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INTEGRATED AGRI-AQUACULTURE IN DESERT AND ARID LANDS: LEARNING FROM CASE STUDIES FROM ALGERIA, EGYPT AND OMAN





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Integrated agri-aquaculture in desert and arid lands: Learning from case studies from Algeria, Egypt and Oman

Edited by

Richard Corner
FAO International Consultant/Technical Editor
United Kingdom of Great Britain and Northern Ireland

Haydar Fersoy
Senior Fishery and Aquaculture Officer
Regional Office for the Near East and North Africa (RNE)
Cairo, Egypt

and

Valerio Crespi
Fisheries and Aquaculture Officer
Subregional Office for North Africa (SNE)
Tunis, Tunisia

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PREPARATION OF THIS DOCUMENT

The FAO Regional Initiative on Water Scarcity for the Near East and North Africa (WSI) was initiated in 2013, in response to a strong request from the 31st Session of the FAO Near East and North Africa (NENA) Regional Conference held in Rome in May 2012, and impacted by outcomes from the Kyoto Framework Agreement 2005–2015, within which lack of water resources is seen as a potential disaster scenario for the region. This document provides results from a WSI sub-project on the use of non-conventional water resources in integrated agriculture - aquaculture (IAA) systems as a means to produce more food per unit of water used, using case studies from three selected countries: Algeria, Egypt and Oman. These countries were identified as representative of cross-regional differences in non-conventional water use for integration of agriculture and aquaculture in the NENA region.

Within the three countries National Task Forces (NTFs) where set up and with the support of national partners, initiated country-based reviews, undertaken by NTFs and national consultants. These reviews included a review of IAA activities undertaken in each country, farm visits, questionnaire surveys and interviews. This was supplemented by farmer to farmer visits that enabled sharing of best management practices on IAA. Activity was concluded with a regional workshop held in Cairo, Egypt on 25–26 June 2019.

The report summarizes evidence of current IAA activity in the three partner countries participating in the project, with full country reports available as appendices. This document is of relevance to IAA practitioners, industry organizations, farmer associations, aquaculture policy makers and other stakeholders in all countries within the NENA region where there is a need to promote the smart use of water to maximize production of food and improve food security, both agricultural and aquaculture-based, in arid regions, using where possible non-conventional and other sources of water. The document concludes with a roadmap for upscaling of IAA in arid lands, developed by the experts who attended the Cairo workshop that should provide a sound basis for future development of Integrated Agriculture-Aquaculture within the NENA region.

The three national reports were edited by Richard Anthony Corner (FAO consultant) and the final document was prepared by Richard Corner, Haydar Fersoy (Senior Fisheries and Aquaculture Officer, FAORNE) and Valerio Crespi (Fisheries and Aquaculture Officer, FAOSNE).

CONTENTS

CONTRIBUTORS

Algeria

Ali Kettaf, Alili Mostefa, Fadila Seridi, Ferhati Bilal, Heba Hamid, Laouaoudja Mohammed Salah, Meziane Noureddine, and Souad Lani,

Eygpt

Adel El Shentenawy; Ahmed Abdel-Moez; Ahmed Saney Eldin Sadek; Amr Bassiouny; Basem Hashim Youssef; Faris Farrag; Sami El-Zeini; Hadeel Alaa Ali Hosney; Hisham Hagag; Hoda Elssewefi; Khaled Mohamed Agag; Mohamed Elsayed Elaraby; Mohammed Abdel Aty Mahdy; Mostfa Hassanen; Moustafa Moussa; Walid Salah Eldin; and Yasser Abdelhakim Mohamed Ahmed.

Oman

Adil Al-Sulaimani; Ahmed Al-Suti; Ahmed Yousuf Al-Busaidi; Dawood Suleiman Al-Yahyai; Fatma Rashid Al-Kiyumi; Halima Rashed Al-Azari; Hussein Al-Masroori; Ishaq Omar Al-Jabri; Saif Ali Al-Khamisi; Waleed Salim Al-Abri; Wenresti Gallardo; Yahya Al Jardani; Zahir Saif AlSalmani; and Ziyin Zhang.

FAO

Ahmed Al Mazrouai; Ghady Chedrawi; Hasna Al Harthy; Heba Fahmy; Hussein Gadain; Jean-Marc Faures; Matthias Halwart; Mohamed AlHamdi; Marianne Guyonnet, Mohamed Yacoub; Nabil Assaf, Nora Ourabah Haddad; Pasquale Steduto; Paula Anton; Ratiba Sengui; and Xinhua Yuan.

ABBREVIATIONS AND ACRONYMS

AFDF	Agriculture & Fisheries Development Fund (Oman)
ANGEM	National Agency for Micro credit Management in Algeria (Agence Nationale de gestion du Micro-crédit en Algérie)
BCM	Billion cubic metres
CNAC	National Unemployment Insurance Fund (Caisse Nationale d'Assurance chômage)
DAS	Division of Agricultural Services (Algeria)
DFFRW	Directorate of Fishing and Fishery Resources in the Wilaya (Algeria)
DGFA	Directorate-General of Fisheries and Aquaculture (Algeria)
DZD	Algerian Dinar (currency)
EASD	Executive Authority for Sinai Development (Egypt)
EGP	Egyptian Pounds (currency)
ETTAHADI	Investment credit granted by the Algerian bank for rural development (Banque algerienne pour le développement rural)
FAO	Food and Agriculture Organization (of the United Nations)
FCR	Feed conversion ratio
FTS	Flow-through system
GAFRD	General Authority for Fish Resources Development (Egypt)
GDP	Gross domestic product
IAA	Integrated Agri-aquaculture
MAF	Ministry of Agriculture and Fisheries (Oman)
MARDF	Ministry of Agriculture, Rural development and Fisheries (Algeria)
MOCI	Ministry of Commerce and Industry (Oman)
MOALR	Ministry of Agriculture and Land Reclamation (Egypt)
MT	Million tonnes
MWRI	Ministry of Water Resources and Irrigation (Egypt)
NCFARD	National Center for Fisheries and Aquaculture Research and Development (Algeria)
NENA	Near East and North Africa (region)
NTF	National Task Force
OR	Omani Riyal (currency)
RAS	Recirculating Aquaculture System
RFIG	Subsidized credit granted by the bank for agricultural and rural development (Algeria)
SMEs	Small and medium sized enterprises
SWOT	Strengths, weaknesses, opportunities and threats (analysis)
USD	United States Dollars (currency)
WSI	Water Scarcity Initiative (FAO)

SUMMARY

The FAO Regional Initiative on Water Scarcity (WSI), initiated in 2013, identified that lack of water resources is a potential disaster scenario for the Near East and North Africa (NENA) region. The WSI initiative developed out of 31st Session of the FAO Near East and North Africa (NENA) Regional Conference held in Rome in May 2012, outcomes from the Hyogo Framework Agreement 2005–2015, and highlighted through work undertaken by the Arab Water Council in reports in 2004, 2012 and 2015.

Several projects were started, including use of non-conventional water resources in integrated agriculture - aquaculture (IAA) systems within the NENA region. Agriculture is the largest food production type in the region and the highest water use. Aquaculture production is also a major food sector and development of integrated systems, for increase productivity and to reduce overall water use in food production, is a useful approach. Water scarcity is particularly acute in arid regions of the NENA region, and is a finite resource, with IAA competing for water with other large sectors including domestic and industrial use. Non-conventional water resources are identified as a potential resource to develop IAA systems in a more unified way, reducing the burden of use on standard renewable water resources.

The principle objective of the work was to build broad partnerships to support greater understanding in implementation and use of non-conventional water resource in IAA systems. The activity was supported by the FAO Regional Initiative on Water Scarcity (WSI) and FAO Global Knowledge Product (GKP) on water. Work was undertaken to summarize current approaches using three selected countries: Algeria, Egypt and Oman, identified to be representative of cross-regional differences in non-conventional water use for integrated agriculture and aquaculture across the NENA region. Three country National Task Forces (NTFs) were set up and with support from national partners country-based reviews were undertaken, which evaluated current activity in each country through questionnaire surveys and interviews with farmers and other stakeholders. Farmer-to-farmer visits provided a key component of the activity that enabled sharing of best management practices on IAA. Activity was concluded with a regional workshop held in Cairo, Egypt on 25-26 June 2019 that aimed to finalize a broad roadmap for further development activity.

Algeria

Development of aquaculture using non-conventional sources of water has developed slowly in Algeria since 2008. Currently there are approximately 600 farmers evaluating development potential through set-up and operation of IAA systems. These operate on a small scale, as farmers develop techniques and approaches to add aquaculture development within their farming systems in the context of arid climates. Some larger commercial scale operations have also been developed. Production of fish in these systems in 2017 was approximately 5 000 tonnes, primarily of tilapia, with some catfish and carps. These are integrated with more conventional agricultural crops such as date palm, cereals and market garden products. Farming experience is limited, often to just the last three to four years using a hobby-oriented approach. Development in extensive and semi-intensive systems is further hampered by limited understanding and training in production and culture practices. Peer-to-peer training is growing and some farmers have been able to benefit from overseas training visits.

Water use is currently based around more convention water use, particularly from groundwater sources drawn into holding basins which then feed the farm. Water quality is occasionally an issue depending on the underlying rock substrate type, with many desert water sources

officially classified as brackish water. Non-conventional sources of water have nonetheless been identified and include desalinated water and treated wastewater; and the use of Chotts, temporary slightly salt-water lakes in desert areas; with each of these having potential to benefit aquaculture-agriculture systems in arid environments. An analysis of farmer questionnaires and interview responses shows that integrating aquaculture with agriculture in arid environments is producing more benefits than conventional agriculture. This includes significantly reducing, and in some cases eliminating, the need for fertilization of crops. Crops are benefitting from increased nutrients from fish farm wastewater, and dual use of the same water means increased production from the same volume.

There is a difficulty at present making the aquaculture component of the system economically viable. The Algerian Governments Horizon 2035 programme has strong plans to increase aquaculture- agriculture production using non-conventional sources of water, supported by legislation updated in 2008 on the integration of aquaculture with agriculture. Overall, aquaculture integrated with agriculture is seen as a positive development for Algeria with firm plans to increase overall production. The case study report concludes with a series of recommendations, which includes setting up demonstration sites in use of non-conventional water, improved training and extension activity and research to better understand the application of non-conventional water in IAA systems in arid environments.

Egypt

Since 2010, use of non-conventional water sources in Egyptian desert-based aquaculture and agri- aquaculture systems has become more economically developed through government and private- backed ventures. Production from IAA farms has increased from 700 tonnes in 2010 to 2 200 tonnes in 2017. Approximately 100 commercial aquaculture desert farms have been set up in desert regions of Egypt, predominantly located in ten governorates within the broader Nile delta, high Egypt near the Nile valley and Sinai Peninsula. Eight fish species are produced, with Nile tilapia (*Oreochromis niloticus*) accounting for 90 percent of desert-based aquaculture production. Water for desert farms comes from underground saline water reserves, desalination plants and/or agricultural drainage. Water varies in salinity between 0.5 and 26 g/litre, and temperature from 22 to 26 °C. European seabass (*Dicentrarchus labrax*) and gilthead seabream (*Sparus aurata*) offer additional potential in higher salinity areas.

Linkage between fish culture in tanks using flow-through systems (FTS), and increased agriculture crop and livestock production derive from increased use of saline fish culture wastewater applied to salinity-tolerant crops using sprinkler and spray systems. Most commercial farms have adopted FTS to irrigate agricultural land for production of vegetables, fruit, arable crops, and clovers produced to feed livestock. Fish farm water contains microalgae and other debris that have consolidate sandy soils, and reduced water usage on vegetable and crop plots. Some IAA farms have introduced biogas production, using fish farm particulate wastes and vegetable matter to generate gas for domestic heating and cooking. The success stories in Egypt show how some companies, and government departments, are responding positively to development of agri-aquaculture systems and are establishing best practices. Aquaponics, linking fish production with soil-less plant production in recirculating systems, offers an additional approach, but in Egypt better research is required to evaluate the most effective and efficient aquaponic practices.

Overall, IAA systems in Egyptian deserts and arid lands offers an efficient approach for aquaculture and agriculture to co-exist within the same farm, reducing overall water use and offering benefits to the farmer. The Egypt report concludes with several recommendations, focused on improved research to establish the best approaches and management practices for agri-aquaculture production, training and extension activity to support rural desert community action groups in setting up systems, and improvements needed in governance and financial resourcing to improve development of IAA further.

Oman

Aquaculture is a promising industry for Oman that can contribute to increased food security and overcome issues of water use in desert and arid environments present in Oman. The Ministry of Agriculture and Fisheries (MAF) have undertaken several initiatives to develop integrated aquaculture and aquaponic sub-sectors as farming systems. Development started in 2012 with a MAF project funded by the Agriculture & Fisheries Development Fund (AFDF). Ten farmers where supported financially and technically to establish freshwater tilapia integrated farms. A phase two project started in 2016 enabled farmers to establish aquaponic units in their agriculture farms. Overall, the production of tilapia increased from three tonnes in 2013 to 70 tonnes in 2017 with establishment of 18 integrated fish farms located in many Wilyas of Oman.

Additional scientific and development research on aquaponics and integrated aquaculture, conducted by MAF and Sultan Qaboos University (SQU), have contributed to the development of these sub- sectors. Research has provided valuable information on biological efficiency, technical requirements to produce fish and agriculture products together in arid environments, and economic assessment that has increased efficiency and return on investment. MAF has built cooperation among private sector, farmers, farmers associations, academic institutions, other governmental authorities and critical stakeholders in the development process. Three success stories are included in the Oman review to show how integrated agri-aquaculture systems can be developed further and provide lessons for others in such development.

