14.782997	23179874.65	0.08	38.9058	17.4145
Bhutan	56.3	16.280224	143822.5058	0.13	27.0035	1.9729
Brunei Darussalam	N/A	1.01	45437.48	0.17	0.79	11.53
Cambodia	48.7	26.58	4231807.98	0.1	38.69	45.71
China	31.4	9.05	169014797.9	0.19	6.47	0.017
India	49.7	15.41	258070806.2	0.22	22.99	0.438
Indonesia	34.8	13.5	65995414.61	0.12	10.94	48.23
Iran (Islamic Republic of)	18.3	8.637349	24851841.82	0.15	6.8394	0.0184
Japan	3.7	1.186174	17515530.27	0.19	1.6013	0.628
Kazakhstan	22.2	4.778831	7499976.204	0.14	7.3136	0.3549
Democratic People's Republic of Korea	N/A	21.64	3782011.91	N/A	4.5	13.43
Lao People's Democratic Republic	N/A	22.38	2388658.49	0.11	39.31	33.88
Malaysia	12.7	8.45	15258738.08	0.22	5.12	15.12
Maldives	14.6	2.76	7397.11	0.15	0.11	0
Mongolia	N/A	13.672882	902333.801	0.13	14.3961	83.134

Country	*Employment indicator: share of agriculture in total employment (%)*	*Economic indicator: share of agricultur e in total GDP (%)*	*Economic indicator: avg annual percentage change in net agri-production (%)*	*Economic indicator: gross fixed capital formation in agriculture as a share of agricultural GDP (%)*	*Environmental indicator: emissions from crops and livestock production as a share of total emission (%)*	*Environmental indicator: emissions from land use as a share of total emissions (%)*
Myanmar	N/A	N/A	N/A	N/A	N/A	N/A
Nepal	66.5	29.407018	5859912.294	0.06	56.2769	17.1325
Pakistan	43.7	24.01	39350126.23	0.08	35.38	5.8
Philippines	31	10.26	21084013.73	0.13	28.4501	8.4651
Singapore	N/A	0.035	30078.15	0.2	0.167	0
Sri Lanka	31.5	8.0618	2875626.961	0.11	20.28	12.2539
Thailand	41.9	9.14	33438422.87	0.17	18.81	5
Timor-Leste	N/A	5.123348	24851841.82	0.03	38.2594	21.9006
Uzbekistan	N/A	17.646849	11081994.69	0.08	13.9738	0.1524
Viet Nam	46.8	16.99	30600757.36	0.15	21.64	4.82
Pacific						
Australia	2.6	2.300117	25838449.5	0.47	12.4413	27.0017
Cook Islands		8.369135	2327.574475	0.11	43.841	0
Fiji		9.220812	200075.1496	0.12	21.622	44.0514
Kiribati		23.751739	13886.04195	0.12	12.1772	0
Marshall Islands		16.078739	3096.044	0.22	0	0
Micronesia (Federated States of)		26.078052	10251.42741	0.13	11.5845	85.6795
Nauru		3.068312	690.074508	0.13	23.4386	0
New Zealand	6.4	5.91089	11441801.27	0.22	45.8512	7.3688
Niue		N/A	1439.455311	N/A	1.5753	98.2041
Palau		3.351414	N/A	0.18	0	0

Country	***Employment indicator: share of agriculture in total employment (%)***	***Economic indicator: share of agriculture in total GDP (%)***	***Economic indicator: avg annual percentage change in net agri-production (%)***	***Economic indicator: gross fixed capital formation in agriculture as a share of agricultural GDP (%)***	***Environmental indicator: emissions from crops and livestock production as a share of total emission (%)***	***Environmental indicator: emissions from land use as a share of total emissions (%)***
Papua New Guinea		19.37144	1964217.047	0.15	7.661	81.5304
Samoa		9.393796	52179.21763	0.1	40.2655	0
Solomon Islands		28.076009	120829.287	0.08	2.5964	72.1507
Tonga		17.620049	32251.11245	0.13	52.051	0
Tuvalu		25.16065	917.916979	0.15	67.2638	0
Vanuatu		25.068068	73613.80668	0.16	76.2314	0

Table 3.1. Biofertilizer use in the crop sector in the Asia-Pacific region

Country	Biofertilizer	Crop	Other details
Asia			
Afghanistan	N/A	N/A	N/A
Bangladesh	*Rhizobium,Klebsiella pneumoniae,* and *Pantoea agglomeran; Trichoderma harzianum; Azospirillum; Bradyrhizobium*	Lentil, peas, oil crops, soybean; sugar cane, mung bean	Nitrogen fixation bacteria, Isolated from sugar cane
Bhutan	Organic farming		
Brunei Darussalam	N/A	N/A	N/A
Cambodia	N/A	N/A	N/A
China	Azolla; algal biofertilizer; biological nitrogen fertilizer, biological phosphate fertilizer and compound bacterial fertilizer, *Rhizobium*,	Rice, sweet corn, tobacco, cassava, wheat, maize, soybean,	
India	Actinobacterial consortium" containing three *Streptomyces* spp; Azotobacters; *Rhizobium; Azospirillum*, Blue Green Algae	Rice, wheat, millets, other cereals, cotton, vegetables, sunflower, mustard, pulses, oilseeds, fodders; maize, sorghum, sugar cane	Increase yield 20–40% for rice, cotton and others
Indonesia	*Rhizobium* sp.; *Bradyrhizobium* sp.; *Azosprillum* sp.; Blue-green algae; azolla-anabena; *Frankia*; mycorrhiza helper bacteria-arbuscular mycorrhizal fungi; PGPR	Legumes; soybean, maize, rice, sugar cane, tree crops, potato, etc.	Nitrogen fixation, yield increase
Iran (Islamic Republic of)	Rhizosphere, cyanobacteria, K- nano fertilizer and N-biofertilizer	Rice, corn, red bean	to increase yield
Japan	Mycorrhizal fungi/nitrogen fertilizers; *Bradyrhizobium*	Leguminous plant; soybean	Increase yield, nitrogen fixation bacteria
Kazakhstan	*Pseudomona, Rhizobium, Azotobacter*	Leguminous crop	Nitrogen fixation
Democratic People's Republic of Korea	N/A	N/A	N/A
Republic of Korea	EXTN-1; plant growth promotion rhizobacteria (PGPR), phosphate solubilization microbes; nitrogen fixing microbes.	Tomato, lettuce	Promotes growth of lettuce, reduces risk of tomato wilt disease
Lao People's Democratic Republic	N/A	N/A	N/A

Country	Biofertilizer	Crop	Other details
Malaysia	None that employ biotechnology only naturally occurring organisms are used	N/A	N/A
Maldives	N/A	N/A	N/A
Mongolia	*Azospirillum*, *Azotobacter* and *Azoarcu*	All cereal crops	Nitrogen fixation bacteria
Myanmar	*Rhizobium*	Wheat; groundnut; sesame	Nitrogen fixation and improve crop production
Nepal	*Rhizobium,* endo-mycorrhiza	Pulse crops	Nitrogen fixation bacteria
Pakistan	BiPower (Produced by NIBGE)	N/A	N/A
Philippines	None that employ biotechnology only naturally occurring organisms are used		
Singapore	Yes	N/A	N/A
Sri Lanka	Many organic and 100% natural biofertilizers are being commercialised in Sri Lanka, but none of the commercialised biofertilizers make use of biotechnology in their process of production	N/A	N/A
Thailand	N/A	N/A	N/A
Timor-Leste	Nitrogen and phosphorus biofertilizer	Rice	to increase yield
Uzbekistan	*Azotobacter*	wheat	Nitrogen fixation.
Viet Nam	*Burkholderia vietnamiensis* (TVV75); *P. aeruginosa* 23(1–1)	Rice; watermelon;	Pathogen inhibition; siderophores production; gummy steam blight causes by *Didymella bryoniae* and vascular wilt caused by *Fusarium oxysporum*; reduced sheath blight disease caused by *Rhizoctonia solani*; bacterial leaf blight caused by *Xanthomonas oryzae*; fruit rot caused by *Phytopthora capsici*

Country	Biofertilizer	Crop	Other details
Pacific			
Australia	Yes	Clover, aloe vera, canola, pea, lentil, faba bean, chickpea	Reactive phosphate rock based, magnesium deficiency, potassium deficiency, soil and plant nutrition.
Cook Islands	N/A	N/A	N/A
Fiji	N/A	N/A	N/A
Kiribati	N/A	N/A	N/A
Marshall Islands	N/A	N/A	N/A
Micronesia (Federated States of)	N/A	N/A	N/A
Nauru	N/A	N/A	N/A
Niue	N/A	N/A	N/A
New Zealand	None that employ biotechnology only naturally occurring organisms are used	N/A	N/A
Palau	N/A	N/A	N/A
Papua New Guinea	N/A	N/A	N/A
Samoa	N/A	N/A	N/A
Solomon Islands	N/A	N/A	N/A
Tonga	N/A	N/A	N/A
Tuvalu	N/A	N/A	N/A
Vanuatu	N/A	N/A	N/A

Table 3.2. Use of biopesticides in the crop sector in the Asia-Pacific region

Country	Biopesticide	Crop	Purpose and other details
Asia			
Afghanistan	Trichoderma; Madex Plus; Dipel 150 Dust	Vegetables; apple; cabbage	Control colding moth in apple; Fight fungal diseases
Bangladesh	N/a		
Bhutan	Butachlor and Metribuzin; neem oil	All crops	Weed control; pest control
Brunei Darussalam	N/A	N/A	N/A
Cambodia	Bacillus thuringienis; Trichoderma	Cabbage; all crops	Suits all types of soil
China	Metarhiziumanisopliae CQMa421; *Coniothyrium minitans* CGMCC8325; *Bacillus methylotro-phicus* LW-6; sophora alopecuroids alkaloid; D-limonene; terpinen-4-ol;	Cotton, rice plant hopper, rice leaf roller; *Sclerotinia* rot of colza; Citrus canker, *Xanthomonas, oryzicola*, cucumber angular leaf spot; cabbage aphid; powdery mildew of strawberry, early blight of tomato	Disease control; high efficiency; 12 million ha
India	Multiple strains	Basmati rice, cotton, mustard, chickpea and groundnut	Insect resistance
Indonesia	Corn1; Soyabean plus	Corn; soybean	Aluminium tolerance
Iran (Islamic Republic of)	Microbial biopesticides	Crops	
Japan	N/A		
Kazakhstan	*Bacillus thuringiensi; Verticillum lecanii; Cydia pomonella*	Leguminous crop	Protect against bacteria, insect, fungal and viral diseases
Democratic People's Republic of Korea	*N/A*	N/A	N/A
Republic of Korea	*Bacillus thringiensis; Beauveria bassiana and Paecilomyces fumosoroseus*	Chinese cabbage; all crops	Targets mite and white fly
Lao People's Democratic Republic	N/A		
Malaysia	None that employ biotechnology only naturally occurring organisms are used		

Country	Biopesticide	Crop	Purpose and other details
Maldives	N/A	N/A	N/A
Mongolia	No		
Myanmar	N/A	N/A	N/A
Nepal	*Bacillus thuriengensis*- 8 strains at NAST	Crucifer plants	Insect resistance
Pakistan	*Trichogramma* (egg parasitoid) Fungi (*Trichoderma* and *Gliocladium*) Baculoviruses; Nuclear polyhedrosis virus (NPV) of *Heliothis armigera* NPV of tobacco caterpillar (*Spodoptera litura*) Granulosis virus (GV) *Bacillus thuringiensis* Neem (*Melia azaderechta*) (Biotechnology is not involved to a large extent)	Sugar cane, pulses, cotton, oil seeds	Pest control; wilt disease treatment; insect control
Philippines	None that employ biotechnology only naturally occurring organisms are used		
Singapore	Yes	N/A	N/A
Sri Lanka	Biotechnology-based biopesticides are not yet commercialised in Sri Lanka	N/A	Currently, plant powders, non-volatile and volatile oils, and plant crude extracts are commercially available for management of insect pests and nematodes. Further, several bacterial and fungal biopesticides have shown promising results for the efficient management of plant pathogens in Sri Lanka.
Thailand	N/A	N/A	N/A
Timor-Leste	Yes		
Uzbekistan	N/A	N/A	N/A
Viet Nam	N/A	N/A	N/A

Country	Biopesticide	Crop	Purpose and other details
Pacific			
Australia	Yes	The biopesticides are disease-specific and hence can be used on a number of crops	Targets: Crown gall disease, blights (by *Botrytis* spp.), dead-arm of grapevine, *Lepidoptera* larvae, Grey-backed cane grub (scarabs), Locusts and grasshoppers, Redheaded pasture cockchafer, *Helicoverpa* spp.
Cook Islands	N/A	N/A	N/A
Fiji	N/A	N/A	N/A
Kiribati	N/A	N/A	N/A
Marshall Islands	N/A	N/A	N/A
Micronesia (Federated States of)	N/A	N/A	N/A
Nauru	N/A	N/A	N/A
Niue	N/A	N/A	N/A
New Zealand	The exact name of the microorganism they are using is not disclosed online as they are still in the research phase.	Kiwi fruit	*Pseudomonas syringae* pv. *actinidiae* resisitance
Palau	N/A	N/A	N/A
Papua New Guinea	N/A	N/A	N/A
Samoa	N/A	N/A	N/A
Solomon Islands	N/A	N/A	N/A
Tonga	N/A	N/A	N/A
Tuvalu	N/A	N/A	N/A
Vanuatu	N/A	N/A	N/A

Table 3.3. Use of marker-assisted selection in the crop sector in the Asia-Pacific region

Country	Marker	Crop	Purpose
Asia			
Afghanistan			
Bangladesh	SSR	Rice	Rice (diversity analysis of 81 AUS and 26 BRRI developed variety)
Bhutan	Stress tolerance trait	Rice and maize	Stress tolerance
Brunei Darussalam	SSR Marker/ST	Rice	High yield; insect resistance
Cambodia		Rice	Development of markers through molecular breeding.
China	Multi-resistant (CC149); Biotic and abiotic stress resistance; SNPs/indels and candidate genes;	Cotton, wheat, soybean, maize, rice	Increase yield and quality; 4.746 million ha (cotton)
India	Biotic and abiotic stress resistance; SNPs/indels and candidate genes; resistance gene analogs (RGAs) identification	Rice, maize, wheat, bajra, jawar, sorghum, mung bean and rice bean	Fe and Zn concentration; MYMV resistance
Indonesia	TS4	Rice	Broad spectrum resistant Xoo strains
Iran (Islamic Republic of)	RAPD, ALPF, reverse hybrid breeding, haploid breeding, mapping QTLS	Rice, corn, canola, maize	Reverse hybrid breeding, haploid breeding, mapping QTLS
Japan	Biotic and abiotic stress tolerance	Rice	N/A
Kazakhstan	SNP	Wheat	Study genetic diversity in bread wheat
Democratic People's Republic of Korea	N/A	N/A	N/a
Republic of Korea	SSR; markers resistance to viral diseases	Tomatoes; Korean Chilli Pepper	Pep MoV
Lao People's Democratic Republic	N/A	N/A	N/A
Malaysia	SSR markers	Rice	Resistance to brown plant hopper
Maldives	N/A	N/A	N/A
Mongolia	No	N/A	N/A

Country	Marker	Crop	Purpose
Myanmar	SSR or SNP	Rice	Adequate genotyping and phenotyping
Nepal	No	N/A	N/A
Pakistan	SSR markers	Wheat, cotton, pulses, potato	Insect resistance
Philippines	DNA fingerprinting for sugar cane. SSRs and SNPs for rice.	Sugar cane and rice	To eliminate susceptibility of sugar cane to downy mildew and smut. Increased root length and biomass in rice
Singapore	SSR markers	N/A	N/A
Sri Lanka	QTL mapping of growth parameters, leaf colour measurements	Rice	Phosphorus deficiency tolerance, salinity tolerance
Thailand	N/A	Cassava; sugar cane	Aroma maker; enhance sweetness
Timor-Leste	No	N/A	N/A
Uzbekistan	N/A	N/A	N/A
Viet Nam	SSR markers	Rice Q5DB variety	Saline tolerance
Pacific			
Australia	CRISPR	Wheat	To study control of development, genome integrity, and epigenetic inheritance
Cook Islands	N/A	N/A	N/A
Fiji	N/A	N/A	N/A
Kiribati	N/A	N/A	N/A
Marshall Islands	N/A	N/A	N/A
Micronesia (Federated States of)	N/A	N/A	N/A
Nauru	N/A	N/A	N/A
New Zealand	For red fleshed apple the red-flesh allele is detected as an additional DNA band on an agarose gel and SNPs for various other traits.	Apple	For pest and disease resistance in the New Zealand apple breeding and also for breeding of red fleshed apples
Niue	N/A	N/A	N/A
Palau	N/A	N/A	N/A

Country	Marker	Crop	Purpose
Papua New Guinea	N/A	N/A	N/A
Samoa	N/A	N/A	N/A
Solomon Islands	N/A	N/A	N/A
Tonga	N/A	N/A	N/A
Tuvalu	N/A	N/A	N/A
Vanuatu	N/A	N/A	N/A

Table 3.7. Status of GM crop commercialization and testing research in the Asia-Pacific region

Country	Commercial cultivation	Approved GM events	Field trial	Experimental
Australia	Canola, cotton	Argentine canola (21), alfalfa (3), carnation (12), cotton (24), maize (27), potato (10), rice (1), rose (1), soybean (17), sugar beet (2) and wheat (1)	Bananas, barley, canola, cotton, grapevines, Indian mustard, maize, papaya, perennial ryegrass, pineapple, safflower, sugar cane, tall fescue, torenia, wheat, and white clover	Cowpeas (IR), bananas (FC), barley (AST, MU, FC, Y), canola (FC, Y), cotton (FY), brassica (FC), safflower (MO), sugar cane (FC, SM, HT), wheat (Y, AST, MU, FC), tobacco (MO)
Bangladesh	Aubergine	Aubergine	Aubergine, cotton, potato, rice	Aubergine (IR), jute (BR, FR, IR), kenaf, lentil, mesta, mung bean, oil palm (IP), papaya (VR), rice (AST), tobacco, potato (FR)
China	Cotton, papaya	Argentine canola (12), cotton (10), maize (17), papaya (1), petunia (1), poplar (2), rice (2), soybean (10), sugar beet (1), sweet pepper (1), tomato (3)	Chili, Chinese cabbage, cotton, groundnut, maize, melon, potato, rice, soybean, sweet pepper, tobacco, tomato	Barley, cotton (FQ, VR), hot pepper, maize (AST), papaya (AFR), potato (IR), rapeseed (FR), rice (AST, CQ, IR), sorghum (AST), soybean (IR), sugar beet (AST), wheat (AST, BR, IR, VR)
India	Cotton	Cotton	Cotton, aubergine, mustard	Banana (AFR), black gram (FR, HT, IR, VR), bell pepper (MR), brassica (AST, FR, IR), cabbage (IR), cauliflower (FR, IR, PC),chickpea (FR, IR), chilli (FR, IR), cassava (NQ), citrus (VR), coffee (FR), cotton (HT, IR), cucurbits (VR), cucumber (VR), aubergine (AST, FR, IR), ground nut (VR), maize (IR), melon (VR), musk melon (EV), mustard (AST, HT, NQ, PC), mustard green (AST), papaya (VR), potato (AST, IR, MT, NQ, VR), pigeon pea (FR, IR), rice (AST, BR, EV, FR, HT, IR), tobacco (AST, FR, IR, VR), tomato (AFR, FR, IR, VR), wheat (AST, IR)

Country	Commercial cultivation	Approved GM events	Field trial	Experimental
Indonesia	_	Maize, soybean, sugar cane	Maize (9), soybean (6) and sugar cane (3)	Cabbage (FR), cacao (IR, VR), cassava (SC), chilli (VR), citrus (VR), coffee (FR), maize (IR), oil palm (IR, MO), papaya (AFR), peanut (VR), potato (BR, IR, VR),rice (AST, FR, IR, VR), shallot, soybean (IR, MO, NQ), sugar cane (AST, IR, VR), sweet potato (VR)
Iran (Islamic Republic of)	_	Rice	Rice	Cotton (IR), maize (IR, FR), rice (AST, FR), potato (IR), sugar beet (IR), wheat (FR)
Japan	_	Alfalfa (5), canola (20), cotton (37), maize (198), potato (8), rice (1), soybean (29), sugar beet (3)		
Republic of Korea	_	Canola (14), cotton (29), maize (75), potato (9), soybean (25), sugar beet (1)		
Malaysia	_	Maize (14), soybean (7)	Argentine canola (1), carnation (8), cotton (4), maize (14), soybean (7) papaya	Banana (AFR), chilli (VR), maize (HT, IR), Aubergine (IR), melon (FR), musk melon, oil palm (MO, PI, Y), orchid (AFR), papaya (AFR, VR), pepper (VR), rice (FR), rubber (Y), teak (WQ), tobacco, winged bean (FR)
Nepal	_	_	_	
New Zealand	_	_	Alfalfa (3), Argentine canola (14), cotton (21), maize (27), potato (11), rice (1), soybean (17), sugar beet (2), wheat (1), onion	Onion (HT), potato (BR), sugar beet (HT), brassica (IR)
Pakistan	Cotton	Maize	Wheat, cotton, maize	Brassica (PC), chickpea (AST, IR), chilli (VR), cotton (IR, VR), cucurbits (VR), potato (VR), rice (AST, BR, FR, IR), sugar cane (IR), tobacco (AST, IR), tomato (IR, PC, VR)

Country	Commercial cultivation	Approved GM events	Field trial	Experimental
Philippines	Maize	Alfalfa (2), canola (2), cotton (8), maize (52), potato (8), soybean (14), rice (1), sugar beet (1)	Cotton, aubergine, rice, papaya	Abaca (VR), banana (VR), coconut (MO), aubergine (IR), mango (AFR), papaya (AFR, VR), rice (AST, BR, FR, NQ, VR), squash (VR), sweet potato (IR, VR), tobacco (GC), tomato (AFR, VR), yellow ginger (MO)
Thailand	_	Maize (12), soybean (2)	Cotton, rice, tomato, pepper	Cassava, cucurbits (VR), mango, orchids (VR), papaya (IR, VR), pineapple, rice (BR, FR, VR), tobacco, tomato (BR), yardlong bean (VR)
Viet Nam	Maize	Maize (14), soybean (8)		Cabbage (IR), cotton (IR), papaya (VR), potato (VR), rice (NQ, IR) tomato (AST, sugar cane (IR), sweet potato (IR)

Notes : AFR: Altered fruit ripening; AST: Abiotic stress tolerance; BR: Bacterial resistance; CQ: Cooking quality; DR: Disease resistance; EV: Edible vaccine; FR: Fungal resistance; FQ: Fibre quality; HT: Herbicide tolerance; GC: Growth control; IP Industrial product; FC: Food Composition for human and animal nutrition, MU: Micronutrient Uptake; SM: Sugar Metabolism; FY: Fibre Yield; IR: Insect resistance; MO: Modified oil composition; MR: Multiple resistance; NQ: Nutrition quality; PC: Pollination control; PrC: Protein content; SC: Starch composition; VR: Virus resistance; WQ: Wood quality; Y: Yield.

Source: ISAAA (2016), GAIN (2016a, 2016b, 2016c), APCTT (2011)

Table 3.8. Use of genome editing in the crop sector in the Asia-Pacific region

Country	Technology	Crop	Purpose
Asia			
Afghanistan	N/A	N/A	N/A
Bangladesh			
Bhutan	No	No	no
Brunei Darussalam	N/A	N/A	N/A
Cambodia	N/A	N/A	N/A
China	TALEN/CRISPR Cas9	Wheat; rice	Disease resistance
India	Cloning gene 'Pi-Kh' by CRISPR	Rice, wheat	Resistance to blast disease; drought resistance
Indonesia	CRISPR CAS9	N/A	N/A
Iran (Islamic Republic of)	No	N/a	N/A
Japan	CRISP-Cas9		Japan is also actively involved in the research and development of innovative biotechnologies, such as CRISP-Cas9.
Kazakhstan	N/A	N/A	N/A
Democratic People's Republic of Korea	N/A	N/A	N/A
Republic of Korea	CRISPR-Cas9 (No insertion of foreign DNA); CRISPR	*Arabidopsis thaliana*, tobacco, lettuce and rice; apple, grapevine	Physiological; climate-change; under research; to increase resistance to fire blight disease; to increase resistance to powdery mildew
Lao People's Democratic Republic	N/A	N/A	N/A
Malaysia	CRISPR-Cas is being employed for genome editing in research, however there is no clear indication of its employment in particular crops	N/A	N/A
Maldives	N/A	N/A	N/A
Mongolia	No	N/a	N/A
Myanmar	CRISPR	Tomato	Improve flavour and quality
Nepal	No	N/A	N/A

Country	Technology	Crop	Purpose
Pakistan	N/A	N/A	N/A
Philippines	CRISPR-Cas	Rice	Enhanced rice blast resistance
Singapore	TALEN/CRISPR	N/A	N/A
Sri Lanka	N/A	N/A	N/A
Thailand	N/A	N/A	N/A
Timor-Leste	No	N/A	N/A
Uzbekistan			
Viet Nam	N/A	N/A	N/A

Pacific			
Australia	CRISPR	Wheat	To study control of development, genome integrity, and epigenetic inheritance
Cook Islands	N/A	N/A	N/A
Fiji	N/A	N/A	N/A
Kiribati	N/A	N/A	N/A
Marshall Islands	N/A	N/A	N/A
Micronesia (Federated States of)	N/A	N/A	N/A
Nauru	N/A	N/A	N/A
New Zealand	CRISP-Cas is being employed for genome editing in research, however there is no clear indication of its employment in particular crops		
Niue	N/A	N/A	N/A
Palau	N/A	N/A	N/A
Papua New Guinea	N/A	N/A	N/A
Samoa	N/A	N/A	N/A
Solomon Islands	N/A	N/A	N/A
Tonga	N/A	N/A	N/A
Tuvalu	N/A	N/A	N/A
Vanuatu	N/A	N/A	N/A

Table 3.10. Application of animal biotechnology in livestock production in the Asia-Pacific region (illustrative examples)

Country	Marker assisted selection breeding	Cloning	Embryo production and transfer	Genomics/ proteomics	Vaccines	Diagnostics
Asia						
Afghanistan	SNP marker http://www.biotech-asia.org/vol13no1/study-of-genetic-diversity-of-sheep-breeds-in-afghanistan/	No	No	Yes http://www.biotech-asia.org/vol13no1/study-of-genetic-diversity-of-sheep-breeds-in-afghanistan/	NDVH7m could be used as a marker vaccine against subtype H7 avian influenza in chicken	PCR is frequently used to detect and quantify NDV
Bangladesh	Genetic selection of dairy traits within or between diversified dairy cattle population and, thus, a DNA marker based selection tool, nucleus breeding flock of native sheep was established in BLRI through selective breeding with the objective of conservation and improvement	No	Livestock Research Institute and Bangladesh Agricultural University: embryo transfer technology, multiple ovulation embryo transfer and artificial insemination programme	Yes	Live attenuated Salmonella vaccine is locally produced and widely used in the field to protect the chickens from fowl typhoid, highly immunogenic live attenuated goat pox vaccine is widely being used in the field to protect the goat population from the killer disease of goat	FMD, peste des petits ruminants (PPR), rinderpest and HPAI using gene sequencing and molecular diagnosis of HPAI through RT-PCR using conventional as well as quantitative PCR systems, ELISA, HI, HA, AGPT, immuno-histo-chemistry, histology and virus culture in embryonated eggs and primary as well