The Oman country report notes that improvement in IAA and aquaponics face many obstacles. Scaling production is difficult due to lack of technical knowledge among farmers, limited availability of high skilled technicians, not having a fish feed factory in the country which limits growth and increases costs, and limited availability of technical equipment. These obstacles will be addressed by MAF in the future and this report shows how the country will overcome these impediments to development of aquaponics and agri-aquaculture systems in Oman's arid desert environment.

Farmer to farmer visits

Farmer to farmer visits took place in Algeria, Egypt and Oman and proved a successful mechanism, which allowed farmers to exchange knowledge, experiences, problems and solutions to the operation of IAA systems in desert arid environments. In total 18 participants attended Algeria and 20 to Egypt in November 2017 and 24 participants visited Oman in March 2018.

Visiting farmers observed different IAA systems used in each farm attended and discussed best practices with the farm owners/operators directly. Visits included aquaponic systems integrated with hydroponically grown herbs and salad vegetables grown in greenhouses, systems using biofloc, open tank/pond flow-through aquaculture systems integrated with crops including Date palm, fodder crops and others to see first-hand how water reduction technology and culture methodology was being used to reduce water resource use and efficiency.

The visits were successful and facilitated discussion and exchange of knowledge, experiences and perspectives on IAA and water resource issues, along with lessons learned, emerging opportunities and challenges in relation to IAA farming systems across the NENA region.

Regional workshop

The workshop was held in Cairo, Egypt, on 25-26 June 2019, and was attended by representatives from ten countries of the region (Algeria, Egypt, Oman, Jordan, Lebanon, Mauritania, Morocco, Palestine, Saudi Arabia and Sudan), particularly people from research institutions and relevant national ministries. The primary objectives of the regional workshop were to share project outcomes with participants and develop a provisional roadmap framework to serve as a guide for public institutions and the private sector, in the use of non-conventional water resources for the promotion and sustainable development of integrated agri-aquaculture in desert and arid lands.

The workshop identified several roadmap priorities to enhance regional cooperation and to strengthening development of the sub-sector, as follows:

1) Develop demonstration integrated IAA units/models using the best environmentally friendly technology (e.g. encompassing smart use of water and natural resources).
2) Development of demonstration IAA units based on the use of rainwater resources in Darfur as a model for Sudan. Sudan is characterized by limited water resources, extremely difficult environmental conditions and the presence of a lot of refugees.
3) Elaboration of information to promote IAA farming systems-including best management practices; practical manuals; labelling and marketing of IAA products; NGO's role, awareness campaign on IAA, establishment of small-scale farmer associations for marketing of products.
4) Establishing a network of centres of excellence on IAA in NENA region, able to provide ad hoc training and technical assistance.
5) Developing financial & economical programmes to launch IAA projects in the region, and aiming to gain financial and technical support from FAO Water Scarcity Initiative, among others.

Further information on the workshop is given in the section 4.3.

Conclusions

The work on "*Integrated Agri-aquaculture in desert and arid lands: Learning from case studies from Algeria, Egypt and Oman*" provides a better understanding for farmers on the challenges and opportunities for IAA in desert and arid lands in the NENA region. Assessment of status in current practices, national implementation of non-renewable water resources for IAA systems, opportunities and threats to IAA system and market considerations in Algeria, Egypt and Oman will further enhance the availability of relevant information within the wider NENA region. Further, it has provided opportunity for farmers to visit others to learn more on techniques being employed in IAA systems, and sharing expertise and experiences. The workshop gathered farmers and regional ministry personnel from 10 countries directly involved in desert and arid land agri-aquaculture. Workshop discussions and consideration of the suitability and use of non-renewable water resources and forms of agriculture-aquaculture development allowed increases resolution of a broad roadmap for development, as an important output from the activities undertaken.

1. Introduction

1.1. Background of the study

Agriculture is the largest food production type in the Near East and North Africa (NENA) region, and aquaculture also makes a significant contribution to improved food security. The combination of agriculture and aquaculture production, referred to as Integrated Agri-Aquaculture or IAA, allows food production to increase and become more productive whilst also making efficient use of water resources. At its heart, freshwater is a fundamental requirement to both agriculture and aquaculture, but stocks are finite in arid regions and water is in short supply and both the agriculture and aquaculture sectors compete for distribution of water resources with other large sectors including domestic and industrial use, further stressing water resources. Non-conventional water resource use in agriculture and aquaculture is identified as a potential mechanism to improve food production output whilst preserving non-renewable and renewable freshwater resources. Non-conventional waters offer the opportunity to utilise water that may otherwise not be put to productive use. The Strategy for Water Security in the Arab Region adopted in June 2011 by Arab Ministerial Council for Water targets to develop, by 2020, alternative and practical solutions for using non-conventional water with focusing on the use of renewable energy in water desalination and water treatment for meeting the increasing water demand (World Water Forum, 2012).

The Hyogo Framework Agreement [on disaster relief] 2005–2015 (UNISDR, 2005) identifies lack of water resources as a potential disaster scenario that may affect the stability of regions to cope in the event of severe water shortage. Countries of the NENA region have specific concerns due to a high proportion of desert and arid lands and a low level of renewable water resources that is expected to be further impacted by climate change through lower regional precipitation (FAO, 2012). These combine to impact food sector productivity, efficiency and total food production potential within the region. The NENA region already operates at one of the lowest levels of renewable water resources per capita and concurrently has the highest withdrawal rate of renewable water resources of any region globally (FAO, 2015a). Eighty-five percent of renewable water is used for irrigation, particularly for agriculture food production. It is therefore important to utilize water resources in the most efficient way possible.

The FAO Regional Initiative on Water Scarcity (WSI), initiated in 2013, also identified that lack of water resources is a potential disaster scenario for the Near East and North Africa (NENA) region. The seriousness of water scarcity within NENA is summarized through reports of the Arab Water Council issued in 2004, 2012 and 2015. In the latter report (Abu-Zeid *et. al*., 2019) a forward by the President of the Arab Water Council, Dr Mahmoud Abu-Zeid, summarised that:

> *"Evidently, the world water crises of the future are already here in the Arab countries. Today, in those countries, the question is whether a water crisis can be averted or whether water can be made more productive. The answer to this question relies on the way we are using and managing water resources in all water use sectors and the irrigation one in particular. Improved water resources management and access to safe water and sanitation for all is hence essential for eradicating poverty, building peaceful and prosperous societies, and ensuring that "no one is left behind" on the path towards sustainable development."*

As a dry region the NENA area also has large areas of arid and desert lands that are currently under- exploited in terms of food production. There are a number of reasons for this including suitability as agricultural land, but limitation on water availability and the quality of available water, which is often saline due to the underlying rock structures within which the water is held or transported. The principal objective of the WSI Initiative as a whole is to build broad partnerships to support greater understanding in implementation and use of non-conventional water resource in IAA systems. The specific objectives of the work were:

1) identify and streamline policies in agriculture water management;
2) identify critical areas requiring action;
3) assist in the formulation of a regional collaborative strategy; and
4) build broad partnerships to support its implementation, including for example the increased but efficient use of non-conventional water sources for food production in desert and arid areas.

These objectives are part of the remit of FAO under its strategic programme for sustainable food production. One such area of interest within the WSI is the proposition for inter-relatedness and potential for integration of aquaculture with agricultural, providing an integrated systems approach to food production that both increases food availability and reduces the total volume of water used per unit of food produced.

Within the overall context of WSI, this study, titled "Integrated Agri-aquaculture in Desert and Arid Lands: Learning from case studies from Algeria, Egypt and Oman" was conducted between 2017 and 2019 under the WSI programme with partial financial support from FAO Global Knowledge Product (GKP) on water. The work considers the use of non-conventional sources of water for use in integrated agriculture-aquaculture systems in the arid environments prevalent in the NENA region, as a means to produce more food per unit of water used (Ahmed *et al*., 2014), as part of increased development for aquaculture in the region (FAO, 2015a).

This report summarises the outcomes from case studies produced by National task forces composed by FAO consultants and national ministerial representatives from Algeria, Egypt and Oman; study tours conducted under the project; and from a regional workshop on integrated aquaculture- agriculture systems used in these countries, undertaken in June 2019. The workshop included recommendations and development of a roadmap for more efficient and better use of non-renewable water resources in food production, particularly in desert and arid lands, but also generally applicable; and determined its potential wider application in the NENA region.

1.2. Objectives of the project

The main objective of the project was to promote and develop national potential on effective and sustainable practices in the use of non-conventional water for integrated agriculture-aquaculture (IAA) production systems in the NENA Region. This was achieved through capacity development of key national stakeholders in the project's beneficiary countries, namely Algeria, Egypt and Oman, selected to be representative of the region as a whole, with the outcomes more widely applicable to other countries within NENA. The project consisted of four phases:

- Nationally-based inception workshops and establishment of a national teams in Algeria, Egypt and Oman. These teams were responsible for undertaking national assessments and preparation of respective national reports on the use of non-conventional water in integrated agri-aquaculture farming systems. Inception activity took place in March 2017.
- Farmer-to-farmer study tours, in which farmer representatives from each country were able to visit IAA farming systems in the three countries, to extend their

experience and understanding of the potential of integrated aqua-agri systems in arid desert environments. Study tours took place in November 2017.

- A regional workshop was attended by representatives from across NENA countries, to consider the outcomes from the national assessments and study tours; and discussed and drafted a road map that will serve to guide public institutions and the private sector on actions to promote and develop integrated agri-aquaculture through the sustainable use of non- conventional water resources to increase food production and efficiency in desert and arid lands. The workshop took place on 25–26 June 2019 in Cairo, Egypt.
- This report, which summarizes the principle outcomes, recommendations and roadmap developed in the previous activity, including three case studies.

1.3. Criteria for countries selection

Selection of countries to be included as case study examples were based on: (i) being broadly representative within the geographical distribution in the NENA region; (ii) levels of implementation of IAA farming systems; and (iii) implementation of good IAA practices. Following a review, Algeria, Egypt and Oman where included within the WSI work.

Algeria is located in northern Africa. The climate of the country is classified as semi-arid to arid, 80 percent of which is covered by the Sahara, and has consistent warm winters and hot summers. (Jacobs and Van't Klooster, 2012). The agricultural sector (inclusive of agriculture, aquaculture and fisheries) contributed on average about 12.3 percent of Algeria's GDP in 2017 and directly employs 1.6 million people (3.9 percent of the population) (World Bank, 2018a). Around 13 000 farmers in Algeria expressed interest in development of aquaculture projects in the country as a means to supplement income and food production, and Algeria aims to produce 100 000 tonnes of additional aquaculture production from the desert and arid lands by 2022 (Win, 2018). In 2016, Algerian farmers harvested the first batch of farmed shrimp in a desert area Wilaya–district-of Ouargla) for example, and other aqua-agriculture integrated farms are producing fish for local consumption since 2008 (FAO, 2018a). For several years, the government has been promoting agriculture in southern Algeria, offering cheap loans and concessions to farmers willing to take up the challenges of growing food in the Sahara and with some success.

Egypt is located in the northern-most region of Africa. The climate of the country is semi-arid to arid. Egyptian Agriculture's (agriculture, aquaculture and fishing) contribution to GDP has fallen in recent times, from approximately 29.5 percent in 1973, to approximately 11.4 percent in 2017 (World Bank, 2018b) but agriculture is still a major economic activity in Egypt, directly employing approximately 7.8 million people in 2017 (International Labour Organization, 2018). In 2010 (most recent data available) the total area of agricultural lands that were irrigated covered 98 percent of the cultivated area (FAO 2018b). Egyptian aquaculture has witnessed rapid development since 1970s. Egypt is among the top 10 freshwater fish-producing countries worldwide, in terms of overall inland fish production, and is number two in tilapia production globally and the country ranks first in Africa for fish production. When compared to Algeria and Oman, the country has a longer history in the application of integrated agriculture-aquaculture systems and therefore has relatively more examples of good practices. Aquaculture in Egypt is not formally recognized as an agricultural activity therefore aquaculture cannot use water from irrigation canals destined for agriculture, for example. However, fish are cultured as primary or secondary crops in combination with fruit and other plant crops and in the country there are dozens of commercial IAA farms within designated arid and desert areas.

Oman, situated on the southeast coast of the Arabian Peninsula in what is Southwest Asia, is the third country to be included within the study. The climate in Oman is dry, and varies mainly from semi-arid to hyper-arid (Gunawardhana *et al*., 2018). Agricultural production played a significant role in the national economy in the period preceding the discovery of oil, when it reduced dramatically. According to recent statistics, however, the number of people employed in agriculture is increasing by approximately 11.7 percent per year (International Labour Organization, 2018) since 2009 to just over 166 000 people in 2017. In 2015, agriculture and fisheries contributed 0.9 percent to 0.7 percent to GDP respectively. In its ninth five-year plan the government of Oman has identified fisheries (including capture fisheries and aquaculture) as one of five key sectors of the economy that should be prioritised for development, as part of its economic diversification goals. It has set a target of increasing total fisheries output to 480 000 tonnes by 2020, and creating an additional 20 000 jobs in the sector (Oxford Business Group, 2019) within which aquaculture and integrated aqua-agriculture will play a significant part. Aquaculture, as an activity, started in Oman in 1986 and has developed only slowly; but there is recognition by policy-makers and the private sector that IAA can contribute significantly to overall food production. The government is supporting development of agriculture, hydroponics, aquaponics and aquaculture sectors through public subsidies and increased access to the needed water supplies.