Country	Marker assisted selection breeding	Cloning	Embryo production and transfer	Genomics/ proteomics	Vaccines	Diagnostics
						as continuous cell line
Bhutan	Genotype data of sheep	No	No	No	FMD, HPAI, Rabies, HS, and NCD	FMD and PPR
Brunei Darussalam	Bioinformatics and molecular genetic studies of domestic and wild buffalo species	No	No	No	No	No
Cambodia	No	No	No	No	FMD Vaccination	ELISA - FMD
China	Germplasm collection of *Camellia japonica* and *Camellia oleifera*	CRISPR-modified goats, sheep, pigs, monkeys and dogs, among other mammals.	Yes	Construction and identification of eukaryotic expression vector and prokaryotic expression vector of chicken INF-αGene; mitochondrial genome sequence was performed on Datong Yak	Vaccine against the viral strains of foot-and-mouth disease	Development of a Luminex assay for the detection of swine antibodies; vaccines for various bovine diseases; PCR-ELISA for various diseases
India	Dairy cattle, horse and silkworm, goats, red jungle fowl and domestic chicken	Yolk protein receptors from Indian silkworms	Gir and Kankrej cattle; Jaffarabadi, Mehsani, Surti and Banni buffalo	Standard karyotypes of livestock species- as diagnostic tools for detecting genetic disorders in breeding bulls	Vaccines for anthrax, bovine tuberculosis, bovine herpes virus, mastitis, Theileriosis, Leptospirosis, canine parvovirus, Canine distemper, canine coronavirus, canine	ELISA-based diagnostics for various cattle diseases

Country	Marker assisted selection breeding	Cloning	Embryo production and transfer	Genomics/ proteomics	Vaccines	Diagnostics
					adenovirus, Salmonellosis, Newcastle disease, infectious bursal disease	
Indonesia	Bali cattle	No	Kampung Unggul Balitnak chicken	Cattle, pigs	No	Diagnosis for quail diseases
Iran (Islamic Republic of)	Molecular analysis of the CDS gene in cattle to diagnose genetic defects	Cloning of sheep, cattle and goats; production of transgenic and knockout mice	Production of IVF cattle, sheep and goat	Isolation of OCT-4 promoter for the control of EGFP gene in an indicator plasmid; sequencing Iranian horse genome and preparing horse parentage genotyping kit using genome-based markers	Recombinant vaccines, study of next generation vaccines	Molecular and immunological methods in diagnosis of pathogens
Japan	Dairy cattle, improvement of meat taste in beef, study of SNPs and meat-quality traits	March 2016: Japan had produced 625 cows by fertilized egg-cell cloning, 415 cows by somatic nuclear transfer (SCNT), 638 swine by SCNT, and 5 goats by SCNT. All production has been done in public research institutions.	NLBC for dairy cattle; NARO Animal Genetics Unit	Genome sequencing of pig decoded 15 000 genes in NARO; use of genetic approach to improve the ability of honeybee as pollinator; genome analysis research; sequencing of genomic DNA has been completed in	No biotechnology application	FMD using RT-PCR, ELISA

Country	Marker assisted selection breeding	Cloning	Embryo production and transfer	Genomics/ proteomics	Vaccines	Diagnostics
				many livestock animals and poultry such as cattle, pig and chicken; genome editing in chicken.		
Kazakhstan	No	No	9h-German Embryo Transfer Research Center - 10 graft-calves born; artificial insemination of cattle	Goat breed	FMD vaccine, brucellosis in cattle	ELISA
Democratic People's Republic of Korea	No	No	No	No	No	No
Republic of Korea	Korean cattle	Cloned pig With controlled expression of proteins.	Korean native cattle (Hanwoo)	Workshop on strategy of genomics research for swine PMWS	Infectious bovine rhinotracheitis/ infectious pustular vulvovaginitis	Establishment of biosecurity systems and disease research on FMD and high pathogenic avian influenza (HPAI)
Lao People's Democratic Republic	Genetic markers for parasitic infections in cattle	No	No	No	FMD vaccine gun trial – funded by Australian Department of Agriculture and Water Resources.	FMD diagnostics
Malaysia	Dairy cattle	No	Beef cattle.	Mitochondrial and nuclear RFLP work as markers for the identification of	Malaysian scientists have developed a live vaccine for haemorrhagic	PCR-ELISA for monitoring of *Leishmania* parasite in livestock

Country	Marker assisted selection breeding	Cloning	Embryo production and transfer	Genomics/ proteomics	Vaccines	Diagnostics
				different breeds of buffaloes and chickens. The cloning of pituitary growth hormone gene using retroviruses as a vector was initiated. A study has been completed to relate the transformable antibiotic resistance traits in *E. coli* strains of bovine, avian and porcine sources from slaughterhouses with the frequency of R plasmids, which are extrachromosomal genetic markers, and are suspected to be responsible for drug resistance	septicaemia— a disabled form of the disease causing bacterium, that triggers an immune response without causing the disease. Malaysian Vaccine and Pharmaceuticals produces vaccines against Newcastle disease, infectious bronchitis, infectious bursal disease, fowl pox, egg-drop syndrome, duck pasteurellosis and swine fever etc.	
Maldives	N/A	N/A	N/A	N/A	Out membrane protein DNA vaccines for protective immunity against virulent avian *Pasteurella*	N/A

Country	Marker assisted selection breeding	Cloning	Embryo production and transfer	Genomics/ proteomics	Vaccines	Diagnostics
					multocida in chickens	
Mongolia	Sheep and cashmere goat genetic improvement, establish nucleus herds of cashmere goats (four) and local sheep (two); genetic diversities of several breeds of cattle and sheep grown in Mongolia	No	Dairy animals	No	No	Immune-genetic analyses, transboundary control of disease and FMD
Myanmar	No	No	Yes https://www.iaea.org/newscenter/news/myanmars-dairy-farmers-benefit-from-cattle-breeding-programme-using-nuclear-based-techniques	No	FMD	BLV provirus was detected by nested PCR and real-time PCR targeting BLV long terminal repeats https://www.ncbi.nlm.nih.gov/pubmed/27771791
Nepal	For healthy farm animals	No	Cattle. In total, some 70 000 inseminations are annually carried out in the country adding about 36 000 high yielding	Study on mitochondrial DNA of Lulu cattle	No	FMD and PPR

Country	Marker assisted selection breeding	Cloning	Embryo production and transfer	Genomics/ proteomics	Vaccines	Diagnostics
			animals per annum in the national bovine (cattle and buffalo) population			
Pakistan	Tharparkar and Red Sindhi cattle; Damani and Nachi goat breeds, Teddy and Beetal goat breeds; buffalo; sheep	No	N/A	N/A	Anthrax; FMD-VRI for foot and mouth disease; vaccines for haemorrhagic septicaemia	Yes
Philippines	Philippine Carabao Center, Molecular Genetics Laboratory undertook genotyping of the Philippine water buffalo using medium density 90K buffalo SNP panel	No	Cattle	Bureau of Animal Industry under Department of Agriculture is carrying out various genomic projects on cattle, swine, poultry, horses and bees.	Vaccines against porcine reproductive respiratory syndrome, hemorrhagic septicemia, classical swine fever and anthrax are available in Philippines for livestock.	Bureau of Animal Industry provides various tests like ELISA for FMD, caprine arthritis encephalitis
Singapore	Cattle	No	No	Yes	For various viral diseases	FMD and swine diseases
Sri Lanka	Example in goats (http://www.nepjol.info/index.php/IJASBT/article/view/14517)	No	First successful animal produced through embryo transplantation technology was a calf. (http://www-	Yes	http://www.daph.gov.lk/web/images/content_image/news_bulletins/epidemiological/veterinary_epidemiological_bulletin_volu	https://bmcresnotes.biomedcentral.com/articles/10.1186/s13104-017-2457-4

Country	Marker assisted selection breeding	Cloning	Embryo production and transfer	Genomics/ proteomics	Vaccines	Diagnostics
			naweb.iaea.org/nafa/aph/stories/2008-calf-embryo.html)		me_5_no_1.pdf http://www.daph.gov.lk/web/index.php?option=com_content&view=article&id=50&Itemid=152&lang=en#research-projects-to-improve-livestock-production-and-health	
Thailand	No	No	No	N/A	Genetic characterization of canine influenza A virus (H3N2)	Invasive and non-invasive diagnostic techniques for pet infectious diseases. Molecular epidemiology of bovine tuberculosis in swamp buffalos in lower northeastern Thailand using spoligotyping.
Timor-Leste	No	No	Dairy cattle	No	No	Avian influenza and transboundary disease precaution from FMD
Uzbekistan	No	Yes	100 million cattle and pigs bred annually by using AI	No	Radiobiological vaccine for the protection of small cattle from	Infection in small cattle

Country	Marker assisted selection breeding	Cloning	Embryo production and transfer	Genomics/ proteomics	Vaccines	Diagnostics
			http://www.tandfonline.com/doi/pdf/10.1080/02648725.2010.10648151?needAccess=true		colibacillosis, salmonellosis and pasteurellosis http://news.uzreport.uz/news_4_e_123297.html	
Viet Nam	Local pig	No	Embryos produced *in vitro* in pigs	Mitochondrial sequence indigenous wild pig (*Sus scrofa*)	N/A	Infections in cattle and water buffalo
Pacific						
Australia	https://www.ncbi.nlm.nih.gov/pubmed/14970683 http://eprints.utas.edu.au/9333/1/2009AIASTAbstractandSpeakerAduliMalau-Aduli.pdf	Pigs, sheep, cattle, goat http://archive.industry.gov.au/Biotechnologyonline.gov.au/human/cloninganimal.html	http://archive.industry.gov.au/Biotechnologyonline.gov.au/human/cloninganimal.html http://tlg.com.au/et-ivf/	Yes	https://www.mla.com.au/research-and-development/animal-health-welfare-and-biosecurity/husbandry/vaccinating/	ELISA, faecal culture and PCR-based tests are used for diagnosis of pathologies in livestock https://www.animalhealthaustralia.com.au/what-we-do/endemic-disease/johnes-disease-in-cattle/testing-and-diagnosis
Cook Islands	No	No	No	No	No	No
Fiji	No	No	No	No	No	No
Kiribati	No	No	No	No	No	No

Country	Marker assisted selection breeding	Cloning	Embryo production and transfer	Genomics/ proteomics	Vaccines	Diagnostics
Marshall Islands	No	No	No	No	No	No
Micronesia (Federated States of)	No	No	No	No	No	No
Nauru	No	No	No	No	No	No
New Zealand	Sheep, cattle	Experimental cloning of livestock, restricted to very small numbers of elite breeding stock. AgResearch is the pre-eminent animal cloning research institute in New Zealand	Embryo transfer is being carried out for sheep and goats in New Zealand.	Parentage tests, single-gene tests, and SNP genotyping.	Equine influenza vaccine for horses.	Research for New Zealand-specific diagnostic techniques to improve detection of the Johne's disease in livestock is being carried out by a company called Beef+Lamb A gene test based on the DQA2 gene that resides on the MHC complex (Hickford et al., 2004) and predicts susceptibility to foot rot has been developed at Lincoln University in New Zealand In 2013, using advanced diagnosis methods (PCR and DNA sequencing),

Country	Marker assisted selection breeding	Cloning	Embryo production and transfer	Genomics/ proteomics	Vaccines	Diagnostics
						scientists discovered that the cause of the anaemia epidemic in cattle was the parasite *Theileria orientalis* Ikeda
Niue	No	No	No	No	No	No
Palau	No	No	No	No	No	No
Papua New Guinea	No	No	No	No	No	No
Samoa	No	No	Used only once in 1984	No	No	No
Solomon Islands	No	No	No	No	No	No
Tonga	No	No	No	No	No	No
Tuvalu	No	No	No	No	No	No
Vanuatu	No	No	No	No	No	No

Table 3.12. State of agricultural biotechnologies application in the forestry sector in the Asia-Pacific region

Country	Biofertilizers	Biopesticide	Tissue culture/ micropropagation	PCR/MAS	Genetic modification	Gene editing/CRISPR
Asia						
Afghanistan	N/A	N/A	N/A	N/A	N/A	N/A
Bangladesh	N/A	N/A	20 species of medicinal plants, hybrid acacia, 11 bamboo and 6 tree species	No	N/A	N/A
Bhutan	Only organic farming	Only organic farming	N/A	N/A	N/A	No
Brunei Darussalam	N/A	N/A	N/A	N/A	N/A	N/A
Cambodia	NPK mixtures – cashew; rubber *A. mangium* and *A. auriculiformis* – NPK	Biological fungicides – citrus roots	*Aquilaria crassa*; *A. mangium*	N/A	N/A	N/A
China	A complex inoculant of N2-fixing, P- and K-solubilizing bacteria from a purple soil improves the growth of kiwifruit (*Actinidia chinensis*) plantlets	*B. bassiana*; Microorganisms like bacteria and fungi are also used for ornamental trees and also pine tree	*Cyclocarya paliurus, Picea asperata* Mast	Chinese jujube	Poplar tree etc	Highly-efficient CRISP-Cas9-mediated targeted mutagenesis of multiple genes in *Populus*

Country	Biofertilizers	Biopesticide	Tissue culture/ micropropagation	PCR/MAS	Genetic modification	Gene editing/CRISPR
India	PSB and *Azotobacter* on *Tectona grandis* (teak); *Azospirillum, Rhizobium*, and *Frankia* used for tree crops	*Metarhizium anisopliae* on coconut rhinoceros beetle. Spraying of spores in its breeding sites	*Tectona grandis, Anogeissus latifoglia*, bamboo spp., saffron and various trees like apple	*Eucalyptus tereticornis* X E. teak	Rubber	Teak
Indonesia	*Frankia* (Actinomycetes) - *Casuarania* tree	N/A	*Frankia* (Actinomycetes) - *Casuarania* tree	*Eusideroxylon zwageri*	Yes	N/A
Iran (Islamic Republic of)	Yes, but for medicinal plants rhizobacteria, mycorrhiza, organic manure	N/A	Propagation of medicinal and odor plants, rangeland species	Study forest species genetics	N/A	N/A
Japan	N/A	N/A	Japanese cedar (*Cryptomeria japonica*), medicinal plants	Genetic diversity and structure of natural fragmented *Chamaecyparis obtusa* populations as revealed by microsatellite markers Genetic structure of island populations of *Prunus lannesiana* (Carr.) Wilson var. *speciosa* (Koidz.) Makino revealed by the chloroplast DNA,	Yes	Yes

Country	Biofertilizers	Biopesticide	Tissue culture/ micropropagation	PCR/MAS	Genetic modification	Gene editing/CRISPR
				AFLP and nuclear SSR loci.		
Kazakhstan	N/A	N/A	N/A	N/A	N/A	N/A
Democratic People's Republic of Korea	N/A	N/A	N/A	N/A	N/A	N/A
Republic of Korea	Oil cake - (*Diospyros× kaki* Thunb.) trees NPK - *Pinus densiflora*	Ddangumi, based on *Monacrosporium thaumasium*, was registered to control root knot nematodes in watermelon	*A.mangium* teak wood trees	*Prunus persica*	Yes	N/A
Lao People's Democratic Republic	N/A	N/A	Teak agroforestry systems funded by ACIAR	N/A	N/A	N/A
Malaysia	Oil Palm and rubber are main tress on which these organic biofertilizers are utilized for. (Source: http://www.fnca.mext.go.jp/english/bf/country_img/malaysia.pdf)	Biological control of white root disease caused by *Rigidoporus microporus* fungus using stems extract of kemunting cina (*Catharanthus roseus*) have been used as a healing agent of infected rubber trees. (Source:https://www.omicsonline.org/stems-extract-of-	Teak	*Neolamarckia cadamba* (burflower-tree), *Duabanga moluccana* (magas)	Oil palm, rubber	N/A

Country	Biofertilizers	Biopesticide	Tissue culture/ micropropagation	PCR/MAS	Genetic modification	Gene editing/CRISPR
		kemuning-cina-catharanthus-roseus-as-biofungicides-against-white-root-fungal-rigidoporus-microporus-of-rubber-trees-hevea-brasiliensis-2155-6202.1000136.php?aid=19740)				
Maldives	N/A	N/A	N/A	N/A	N/A	N/A
Mongolia	N/A	N/A	N/A	N/A	N/A	N/A
Myanmar	N/A	N/A	*Desmodium triquetrum* DC Medicinal plant, *Muse acuminata* or *M. balbisiana*	N/A	N/A	N/A
Nepal	N/A	N/A	Timber and fuel wood species, bamboo species, orchids, ornamental and other medicinal plants, *Atropa belladonna* *Pyrethrum* sp. *Solanum laciniatum*	Genetic diversity analysis	N/A	N/A
Pakistan	N/A	N/A	Medicinal and vegetative crops	Blue pine (*Pinus wallichiana*)	N/A	N/A

Country	Biofertilizers	Biopesticide	Tissue culture/ micropropagation	PCR/MAS	Genetic modification	Gene editing/CRISPR
Philippines	Used on agricultural and horticultural crops, trees and ornamental plants but not the ones that employ biotechnology as they are mainly made using naturally occurring organisms and organic products (Source: National Institute of Molecular Biology and Biotechnology, University of Philippines Los Baños).	No specific biopesticides is present for forest application and are also mainly of organic nature with no use of biotechnology	*Gliricidia sepium*	*Gliricidia sepium*	N/A	No
Singapore	Endomycorrhizal fungi, known as vesicular abuscular mycorrhiza for narra, mahogany, acacia, gmelina, etc. (except eucalyptus and dipterocarps) only at research level*	Names not mentioned	N/A	N/A	N/A	N/A
Sri Lanka	100% organic biofertilizers are	Biopesticides commercialised in Sri Lanka do not	Khaya, teak, bamboo, sugar cane	Rubber, sugar cane	N/A	N/A

Country	Biofertilizers	Biopesticide	Tissue culture/ micropropagation	PCR/MAS	Genetic modification	Gene editing/CRISPR
	used in the forestry sector in Sri Lanka.	involve any use of biotechnology.				
Thailand	Mycorrhizal fungi for fruit tree	N/A	Rubber and teak, eucalyptus	Rubber, teak, eucalyptus	Rubber and teak	No
Timor-Leste	N/A	N/A	N/A	N/A	N/A	N/A
Uzbekistan	N/A	N/A		N/A	N/A	N/A
Viet Nam	*Leucaena leucocephala* - rhizobia inoculations	N/A	*Aquilaria crassa*; Mangosteen tree *A.mangium*	*Eucalyptus urophylla*	N/A	N/A
Pacific						
Australia	Biofertilizers used are naturally occurring. No biotechnology-based biofertilizer is being researched upon or applied in Australia for the forestry sector yet	The biopesticides are disease-specific and hence can be used on a number of crops and/or trees. Targets: crown gall disease, blights (*Botrytis* spp.), dead-arm of grapevine, Lepidoptera larvae, grey-backed cane grub (scarabs), locusts and grasshoppers, redheaded pasture cockchafer, *Helicoverpa* spp	Teak, bamboo, eucalyptus	Acacia, eucalyptus	Yes	CRISPR or other gene editing techniques such as RNAi have not yet been used for forestry sector in Australia.
Cook Islands	N/A	N/A				N/A

Country	**Biofertilizers**	**Biopesticide**	**Tissue culture/ micropropagation**	**PCR/MAS**	**Genetic modification**	**Gene editing/CRISPR**
Fiji	None	N/A	Sandalwood micropropagation has been established in Fiji with cooperation with CePaCT	N/A	N/A	N/A
Kiribati	N/A	N/A	N/A	N/A	N/A	N/A
Marshall Islands	N/A	N/A	N/A	N/A	N/A	N/A
Micronesia (Federated States of)	N/A	N/A	N/A	N/A	N/A	N/A
Nauru	N/A	N/A	N/A	N/A	N/A	N/A
New Zealand	No use of bioferilizers for forestry application could be located online	No forest-specific biopesticides are under application in New Zealand; however, there many available for apple and pipfruit cultivation	Many species including radiata pine	Radiata pine	Radiata pine	No application as of yet, only some research is being carried out using CRISP-Cas9 which is also not focussed towards the forestry sector.
Niue	N/A	N/A				N/A
Palau	None	None				None
Papua New Guinea	None	None				None
Samoa	N/A	N/A				N/A
Solomon Islands	None	None				None
Tonga	None	None				None

Country	Biofertilizers	Biopesticide	Tissue culture/ micropropagation	PCR/MAS	Genetic modification	Gene editing/CRISPR
Tuvalu	None	None				None
Vanuatu	None	None				None

Table 3.16. Biotechnology application in the fisheries/aquaculture sector in the Asia-Pacific region

Country	MAS	Genomics/proteomics	Vaccines	Diagnostics
Asia				
Afghanistan	Development and characterization of microsatellite markers in *S. richardsonii* and implementation of MAS http://14.139.56.90/bitstream/1/2032171/1/IVRI%20BT%203152.pdf	RFLP, RAPD, AFLP, microsatellite, SNP, and EST markers are the popular genetic markers employed in aquaculture. Genetic studies of S*chizothorax richardsonii* and *Tor putitora* https://scholar.google.co.in/citations?view_op=view_citation&hl=en&user=UDe9e9MAAAAJ&citation_for_view=UDe9e9MAAAAJ:u5HHmVD_uO8C	ERM oral vaccine and ELISA	Diagnostic test for the identification of a filterable agent isolated from diseased rainbow trout in cold water fishery, trichodiniasis, whirling disease, costiasis, argulusis and dactylogyrosis in richhardsonii and golden mahseer.
Bangladesh	Induced breeding techniques in carp, pabda, catfish, koi and others; genetic stock improvement of 2 indigenous and exotic carp and tilapia through selective breeding; production of all monosex population (all males and all females) in tilapia and silver carp by sex reversal and chromosome manipulation technique; detection of introgressed hybrids in carps in the hatcheries using micro satellite DNA markers; stock discrimination of hilsa by	Used for improved rohu (*Labeo rohita*) stock developed and other endangered species, genetic improvement of fish	No	Techniques are used by BFRI Fish/shrimp disease diagnosis, prevention and control

Country	MAS	Genomics/proteomics	Vaccines	Diagnostics
	allozyme and DNA-RFLP markers.			
Bhutan	No	Golden mahseer preservation	No	No
Brunei Darussalam	Black Tiger Shrimp	No	No	No
Cambodia	*Clarias batrachus*- mitochondrial DNA markers	N/A	N/A	N/A
China	Ornamental and fish genetic breeding; *Cyprinus carpio* L; pearl oyster *Pinctada fucata*	China has accomplished the complete mitochondrial genome of *Trachinotus blochii*, and *Trachinotus ovatus*. Applications of selective breeding technologies, including molecular marker-assisted, genome-wide selective and sex control breeding are used in genetic breeding of fishes. There has been research on hypoxia signalling pathway and its regulation, as well as the mechanism of hypoxia adaptation in fish. Recently, studies include sexual dimorphism and sex determination in fish, through biotechnological manipulation for sex control breeding. Genome sequence of *T. blochii*; golden pompano *Trachinotus ovatus*; genomic data of diverse aquatic viruses, such as irido-, herpes-, reo- and rhabdoviruses,	Zebra fish immunisation, turbots	Freshwater cultured snakehead fish, *Ophiocephalus argus* (Cantor) Mass mortality caused by cyprinid herpesvirus 2 in Prussian carp (*Carassius gibelio*)

Country	MAS	Genomics/proteomics	Vaccines	Diagnostics
India	Nile and red hybrid tilapia; catfish	Genome sequencing of *Labeo rohita* and *Clarius batrachus*, marine actinomycetes, transcriptome profiling of immune responsive genes in golden mahseer Description of two new species of the genus *Thaparocleidus* Jain Muscle proteomics of Indian carp catla	Bacterial vaccines for fish, innate immunity of goldfish infected with *Aeromonas hydrophila* Association of *Enterobacter cloacae* in the mortality of *Pangasianodon hypophthalmus*	Species like silver carp (*Hypophthalmichthys molitrix*), Indian carp (*Catla catla*), isolation and identification of *Vibrio* spp. in diseased *Channa punctatus*
Indonesia	DNA barcoding/SNP markers in fisheries	Snakehead murrel	Vaccines for Koi herpes virus infection in common carp	N/A
Iran (Islamic Republic of)	Identification of genes associated with quantitative traits in cellular organelles and tissues for use in aquaculture breeding	Molecular genetic testing of seafood, fish DNA bar-coding, genetic engineering of fishes, preparation and collection of aquatic and plasmid gene banks	Yes	Yes
Japan	MAFF is promoting research into the CRISP-Cas9 application for the breeding of tuna with reduced aggressiveness and as a more suitable for fish culture.	N/A	Diagnosis, prevention, and treatment of fish/shellfish diseases and diagnosis for the fungal infection in fish	Diagnosis, prevention, and treatment of fish/shellfish diseases and fungal infections in *Saprolegnia* spp.
Kazakhstan	No	Mitochondrial genome sequences of ship sturgeon *Acipenser nudiventris* from the Caspian Sea were determined by PCR-based sequencing method		

Country	MAS	Genomics/proteomics	Vaccines	Diagnostics
Democratic People's Republic of Korea	N/A	N/A	N/A	N/A
Republic of Korea	N/A	*Haliotis discushannai*- genomic studies	Vaccine against streptococcal infections in olive flounder, *Paralichthys olivaceus*	PCR method for detecting *Kudoa iwatai*
Lao People's Democratic Republic	N/A		N/A	Prevalence of *Fasciola gigantica* infestation in beef cattle - iELISA approach
Malaysia	Shrimp	Whole genome sequencing of commercially important and endangered Asian Arowana was completed in 2015. Use of mitochondrial DNA (mtDNA) based markers to assess genetic relationships among Asian Arowana species, an ornamental fish. Gene identification from database along with mRNA expressions studies using quantitative real time polymerase chain reaction (qRT-PCR)	StrepToVax: feed-based vaccine against *Streptococcus agalactiae* infection in tilapia http://www.dof.gov.my/fri.php/database_stores/store_view/83	ELISA for detection of KHV http://psasir.upm.edu.my/4675/1/Detection%20of%20Koi%20Herpesvirus%20%28KHV%29%20in%20Cyprinius%20carpio%20%28Koi%29%20Stocks%20using%20Enzyme-Linked%20Immunosorbent%20Assay%20%28ELISA%29.pdf
Maldives	Maldive clown fish	N/A	N/A	N/A
Mongolia	No	No	No	No
Myanmar	Genetic diversity of mrigal carp in Myanmar using microsatellite DNA marker	Yes	Shrimp diseases	Viral diseases determined by PCR

Country	MAS	Genomics/proteomics	Vaccines	Diagnostics
	Genetic variation of catla using RAPD marker.	https://www.nature.com/ng/journal/v46/n11/full/ng.3098.html#auth-2	PCR method to detect shrimp viral diseases including WSD, IHHN, TS and YHD https://repository.seafdec.org.ph/bitstream/handle/10862/3091/WahSLP2016.pdf?sequence=1	https://repository.seafdec.org.ph/bitstream/handle/10862/3091/WahSLP2016.pdf?sequence=1
Nepal	No	No	No	N/A
Pakistan	Marker assisted breeding for *Catla catla* (thaila); *Labeo rohita* (rohu) and *Cirrhinus mrigala* (mori)	N/A	N/A	N/A
Philippines	Induced breeding of the giant trevally *Caranx ignobilis*.	Department of Science and Technology has launched a genomics program for fisheries diversities analysis.	Yes	SEAFDEC/AQD offers disease diagnostic services, with viral diseases determined by PCR. The Shrimp Pathogenomics Program aims to develop a Shrimp pathogen bio-bank, an online shrimp pathogen information resource, a country-wide biosurveillance system and a pathogenomics initiative to sequence the entire genomes of at least 300 shrimp pathogens with the goal of developing diagnostic tools for the biosurveillance and management of shrimp diseases in the country.
Singapore	Wild-type zebrafish; tilapia	N/A	N/A	N/A