1.4. National partners

National partners who took part in the WSI project included line ministries of the countries who participated in the project, namely: the Algerian Ministry of Agriculture, Rural Development and Fisheries; the Egyptian Ministry of Agriculture and Land Reclamation; and the Omani Ministry of Agriculture and Fisheries. Farmers from all countries involved are developing their respective agricultural, aquaculture and IAA businesses to support project outcomes and to improve food production and food security in their respective countries.

2. Water resources and integrated aquaculture-agriculture (IAA) systems

2.1. Water scarcity

Water is vital to sustain life, economic development, food production and to maintain the environment. Freshwater resources are limited, however. Freshwater constitutes just 2.5 percent of global water resources, of which approximately one-third is groundwater (FAO, 2013). Although water is a renewable resource, the rate of water use and growth in demand from agricultural and non- agricultural (industrial, municipal and domestic consumption) uses means there is potential for this use to outpace the rate of water renewal, thus increasing the threat of scarcity and increasing the likelihood of lack of water being a major social, political and economic issue. In 2003, the United Nations General Assembly proclaimed the period 2005–2015 the International Decade for Action 'Water for Life' with the aim of promoting efforts to fulfil international commitments made on water and water-related issues by 2015 (Maestu, J, 2015). Yet despite progress made to manage and protect water resources across the world during the past few decades, water scarcity remains one of the most significant threats facing the world today, and an estimated 4 billion people globally facing severe water scarcity for at least one month per year (Mokennen and Hoekstra, 2016). These authors conclude their assessment by noting that capping water consumption by river basin area, increasing efficiency in water-use, and better sharing of limited freshwater resources are critical in reducing the threat posed by water scarcity (*sic*. availability) on biodiversity and human welfare.

Water scarcity refers to "scarcity in availability due to its physical shortage, or scarcity in access due to the failure of institutions to ensure a regular supply or due to a lack of adequate infrastructure." (UN-Water, 2018). The definition includes water stress, water shortage or deficits, and water crisis. The international community has increasingly addressed water scarcity, especially since the 1992 Rio Summit and the adoption of Agenda 21 on sustainable development (Gupta *et.al*., 2013), but World Economic Forum (WEF) listed water crises in the top five global risks in 2015 (WEF, 2015).

Availability of natural water resources varies considerably all over the world, and through time. Regions with limited water resources and/or high water stress are often associated with periods of water shortage, for example. Water stress can also be associated with competition for use of those resources among different actors that can lead to dispute. This can happen between countries where availability of water resources in one country can depend on flows from another; or groundwater aquifers span more than one nation, giving way to transboundary disputes. International conflicts over access and control of water resources have been increasingly triggered by competition for them according to Yoffe *et al*. (2004). As an example, the construction of the Grand Renaissance Dam on the Blue Nile in Ethiopia commenced in 2011 and is a continuing source of tension between Ethiopia and Egypt despite being 10 years away from being full. The initial tension appeared to diminish in May 2015 with a "Declaration of Principles" which was signed by the three countries, but progress has been difficult and frustrations are evident Ethiopia, Egypt and Sudan. The competition for water and the potential for conflicting demands is also increasing between different sectors. (FAO, 2011).

It is generally recognized that freshwater resources are sufficient for today's world population although sources are not disturbed evenly. However, water stress and climate change are putting pressure on aquatic ecosystems (wetlands, lakes, rivers, streams, etc.) and the fish and wildlife that depend on them. The global use of freshwater doubled between 1964 and 2014 as a result of population growth, urbanisation, industrialisation and increased production and consumption. According to FAO (2016) AQUASTAT data, at global level, withdrawal ratios for specific requirements include 69 percent of agricultural activity, 12 percent for municipal requirements and 19 percent for industrial use. These global figures hide a large differential and divergence in the degree of water withdrawn regionally. Although the average withdrawal for agriculture is 69 percent globally, this ranges from 21 percent of the total water withdrawal in Europe, to 82 percent on average in Africa. Within regions there is also variation.

2.2. Context for NENA countries

The NENA region comprises the following 19 countries: People's Democratic Republic of Algeria (hereafter referred to as Algeria), Kingdom of Bahrain (Bahrain), Arab Republic of Egypt (Egypt), Islamic Republic of Iran (Iran), Republic of Iraq (Iraq), Hashemite Kingdom of Jordan (Jordan), State of Kuwait (Kuwait), Lebanese Republic (Lebanon), Socialist People's Libyan Arab Jamahiriya (Libya), Islamic Republic of Mauritania (Mauritania), Kingdom of Morocco (Morocco), sultanate of Oman (Oman), State of Qatar Qatar), Kingdom of Saudi Arabia (Saudi Arabia), Republic of the Sudan (Sudan), Syrian Arab Republic (Syria), Republic of Tunisia (Tunisia), United Arab Emirates and Republic of Yemen (Yemen). Extreme water shortage is evident in a large proportion this region. It is evident that these countries are having or will have severe difficulties in meeting their food requirements using existing water resources available within their boundaries. Water scarcity remains a key challenge for agriculture and food production in particular, which is a significant sector in rural areas of the region. Most of water in the NENA region is used for agricultural production, which dominates land use too and constitutes a critical pressure on freshwater resources (FAO, 2015a).

The NENA region has the lowest renewable water resources per capita of any region in the world, with six percent of world's population but only 0.6 percent of the world's accessible renewable water. Worldwide, water resources average 6 400 m^3 per capita, whereas the NENA average is currently only one-tenth of that level at 688 m^3 per capita, significantly below the 1 000 m^3 per capita water poverty line, and many NENA countries have significantly less than that (FAO, 2015a). Critically, more than 60 percent of the water within the NENA region originates from outside the region.

The Nile River passes through 11 African countries before reaching Egypt for example, which nonetheless relies on the Nile as its primary renewable source of freshwater, providing more than 95 percent of the available supply. Like Egypt, however, those other African countries through which the Nile flows are also, variably, competitively dependent on the Nile to contribute to their respective water supplies. In this context, increasing population and urbanisation, and increasing agricultural requirements but declining availability of freshwater has been a challenge in Egypt, increasing brought about in large part by competition for it, in a region that has no technical basis or mechanism for regional cooperation on water (Abu Qdais, 2003). At a regional level, a similar situation occurs within the Jordon river basin, for example, where several originating sources converge through the basin, with competition from several countries in its allocation, distribution and use (Earle *et al*., 2015).

Both Algeria and Oman face a slightly different, but no less difficult challenge. They have limited renewable water resources which is based primarily on groundwater, generally present in shallow and deep horizons. Algeria is Africa's second most water scarce country, after Libya. There are no large rivers in Algeria. Water is also unevenly spread over the country. While most regions in Algeria suffer from water shortage, yearly floods can also occur after heavy rains. A real challenge in managing Algeria's water resources is the large fluctuations in supply from year to year and between regions. Large efforts have been undertaken by the state to mobilize water resources by building dams (Jacobs and Van 't Klooster, 2012) in order to contain these water resources, that would otherwise quickly dissipate.

Water supply in Oman is heavily reliant on aquifers and several of these exist. The main aquifer systems include alluvial aquifers, regional quaternary aquifers, the aquifers of the Hadramawt Group and the aquifers of the Fars Group. These resources are nonetheless shared, with many of their small aquifer systems being part of large regional aquifers that extend throughout the Middle East, many of which that have withdrawal rates that are higher than renewal rates, or suffer problems of contamination, and are generally considered over-stressed (EcoMENA, 2019). Access to freshwater in Oman is also regionally defined, with fresh groundwater mostly available in the northern and southern extremities of Oman where precipitation and recharge occur (FAO. 2018b).

2.3. Coping with water scarcity and types of non-conventional water resources

Water scarcity remains a global challenge, in many cases associated with the poor management of existing freshwater sources and the need for better infrastructure to obtain, contain and to transport water to where it is needed. Adoption of non-conventional water resources as a means of supplementing available water, for uses where high quality freshwater is not essential, is also required. In the coming years, water scarcity is projected to negatively impact 60 percent of all countries and communities around the world (Qadir *et al*., 2007), that will be exacerbated by climate change. Under various scenarios developed by the Intergovernmental Panel on Climate Change (IPCC), climate change is expected to increase temperatures, reduce rainfall and soil moisture in the NENA region, whilst at the same time producing warmer conditions in which evaporation will increase, thus increasing the demand for water for food production (IPCC, 2014). Since 1998 many countries, including Jordan, Syria, and Yemen have suffered their worst-ever droughts, that became more evident over 2007 to 2010 (Powell, 2016) exacerbated by global warming. In response to this increasing threat and as a response to water scarcity, many countries have increasingly enforced restrictions on the use of renewable water resources in response to droughts becoming much more frequent and severe, which affects competition for resources between countries and within countries between users in municipal, industrial and agricultural sectors, that impacts water and land use management regimes. As an example, the government of Egypt called for the prohibition of rice cultivation in desert lands in April 2013. (US Commercial Service, 2014).

Over the next decades, water scarcity is projected to become more severe creating further restraints (e.g. Droogers, *et al*., 2012; Odhiambo, 2016). Urbanized land is likely to double by 2030, in order to accommodate economic development and another 1.5 billion people moving to cities (UNDESA, 2014), where clean high quality water will be an increasing requirement. Agriculture lands and food production will also have to increase to maintain and develop food supply and food security, and this must develop include further development of aquaculture as a protein source, undertaken in part through the use of non-conventional sources of water and increased efficiency in use. In essence, more high quality food for the same level or lower level of overall water use (Ahmed, Ward, and Saint, 2014) with a higher proportion of non-conventional water use to produce that food. There is therefore a need to develop robust technical, policy and economic regimes for water conservation and increased supply through the use of non-conventional sources of water for the agriculture and aquaculture sectors within the NENA region. Non-conventional sources of water, in this context, can include:

- Provision of water through desalination of brackish water and seawater (See Gude, 2017). Seawater desalination in Oman started to supply potable water to Muscat and coastal areas in the early 1970s (FAO 2018b). Egypt is planning to build the world's largest desalination plant to provide additional water resources as it diversifies methods of overcoming its water scarcity (Egypt is Building World's Largest Seawater Desalination Plant, 2017). Prospects for desalination in Algeria is reviewed by Mitiche *et al*. (2010) and includes provision of drinking water through a reverse osmosis desalination plant opened in 2014 (Freyberg, 2014).

- Rainwater harvesting (See Abdulla and Al-Shareef, 2009).
- Use of treated and/or untreated municipal and industrial wastewater (See; Faour-Klingbeil and Todd, 2018) for irrigation (see Hussain *et al*., 2002). There are a number of potential disease issues in using untreated wastewater (e.g. see Dickin *et al*., 2016; Shomar and Dare, 2015), whereas treated wastewater is able to remove many of these issues and provide water of sufficient quality for use in irrigation (Nakib *et al*., 2016).
- Use of naturally occurring low to moderately saline water directly in agriculture and aquaculture systems, by selection of species that can tolerate salts. Egypt has increasingly used the mixing of saline and freshwater to increase volumes whilst maintaining a salinity that remains usable for agricultural and aquaculture purposes, for example.

Overall, there will be a need to both conserve water and increase the utilization of non-conventional sources with the NENA region, where arid and semi-arid environments predominate. Use of non-conventional sources of water will allow increased food production to occur, but there is a need to gain more from the same amount or lesser amount of water. In the context of this project, integrated agriculture-aquaculture systems will need to develop to provide this increased production and allow diversification of end products for rural communities and for supply to the general market.

2.4. Integrated agriculture-aquaculture food production techniques

2.4.1. Introduction to integrated aquaculture-agriculture (IAA)

Conventional freshwater aquaculture systems are land intensive and require a high level of water use. Typical examples would include extensive shrimp ponds that can cover several hectares with production of natural foods (e.g. phytoplankton) on which the shrimp feeds, and other similar for fish production, in extensive carp pond farming for example. Total water use for such extensive ponds can significant, at up to 45 000 litres of water per kilogram of fish produced. Semi-intensive pond or tank systems, where additional food sources are added to supplement natural food growth require significantly less water but nonetheless still needs a high level of water input, varying between 2 000 and 5 000 litres/kilogram (Verdqegem *et al*., 2006). Such systems, used in more water-rich environments, would in general be unsustainable within the NENA region, for the reasons outlined above.

Within arid and semi-arid zones, but also more generally, it is recognized that aquaculture operations must intensify in a manner that reduces water use per kilogram of production (Klinger and Naylor, 2012). In aquaculture terms, the active search for synergies with agricultural and livestock farming has led to a number of developments and management concepts, that together are referred to as Integrated Agriculture-Aquaculture (IAA).

IAA is a production system and practice in which two or more aquaculture and agricultural activities are concurrently or sequentially taking place (Prein, 2002). Wastes from one system in IAA are recycled as inputs to another, and thus, pollution is reduced (Jamu and Piedrahita, 2002). IAA comes in several forms including livestock-fish, birds-fish or rice-fish production systems. Typically these systems are extensive or semi-intensive and involve adding animal waste to a fish pond system in order to boost fertilization of water to improve secondary growth of zooplankton and phytoplankton as food for the fish, either through addition of manures or housing livestock directly above the pond in enclosures so that manures can pass directly into the pond. The agricultural element tends to be the preeminent crop, and fish are grown to provide a secondary crop, as well as provide waste waters rich in nutrients that can benefit the agricultural component of the system, in what is referred to Integrated Irrigation-Aquaculture (IAA) systems. Under such systems water is re- used on site to support agriculture and is not directly wasted as it might be in other fish production systems.