Country	MAS	Genomics/proteomics	Vaccines	Diagnostics
Sri Lanka	Microsatellite based selection http://ris.org.in/images/RIS_images/pdf/Prof-Athula-Perera.pdf	Yes	No	Yes
Thailand	Mud crabs (*Scylla serrata, S. oceanica*, and *S. transquebarica*), oysters (*Crassostrea belcheri, C. iredalei, Saccostrea cucullata, S. forskali* and *Striostrea mytiloides*), abalone (*Haliotis asinina, H. ovina* and *H. varia*) and blue swimming crab (*Portunus pelagicus*); Asian seabass (*Lates calcarifer*); freshwater mussels (Mollusca–Bivalvia–Unionoida) Source: http://www.biotec.or.th/amgb/index.php/research-development	N/A	N/A	DNA diagnostic kit for detection of shrimp white spot virus
Timor-Leste	No	No	No	No
Uzbekistan	No	No	DNA vaccine	Disease in rainbow trout and salmon ftp://ftp.fao.org/docrep/fao/010/a1120e/a1120e01.pdf Viral haemorrhagic septicaemia is an infectious disease of rainbow trout http://www.cabi.org/isc/datasheet/66346

Country	MAS	Genomics/proteomics	Vaccines	Diagnostics
Viet Nam	*Clarias macrocephalus* (catfish); spiny lobster (*Panulirus homarus*) Genetic diversity of common carp (*Cyprinus carpio* L.) using four microsatellite loci to investigate genetic diversity and population structure	N/A	N/A	N/A
Pacific				
Australia	RFLP, microsatellite and SNPs	Yes	No	Western Australia has fish-health programme and routine service to mariculture and aquaculture is undertaken.
Cook Islands	N/A	N/A	N/A	N/A
Fiji	N/A	N/A	N/A	N/A
Kiribati	N/A	N/A	N/A	N/A
Marshall Islands	N/A	N/A	N/A	N/A
Micronesia (Federated States of)	N/A	N/A	N/A	N/A
Nauru	N/A	N/A	N/A	N/A
New Zealand	Improvement through maintenance of superior genetic pools through DNA based markers and conventional	Polymerase chain reaction based tests for monitoring of genes and genomic analysis to establish high-performance hapuku, kingfish and abalone broodstock	Research on vaccines for salmon	Yes

Country	MAS	Genomics/proteomics	Vaccines	Diagnostics
	breeding in hapuku, kingfish and abalone broodstock.			
Niue	N/A	N/A	N/A	N/A
Palau	N/A	N/A	N/A	N/A
Papua New Guinea	N/A	N/A	N/A	N/A
Samoa	N/A	N/A	N/A	N/A
Solomon Islands	N/A	N/A	N/A	N/A
Tonga	N/A	N/A	N/A	N/A
Tuvalu	N/A	N/A	N/A	N/A
Vanuatu	N/A	N/A	N/A	N/A

Table 4.6. Livestock biotechnology capacities in the Asia-Pacific region (illustrative examples)

Country	Institutions/infrastructure for R&D	Educational institutions
Asia		
Afghanistan	Ministry of Agriculture International Livestock Research Institute	Agriculture college
Bangladesh	Bangladesh Livestock Research Institute Bangladesh Agricultural University Sericulture Research Institute, National Institute of Biotechnology	Bangladesh Livestock Research Institute Bangladesh Agricultural University, Sericulture Research Institute
Bhutan	National Artificial Insemination Program and Semen Processing Centre, Thimphu National Centre for Animal Health Animal Genetic Resource Centre at the Livestock Services Division in the Ministry of Agriculture	Yusipang, Thimphu Bajo, Wangdue Jakar Bumthang Wengkhar Mongar
Brunei Darussalam	The Brunei Darussalam Halal Centre will cooperate with three international institutions: (1) Florida State University, (2) the Graduate School of Engineering at Osaka University and (3) Japan Food Research Laboratories; Headquarters of the Halal Industry Innovation Centre in the Bioinnovation Corridor	University of Brunei Darussalam
Cambodia	The Agricultural Sector Strategic Development Plan (ASDP), 2014–2018- Rectangular Strategy-Phase III: Pillar No 2 of Rectangular strategy emphasizes - Promotion of livestock and aquaculture Framework for Livestock - 2016	
China	Ministry of Agriculture National GE Animal Technology Research Center	Lanzhou Veterinary Research Institute Provincial educational and research facilities
India	Indian Council of Agriculture of Research (ICAR) Institutions under the Department of Animal Husbandry and Fisheries, Government of India Fisheries institutes in states	State Veterinary and Animal Science Universities ICAR-Indian Veterinary Research Institute ICAR-National Dairy Research Institute Private dairy and livestock institutions such as BAIF, Pune

Country	Institutions/infrastructure for R&D	Educational institutions
Indonesia	Department of Animal Husbandry, Dairy and Fisheries Hasanuddin University Assessment Institute for Agricultural Technology in Makassar Agency for Agricultural Research and Development	Airlangga University College, District of Banyuwangi, Faculty ofVeterinary Medicine. Airlangga University, Faculty of Veterinary Medicine. Bogor Agricultural University, Faculty of Veterinary Medicine. Gadjah Mada University, Faculty of Veterinary Medicine Hasanuddin University, Faculty of Veterinary Medicine
Iran (Islamic Republic of)	Royan Institute for Animal Biotechnology National Institute of Genetic Engineering Biotechnology Iran Organization of Science and Technology Pasteur Institute of Iran Agriculture Biotechnology Research Institute of Iran Razi Institute in Iran	Royan Institute for Animal Biotechnology National Institute of Genetic Engineering Biotechnology Iran (Animal Biotechnology Department) Iran Organization of Science and Technology Pasteur Institute of Iran Agriculture Biotechnology Research Institute of Iran Razi Institute in Iran
Japan	Hiroshima University (Faculty of Biological Productivity) Hokkaido University Obihiro University of Agriculture and Veterinary Medicine (Faculty of Animal Husbandry) Okayama University Prefectural University of Kumamoto (Faculty of Symbiotic) National Livestock Breeding Centre Institute of Livestock and Grassland Science – National Agricultural and Food Research Organization National Institute of Animal Health RIKEN	Hiroshima University (Faculty of Biological Productivity) Hokkaido University Obihiro University of Agriculture and Veterinary Medicine (Faculty of Animal Husbandry) Okayama University Prefectural University of Kumamoto (Faculty of Symbiotic) National Livestock Breeding Centre in japan Institute of Livestock and Grassland Science – National Agricultural and Food Research Organization National Institute of Animal Health
Kazakhstan	Department of Animal Husbandry, Dairy and Fisheries, Ministry of Agriculture	Kazakhistan State Agrotech University Agrarian Technical University Kazakh National Agrarian University

Country	Institutions/infrastructure for R&D	Educational institutions
Democratic People's Republic of Korea	N/A	N/A
Republic of Korea	Ministry of Agriculture, Food and Rural Affairs Department of Animal Husbandry, Dairy and Fisheries	Seoul National University Choubuk National University Konkuk University
Lao People's Democratic Republic	Department of Animal husbandry, Dairy and Fisheries, Ministry of Agriculture National Agriculture and Forestry Research Institute	Faculty of Veterinary Medicine, Khon Kaen, National University of Laos Nabong Faculty of Agriculture National University of Laos Champasack University Souphanouvong University Savannakhet University
Malaysia	Malaysian Agricultural Research and Development Institute	The Veterinary Faculty of University Pertanian Malaysia Department of Genetics and Cellular Biology and The Institute for Advanced Studies, University Malaysia
Maldives	N/A	Maldives National University
Mongolia	Research Institute of Animal Husbandry Department of Microbiology and Infectious Diseases School of Veterinary Science and Biotechnology Mongolian State University of Agriculture	Research Institute of Animal Husbandry School of Veterinary Science and Biotechnology Mongolian State University of Agriculture
Myanmar	Ministry of Livestock, Fisheries and Rural Development, Directorate of Livestock, Fisheries and Rural Development; Livestock Breeding and Veterinary Department International Livestock Research Institute Livestock Breeding and Veterinary Department CP Livestock Corporation Nay La University of Veterinary Science	University of Veterinary Science, Yezin

Country	Institutions/infrastructure for R&D	Educational institutions
Nepal	Nepal Agricultural Research Council National Livestock Breeding Centre (NARC) Animal Health Research Division under (NARC) Department of Livestock Services and one research laboratory	Nepal Agricultural Research Council National Livestock Breeding Centre Animal Health Research Division under NARC
Pakistan	Directorate of Animal Husbandry, Ministry of Food and Agriculture Pakistan Agricultural Research Council Animal Sciences Institute, Islamabad Department of Poultry Production and Research, Karachi National Institute for Biotechnology and Genetic Engineering	University of Veterinary and Animal Sciences, Lahore There are more than 10 universities offering courses in biotechnology
Philippines	Philippine Carabao Center Livestock Biotechnology Center	There are more than 10 universities offering courses in biotechnology.
Singapore	Department of Animal Husbandry, Dairy and Fisheries Genetic Modification Advisory Committee under Ministry of Trade and Industry National University of Singapore Institute of Molecular and Cell Biology Temasek Life Sciences Laboratory IMCB, under A *STAR.	Temasek Polytechnic NGEFAnn Polytechnic
Sri Lanka	Ministry of Livestock and Rural Development Department of Animal Production and Health	Veterinary Research Institute, Institute of Continuing Education for Animal Production and Health, Gannoruwa, Peradeniya. Sri Lanka School of Animal Husbandry, Karandagolla, Kundasale
Thailand	Ministry of Agriculture and Cooperatives Department of Agriculture and Water Resources	Kasetsart University Faculty of Veterinary Medicine, Chiang Mai University
Timor-Leste	Livestock and Veterinary, Ministry of Agriculture, Forests and Fisheries	
Uzbekistan	Ministry of Agriculture, Animal Industry and Fisheries Livestock Development Research Institute Uzbekistan Breeding Company	Tashkent State Agrarian University Andijan Agriculture Institute Samarkand State Institute of Agriculture

Country	Institutions/infrastructure for R&D	Educational institutions
Viet Nam	Ministry of Agriculture and Rural Development	Viet Nam National University of Agriculture, Faculty of Veterinary Medicine Nong Lam University An Giang University

Pacific		
Australia	CRCSI MLA CSIRO	21 institutes providing courses in agricultural biotechnology which includes both crop and livestock biotechnology
Cook Islands	None	None
Fiji	None	School of Agriculture and Food Technology at University of South Pacific
Kiribati	None	None
Marshall Islands	None	None
Micronesia (Federated States of)	None	None
Nauru	None	None
New Zealand	Agresearch	Lincoln University Massey University
Niue	None	None
Palau	None	None
Papua New Guinea	National Agriculture Research Institute	Papua New Guinea University of Technology University of Goroka University of Natural Resources and Environment University of Papua New Guinea
Samoa	None	None
Solomon Islands	None	None for livestock science
Tonga	None	HANGO Agriculture College
Tuvalu	None	None
Vanuatu	None	Vanuatu Agriculture in Animal Science (Livestock).

Table 4.9. Forest R&D academic/research institutions

Country	Institutions
Asia	
Afghanistan	• Agriculture research institute in Afghanistan
Bangladesh	• Bangladesh Forest Research Institute (BFRI) • Bangladesh Forest Industries Development Corporation (BFIDC) • Institute of Forestry at the Chittagong University
Bhutan	• N/A
Brunei Darussalam	• The Forestry Department
Cambodia	• Institute of Forest and Wildlife Research and Development • Royal university of agriculture
China	• State Forestry Administration • Chinese Academy of Forestry
India	• The Ministry of Environment, Forest and Climate Change (MoEFCC) • Department of Forest Development Corporations (FDCs) • Council of Forestry Research and Education (ICFRE)
Indonesia	• The Forest Research and Development Agency (FORDA) • Yogyakarta Forest Biotechnology and Tree Improvement Research Office • Samarinda Dipterocarp Research Office • Pelambang Forest Research Institute • Banjarbaru Forest Research Institute • Faculty of Agriculture, Khairun University • Faculty of Agriculture, Padjadjaran University • Faculty of Forestry, Bengkulu University • Faculty of Forestry, Bogor Agricultural University • Faculty of Forestry, Domuga Kotamubago University • Faculty of Forestry, Gadjah Mada University • Faculty of Forestry, Haluoleo University • Faculty of Forestry, Hasanuddin University • Faculty of Forestry, Institute Pertanian Stiper • Faculty of Forestry, Kuningan University • Faculty of Forestry, Lambung Mangkurat University • Faculty of Forestry, Lampung University • Faculty of Forestry, Lancang Kuning Riau University • Faculty of Forestry, Merdeka Madiun University • Faculty of Forestry, Muhammadiyah Malang University • Faculty of Forestry, Muhammadiyah Sumatera Barat University • Faculty of Forestry, Mulawarman University • Faculty of Forestry, Negeri Papua University • Faculty of Forestry, Nusa Bangsa University • Faculty of Forestry, Palangkaraya University • Faculty of Forestry, Pattimura University • Faculty of Forestry, Sam Ratulangi University

Country	Institutions
	• Faculty of Forestry, Satria University • Faculty of Forestry, Tadulako University • Faculty of Forestry, Tanjungpura University • Faculty of Forestry, University of Jambi • Faculty of Forestry, University of North Sumatra • Faculty of Forestry, Winaya Mukti University • School of Life Sciences and Technology, Bandung Institute of Technology
Iran (Islamic Republic of)	• Research Institute of Forest and Rangeland
Japan	• The University of Tokyo Forest • Hokkaido Research Center • Tohoku Research Center • Tama Forest Science Garden • Kansai Research Center • Shikoku Research Center • Kyushu Research Center • Forestry and forest Products Research Institute • Forest Tree Gene Bank
Kazakhstan	• Mangyshlak experimental botanical garden,Aktau,Kazakhstan • Consevation of genetic resources in Western, Kazakhstan. • National Biotechnolog Center, Astana, Kazakhstan. • (eproduction of plant material of tree.,) • Institute of Genetics and Cytology, Almaty, Kazakhstan. • (Reproduction of genetic resources of Kazakhstan)
Democratic People's Republic of Korea	• Ministry of Forestry
Republic of Korea	• College of Forest Environmental Science, Kangwon University • College of Forest Science, Kookmin University • Department of Forest Environmental Sciences, College of Agriculture and Life Sciences, Seoul National University • Department of Forest Resources, Yeungnam University • Department of Forest Resources, College of Life Science, Gyeongnam National University of Science and Technology
Lao People's Democratic Republic	• NAFRI • Bolikhamxay Agriculture and Forestry School • Champasack Agriculture and Forestry School • Champasack University • Department of Forest Resources, Faculty of Agriculture and Forest Resources, Souphanouvong University • Dongkhamxang School of Agriculture and Forestry • Faculty of Forest Science, National University of Laos (NUOL) • Louang Prabang Agriculture and Forestry School • Muang Mai School of Forestry • Sepone Agroforestry Training Center
Malaysia	• Forest Research Institute Malaysia (FRIM)

Country	Institutions
Maldives	• The Ministry of Fisheries, Agriculture and Marine Resources (MOFAMR)
Mongolia	• Plant Protection Research Institute
Myanmar	• Myanmar Naing-Ngan Forest School. • Central Forestry Development Training Centre. • The Dry Zone Greening Department of Myanmar. • Institute of Forestry at Yesin. • Myanmar Forest Scholl at Pyin Oo Lwin. • MTE training schools
Nepal	• Intitute of Forestry, Tribhuvan University • King Mahendra Trust for Nature Conservation • Timber Corporation of Nepal • Resin and Turpentine Factory • Herb Production Company • Community Forestry Users
Pakistan	• Department of Forestry
Philippines	• University of Philippines offers course in forest biotechnology • Department of Science and Technology- Forest Products Research and Development Institute (DOST-FPRDI)
Singapore	• Ministry of the Environment and the Water Resources (MEWR)
Sri Lanka	• Sri Lanka Forestry Institute (SLFI) • University of Peradeniya in Sri Lanka • Sri Lankan Department of Forestry • Smithsonian Tropical Research Institute (Centre for Tropical Forest Science)
Thailand	• The Royal Forest Department • The Ministry of Agriculture and Cooperatives • National Forest Policy Committee (NFPC) • Department of Marine and Coastal Resources (DMCR) • Ministry of Natural Resources and Environment (MONRE)
Timor-Leste	• N/A
Uzbekistan	• Institute of Genetics and Experimental Biology of Plants. • Tashkent Agricultural Institute. • Forestry enterprises. • The Academy of Sciences, which includes the Scientific production corporation • Botanika.
Viet Nam	
Pacific	
Australia	• Institute of Foresters of Australia • Australian National University • University of Melbourne • Southern Cross University

Country	Institutions
Cook Islands	N/A
Fiji	• College of Agriculture, Fisheries and Forestry of the Fiji National University
Kiribati	N/A
Marshall Islands	N/A
Micronesia (Federated States of)	N/A
Nauru	N/A
New Zealand	• Sicon research (New Zealand's Forest Research Institute Limited)
Niue	N/A
Palau	N/A
Papua New Guinea	• The Papua New Guinea Forest Research Institute (PNGFRI)
Samoa	N/A
Solomon Islands	N/A
Tonga	N/A
Tuvalu	N/A
Vanuatu	N/A

Table 4.12. Institutes and educational institutes engaged in agricultural biotechnology in the fisheries/aquaculture sector in the Asia-Pacific region (illustrative examples)

Country	Institutions/infrastructure for R&D	Educational institutions
Asia		
Afghanistan	Ministry of Agriculture	Agriculture College
Bangladesh	Bangladesh Fisheries Research Institute	Bangladesh Fisheries Research Institute
Bhutan	National Research and Development Centre for Aquaculture	N/A
Brunei Darussalam	Fisheries Research Centre at Bio-innovation Corridor	University of Brunei Darussalam
Cambodia	Royal University of Agriculture	Ministry of Agriculture
China	East China Sea Fisheries Research Institute, Chinese Academy of Fisheries Sciences, Shanghai Yellow Sea Fisheries Research Institute, Chinese Academy of Fisheries Sciences, Qingdao South China Sea Fisheries Research Institute, Chinese Academy of Fisheries Sciences, Guangzhou	Lanzhou Veterinary Research Institute Zheijiang University
India	Indian Council of Agricultural Research Institutions under the Department of Animal Husbandry and Fisheries, Government of India Fisheries Institutes in states	State Fisheries Universities ICAR-Central Institute of Fisheries Education Faculty of Fisheries in various universities
Indonesia	The Agency for Research and Development of Marine Affairs and Fisheries is the research organization under the Ministry of Marine Affairs and Fisheries that is responsible for the conduct of research. Various research institutions are under this agency. Under the capture fisheries umbrella are the Marine Fisheries Research Institute, Jakarta), Inland Fisheries Research Institute, Palembang and the Freshwater Research Institute, Bogor, Research Institute for Freshwater Aquaculture, Brackish water Aquaculture and Mariculture, Research Institute for Post-harvest Technology and Research Institute for Socio-economics.	Ministry of Marine Affairs and Fisheries has an Agency for Human Resources Development that is responsible for fisheries education, training and extension. Education is available in high schools and colleges, and universities offering an academic education in fisheries subjects.
Iran (Islamic Republic of)	Iran Fisheries Research Institute Agricultural Technology Research Institute of Iran, Marine Biotechnology Department	Iran Fisheries Research Institute

Country	Institutions/infrastructure for R&D	Educational institutions
Japan	National Research Institute of Aquaculture Ministry of Agriculture, Forestry and Fisheries Japan Fisheries Research and Education Agency Hokkaido National Fisheries Research Institute Tohoku National Fisheries Research Institute Japan Marine Fishery Resources Research Centre National Research Institute of Fisheries Engineering	National Research Institute of Aquaculture Japan fisheries research and education agency Hokkaido National Fisheries Research Institute Tohoku National Fisheries Research Institute Japan Marine Fishery Resources Research Centre National Research Institute of Fisheries Engineering
Kazakhstan	Kazakhstan Institute of Fisheries	
Democratic People's Republic of Korea	N/A	N/A
Republic of Korea	Ministry of Oceans and Fisheries National Institute of Fisheries Science Private aquaculture companies with R&D laboratories	Pukyong National University
Lao People's Democratic Republic	Department of Livestock and Fisheries Mekong River Commission	
Malaysia	Fisheries Research Institute Malaysia The National Prawn Fry Production and Research Centre The Freshwater Fisheries Research Centre The Brackish water Research Centre The Marine Fish Production and Research Centre The Fisheries Research Institute The Likas Research Station	University College of Science and Technology The Science University in Penang The University of Malaya The University of Malaysia Sarawak The Putra University The University of Malaysia The National University Malaysia The University of Technology Malaysia
Maldives	Marine Research Centre Ministry of Fisheries and Agriculture	
Mongolia	Food and Agriculture Organization (FAO) programme on "Developing aquaculture for improved fish supply in Mongolia National Biotechnology Board	Government research institutes

Country	Institutions/infrastructure for R&D	Educational institutions
Myanmar	Network of Aquaculture Centres in Asia Pacific	
Nepal	National Agricultural Research Council research and development programme on fish farming Tarahara and Parwanipur Fisheries Research Programmes under the Regional Agricultural Research Centers for Warm Water Aquaculture Fisheries Research Center Pokhara for lake and reservoir fisheries Fisheries Research Center Trishuli on riverine species Fisheries Research Division Godavari on cold water fisheries	Fisheries Research Center Pokhara for lake and reservoir fisheries Fisheries Research Center Trishuli on riverine species Fisheries Research Division Godavari on cold water fisheries
Pakistan	Department of Fisheries, University of Veterinary and Animal Sciences, Islamabad	Department of Fisheries, Punjab Government Department of Zoology, Punjab University Lahore University of Karachi (Centre of Excellence in Marine Biology and Marine Reference Collection and Resource Centre) National Institute of Oceanography, Karachi National Institute of Agriculture Biotechnology Veterinary Research Institute, Lahore
Philippines	National Fisheries Research and Development Institute Southeast Asian Fisheries Development Center Aquaculture Department National Fisheries Biological Center	The Marine Science Institute of the University of the Philippines
Singapore	Ministry of Agriculture Marine Fisheries Department	National University of Singapore
Sri Lanka	National Committee on Livestock, Aquaculture and Fisheries is responsible for facilitating interaction among scientists in the sector, exchange research information and to identify research priorities and needs.	N/A
Thailand	Department of Fisheries	
Timor-Leste	Department of Fisheries	

Country	Institutions/infrastructure for R&D	Educational institutions
Uzbekistan	Uzbekistan Commission on Fish Resources and Fish Reproduction Protection State Fisheries Department Ministry of Agriculture and water resources	-
Viet Nam	Fisheries Institute of Technology and Training Nha Trang University Institute of Aquaculture Institute of Marine Science and Fishing	College of Fisheries
Pacific		
Australia	Abrolhos Islands Research Institute Aquaculture and Native Fish Breeding Laboratory Australian Institute of Marine Science BASF Commonwealth Scientific and Industrial Research Organisation Ecosystem-Based Fisheries Management Flinders University Centre for Marine Bioproducts Development Indian Ocean Marine Research Center Pemberton Freshwater Research Centre South Australian Research and Development Institute The University of Western Australia University of New South Wales Centre for Marine Bio-Innovation Watermans Bay Marine Research Facility Western Australian Marine Sciences Institution	The Australian Maritime and Fisheries Academy Australian Maritime College University of Tasmania Institute of Marine and Antarctic Studies Centre for Marine Bioproducts Development in Flinders University, School of Tropical and Marine Biology in James Cook University Southern Cross University of New South Wales Centre for Marine Bio-Innovation
Cook Islands	None	None
Fiji	None	The College of Agriculture, Fisheries and Forestry of the Fiji National University provides higher level education on fisheries
Kiribati	None	None
Marshall Islands	None	None
Micronesia (Federated States of)	None	None
Nauru	None	None

Country	Institutions/infrastructure for R&D	Educational institutions
New Zealand	National Institute of Water and Atmospheric Research Cawthron Institute	University of Auckland is the main driver of fisheries research and education in New Zealand Various other universities also provide courses in fisheries
Niue	None	None
Palau	None	None
Papua New Guinea	None	None
Samoa	None	None
Solomon Islands	None	None
Tonga	None	None
Tuvalu	None	None
Vanuatu	None	Vanuatu Agriculture College provides certificate courses in animal science (aquaculture)

Table 5.4. Illustrative examples of policies, legislation and international collaboration relating to livestock biotechnology in the Asia-Pacific region

Country	Policy/legislation	International collaborations
Asia		
Afghanistan	N/A	International Livestock Research Institute
Bangladesh	Bangladesh Biosafety Rules (2012 BR) Biosafety Guidelines (2007 BG) National Guidelines for Fish and Animal Biotechnology (2006)	International Livestock Research Institute
Bhutan	RNR frame work for Bhutan in livestock research Ministerial Decree 2000 National Bio safety Framework 2006 National Environment Protection Act 2007	Bangladesh is a member of the World Organization for Animal Health (OIE) and the Codex Alimentarius (Codex), although its activity in these two international bodies has been limited.
Brunei Darussalam	Sixth National Development Plan (1991–1995) Tenth National Development Plan (NDP) (2013–17) Buffaloes act 1908	International Livestock Research Institute
Cambodia	The Agricultural Sector Strategic Development Plan (ASDP), 2014–2018- “Rectangular Strategy-Phase III” Pillar No 2 of Rectangular strategy emphasizes - Promotion of livestock and aquaculture 10 years Strategic Planning Framework for Fisheries, 2010–2019 “Policy Statement for Fisheries" Framework for Livestock - 2016	SEARCA; Philippines and Brunei have agreed to cooperate in developing their halal industry.
China	Agricultural Genetically Modified Organisms Safety Administration Regulations (2001) 13th five year plan (2016–2020)	Culture-based fisheries development in Cambodia funded by ACIAR Village-based biosecurity for livestock disease risk management in Cambodia The MEKARN program with support from SIDA
India	National Livestock Policy 2013 National Policy for Containment of Anti-microbial Resistance 2011 (Livestock production)	The scientific competence and excellence in conducting various research programmes at the institute has attracted funds from various National and International

Country	Policy/legislation	International collaborations
	Indian Veterinary Council Act, 1984	Organisations / agencies. To exchange information and acquire current and advanced knowledge in basic and applied fields of Dairy Science, the Institute maintains close liaison with various ICAR/CSIR Institutes, Dept. of Biotechnology, Dept. of Science and Technology, NDDB, Ministry of Food Processing and Industry, SAUs and various State Government Agencies at National level and several International Organisations such as World Bank, IAEA, UNDP, IDF, DAAD, Volkswagen Foundation, AvH Foundation and several leading institutions in UK, USA, Canada, Germany, Netherlands and Australia. ILRI-ICAR Partnership
Indonesia	Self Sufficiency Program On Beef In 2014 Law on Animal Husbandry and Veterinary Act No. 6/1967, - Article 13 National Policy, Strategy and Management Plans for the Conservation of Farm Animal Diversity National Livestock Breeding Policy	Indonesia-ILRI The MEKARN program with support from SIDA - on livestocks ACIAR
Iran (Islamic Republic of)	National Bio safety Framework (2007) Cartagena Protocol (2003)	
Japan	Cartagena Protocol on Biosafety in 2003. Prefectural rules on use of GMOs	International Livestock Research Institute
Kazakhstan	The Law of the Republic of Kazakhstan “Specially Protected natural areas. National strategy and action plan on conservation and sustainable use of biological diversity Cartagena Protocol on Biosafety in 2008	RCB-AIST Agreement for Joint Research Training and Capacity Building in Bio-imaging and Biotechnology
Democratic People’s Republic of Korea	N/A	Harbin veterinary Research institute for development of vaccine and diagnostic reagents FAO John Innes Centre of the United Kingdom Murdoch University of Australia University of Liege of the Belgium Rural development administration of South Korea China and