The synergic integration of aquaculture within wider farming systems has been promoted as a way of increasing food production, conserving the environment by reducing wastes and promoting water re-use (Ahmed, Ward and Saint, 2014) and as a means to improve overall food production and security. In IAA system, economic and biological interaction between components is favourable and farmers can produce multiple outputs from the same farm in a relatively environmentally friendly manner (Prein, 2002). Total yield from IAA systems is generally higher than monoculture systems but it also promotes increased social, economic and environmental benefits. IAA, among others, improves water re-use and soil quality on the farm. Easy market access and selling of these eco-friendly products may also fetch higher prices than conventionally produced outputs, if marketed correctly that improves the financial security of the farmer. IAA systems in general needs proportionately less labour input when compared to traditional fish and agricultural farming practice.

In the NENA context intensification of IAA is required as a means to re-use water and produce multiple products (e.g. fish and vegetables) using the same quantity of water. Based on country reports, it seems that the dominant methods of production include relatively small extensive to semi-intensive fish production systems in tanks or ponds, with wastewater from fish used for irrigation, to fertilize the land and improve soil integrity to improve agricultural productivity. Under such systems, fish is grown for home use and sale at local markets and agricultural crops for sale in usual markets, and on occasion fodder grown to feed livestock, that are then sold. A proportion of the water level in fish production needs to be replaced regularly as a means to maintain dissolved oxygen concentration, and to assist in maintaining a lower temperature in the hot climates. The “waste” water is used for irrigation purposes. In some instances irrigation channels can be used to grow fish also. More intensive aquaponic systems are used to grow fish more intensively in directly linked systems of food production, particularly with market garden and salad products that are often grown under conditions of very low or no soil, in greenhouses and other buildings.

2.4.2. Aquaponics

Briefly, aquaponics is an intensive sustainable agricultural production system that combines hydroponics and recirculating aquaculture systems to produce a range of crops (FAO, ICLARM, and IIRR, 2001). Recirculating aquaculture systems (RAS) are systems in which aquatic organisms are cultured with minimal discharge of waste products and minimal water loss. Although relatively expensive, it is the most efficient water-saving technology in aquaculture. RAS allows use of by-products and the water nutrient concentrations for vegetable crop production. It is, therefore, of great beneficial to IAA (Somerville *et al.*, 2014).

Water is recirculated around the system, so that dissolved and particulate nutrients added to the water by fish then supplement the crop growth. Plants remove nutrients, allowing the water to be recirculated. Such systems may in addition require mechanical filtration to remove particulate material that is not required by the plants, and biological filtration using bacterial chambers, to remove any remaining dissolved nutrients in the water, before the water is recirculated. Thus an aquaponics system is composed of three basic elements, namely fish, plants and bacteria.

In this system, aquaponics technology integrates the production of fish (aquaculture) and plants (hydroponics) and benefits from using less energy and up to 90 percent less water than conventional farming practices while producing remarkably greater amounts of chemical-free food in the same unit of space and time. Water, typically from boreholes, needs to be added to the system to replace water lost through evaporation. This may be higher in areas that maintain high temperatures, such as arid zones. More extensive systems can include water temperature controls. Dissolved nutrients such as phosphorus and nitrogen are taken up by the plants, which do not therefore need additional fertilization.

It is highly suited for small farm producers targeting local markets with market garden-type crops. Most aquaponics operations are small in scale (<50 tonnes per year) (Diver and Rinehart, 2010). Aquaponics systems can be used for indoor farming or greenhouse based farming systems that can yield profitable crops all year round. More than 150 different vegetables, herbs, flowers and small trees have been grown successfully in aquaponic systems, through research, domestic and commercial units with reduced water and fertilizer inputs (FAO, 2015b).

3. Methodology

3.1. Establishment of national task forces

Project partners Algeria, Egypt and Oman established a National Task Force (NTF), whose primary aim was to conduct field research and to prepare a national report on use of non-conventional water sources in food production in arid environments, focusing on integrated aquaculture-agriculture systems. At the early stage of the project, each group had a country-based meeting to establish to key requirements. Participants included representatives from national competent authorities, NTF members, local experts and FAO technical officers and FAO Country Representatives. FAO proposed an outline schematic for the report, and NTFs revised the national report template based on local needs, which was then adopted as the means to gather the necessary information. Discussions were held on a programme of work, which was agreed and subsequently implemented.

3.2. Preparation of national reports

NTFs undertook a nationally-based review of national strategies for use of integrated agriculture-aquaculture systems. Although there were variations in the assessment undertaken across the three partner countries, each report more or less covered the following:

- Introduction and background assessment.
- Status of water resources, culture systems and management.
- Sector performance, including economic, human resources and market requirements.
- Review of governing regulations.
- Research, education and training.
- Trends, issues and development.
- Integrated agriculture-aquaculture success story examples.
- Roadmap considerations and recommendations.

3.3. Farmer to farmer visits

Three farmer to farmer visits were conducted through the project. Farmer representatives, including farm owners and senior farm technical staff, visited integrated agriculture-aquaculture farms in each partner country. The principle idea of the visits was to share experiences and expertise across the regional sectors, and provide the opportunity for participants to evaluate agri-aquaculture technologies and systems in use in respective countries. The primary aim of the visits, which took place over November 2017 and March 2018 (Table 1), were to exchange ideas, knowledge, expertise and best practices, for the benefit of all. Table 1 provides some details on the visits.

At each visit, farmers attended meetings and were given an overview of IAA practices in the host partner country. This was followed by visits to specific farms located in arid desert environments, to provide host farm owners and technical staff the opportunity to share details on cultivation systems and practices, water requirements and sourcing, methods and approaches to integrated-irrigation aquaculture (IIA) and IAA, problems and issues involved and how these are being resolved or mitigated against, and overall management issues associated with the systems viewed. During the Algeria visits in November 2018, the farming participants joined the 7th International Fair on Fisheries and Aquaculture ("Salon International de la Pêche et l'Aquaculture"), held in the city of Oran on the Mediterranean coast.

Table 1

Details of farmer-to farmer visits undertaken during WSI project period

Partner country visited	Dates of visit	Number of farms visited	Number of farmer participants
Algeria	6-10 November 2017	4	18
Egypt	12-16 November 2017	5	20
Oman[1]	25 February-1 March 2018	6	24

Note 1: Attendance of Omani farmers to other countries was supported financially by FAO-Oman through the FAO-South-South Cooperation Programme.

The visits allowed the farmers to:

- better grasp the concept of water-smart integrated-irrigation aquaculture (IIA) production systems,
- understand the role and contribution of the public and private sectors in development of IIA and IAA,
- further the farmers' understanding of IAA-based concepts, and the issues and management decisions required to provide a sustainable system,
- understand the need for sustainable seed and feed supply,
- learn about agriculture and aquaculture species diversification, including what this entails and what options are available,
- see directly the advancement in IAA systems, the role of extension work and development of value chains and marketing of IAA products, and
- to exchange ideas and establish links between representatives of entities//farms and represented institutions for future collaboration and cooperation.

3.4. Regional workshop

A regional workshop was held in Cairo, Eyypt on 25–26 June 2019. Representatives from the Algerian, Egyptian and Omani NTFs attended the workshop, along with national representatives from Jordan, Lebanon, Mauritania, Morocco, Palestine, Kingdom of Saudi Arabia and Sudan. The workshop agenda is presented in Appendix A.

The first day was organized in plenary sessions that covered several topics including introduction to FAO water scarcity initiative; general overview of the project and main results achieved through case reports and farmer to farmer initiative; workshop objectives and approach; definition and use of non-conventional water resources; presentation of national assessments on the agri-aquaculture sector in desert and arid lands. The second day was dedicated to the presentation of a draft structure of the regional roadmap followed by a brainstorming session consisting of two working groups that considered i) water resource requirements and suitability of water saving systems available for the region and; ii) suitability of different integrated agri-aquaculture systems applicable to the region. At the end, participants reached a consensus on the structure of a roadmap and identified some immediate actions needed to promote and develop the IAA practices in the region.

4. Results

This section provides a summary of the key findings from the country assessments carried out by National Task Forces, and is based on reports delivered by country partners in Algeria, Egypt and Oman, and the regional workshop held in Cairo, Egypt in June 2019. Full reports from partner countries are available in Appendix B.

4.1. Partner Country Reports summary results

4.1.1. Integrated agriculture-aquaculture activities

Integrated agriculture aquaculture activities in the three selected countries remains relatively small as a proportion of overall production using more traditional agriculture and aquaculture methods. Each of the country reports show that the introduction of IAA is relatively recent, in Algeria since 2015, in Oman since 2013 and in Egypt, slightly longer, since approximately 2010. Overall production figures are therefore relatively small, but growing.

In Algeria, there are approximately 600 farmers assessing the development potential of IAA, generally operating on a small, sometimes hobby-scale as a means to develop techniques and approaches to arid aquaculture development, although some larger commercial scale operations have also been developed. Half of the farmers are located in arid areas of Algeria. Total production from all aquaculture sources in 2017 is estimated at approximately 5 000 tonnes, primarily of tilapia, with some catfish and carps. Within this, approximately 1 700 tonnes is produced through ten IAA projects in development in Ouargla and Bechar provinces, where fish production is integrated with more conventional agricultural crops such as date palm, cereals and market garden products. In most cases production of fish is undertaken using ponds or tanks fed from water holding basins on site at relatively low stocking densities, supplied from conventional groundwater water sources; and one aquaponics unit, also fed from groundwater. The Algerian study noted that their focus was mainly in southern Algeria where integration of aquaculture with irrigation-based agriculture is a highly strategic activity, for climatic and economic reasons and is a growing sector. The report also identified that is was difficult to estimate the totality of farms "*….which are believed to count in their thousands*". Aquaculture production of shrimp through a South Korean-Algerian cooperation and fish production in cages in dams was also identified.

In Oman, 70 tonnes of fish were produced in 2017, the output from approximately 18 IAA farms spread across 10 wilyas (districts), that have been developed under projects organized by the Ministry of Agriculture and Fisheries (MAF) since 2013, with the financial support of the Agriculture & Fisheries Development Fund (AFDF). Work was undertake with the support of the Aquaculture Centre, established by MAF in 2006, which has drafted best practices for IAA and developed the Al-Rumais aquaponic research unit to conduct research to better understand the requirements and issues involved in IAA activity, and several of the 18 IAA farms are using aquaponics technology. Oman law limits the amount of physical space that an agricultural farmer can use for aquaculture production to 10 percent of the overall farm area.

Egypt is the largest producer of aquaculture products out of the three partner countries in the project. Overall production from pond aquaculture of fish and shrimp was 1 175 thousand tonnes in 2015, mainly concentrated in the Nile delta using water resources from the Nile itself. IAA production is currently a very small proportion of this overall production, estimated to be 3 895 tonnes in 2015, using intensive flow-through tanks to produce 8 species of fish, 95 percent of which is tilapia. The case study reported up to 100 artisanal and commercial farmers actively pursuing IAA activity in the Sinai, High Egypt and Nile desert areas, through a combination of private sector investment and government projects. Most of the 23 government projects are centred in the Sinai Peninsula, introducing IAA to Bedouin community farms. Most farms appear to operate at relatively low stocking densities using farm-made feeds. The primary difference between the artisanal and commercial farmers relate to stocking density in the pond systems used, rather than any specific difference in approach. Stocking density is higher in commercial farms that use aeration as a means to stabilize dissolved oxygen concentrations and lower in artisanal farms that do not use aeration systems, but maintain sufficient levels by using higher proportions of replacement water ever two to three days. A similar approach to water renewal within basins is reported for Algerian desert aquaculture, which suffers from high water use in crop production and high evaporation due the high temperatures and done to also maintain water quality for fish production. Similar to other countries in the study, the main water source used for IAA systems in Egyptian desert environments is slightly to moderately saline waste irrigation water and some groundwater, which is generally of reasonable quality and very low salinity that does not require specific treatment or is supplemented by addition of freshwater. In Egypt, in particular, irrigation ditches themselves are also sometimes used to grow fish, feeding on whatever is available in the ditches before being harvested.

4.1.2. Main sources of water used in agriculture and aquaculture

The main sources of water reported to be used in IAA systems in partner countries do not currently come from non-conventional sources, although specific non-conventional sources of water had been identified as having potential for future development, and some small sources are already used.

The primary resource used for the low level of production currently undertaken using IAA systems is groundwater, generally pumped on site from wells, either directly delivered or stored in basins/reservoirs which then feed the fish ponds or aquaponic system used, particularly in Algeria and Oman. In Egypt water used for crop irrigation must be re-used in aquaculture systems. Water in tanks or ponds is replenished on a regular basis as a means to maintain water temperature and to improve dissolved oxygen content, particularly where aeration is not used. As a general rule farmers in desert areas noted that in winter water in basins became too cold for fish and in summer was too hot, so farmers replenished water stocks regularly, which also replaces water lost through evaporation, but also requires the release of a high proportion of the pond water at regular intervals. This water is not wasted, however, instead used in irrigation for crops, either through inefficient direct application or, in some cases, through sprinkler, drip-feed and other more efficient irrigation systems.