Country	Policy/legislation	International collaborations
		Serbia will enhance cooperation in agricultural investment and technological development especially in the areas of Meat Processing, vegetable and Fruit processing. Commonwealth Scientific and Industrial Research Organization (CSIRO)
Republic of Korea	Framework Act on Agriculture and Fisheries, Rural Community and Food Industry Livestock Processing Control Act (Pharmaceutical products produced from GE animals come under pharmaceutical affairs act) Amendments to the enforcement regulations of the Act on promotion of environmentally friendly farming and fisheries and management and support of organic foods" – June 3rd 2017 Inland Water Fisheries Development Promotion Act (1975, as amended)	Republic of Korea, along with FAO, is planning to help develop fish farms in the Democratic People's Republic of Korea University of the Republic of Korea and US – 'gi blue' a cloned pig Chinese/Republic of Korea joint venture firms to mass produce cloned beef.
Lao People's Democratic Republic	The Ministry of Agriculture and Fishery (MAF) has a Livestock Strategy for Agricultural Development, 2011–2020 NABP – II program	FAO-Lao People's Democratic Republic Government collaboration- "Sustainable insect farming and harvesting for better nutrition, improved food security and household income generation" A current project on "development of a bio-secure market-driven beef production system in Mekong region in Lao People's Democratic Republic and another is focusing on improving risk management on trans-boundary livestock diseases" – funded by ACIAR Culture-based fisheries development in Lao People's Democratic Republic funded by ACIAR The MEKARN program with support from SIDA - on livestocks
Malaysia	The National Agro-Food Policy (2011 - 2020) Animals Act 1953 Malaysian Livestock Breeding Policy 2013 Biosafety Act 2007	ACIAR CSIRO
Maldives	N/A	N/A

Country	Policy/legislation	International collaborations
Mongolia	Law on Animal Husbandry Genealogy and Health Protection (2001)	
Myanmar	Animal health and Development law	Research Institute of Animal Husbandry cooperates with international organizations (FAO, IAEA and World Bank), and with the scientists of the USA, France, Japan, China, Russian Federation, Norway, Switzerland, Italy, Kazakhstan, Republic of Korea, Germany, and Hungary implementing collaborative research projects on animal genetics, pasture management, feed production, and advanced reproduction technology for farm animals. For instance, research projects for selective breeding, nutrition and feeding technologies of Montbeliarde breed cattle and Alpine breed dairy goats imported from France are now being implemented.
Nepal	Animal Feed Act, 1976 Animal Health and Livestock Services Act, 1999 Animal Health Program Implementation Procedure, 2013 Animal Slaughterhouse and Meat Inspection Act, 1999 Forestry Sector Policy, 2000 (Forest Policy, 2000) National Micro-Finance Policy, 2005 Dairy Development Policy, 2007 Agriculture Bio-diversity Policy, 2007 Trade Policy, 2009 - Climate Change Policy, 2011 Breeding Policy, 2011 Birds Rearing Policy, 2011 Livestock Insurance Policy and Agriculture and Livestock Insurance Regulation Cartagena Protocol on Biosafety on March 2, 2001	International Livestock Research Institute
Pakistan	The Government of Pakistan's 2005 Biosafety Rules	Programmes on large and small ruminant breeding were executed in collaboration with the livestock departments of Punjab, Sindh, NWFP, Baluchistan and AJK.

Country	Policy/legislation	International collaborations
Philippines	Animal Welfare Act 1998	N/A
Singapore	Animals and Birds Act 1965 Wholesome Meat and Fish (Fees) Rules 2006	Asia-Pacific Economic Cooperation (APEC) World Organisation for Animal Health.
Sri Lanka	National Biotechnology Policy of 2010 Animal Act No. 29 of 1958 Animal Act Regulations Amendments of 2009 National Aquaculture Development Authority of Sri Lanka Act (1998)	N/A
Thailand	Royal Ordinance on Fisheries B.E. 2558 (2015) Animal Anti-Cruelty And Welfare Act, 2014	Collaboration between Department of Livestock Development, Thailand and National Institute of Animal Health, National Agriculture and Bio-Oriented Research Organization, Japan for Avian Influenza and Swine influenza, Zoonotic Diseases Collaboration Center (ZDCC) Project, 2015 Scientific collaboration between Animal, Plant and Fisheries Quarantine and Inspection Agency (QIA), Republic of Korea and National Institute of Animal Health, Thailand for the joint research project on the Molecular Epidemiological Analysis of Brucella Species from a variety of Animals and application on Diagnostics for *Brucella canis* in Thailand (2013) OIE Laboratory Twinning Project on New and Emerging Diseases Emerging Infectious Diseases) between Thai-NIAH and Australian Animal Health Laboratory, World Organization for Animal Health (2014)
Timor-Leste	N/A	
Uzbekistan	No official policy. Uzbekistan Policy and Strategic Plan is currently under active consideration by MAWR.	N/A
Viet Nam	Decision no 10/2008/QĐ-TTg dated 16/01/2008 by Prime Minister approving the strategy on animal breeding development up to 2020 Decision no 124/QĐ-TTg dated February 2nd 2012, approving the	The Viet Nam National Institute of Animal Science (NIAS) and the International Livestock Research Institute (ILRI) are enhancing their collaboration to further advance livestock research in the country

Country	Policy/legislation	International collaborations
	master plan of production development of agriculture to 2020 and a vision toward 2030 (land, material area for animal feed production, breeding) Decision no 899/QĐ-TTg dated June10th 2013, approving the project “Agricultural restructuring towards raising added values and sustainable development” that show general orientation about agricultural restructuring and sub-sectors restructuring (include livestock: section II, point 2b) Decision no 984/QĐ-BNN-CN dated May 9th 2014 by Minister of Agriculture and Rural Development about approving the project livestock restructuring Decision no 985/QĐ-BNN-CN dated May 9th 2014 by Minister of Agricultural and Rural Development promulgating plan on livestock restructuring.	Viet Nam’s Ministry of Agriculture and Rural Development (MARD) and CGIAR recently evaluated on-going research by CGIAR centres in the country and developed plans for further collaboration in agricultural research for development The Viet Nam Government is supporting the World Bank-funded Livestock Competitiveness and Food Safety Project (LIFSAP), which aims to improve the competitiveness of household-based livestock producers by addressing production, food safety and environment risks in supply chains The MEKARN program with support from SIDA
Pacific		
Australia	Gene Technology Act 2000	N/A
Cook Islands	N/A	N/A
Fiji	Animals (Control of Experiments) Act [Cap 161], 1957	N/A
Kiribati	N/A	None for biotechnology
Marshall Islands	N/A	N/A
Micronesia (Federated States of)	N/A	Western SARE (Sustainable Agriculture Research and Development) issues grants and education towards sustainable development of agriculture. It has several projects in Federated States of Micronesia that work towards both the sectors of crops, livestock and fisheries.
Nauru	N/A	N/A
New Zealand	Hazardous Substances and New Organisms Act 1996 Resource Management Act 1991 Animal Control Products Limited Act 1991	N/A

Country	Policy/legislation	International collaborations
	Animal Products Act 1999 Animal Welfare Act 1999	
Niue	Niue Agriculture Sector Plan 2015–2019	N/A
Palau	N/A	N/A
Papua New Guinea	Animal Act, 1952.	N/A
Samoa	The Agriculture Sector Plan for 2016 to 2020	N/A
Solomon Islands	Agriculture and Livestock Act, 1996 Agriculture and Livestock Sector Policy 2015–2019	N/A
Tonga	Animal Diseases Act 1978 Pounds and Animals Act 1989	HANGO Agricultural College Project, 2015 is funded by European Union-The Pacific Agriculture Policy Project (PAPP) and The Pacific Community (SPC)
Tuvalu	N/A	N/A
Vanuatu	N/A	The Australian Centre for International Agricultural Research collaborates with home-grown organisations in Vanuatu, developing sustainable strategies to enhance production of sustenance farming and cash crops as well as large-scale developments in the agriculture, fisheries and forestry industries

Table 5.6. Policies and international collaborations related to forestry

Country	Forest policies/acts/plans	International collaborations
Asia		
Afghanistan	The National Forest Policy	Asian Development Bank International Monetary Fund World Bank
Bangladesh	National Biotechnology Policy (2005) Master Plan for the Forestry Development (1993) National Environmental Management Plan (1994) The Forest (Amendment) Act (2000) National Land Use Policy (2001) Social Forestry (Amendment) Rules (2010) Forest Produce Transit (Control) Rules (2011)	None
Bhutan	Forest and Nature Conservation Act (1969) The Forest Master Plan (1991) Fiscal Year Plan (8FYP) on Forestry (Eighth) (1996)	The Third Forestry Development Project assisted by World Bank/SDC, duration of 1994–2002, costing US$ 6.8 million Bhutan–German Sustainable RNR Development Programme; supported by Germany; duration of 1997–2000; costing US$ 2.6 million Integrated Forestry Management; assisted by Austria; duration 1999–2001; costing US$ 2.3 million Jigme Dorji Wangchuck National Park; supported by UNDP/GEF; duration 1997–2001; costing US$1.6 million Royal Manas National Park, supported by WWF; costing US$ 0.9 million Biodiversity Conservation; supported by the Netherlands; duration 1997–2002; costing US$ 1.7 million Wang Watershed Development; supported by EU; costing US$ 8.4 million Institutional Development Initiative; supported by IDF; duration 2000–2002; costing US$ 0.5 million An environment and biodiversity conservation project has been in place supported by the Global Environment Facility (GEF), WWF, and Austria
Brunei Darussalam	National Forestry Policy (1989) 5th National Development Plan (NDP) (1986–1990)	N/A

Country	Forest policies/acts/plans	International collaborations
	Forest Act (1934)	
Cambodia	Number NSRR/RKM/0196/13 Promulgating Law on Establishment of Ministry of Agriculture and Fisheries National Forest Programme 2010–2029 – under National Strategic Development Plan 2014–2018 National Policy on Green Growth (2013) Law on Forestry (2002) Law on the Establishment of the Ministry of Agriculture, Forestry and Fishing (January 1996) Law Decree on Forestry Administration (KR.C No. 35 of 1988)	ACIAR International Development Research Centre
China	Forest Law of the People's Republic of China (1998) National Forest Protection Program (1992) Simao Forestry Action Programme Qing Fang Forestry Action Programme Forestry Action Plan for China’s Agenda 21 (1999)	N/A
India	National Biotechnology Development Strategy 2015–2020 National Forestry Action Programme (1927) Indian Forestry Act (1998) National Forest Policy (1986) Environment Protection Act (1961) Forest Action Plan in the 8th National Development Plan (1997–2001) National Forest Policy (1991)	
Indonesia	Forest Act 1999 Government Regulation No. 24/2010 on the Use of Forest Areas (1 February 2010) Government Regulation No. 10/2010 on the procedure of altering the appropriation and function of forest areas (22 January 2010) Minister of Forestry Regulation No. P.4/Menhut-II/2011 - Forest Reclamation Guidelines (14 January 2011) Law No. 41/1999 on Forestry Affairs (30 September 2009)	Indonesia signed the UNFCCC in January 1992 and has actively participated in REDD+ discussions Republic of Korea-Indonesia Joint Project for Adaptation and Mitigation for Climate Change in Forestry

Country	Forest policies/acts/plans	International collaborations
	Government Regulation No. 60/2012 on the amendment of No. 10/2010 on Procedures for Altering the Appropriation and Function of Forest Areas (6 July 2012) Ministry of Forestry Decree No. 7416/Menhut-VII/IPSDH/2011 on the Determination of Indicative Maps for Postponing New Licenses, Forest Area Utilization and Designation Changes of Forest Areas and Other Designated Areas (22 November 2011)	
Iran (Islamic Republic of)	Environmental Protection and Enhancement Act (1974) Plants Protection Act (1967)	N/A
Japan	Basic Policy and Action Plan for Revitalization of Japan's Food, Agriculture, Forestry and Fisheries Forest Law (revised) National Biodiversity Strategy of Japan Forestry Basic Law Law of Administrative and Management of National Forests Forest Pest and Disease Control Law Nature Conservation Law Natural Parks Law	Japan is implementing the ODA on forest and forestry matters through multilateral organisations, such as UNEP, FAO, CGIAR, and ITTO.
Kazakhstan	The Forest Code of the Republic of Kazakhstan (1993) The Law on Conservation, Restoration and Wise Use of Wildlife (1993) The National Environment Action Plan	Collaboration with the private sector
Democratic People's Republic of Korea	N/A	N/A
Republic of Korea	1st National Forest Plan (1973–1978): Forest Rehabilitation Project 2nd National Forest Plan (1979–1987): Forest Rehabilitation Project 3rd National Forest Plan (1988–1997): Forest Resource Establishment Project 4th National Forest Plan (1998–2007) 5th National Forest Plan (2008–2017) Forest Law (1961) The Framework Act on Forest (replaces the 1961 Forest Law) (2001)	The Korea Forest Services has signed bilateral agreements on forestry cooperation with 27 countries (Algeria, Argentina, Australia, Austria, Benin, Brazil, Chile, China, Ecuador, Ethiopia, Indonesia, Japan, Kazakhstan, Kyrgyzstan, Lao People's Democratic Republic, Mongolia, Myanmar, New Zealand, Paraguay, Philippines, Russian Federation, Tajikistan, Tunisia, Turkmenistan, Uruguay, Uzbekistan, Viet Nam)

Country	Forest policies/acts/plans	International collaborations
	Act on the Promotion and Management of Forest Resources (2005) Act on National Forest Management (2005) Act on Forest Culture and Recreation (2005) Erosion Control Act (1962) Act on Distribution of Special Employees for Forest Protection (1963) Act on Forestry Cooperatives Federation (1993) Act on Promotion of Forestry and Mountain Villages (amended) (2001) Act on Establishment and Promotion of Forest Arboretum (2001) Forest Land Management Act (2002) Act on Pine Wilt Disease Prevention (2006)	
Lao People's Democratic Republic	MAF Minister's Order Regarding the Enhancement of Forest Regeneration in the Country Wide No. 0111/MAF 24 November 2008 Forestry Law No.6/NA 24 December 2007 Strategy on Climate Change of the Lao People's Democratic Republic Forestry Strategy to the Year 2020 of the Lao People's Democratic Republic Strategy for Agricultural Development 2011 to 2020 (Lao People's Democratic Republic) National Socio-economic Development Plan 2011–2015 (Lao People's Democratic Republic) Agricultural Master Plan 2011–2015 (Lao People's Democratic Republic) National Environment Strategy to the Year 2020 (Lao People's Democratic Republic) Forestry Strategy to the Year 2020 Forest Law Enforcement, Governance and Trade (Lao People's Democratic Republic) The Forest Resources Inspection Strategy Action Plan	ACIAR Reducing Emissions from Deforestation Ministry for Foreign Affairs (Finland) Ministry for Foreign Affairs (Japan) World Bank FAO German Development Bank
Malaysia	The National Forest Policy (1978)	Collaboration in forestry at the regional level is implemented through the

Country	Forest policies/acts/plans	International collaborations
	The National Forestry Act (1984)	Association of South East Asian Nations administrative structure through the following: a) ASEAN Common Forestry Policy b) Technical Cooperation c) Forestry Institutions d) Cooperation in Intra-ASEAN Timber Trade; and e) ASEAN Common stand on international issues on forestry. Also present are collaborations with International Timber Trade Organization (ITTO), Malaysia– Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) on sustainable forest management and conservation, Malaysia-EC projects on training of forest workers in Sabah, Malaysia-Japan project on multi storied forest management etc.
Maldives	National Biodiversity Strategy and Action Plan (2001)	FAO assistance in Maldives is shaped by the 2013–2017 FAO Country Programming Framework
Mongolia	National Policy on Environmental Protection (1997) Forest Law (1996) Law on Forest Fire Protection (1996) Law on Forest Resource Fee (1996) National Environmental Action Plan (1993–2010)	N/A
Myanmar	National Forest Policy (1995) National Forestry Action Plan (1995) Wild Plants and Natural Areas Law (1994) Nationwide Tree Planting Programme (1999)	Regional Wood Energy Development Programme for Asia. Regional Project on Assistance for the Implementation of the model forest approach sustainable forest management in the Asia Pacific Region. Forestry Research Support Programme for Asia and Pacific Information and Analysis for Sustainable Forest Management Linking National and International Efforts in South Asia and South East Asia. Strengthening Reforestation Programmes in Asia A national workshop was held in November December 1995 Four zonal working groups on mangrove, teak, hilly, and dry zones to deliberate and make recommendations on policy,

Country	Forest policies/acts/plans	International collaborations
		problems and constraints, people's participation, technical matters, and suggested problem resolution on re-afforestation programmes. Forestry Planning and Policy Assistance in Asia and the Pacific Region The Forestry Department and UNDP/FAO are implementing three projects Environmentally sustainable food security and micro-income opportunity in the dry zone. Environmentally sustainable food security and micro income opportunity in the critical watersheds of Shan State. Environmentally sustainable food security and micro income opportunity in the Ayeyarwady (mangrove) delta, Phase III.
Nepal	Master Plan for the Forestry Sector (1988) The Forest Act (1993) Forest Protection Special Act (1968) Forest Products Sales and Distribution Rules (1971) The Private Forest Rules (1984)	Many donor agencies have been assisting the country in forestry sector development, including DANIDA, USAID, FINNIDA, ADB, IFAD, AusAID, GIZ, SDC, DFID, UNHCR, EEC, JICA, UNDP, WWF, FAO, the Netherlands, WB, CARE, The country has also received support from several regional/ sub regional projects
Pakistan	The Master Plan for Forestry Development (1993–2018) National Conservation Strategy (1992)	Financial assistance from FAO, UNDP, World Bank; ADB, International Fund for Agricultural Development
Philippines	Forest management in the country is governed by Presidential Decree No. 705, as amended, otherwise known as the "Revised Forestry Code of the Philippines" (1975) Master Plan for Forestry Development (1988) Community Based Forest Management Strategy (1995)	Forestry Sector Project was implemented through financial assistance from ADB, Japan-OECF, and the Philippines Government.
Singapore	National Biodiversity Strategy and Action Plan (2009)	APEC
Sri Lanka	Sri Lanka National Biotechnology Policy 2009 Forestry Sector Master Plan (1986) National Forestry Policy (1995) National Conservation Strategy (1988) National Environmental Action Plan (1998) Five Year Implementation Programme (1997)	Forest Sector Development Project, co-financed by the World Bank, FINNIDA, ODA, and UNDP\FAO, was launched in 1990 Combat Desertification (1999)

Country	Forest policies/acts/plans	International collaborations
Thailand	Forest Action plan in the 8th National Development Plan (1997–2001) National Forest Policy (1991)	International Tropical Timber Agreement; (ITTA), CITES, RAMSAR, World Heritage Convention; Forestry Research for Asia and the Pacific (FORSPA); Regional Wood Energy Development Programme (RWEDP); Information and Analysis for Sustainable Forest Management; Model Forest Approach for Sustainable Forest Management; Regional Community Forestry Training Programme (RECOFT); Asian Institute of Technology (AIT).
Timor-Leste	Law (Act or Code) on Forest with National Scope (2000) Forest Policy Statement with National Scope (2007) National Development Plan (2002) National Forest Policy (2005)	N/A
Uzbekistan	Law on “Protection and use of wildlife” (1985) Law on “Protection of nature” (1992) Law on “Land” (1990) Law on “Protection of air” (1996) Law on “Water and water use” (2001) Law on “Water and water use" (2003)	Asia Japanese International Cooperation Development Bank Agency
Pacific		
Australia	National Forest Policy Statement (1992) Wood and Paper Industry Strategy (1995) Vision 2020 Strategy document (1998) Environment Protection and Biodiversity Conservation Act (1999)	No Data Available
Cook Islands	N/A	N/A
Fiji	Forest Policy (2007) Forest Decree (1992)	N/A
Kiribati	N/A	N/A
Marshall Islands	N/A	N/A
Micronesia (Federated States of)	National Environmental Management Strategy (1991) National Biodiversity Strategy and Action Plan (2002)	N/A
Nauru	N/A	N/A
New Zealand	Forests Act 1949 Forests Amendment Act 1993 Forests Act 1949	

Country	Forest policies/acts/plans	International collaborations
	Forestry Encouragement Act 1962 Forestry Rights Registration Act 1983 Forests (West Coast Accord) Act 2000 Resource Management Act 1991	
Niue	N/A	N/A
Palau	N/A	N/A
Papua New Guinea	The National Forest Policy (1990) Forest Act (1991)	Several donors have been providing support to the forestry sector development in the country including: the Japanese Government (JICA), ITTO, the New Zealand Government, Australia (AusAid), bilateral NGOs from the USA (McArthur Foundation), WB, UNDP, GEF, and FAO.
Samoa	National Environment Management Strategy Forest Act (1967) Forest Regulation (1969) Lands Act (1964) National Forest Policy (1995)	The establishment of field trials for priority tree species in collaboration with SPRIG Slow release fertilisers and testing other alternative growing media studies in collaboration with ACIAR; Testing of silvicultural systems appropriate for natural regeneration
Solomon Islands	The National Forest Policy (1994) Forest Act (1999)	N/A
Tonga	Forest Act (1991)	In the forest sector development the government received support from partners, particularly from international institutions, including: New Zealand Overseas Development Assistance; Australian International Development Assistance Bureau (AIDAB), FAO, European Community, German Technical Cooperation (GIZ), CIRAD-Foret, UNDP/South Pacific Regional Environmental Programme (SPREP) and South Pacific Forestry Development Programme (SPFDP), and Japan Overseas Co-operation Volunteers
Tuvalu	N/A	N/A
Vanuatu	National Forest Policy Reviewed and revised in 2013, it was initially established in 1998	Many donor agencies have been involved in the forestry sector development in the country. They include AusAID, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), the European Union, New Zealand Official Development Assistance, FAO and United Nations Development Programme.

Table 5.8. Enabling environment in various countries of the region in fisheries/aquaculture

Country	Policy/legislative system
Asia	
Afghanistan	N/A
Bangladesh	Bangladesh Biosafety Rules (2012 BR)
	Biosafety Guidelines (2007 BG)
	National Guidelines for Fish and Animal Biotechnology (2006)
Bhutan	N/A
Brunei Darussalam	N/A
Cambodia	Agricultural Sector Strategic Development Plan, 2014–2018- "Rectangular Strategy-Phase III"
	Pillar No 2 of Rectangular strategy emphasizes promotion of livestock and aquaculture
	10-year Strategic Planning Framework for Fisheries, 2010–2019.
	"Policy Statement for Fisheries"
China	Agricultural Genetically Modified Organisms Safety Administration Regulations (2001)
	13th Five-Year Plan (2016–2020)
India	Guidelines for Regulating Establishment and Operation of Specific Pathogen Free (SPF) Shrimp Broodstock Multiplication Centres (BMC) and Proforma for Submitting Proposal for Establishment of Shrimp BMC
	Guidelines on Fish Seed Data (21.06.17)
	National Policy on Marine Fisheries 2017
	Guidelines for Import of Asian Seabass/Barramundi (*Lates calcarifer*) Seeds and Fingerlings
	Guidelines for the States for Framing a Bill on Inland Fisheries and Aquaculture
	Guidelines for Developing Fish Seed Certification and Accreditation System in India
	Comprehensive Marine Fishing Policy 2004
	Notification regarding Guidelines for Regulating Hatcheries and Farms for Introduction of *Litopenaeus vannamei*
	Guidelines Culture of SPF
	Guidelines *L. vannamei* in FW (29–9-2011)
	Amendment to the Guidelines for Regulating Hatcheries and Farms for Introduction of *Litopenaeus vannamei*
	Notification Amending the Costal Aquaculture Authority Rules, 2005

Country	Policy/legislative system
	Notification Regarding Guidelines for Farms for *Penaeus monodon* Culture to Take *Litopenaeus vannamei* Notification regarding Guidelines for Seed Production and Culture of Specific Pathogen Free (SPF) *Penaeus monod* Tilapia Policy Guidelines
Indonesia	N/A
Iran (Islamic Republic of)	National Biosafety Framework (2007) Game and Fish Law (1967)
Japan	Fisheries Law (1949, as revised in 1962) The Fisheries Cooperative Association Law (1948) The Law to Ensure Sustainable Aquaculture Production (1999)
Kazakhstan	Water Code of the Republic of Kazakhstan (2003) Protected Natural Areas National Strategy and Action Plan on Conservation and Sustainable Use of Biological Diversity
Democratic People's Republic of Korea	N/A
Republic of Korea	Framework Act on Agriculture and Fisheries, Rural Community and Food Industry Livestock Processing Control Act Quality Control of Fishery Products Act Control of Livestock and Fish Feed Act Pharmaceutical products produced from GE animals come under pharmaceutical affairs act. "Amendments to the enforcement regulations of the Act on promotion of environmentally friendly farming and fisheries and management and support of organic foods" – June 3rd 2017 Inland Water Fisheries Development Promotion Act (1975, as amended)
Lao People's Democratic Republic	NABP – II program
Malaysia	The National Agro-Food Policy (2011–2020) Sabah Inland Fisheries and Aquaculture Enactment 2003 The Fisheries Act 1985
Maldives	N/A
Mongolia	N/A
Myanmar	National Fishery Policy Land Use Policy Myanmar Marine Law

Country	Policy/legislative system
	Aquaculture Law
Nepal	N/A in terms of EE for AB
Pakistan	The Government of Pakistan's 2005 Biosafety Rules
Philippines	The Fisheries Code 1998
Singapore	N/A
Sri Lanka	National Biotechnology Policy of 2010 Fisheries and Aquatic Resources Act (1996) National Aquaculture Development Authority of Sri Lanka Act (1998)
Thailand	Royal Ordinance on Fisheries B.E. 2558 (2015)
Timor-Leste	N/A in terms of EE for AB
Uzbekistan	N/A
Viet Nam	N/A
Pacific	
Australia	Gene Technology Act 2000 Fish Resources Management Act 1994
Cook Islands	N/A
Fiji	Fisheries Act Cap 158 Marine Spaces Act Cap 158A Fisheries Offshore Decree
Kiribati	Kiribati's National Fisheries Policy 2012 – 2025
Marshall Islands	Fisheries is an important focus sector in Marshall Islands Country Programming Framework (CPF) 2013–2017 Marshall Islands Mariculture Development Plan Marshall Islands Marine Resources Authority Act, 1988 Marshall Islands Marine Resources Act of 1997
Micronesia (Federated States of)	Micronesia Strategic Development Plan of 2015–2017 includes need of capacity building in the sector of fisheries
Nauru	Nauru Fisheries and Marine Resources Authority Act 1997 Fisheries Act 1997
New Zealand	Fisheries Act 1983 Marine Mammals Protection Act 1978 Marine Reserves Act 1971
Niue	Niue Agriculture Sector Plan 2015–2019
Palau	Marine Protection Act of 1994

Country	Policy/legislative system
Papua New Guinea	Fisheries Act, 1998
Samoa	Local Fisheries Regulations, 1995
	Fisheries Management Act, 2016
	The Agriculture Sector Plan for 2016 to 2020
Solomon Islands	Fisheries Management Act, 2015
Tonga	Aquaculture Management Act 2003
	Fisheries Management Act 2002
	Fisheries Act 1989
Tuvalu	Fisheries Act 1978 (subsequently amended in 1987, 1990 and 1991)
	Marine Resources Act 2006
	Marine Zones Act of 1993
	National Fishing Corporation of Tuvalu Act of 1980
	Livestock Diseases Act 1985
Vanuatu	Fisheries Act 1982 (amended many times)
	Fisheries Regulations, 1983
	Maritime Zones Act, 1981