In Oman in particular, not wasting water is specified as a legislative requirement for IAA farms and waste water from the fish production system can only be used for irrigation of crops and not wasted or used for any other purpose. In Algeria groundwater is generally slightly to moderately saline as a result of the underlying geology and is considered within the country as non-conventional because of this but is nonetheless used directly for aquaculture and agriculture production. Some of the farms visited in the project contain small desalination units to lower the overall level of salts present. It is reported that such salts derive from the underlying rock geology, rather than from seawater intrusion in areas where IAA is taking place. In Oman, groundwater is extracted via wells also, although a more traditional method of water sourcing, the aflaj, provided water to some farms. The aflaj is a historic series of channels that enable flows of water, typically from groundwater sources located away from the farms, to be channelled to where it is needed and are used for agriculture irrigation and more recently for aquaculture systems too. In Egypt the report specifies that aquaculture activity, in general, is not able to use freshwater in production under the law, but relies instead on waste irrigation water collected through an extensive system of irrigation channels to provide the necessary resource. In the context of IAA systems in desert environments, however, the report is not completely clear to what extent the legislation is fully implemented, given several of the IAA systems developed for Bedouin communities high groundwater removed via wells as their water source.

In all three countries non-conventional sources of water have been identified through the project as potential future sources of water for IAA systems. These include potential future use of desalinated water and treated wastewater on Oman, and in Algeria the additional use of Chotts, high elevation temporary slightly saline lakes that develop after the spring thaw in the Atlas mountains of the Maghreb, although there appears to be no approval to use such waters for aquaculture production at present. Saline water flowing through the Oued Rhir valley is similarly identified and the report suggests aquaculture should be permitted in the area. In Egypt there are extensive systems of irrigation channels that collect various forms of water, mainly from agriculture, to which freshwater is added before reuse. The Egypt report does not make it clear whether reuse could be for the aquaculture component of an IAA system, but this remains a possibility. More generally, in desert regions specifically, the Egypt report suggests waste irrigation water is liable to be the main source for aquaculture and IAA systems for some to come, but does not dismiss other forms of wastewater use in future. In all cases the use of wastewater is seen as an opportunity for IAA, but in there may be some cultural issues to overcome before it can be widely developed; and technically there is currently a limit on wastewater treatment infrastructure, although this is growing year-on-year throughout the region.

In Algeria, the national reports highlights that in the National Water Plan (NWP) issued in 2010, the total water potential available in the country to be 19.4 billion cubic meters (BCM) per year. This potential consists of 14.4 BCM of renewable water resources, of which 11.4 BCM comes from surface water, 3 BCM is groundwater and the remaining 5 BCM comes from non-renewable sources of brackish water, the latter exclusively located in the south of the country, according to the Ministry of Water Resources in 2017. Added to this are potential non-conventional resources, consisting of 770 million m^3 of desalinated water and 640 million m^3 of treated wastewater, output from nearly 100 treatment and purification plants, the latter expected to increase in the coming decades due to major efforts from the State in terms of investments in hydraulic infrastructures. In Algeria the water supply for agriculture amounts to 6.78 BCM currently, primarily from groundwater (circa 4 BCM) and surface water (2.78 BCM). A very small fraction of treated wastewater is used, amounting to approximately 60 million m^3, with an outlook of 100 million m^3 in the long term. In the longer term the reports identify that water consumption for agriculture is expected to rise 12.4 BCM by 2035.

The Oman report does not make a specific assessment of overall water resources or potential through non-conventional resources, and no reference to specific use in agriculture, aquaculture, or IAA systems.

In Egypt, the report (Appendix B2) identified work by Abdel-Shafy and Mansour (2013), Abdel-Shafy and Kamel (2016) and Sharaky *et al*., (2017) to give an overview of available water resources, that highlights an estimated 80 percent of Egypt's water comes from the Nile and 20 percent from groundwater. The report itself does not give total usage from all sources or a specific breakdown by source, but does highlight that 5.5 BCM of drainage water are being reused, mostly after mixing with additional freshwater. This is mainly for re-use in agriculture, but is presently also the only source available for aquaculture development, which the report highlights as one reason why aquaculture expansion is currently difficult in Egypt. In Egypt, the Ministry of Agriculture and Land Reclamation (MOALR) made an application for a change in the law related to water use in aquaculture in 2010, but is still under review by the government.

4.1.3. Water allocation changes; utilization of non-conventional water resources

Currently, none of the country reports highlight specific policy or changes in current policy concerning allocation of non-conventional sources of water to agriculture, aquaculture or IAA systems. Presently, the three countries focus on agriculture specifically in allocation of water. In Egypt legislation limits all aquaculture development to use of irrigation water only, but Algeria and Oman are less clear. Policies do not specifically separate aquaculture under an IAA system in that development.

As mentioned previously, the limited number of farms that are developing IAA systems utilize the same sources of water for all aspects of farming activity, including the aquaculture component of the IAA system. Most water for agriculture currently comes from groundwater resources in Algeria and Oman, and from the Nile Delta and desert saline groundwater deposits in Egypt. In Algeria, for example, it is noted specifically that legislation does not distinguish between forestry, agriculture and in-land aquaculture in terms of water use and there is no specific allocation to the aquaculture or IAA sectors. Oman identifies that IAA is a very recent activity and there is currently no specific approach to resourcing water for IAA systems, although a lot of work is underway to promote soil-less agriculture with fish production, in aquaponic systems, over other forms of fish/agriculture production, as a means to limit the amount of water used overall. Through legislation, applicants for IAA systems are required to identify sources of water to be used and must not impact crop production in any way.

Egypt has the most advanced use of IAA of the three nations and the success story examples provided in the report identify several approaches to non-conventional water use, although ultimately these are currently on a relatively small scale. These include use of brackish water unsuitable for other uses to grow tilapia with wastewater from the recirculating aquaculture system (RAS) fish component used to grow salt-loving *Salicornia* species, among other similar crops. Another promising approach appears to use waste brine water from a desalination plant to fill an open-cut sand mine with water in which fish are grown in polyculture (not IAA), available for recreational fishing and some harvesting. Each of the examples presented in the report reflect individual entrepreneurial actions, rather than government policy in relation to water allocation or use of non-conventional water resources for IAA systems. The Egyptian Government has announced, however, an ambitious plan starting in 2015 to reclaim 1.5 million feddans of land for agricultural and municipal development, which includes application of IAA on farms that will presumably have non-conventional water resources available as part of that development. Overall, the extent of non-conventional water resources varies, as does its use, but there does not appear to be specific changes in relation to use of non-conventional water resources specifically in Egypt, from the proscribed requirement that aquaculture can only use waste water from irrigation as its water source, although this is not universally applied.

4.1.4. National regulations for implementation and water use in IAA systems

Each of country reports outline, in broad or finer detail, the laws, regulations and decrees that regulate agriculture and aquaculture activity in respective countries, but reports focus more generally on Agriculture in the Algeria report (Appendix B.1), on governing institutions and not the legal requirements themselves in the Egypt report (Appendix B.2), and on aquaculture in the Oman report (Appendix B.3).

More generally, in Algeria, Egypt and Oman it appears the laws and regulations do not, in general, distinguish between use of water in agriculture and aquaculture, in terms of water sourcing and providing water as a resource for respective activities in irrigation and aquaculture activity. Agriculture dominates use of water resources, however, particularly in Algeria and Egypt, and agriculture is therefore the dominant focus in regulation.

In Algeria and Egypt aquaculture is amalgamated with fishing, under more general fisheries-related legislation. In Egypt there is no legal definition of aquaculture within Egyptian legislation for example and in Algeria, Law No.01-11 of 2001 relates to both Fisheries and Aquaculture, and its regulation. The relative newness of integrated aquaculture-agriculture systems means there is no specific legislation related to IAA systems, or specific water use requirements for such systems of production in these countries. Oman has specific legislation related to agriculture and preservation of water resources but the Oman report focuses on aquaculture legislation specifically.

The laws and regulations on agriculture in Algeria, outline land policy, agricultural policy, ownership and rights for farmers, and definitions on agricultural activities and operation methods for agricultural lands within the national domain that set out the rights and obligations of farmers. In a fisheries and aquaculture context Legislative Decree No 94-13 dated 28th May 1994 refers, in Article 17, to definitions of fishing establishments, being any establishment in the national domain supplied by sea water, fresh or brackish water for the purposes of catching, and rearing/growing of marine or freshwater animals and plants. An Executive Decree approved in 2004 and a Ministerial Decision approved in 2010 set out hygiene and sanitation requirement for fishery products and thresholds for chemical, microbiological and toxicological contaminants in fishery and aquaculture products respectively. The primary law related to use of water in Algeria appears to be Law No. 05-12 of the 28th of Joumada Ethania 1426 corresponding to the 4th of August 2005, which through various articles and in broad terms lays out the principles and rules on water use in agriculture, how concessions for water use are determined and fees paid, and define the circumstances under which water can be abstracted through well digging or other means. The Algeria report notes that there is no equivalent legislation related to non-conventional water use in IAA systems, and appears not to differentiate between types of water resources. The Algeria report nonetheless highlight that in Saharan regions, including Algeria, most of the waters are considered brackish water in terms of mineral composition, and they are therefore considered non-conventional waters, for the most part unfit for human consumption without prior treatment. The report identifies water quality standards for aquaculture in Morocco and suggest similar requirements are applied in Algeria. There appears to be no current legislation related to aquaculture as a sector of fisheries or to development of IAA farms in particular in the context of both aquaculture and agriculture and conventional and non-convention water use for these. Establishment of IAA systems in Algeria gained a legislative boost in 2104 with introduction of Ministerial Circular No. 91 that sets out the terms and conditions for the implementation of a sustainable development agenda for fish farming integrated with agriculture and among other elements describes the procedures and good practices for identifying farms, their orientation and maturation of projects, authorization required and financial support given for such development.

It has already been established that in Egypt there is no legal definition for aquaculture. The report authors concentrated on outlining the Ministries responsible for specific activities. Overall responsibility for agriculture and aquaculture from a legislative point of view is conferred on the Ministry of Agriculture and Land Reclamation (MOALR) who have powers to generate policy and legislation. Management of aquaculture is undertaken by the General Authority for Fish Resource Development (GAFRD), including licencing and development, including training and extension work. Water for agriculture and aquaculture is managed separately, the responsibility of the Ministry of Water Resources and Irrigation (MWRI), who approve sourcing for inlet, waste outlet and quantities of water used by fish farms. MWRI and ultimately for approval of fish farm establishments. The country report did note that improvement in legislative requirements for the management and control of production in integrated systems is required, because legislation and regulations do not specifically mention, or cater for, such systems of production.

Oman has specific aquaculture legislation, coordinated by the Ministry of Agriculture and Fisheries (MAF). The law of fisheries and protection of living aquatic resources issued by Royal Decree No. 59/1993 is the current piece of legislation governing fisheries and aquatic activities. A specific By-Law for aquaculture and its quality control was issued in 2004, and updated with more detail on licencing requirements and procedures through Ministerial decision No.177/2012 issued in 2012. This was further amended in 2014 by the Ministerial Decision No. 102/2014, which added the formation of a technical committee for evaluation of aquaculture applications. The legislation from 2014 requires that integrated agriculture-aquaculture activities should have sufficient water resources, without specifying the type of water resource used, should not impact crop production, shall comply with water quality requirements laid down by MAF as the competent authority and defines that water discharged from farmed species ponds to irrigate cultivated areas and is prohibited to use it for any other purpose, as mentioned previously. Further Ministerial Decision No. 272/2014, issued in 2014, and amended in 2017, controls issues around changing of use of land, rent, and establishing houses or service buildings on agriculture lands. In this context it is laid down that the aquaculture activity or the fish component of any IAA system cannot be more than 10 percent of the total area of a farm and should be built on the vacant areas or less fertile areas inside the farm.

4.1.5. Most suitable agri-aquaculture farming systems used in desert and arid lands

Reports from Algeria, Egypt and Oman defined aquaponics as the most suitable system for development of IAA systems. Aquaponics allows recirculation of water through fish and through potted vegetables, salad and herb agricultural products as a means for fish to provide additional nutrient requirements for agri-products. In recirculating water, water loss is more limited, although in hot arid and desert environments loss through evaporation was identified as a critical component, and need for replacement. Further the farmer to farmer visits confirmed that without a comprehensive system of water biofiltration here was also a need to replace the entire systems water every now and again, as a means to control overall water quality. Such water was not wasted, however, being returned to irrigation water for crops. In the meantime, biofiltration within aquaponic systems is necessary to remove and/or convert harmful nutrients such as ammonia produced by fish into less harmful and more useful products such as nitrate.

The other main system identified as suitable were purely flow-through systems, whereby the waste water from fish culture was subsequently used for irrigation of crops such as date palm. Whilst it was recognised that flow-through systems were more water intensive, water was not wasted, by being used for irrigation purposes subsequently. Additional benefits of using such a system were noted, in reducing levels of fertilizer required for crop nutrient enhancement, and in predominantly san areas the particulate wastes from fish production increased compaction around date palm in particular, that had the net benefit of increasing water retention in the soil and further reducing water requirements. Other systems in specific locations are reported in Appendix B.

4.1.6. Existing water-saving national policies, strategies and programmes

The report from Algeria notes that a strategy for the use of non-conventional water resources is being developed. The Oman report did not assess overall water availability or identify specific national policies or programme in saving or improving the efficiency of water use. The report does, however, reflect the importance placed on development of IAA systems using aquaponics, producing fish in RAS alongside soil-less crops such as market garden products, as a strategic means of gaining more food from the same amount or less water use. In Egypt, broad water strategy is not identified in the country report, although it highlights the current legal limitation on aquaculture as a whole, using waste irrigation water only for production. It is unclear whether this applies also to IAA systems, given some of the reported IAA systems are supplemented by groundwater as well. There is insufficient detail in the report to ascertain whether IAA systems developed under the large land reclamation programme, that Egypt is undertaking, will include specific policy on wastewater re-use for such systems, but this remains an opportunity.

4.1.7. Technical capacities, training and extension

Technical capacity of farmers in Algeria, Egypt and Oman is identified as one of the primary issues to overcome for better development of desert-based and integrated agriculture-aquaculture systems.

The Egyptian report especially highlighted research that showed Egypt is in a paradoxical situation, of producing significant quantities of aquaculture products and developing desert agriculture-aquaculture systems, but with an apparent low level of support for research and development. It was further noted that the quantity of research publications on Egyptian desert-based aquaculture and IAA is low, compared to the number of researchers in the field of aquaculture within the country, although proportionally, given the size of the industry as a whole the number of researchers in aquaculture and IAA is also low. The Egypt report does not specifically outline the training and extension activity undertaken at a national or local level but primary responsibility for this work appears to rest with GAFRD, alongside a number of universities and research centres.

In Algeria training is devolved from Wilayas Directorate of Fishing and Fishery Resources and their local branches who provide, through local chambers, activity on supervision, monitoring and extension of aquaculture activities, including organizing periodic training programs for outreach and extension to groups of approximately twenty farmers. There are also professional training centres and universities providing training for farmers. The Algeria report notes that training is not comprehensive, however, and that the farmers who participated in the assessment lacked basic knowledge on feeds, feeding requirements and general expertise and experience in growing fish. There is currently no association available for IAA farmers, although several freshwater farming association are listed and the report notes that attempts have been made to demonstrate the benefits of associations in addressing food problems, marketing problems and training needs, through awareness- raising initiatives aimed at IAA farmers. Peer-to-peer training is being undertaken, in which more experience desert-based IAA farmers offer their experience and expertise on a personal basis, and since 2014 there has been a collaboration framework with the People's Republic of China that allows up to fifteen farmers each year to benefit from a 25-day trip to China, to learn about the practice of fish farming integrated with agriculture undertaken there. The Ministerial Circular No. 91 introduced in 2014, places a large emphasis on training and extension work for new investors. Several pilot projects are being conducted by the scientific research sector to test the potential of non-conventional waters in agriculture, agri-aquaculture and hydroponics (without the use of soil), including, for example tilapia breeding trials using a closed recirculating water system in Biskra, carried out by the Center for Scientific and Technical Research on Arid Regions and research conducted at the University of Ouargla.

The Oman report identifies comprehensive formal training activity offered in Oman as a means to improve the overall technical capacity of future farmers, highlighting universities offering marine courses that include courses on aquaculture production and fish nutrition. The report highlights that Sultan Qaboos University in particular has established a marine science department who have conducted research and experiments on fish culture using freshwater, brackish water and treated sewage water, since 1986. Al-Sharqiuah University opened in 2014 and currently has no graduates but offers courses in a range of subjects related to aquaculture, though IAA is not mentioned specifically. The report also highlights a government run institute, the Fishermen Training Institute, which offers a three-year vocational diploma in aquaculture for Grade 12 school leavers, who undertake basic education requirement in the first year and specialist aquaculture courses for the following two years. Government support extends to frequent meetings between the operators of the 18 IAA systems developed thus far, and the Ministry of Agriculture and Fisheries to discuss farming issues and obstacles the farmers are facing, along with periodic visits by specialists from MAF to farms, who monitor the works and provide extension activity to farmers.

Overall each of the country reports highlight that formal and informal training, extension activity and research is required across all areas of aquaculture production in particular, to enable farmers to maximise their long-term sustainability from aquaculture and from IAA systems being developed.

4.1.8. National markets for IAA products

Oman and Algeria reports show that it can be tricky to market fish products produced from wastewater and other non-conventional sources of water, in part due to cultural reasons and where historically fish has not been a main protein source. Consumption of fish has much to do with social norms, and is traditionally much lower in areas that are far from the sea or rivers (fisheries) or aquaculture producing areas. In Algeria for example, the country report notes that annual fish consumption is low in a global context, estimated at 6 kg per capita per year in 2015, and that marketing of products to groups who more traditional gain protein through camel and other meat is therefore difficult. In Algeria the investigation undertaken showed there were no associations developed in the field of agri-fish farming that might support, among other things, the marketing of IAA produced commodities. There were variations in regions, however, with farmers that participated in the country assessment, located in Guerta-Biska noting difficulties in gaining acceptance in local markets, compared to a farmer in Reganne-Adrar who stated they were currently unable to keep up with local demand.

The Oman report notes that there is limited access to markets due primarily to underdeveloped infrastructure. Statistics from the Directorate General of Marketing and Fish Investment showed there was just 392 outlets for fish in 2016; and according to a survey conducted by the Oman Ministry of Fisheries in 2013, the combined capacity of all the Sultanate's markets is limited to just 1 500 tonnes of tilapia. The authors of the Oman report noted that here is currently there is a program of subsidy for local production of tilapia, introduced by the Ministry of Ministry of Commerce and Industry, which they suggest needs to include marketing and improvement in sales outlets. MAF in conjunction with Ministry of Commerce and Industry (MOCI) do support tilapia farmers in marketing their products through big hypermarkets for a price around 2.0 Omani Rials (OR) per kilogram. The report also highlights that hotels and restaurants are promising outlet markets for locally produced tilapia, although farmers also face difficulties in reaching these, but that the difference between costs of production, estimated at OR 0.6 to 0.9 and sales, at OR 2.5 to 3.0 means it should be profitable.

In Egypt, marketing of fish products is less of an issue that in the other locations. The country report noted that 98 percent of all fish produced in the country (from fisheries and aquaculture) is marketed, sold and consumed internally, and the quantity of fish consumed per capita is large in global terms at 20 kg per person per year. There is a well-established, though not necessarily well-organized (see below), sales infrastructure and many stakeholders are involved in the domestic fish marketing chain including (fishers and) aquaculture producers, traders, agents, intermediaries, processors and transporters. The market chain from production to consumption encompasses primary, secondary and retail markets, involving sales agents, suppliers, wholesalers and retailers. Although long developed, the authors undertook a strengths, weaknesses, opportunities and threats (SWOT) analysis to define among other things weaknesses associated with desert-based aquaculture which highlighted several market-related concerns, which included the marketing of products in unhygienic conditions with inadequate ice facilities; pointed out that retail traders are not equipped to market products operating in unhygienic sales conditions with inadequate chilling facilities to retain freshness in the products, for example; and highlighted the inadequate processing facilities for tilapia, the most produced fish species, in order to add value.

In all the cases above, there was no specific reference to the ability of farmers producing more environmentally sustainable products, through IAA for example, gaining a specific price advantage from such production; and no mention of accreditation or certification of such products.

4.1.9. Socio-economic aspects (incentives, farmer organizations, access to inputs)

a) Incentives

In Algeria support for the development of agricultural and aquaculture activity is not differentiated. Broadly the Algeria report specifies there are 34 support schemes for agricultural activities including subsidized or zero-rate credit granted by the Bank for Agricultural and Rural Development (RFIG), investment credit granted by the Algerian Bank for Rural Development (Banque algerienne pour le développement rural) (Ettahadi) underpinned by the Ministry of Agriculture, Rural Development and Fisheries. In Egypt and Oman specific incentives for IAA farmers were not identified although there is a need to credit facilities for artisanal and commercial desert aquaculture, so that small, medium and large-scale systems can be developed in Egypt and similar calls within Oman for small and medium-sized enterprises.

b) Farmer organizations

Farmer associations is an area where improvement must be made, according to each country report. In Oman the key farming association is the Omani Farmers Association. It has only recently developed from a smaller Governorate level association in Al-Batinah that had become so successful developing marketing activity and introducing new farming technology, that with government approval became the national association in 2016. It is not clear to what extent the associations will be able to support farmers wishing to introduce fish, or support the aquaponic IAA systems already developed, but time will tell. It was, however, noted that there are frequent meetings between the Ministry of Agriculture and Fisheries and those involved in farming using IAA systems. The full extent of Algerian associations could not be fully determined through the study undertaken, although seven associations in four Wilayas relevant to freshwater fish culture and agriculture were identified (Appendix B, Table B1.3). For Egypt no specific aquaculture associations, or farmer associations were identified, but the SWOT analysis undertaken highlighted weak aquaculture and fisher's cooperative societies and traders associations as a weakness to be overcome.

c) Farmer access to farm inputs

The provision of quality feed for fish appears to be the most difficult requirement for farmers, given that many of the farmers interviewed for the project, in Algeria and Egypt, produce farm-based feeds of poor quality that do not reflect the nutritional requirements of fishes, and no access to or lack of financial capability to purchase expensive feeds. According to farmer technical sheets completed during the project (Appendix C) most farmers identified they had access to fish locally or as a minimum within the country. In some cases, farms included hatcheries in order to be self-sustainable. Very few of the farmers in Algeria and Egypt reported specific difficulties with access to needed pipes and fittings, water pumps, air pumps, greenhouse materials for hydroponic/aquaponic systems or in access to tanks in which to grow fish (Appendix C).

In Oman IAA farmers import expensive feeds due to the lack of a feed factory in the country, which is recognized as a major economic challenge for farmers. In Oman most IAA systems are aquaponic systems involving RAS, which is highly technical and expensive to set up. Support is gained for development but availability of equipment is difficult, along with gaining sufficient people with the correct technical skills to operate the system.

None of the farmers reported difficulties at present, in obtaining water to support their farms and electricity requirements were met, and most maintained backup systems (e.g. generators) in the event of electrical failure.

4.2. Farmer to farmer visits

Farmer to farmer visits were undertaken in Algeria, Egypt and Oman (Figure 1).

Figure 1
Farmers visiting an aquaponic farm in Oman

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4.2.1. Algeria

Eighteen participants attended the Algeria farmer-to-farmer visits, visiting four farms in the arid district of Ouargla, Algeria. The farms provided a variety of IAA systems or systems in the process of development that enabled participants to evaluate and gather information. Systems visited were:

a) "Pescado de la Duna", a fish farm which uses a flow through system for the intensive culture of North African catfish (*Clarias gariepinus*) with an annual production of 300 tonnes.

b) An integrated agri-aquaculture farm of 20 hectares. The farm uses underground water resources to culture Nile tilapia (*Oreochromis niloticus*) and crops (tomatoes, cucumbers, dates and olive trees).

c) A governmental aquaculture facility established through the Korea International Cooperation Agency (KOICA) cooperation. The farm uses biofloc technology to farm whiteleg shrimp (*Penaeus vannamei*).

d) The last visit was devoted to a farm specialized in rearing of the algae *spirulina*.

In Ouargla, following an invitation, the group met with local government administration members, headed by the Governor, and provided an opportunity to reiterate the importance of application of IAA systems to improve food production potential using non-conventional sources of water. Participants were individually introduced to the Governor and local Government attendees. FAO staff gave a briefing on the objectives of the field visit and the discussions taking place on IAA farming systems.

In Oran, the group joined International Fair on Fisheries and Aquaculture ("Salon International de la pêche et l'aquaculture"). FAO had an exhibition stand at the fair which brought together industry experts, investors, research centres, national and international agencies and organizations. In a media interview made at the opening session of the fair, FAO explained the objectives of the field visits and the work being undertaken within the project and the fair offered the opportunity for farmer-to-farmer visit participants to establish contacts with public and private aquaculture sector, and particularly with the suppliers (e.g. of feed, seed, and equipment).

Visiting farmers observed the different IAA systems used in each farm attended and discussed best practices with the farm owners/operators. Visits in Algeria offered specific assessment of aquaponics and the use of biofloc technologies, and were generally viewed as the more highly technical and advanced technology being used within IAA systems. The visits to Algerian farms were successful and facilitated discussion and exchange of knowledge, experiences and perspectives on IAA and water resource issues within Algeria, along with lessons learned, emerging opportunities and challenges in relation to IAA farming systems.

4.2.2. Egypt

20 participants attended the Egypt farmer to farmer visits in November 2017 that facilitated visits to five farming systems, all of which use aquaponic technology to grow a variety of products, in conjunction with fish production.

Participants were shown soilless hydroponic beds in greenhouses, holding different varieties of organic lettuce, herbs, and vines grown using recirculated water connected to fish tanks growing Nile tilapia or North African catfish. Visiting participants were able to discuss in detail the fact that the fish production technology used provided up to 90 percent of the nutrients that plants need to grow, and which additional nutrients needed to be added to the system in order to provide the necessary full nutrient compliment needed for crop growth. Interestingly for the attending farmers, the use of aquaponic technology enabled Egyptian farmers to limit water loss within the system to as low as five percent, through recirculation and provision of greenhouse cover that limited evaporation from the system, which showed participants the efficiency in food production that IAA systems afford the farmer, and how both crops and fish production could be operated through integration and technologically how water resources could be used efficiently.

The final day of the farmer to farmer visit to Egypt was devoted to plenary lectures and discussions in the FAO office of RNE, in which participants discussed what they had seen and the positives of aquaponic type production of crops and fish. FAO delivered a presentation titled: Support to sustainable aquaculture development through the smart use of water in desert and arid lands as a means to generate discussion and conclusions drawn.

4.2.3. Oman

Nine participants from Algeria (7 farmers and 2 ministerial officers), six from Egypt (6 farmers and 1 ministerial officer) and eight from Oman (8 farmers and 4 ministerial officers) visited seven Omani aquaculture farms in February 2018. The farms provided a variety of IAA systems or systems to be developed for participants to evaluate and gather information. Systems available were:

a) Three recirculating aquaponic systems growing salad vegetables and herbs, linking water flows to provide nutrients from tilapia culture in tanks through soil-less production of agricultural crops. Excess nutrients were removed via filtration using available clay balls to mope up the excess. The farmers visited noted in particular that several critical nutrients could not be provided, adding iron and essential amino acids to the water column was a necessary requirement for the plant production. Biofiltration to remove ammonia produced by the fish was also necessary, through nitrification bacteria to convert the ammonia to less harmful and more useful nitrate, to support plant growth.

b) Although recirculating systems are used, it was noted that there comes a point when the water needs to be changed, either partially or completely, at which point the waste water is used for irrigation, for date palm and other agricultural crops grown in soil. The predominant water resource for recirculating systems was groundwater, although one farm used the more traditional "falaj" system of irrigation that transfers water from mountain areas to lower lying domestic and farming requirements.

c) One farm visited provided fish resources by growing fingerlings of various species, including ornamental fish. The site used a flow-through system, based on groundwater input and release of approximately 114 cubic meters of wastewater from the fish tanks every day, which are used to irrigate the date palm and other plants. By discharging the water directly, containing fish dissolved and particulate wastes, the farmer estimated they are reducing plant fertilizer use by approximately 50 percent, the plants able to utilize fish waste over time.

d) The three remaining sites visited grew fish only, with plans to include aquaponic systems in the future to grow salad vegetables. One clear requirement the fish farmers noted was the need for increased information and capacity building on the integration between agricultural, and for themselves to become more confident in making the right decisions for investment in the correct type of system.

More generally, the feedback from the Oman farm visits was positive. Participating farmers recommended focusing on the rational use of water and were able to see first-hand the added value to agriculture of integrating fish farming. Participants agreed that there is a need for regular trainings in the Aquaponics field with a more scientific perspective. Photos of farmer to farmer visits are provided in Appendix D.

4.3. Regional workshop outcomes

The objectives of the workshop were met and the workshop was very well received by those participating. This event gave the opportunity to share valuable information on the methodology used and tested during the project by the three selected countries (Algeria, Egypt and Oman). The workshop participants highlighted the importance of the farmer to farmer exchanges as one of the best methods of learning, by being able to see alternative methods and technologies, enhancing their current perspective and giving opportunity for consideration to initiating new approaches, systems and technology upon return to their home country.

Representatives from participating nations delivered national reports on use of non-conventional water for IAA farming systems in desert and arid lands, including perspectives on the main issues affecting development of the sub sector including associated main national supportive policies, summarized as follows:

Algeria

- Algeria started utilizing non-conventional water resources such as desalinated sea water, using underground brackish water, and using treated wastewater.
- There are two dominant models for IAA which are (a) Le modèle d'élevage intensif à grande échelle (The large-scale intensive breeding model), and (b) Le modèle d'élevage à petite et moyenne echelle. (The small- and medium-scale breeding model). Both of them are using freshwater resources.
- Algeria is tending to use water domes for aquaculture, as agreed between governmental sectors.
- The IAA farms in the south are producing tilapia and catfish.
- There is an action plan for 2017-2019 which includes Hassi Benabdallah Farm Equipment establishing a food factory with a production capacity of 10 tonnes/day.
- The shrimp farm in Ouargla is expected to play a pivotal role in supporting the "ambitious" program of aquaculture development in the Saharan regions.
- The main recommendations from Algeria are: (a) technically support graduates of the institutes that benefited from provision of agricultural lands by supporting them with the fry and food at first; (b) adopt a unified and standard training program for farmers; (c) prepare a technical manual for aquaculture integrated to agriculture according to the specificities of each wilaya; (d) follow up a farm that uses wastewater for irrigation of fruit trees and production of carp in a pond; and (e) coordinate with the various sectors involved in the aquaculture activity to ensure better management of the technical aspects of IAA.
- Algeria is suffering from unpredictable natural disasters and they are trying to figure out a method to calculate and harvest the water from these events.

Egypt

- The highest production for Egyptian aquaculture (tonnes) per system types in 2015 is around 700 kg, using semi-intensive earthen ponds.
- There were 35 projects using IAA in Egypt, relying on underground water as a water source. It was noted in the meeting that many projects have currently stopped producing due to problems with supply of energy resources needed for operating the systems.
- IAA is not a universally accepted concept for food production within Egypt and gaining licences continues to prove difficult. Egypt governorate is not accepting the Agri-aquaculture concept and not providing licences for practices. That said, various approaches for IAA systems are implemented in Egypt by various companies and individuals.
- Some IAA projects are implemented in South Sinai to attract Bedouin communities to provide them with a source of food and as a means to fight terrorism.
- There is an initiative being developed by the President of Egypt in consideration of applying by integrated systems with 1.5 million acres.
- Some aquaponics systems failed because they were not designed correctly, which highlights the need for correct technological knowhow and correct systems design.

- The limitations for spreading IAA in Egypt are: (a) limited of aquatic desert fish species; (b) poor fish market infrastructure; (c) poor market of retail traders; (d) shortage of hygiene requirements; (e) inadequate of tilapia cultured processing; (f) high energy cost; (g) lack of concern from the government to support NGOs; and (h) weak aquaculture and fishermen's cooperative.
- The opportunities behind using IAA are: (a) high seasonality demand for freshwater fish, mainly in spring and summer; (b) big opportunity to sale the fish live with extra sale price ranging between 15 to 30 percent compared with fresh fish; (c) Increase employment opportunities, and maintained rural communities; (d) Increase in fish price can increase incomes; (e) Improvement of socio-economic conditions; and (f) export potential.
- The water consumption, environmental conditions, and growth rates for agriculture crops should be well-known to enable anyone going to construct IAA systems to choose the suitable type of crops.

Jordan

- The country has limited water resources, with low rates of rain, except for 2018 where it reached 100 percent for some areas in the country.
- The national culture in the country and the area generally, is not to eat fish regularly, and this is why there is no market for fish; and will not accommodate the huge amounts that will be produced in case of large IAA systems.
- Until now the country has not taken a step forward in applying IAA systems, due to fish having no market.
- There is a trend in the country to use non-conventional water resources for agriculture to cope with water crisis.

Lebanon

- There are 40 rivers in the country, just 17 of them are permanent.
- The legislation for managing water resources was renewed in 2 000 but practical approaches under this legislative umbrella are required.
- Water management is carried under ten authorities.
- All practices for water irrigation are old and cause a lot of water losses.
- The country is using some lakes to harvest rain water and some is used it as fish ponds.
- Re-using treated wastewater is undertaken in the country but is not currently a dominant practice.
- There is no local culture in eating fish on a regular basis, and therefore do not favour IAA systems.

Mauritania

- Mauritania is known for its abundant fish resources thanks to an exceptional coastal ecosystem ("upwelling").
- The country is one of the largest countries to export sea-caught fish.

- There are no practices for IAA systems in the country.
- Mauritania uses limited amounts of non-conventional water resources in agriculture (about 5 percent).
- There is one activity using treated domestic wastewater for Agriculture Irrigation, at Nouakchott.
- The challenges Mauritania encounters are (a) impacts of climate change: desertification, salinization of soil, deficit of rainfall; (b) finding enough water and land to support the Mauritania's food needs; (c) the need for a comprehensive approach to coastal management; (d) freshwater stored in the natural depressions became progressively salty in contact with the haline soils; and (e) evaporation causing seasonal lakes to dry out between January and March, and created hyperhaline and coastal lagoons.
- The country has a challenging environment in providing consultancy and advisory services in native Arabic, which highlights the need for more skilled technicians and training.

Morocco

- Morocco is increasingly using non-conventional water resources through the re-use of waste water and desalination of seawater.
- Until now Morocco does not use non-conventional waters for the purposes of continental and marine aquaculture.
- Treatment wastewater re-use capacity is approximately 38 million m^3/year.
- The re-use of treated wastewater in agriculture is conducted in three on-going projects namely: Tiznit Project, SETTAT Project, and Oujda Project.
- Use of desalinated water in agriculture is conducted through two projects namely: Chtouka Project, and Dakhla Project.
- The challenges in using non-conventional water resources are (a) difference between the level of treatment required when using treated wastewater; (b) inadequacy between sanitation and re-use; (c) low mastery of industrial waste, where quality is not guaranteed; (d) multiplicity of stakeholders and insufficient cooperation; and (e) high costs of treatment, transfer and distribution.

Sultanate of Oman

- IAA projects have been undertaken since early 2000s but officially in 2013, with 21 tilapia farms established by local farmers with the support from MAF. It is expected that the number of farms will be 24 by 2019.
- Illustrations were given of a large-scale commercial aquaponics farm is Al-Arfan Farms, and a small-scale aquaponics farm owned by Rabab & Abdul Razaq.
- Tilapia is main fish species grown, although a general problem in local culture accepting tilapia in their diet was noted; while agricultural crops include lettuce, tomatoes, basil, cucumber, strawberries, dates palm.
- Just 10 percent of the water from fish basins are used for vegetables grown in greenhouses.

- Technical challenges include lack of experience and skilled labour, lack of fish feed and unavailability of a feed factory, general weather conditions, and limited access to markets.
- Organizational challenges include the physical distance between Farmers, who are scattered across the country which limits interaction, and at individual level there is a conflict between limited individual production capability versus the need to supply mega markets with higher level of output.
- Environmental and financial challenges include water availability, high water salinity, high air temperature, and high investment cost.
- The added value products are a must for IAA systems sustainability.
- Creating an association for the farmers will allow them to exchange their experiences and lessons learned.
- Some farmers noted that the system needs subsides to be sustainable. Governmental financial assistance mechanisms exist, such as the Development Bank who are able to provide facilities (including loans, land, equipment, and technical advice) for those who want to develop IAA systems.

Palestine

- Non-conventional water resources are not used efficiently since we are suffering from the lack of treatment stations.
- The treated wastewater is used to produce grass but this just a tentative project.
- Total water produced in the country is approximately 1200 million m^3. Within this Palestine get just 200 000 m^3 and the rest goes to Israel. This amount of water is small and inadequate for domestic needs.
- Most of waters used in agricultures comes from fountains and rainwater harvesting.
- Aquaculture started in 2012, with a project funded from a Brazilian Association in southern area of the country, but one of the main problems was sourcing fingerlings, as they are provided from Israel.
- To overcome the problem of fingerlings availability, they decided to construct a hatchery to produce the fingerlings to support the farmer. It was a small scale.
- The problem that local people not accepting the taste of fish that produced from freshwater.
- The IAA systems are not used in the country due to the public acceptance problem and the problem with fingerlings.

Kingdom of Saudi Arabia

- The fish farming sector was limited to the production of the inland water aquaculture.
- There are 108 projects in the country with inland water aquaculture, 34 closed systems and 74 open systems with an annual production capacity of 8 546 tonnes. 90 percent of the production is tilapia, carp and catfish.
- The largest two inland fish farms are Kindle Project 350 Basin, and Maram Project 600 Basin, containing 80 000 Date Palm.

- There are 12 projects in modern aquaculture (Aquaponic & Hydroponic).
- The country is using one farm through IAA system techniques.
- The country strategy is to achieve production of 600 000 tonnes of fish and shrimp by 2030, primarily in sweater, although with a significant contribution from inland water aquaculture projects.
- The country is providing facilities (including loans, land, equipment, and experts) for those who want to invest in IAA systems.

Sudan

- There is a trend in the country for increasing of aquaculture activities and numbers of fish farms, especially in Khartoum state (400 farms).
- Freshwater culture began in 1953 by using extensive and semi-intensive pond culture of indigenous Nile tilapia in monoculture or polyculture systems.
- IAA is not a mature practice in Sudan with only a limited number of private sector people singing the praises of IAA systems.
- The challenges in Sudan are (a) the market demand for undersized fish and under-investment in the fisheries sector; (b) multi-dimensional, complex and seemingly resistance to change in order to use IAA systems; (c) weak institutional capacities in terms of manpower and research; (d) weak policy framework and fisheries legislation; and (e) there are problems in areas of communication, availability of information, coordination and cohesion between and within the various administrative levels of government.
- The quantity non-conventional water is generally insignificant and its use is still very limited and at an early stage. National development of such water includes a desalination in Port Sudan and sewage treatment in some parts of Khartoum.

5. Conclusions and future perspectives

Outcomes from the regional reviews from Algeria, Egypt and Oman, and presentations and discussion made during the regional workshop held in Cairo, Egypt in June 2019 with representatives from across the NENA region, there was general acceptance that IAA was a viable option to increase food production whilst reducing water use. The farmer to farmer visits highlighted some operations in practice and provided opportunity to discuss in detail the best practices available.

There are several challenges for implementing IAA in the NENA region, which still relies heavily on use of renewable water resources, such as groundwater, rather than non-conventional water resources. Further these challenges may explain there is relatively limited adoption of technology and approaches to IAA currently and highlighting that further work, outreach, training and skills development and financial investment is required.

5.1. Water resources challenges

a) Lack of enabling environment

Policy and regulation are developed separately, for conventional agriculture and conventional aquaculture, which is also often mixed in with fisheries, and using conventional water resources. Thus, there is a need for attention to be paid by public sectors and regulators to provide policy and regulation for the mixed systems approach required for the adoption of integrated agri-aquaculture systems, including the approach to provision of water resources from non- conventional sources.

b) Technology

The use of saline and brackish water, as non-conventional water resources, in the agricultural and aquaculture businesses, is very limited in the region. Reasons for this are the following:

- The technology required for desalination processes, on a scale and with technology that is sufficient for a farmer's needs, is very complicated and technologically advanced for most small to medium scale farmers.
- There is a general lack of skills and experience in the adoption and use of technology within the region.
- Where technology has been applied, there is a specific problem in the availability of spare parts to maintain operational activity; and
- Adoption of technology generally requires high capital and operational costs, which is often beyond the means of the farmer, which limits adoption.

5.2. Proven IAA technology

Generally, an agri-aquaculture system is developed by an agricultural farmer (rather than an aquaculture farmer adding crops to their system), as a means to increase production and productivity, and for efficient water use within the system as a whole. Adoption of IAA systems by agricultural farmers requires various new and innovative technological components that include high grade water quality, pumping and water treatment, adoption of unfamiliar and novel aquaculture species, and improvement in systems of monitoring and control, among others, which are not common to the regular farmer.

In the context of adding aquaculture to an existing agriculture farm, there are various available options to build the IAA system, that could include ponds or tanks, water flow-through systems through water replacement and on to zero discharge systems; that may be applicable depending of the fish production level, agricultural crops grown and systems available. Within the NENA region as a whole there was thought to be a very limited expertise, in government, research institutions and through consultants, available to advise the farmer on precise requirements, and selection and design of feasible systems that matches the location specifics. The main challenges are similar to those for adoption of technology outlined above, namely:

- The complexity of available IAA technologies for farmers to deal with independently.
- Lack of skills and experience in technology, fish cultivations, potential diseases, soil-less agriculture techniques, at both the farmer level and more generally.
- Difficulties in the availability of cost-effective and appropriate fish feed (specific for the species grown).
- Availability of spare part to maintain operational activity.
- High capital and operational costs.

5.3. Products Marketing and public acceptance

There is a disadvantage in the market value of products and market acceptance of the main products produced out of IAA systems:

a) Fish:

Many people living in desert are not used to eating fish, which currently limits access to local markets. More broadly, there was a consensus that in other countries people prefer eating natural marine fish and not freshwater fish, that often resulted in low market values of the fish produced in IAA systems.

b) Vegetables:

The cost of producing vegetables within an IAA system were thought to be higher than from conventional agricultural systems. IAA system products need to be marketed with an eco- or bio-branding at a premium price, and to specific types of customer in order to sustain the business.

5.4. Financial and economic feasibility

Financial feasibility of using IAA systems is not currently attractive due to high capital and operational costs associated with the system implementation and operation. The cost of energy was identified as one of the limiting factors to achieve financial sustainability (e.g. Egypt case study). Financial sustainability remains a problem, despite the fact that the implementation of IAA systems has many socio-economic opportunities around job creation, improve livelihood of communities in desert/arid conditions, contribution to water resources managements at national & regional level, and others. Despite these positives, there is limited attention given to support and promote IAA systems in the region. There is therefore a need for incentive mechanisms to promote adoption, through financial and technical support, needed to attract and stimulate the private sector, investors and farmers to adopt IAA system in the region.

As part of the discussion on IAA systems a Build-Operate-Transfer approach (referred to as BOT approach) was proposed, for development of IAA pilot projects that are built by the government/public funds to promote IAA technologies. There was some disagreement amongst participants that in part was driven by perceived stereotype experience of some participants related to public/governmental projects being inefficient in implementation and operation. There was, however, general consensus that some form of new management scheme (e.g. Private-Public Partnerships, concession contracts, performance management contract) is needed for development and expansion of IAA projects.

5.5. Broad roadmap for future activity

Within the regional workshop two established working groups were initiated and focused on (1) Water Resources: the most suitable/appropriate water resources for agri-aquaculture development in the region and (2) Integrated agri-aquaculture: the most suitable integrated agri-aquaculture farming systems for the region. Overall results from the working groups were presented in plenary session at the workshop and are summarised in section 4 (this report).

The developed activities within the road map matrices developed out of each working group discussion (Table 2 and Table 3, respectively) formulated a good base to identify the top priority activities and interventions required to improve sustainable development of IAA, and associated ethical and sustainable use of non-renewable water resources; covering technical, policy/governance, social, economic and other requirements. The actions proposed support components of the FAO regional action programme on water resources use and development of aquaculture, most especially in desert and arid lands.

The participants agreed on the following top priority actions:

- Develop demonstration IAA units/models/pilot-schemes that utilize environmentally sustainable and state-of-the-art technology, and develop capacity building and training enhancement, that demonstrates and promotes IAA development potential within the wider region.
- Develop activities that will promote implementation of IAA by encouraging and facilitating Build-Operate-Transfer projects; development of best management practices and manuals to support farmers; and through marketing potential of IAA products through certification, eco-labelling, awareness campaigns, use of web to market products, unifying the small farmers for marketing of products and potential NGO role in these activities.
- Develop a centre of excellence and/or platform that enhances regional understanding of the technical, legislation, best IAA practices, assessment of on-going projects and troubleshooting ideas to overcome resistance to and to overcome requirements for implementation and development of IAA.
- Develop demonstration IAA units/models/pilot using rain harvesting water resources in Darfur as a model for Sudan in the development of IAA, accounting for limited water resources, environmental conditions and consideration of social requirements in relation to potential for refugees.
- Develop a financial and economic programme to be used to investigate the feasibility of IAA projects in the region and to support development.

Participants also agreed that in case of budget limitation, technical projects should be prioritized over purely management proposals.

Table 2

Suitable water resources for IAA systems

Working group 1: Water Resources: *which are the most suitable/appropriate water resources for agri-aquaculture for the region*						
Questions	**Status**	**Target**	**Actions**	**Who needs to be involved?**	**What consultation method will be used?**	**Timeframe**
Level of accessibility to water resources						
Quantity and quality data availability	Limitation and efficient use is low Water quality is low	Increase efficiency and availability	Use additional resources/non-conventional/water harvesting techniques Inventory and mapping of available underground waters Ease the license procedures	Public institutions Private sector Farmers associations & cooperatives	Dialogue, extension, monitoring, publication, meetings.	1–3 years
Environmental sustainability (Clear policy regulations)	License with some restriction	Sustainable use for water and IAA	Review and update of regulations and monitoring	Public institutions Private sector Farmers associations & cooperatives	Dialogue, extension, monitoring, publication, meetings.	1–3 years
Capacity building, training, Education and communication	Limited	Promote the IAA concept	Build capacity for the key actors on IAA techniques, sustainability and EIA and feasibility and economical value, water availability		Dialogue, extension, monitoring, publication, meetings.	1–3 years

Market development and trade	Limited	Prepare/Develop the market	Raise awareness for consumers Improve the extension services Standardization/certification Diversification of cultured species of fish and crops Value chain and cost-effective analysis		Dialogue, extension, monitoring, publication, meetings.	1–3 years
Socio-economic aspects (labor/ job creation, incentive, food security, culture, acceptance etc.)	Limited	Improve livelihood in rural and desert area in particular youth and women	Representative Pilot project in the rural/desert area for pear to pear extension Subsidized the IAA project, especially for youth and women Small-scale farms and or cooperatives when applicable small and medium-sized enterprises (SMEs)	Public institutions Private sector. Farmers associations & cooperatives With focus on small scale farmers	Dialogue, extension, monitoring, publication, meetings.	1–3 years
National, regional and inter-regional cooperation	Limited	Improve the regional cooperation Intergovernmental coherence At national level	Establishment of a regional network/hub of reference centres on IAA Establishment of inter sectorial committee Exchange of experts visits At national level, identify a leader farmer		Dialogue, extension, monitoring, publication, meetings.	1–3 years

Availability and feasibility of water resources technologies						
Technologies exchange /innovation	Limited new technology	To improve abstraction and treatment	Platform exchange program and pilot for best practice	Public, government and private sector	Dialogue, extension	1–3 years
Capacity building, training, education and communication	Limited	Technology of water resources	Training program for engineering, exhibition for new technologies	Public, government and private sector	Monitoring, publication, meetings	1–3 years
Socio-economic aspects (labour/ job creation, etc.)	Limited		Developing and social economic studies for the promotion of IAA in the region	Public, government and private sector	Dialogue, extension, monitoring, publication, meetings	1–3 years
Research and development	Limited	To improve abstraction and treatment. Technology for water resources	Adoption of IAA technology	Public, government and private sector	Dialogue, extension, monitoring, publication, meetings	1–3 years
National, regional and inter-regional cooperation	Limited		Developing regional network for advanced water treatment technology for IAA	Public, government and private sector	Dialogue, extension, monitoring, publication, meetings	1–3 years

Table 3
Integrated agri-aquaculture (IAA) systems

Working group 2: Integrated agri-aquaculture: *which are the most suitable integrated agri-aquaculture farming systems for the region*						
Questions	**Status**	**Target**	**Actions**	**Who needs to be involved?**	**What consultation method will be used?**	**Timeframe**
Level of accessibility to integrated agri-aquaculture farming information						
System selection for agri-aquaculture integrated farming systems (advice)	Limited	To be accessible	To develop information center and/or platform (technical, legislation etc.) Best IAA practices	Concerned authorities (Ministries) + Private sector	Workshops, farmer- to-farmer (B-to-B), model farms	1 year
Capacity building, training, Education and communication	Not available-limited	Improving capabilities	Training and hands-on experience on technology and management. internship for small farmers producing brochure	Government + Private sector + international organization	Training (individual + training of trainers), exchange programs with other countries	Continuous (minimum 6 months)
Environmental sustainability; (Clear policy and regulations)	Moderate-Good	More environmentally friendly	Developing demonstration IAA units that have the most environmental friendly technology	Government + Private sector	Top-down approach	0.5–2 years

Market development and trade	Limited	To be more efficient	Developing promotion package (Certificate, labelling, NGO role, awareness campaign, electronic market, unifying the small farmers for marketing, Encourage/ facilitate BOT (Build-Operate-Transfer) projects	Private sector + support of the concerned authorities	Exhibition, collaboration with hypermarket and restaurants, TV programs	1 year Continuous
Socio-economic aspects (Labour / job creation, intensive, food security, culture, acceptance etc.)	Limited	To be promoted	Establishing SMEs and start-up with governmental support to be based nearby residential area with access to water sources.	Government + private sector	Top-down approach	0.5–3 years
National, regional and interregional cooperation;	Limited	To be promoted	Developing regional and inter-regional centres of excellence/network to collaborate in research, consultancies, education, training etc.	International, regional and national organizations	Meetings, workshop, visits, data collection	2 years Continuous
Availability & Feasibility of integrated agri-aquaculture farming technologies						
Technology Exchange /innovation.	Limited	To be promoted	Attract innovative ideas through competition (at university and college students level) to use and assess renewable energy and processing techniques in IAA	Government + private sector	Competitions, R&D projects, university projects,	2–3 years Continuous

Capacity building, training, education and communication	Not available - limited	Improving capabilities	Training and hands-on experience on technology and management. Internship for small farmers producing brochure	Government + Private sector + international organization	Training (individual + training of trainers), exchange programs with other countries,	Continuous (minimum 6 months)
Socio-economic aspects (labor/ job creation, intensive, etc.)	Limited	To be promoted	Establishing SMEs and start-up with governmental support to be based nearby residential area with access to water sources.	Government + private sector	Top-down approach	0.5–3 years
Research & development	Moderate	To be promoted	Establishment and/or reinforcing of a public research centre in IAA	Government (ministries and universities)	Meetings, discussion	1–2 years
Regional and interregional cooperation	Limited	To be promoted	Developing regional and inter-regional centres of excellence/network to collaborate in research, consultancies, education, training etc.	International, regional and national organizations	Meetings, workshop, visits, data collection	2 years Continuous

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7. Further reading

The following is a list of useful documents, web resources and other materials on non-conventional uses of water in agriculture and aquaculture, desert-based integrated agriculture-aquaculture systems and other relevant information that may be useful to regional practitioners, policy makers, government departments, farmers and farm owners, and other stakeholders. The list is not exhaustive, but provides a good selection of relevant materials, from that which is available.

1) Sharing innovative, water-saving agri-aquaculture experiences across the Near East and North Africa (www.fao.org/blogs/blue-growth-blog/sharing-innovative-water-saving-agri-aquaculture-experiences-across-the-near-east-and-north-africa/en)
2) Every drop counts www.fao.org/fao-stories/article/en/c/1111580/)
3) Non-conventional water resources use in Mediterranean agriculture (http://ressources.ciheam.org/om/pdf/b53/00800761.pdf)
4) An Overview of Conventional and Non-Conventional Water Resources in Arid Region: Assessment and Constrains of the United Arab Emirates (UAE) (https://file.scirp.org/pdf/JWARP20100200010_12015024.pdf)
5) Water use in Egypt.

   (https://apps.icarda.org/wsInternet/wsInternet.asmx/DownloadFileToLocal?filePath=Working_Paper_Series/Water_Agriculture.pdf&fileName=Water_Agriculture.pdf)
6) Evaluation of non-conventional water resources supply in Jordan (https://www.sciencedirect.com/science/article/abs/pii/S0011916401001680)
7) Non-conventional water

   (https://menanwc.org/community-type/technical-communities/non- conventional-water)
8) Global Water Partnership: Non-Conventional Water Resources Management (https://www.gwp.org/en/GWP-Mediterranean/WE-ACT/Programmes-per-theme/Non- Conventional-Water-Resources-Management/)
9) Non-Conventional Options for Water Supply Augmentation in the Middle East: A Case Study (https://www.tandfonline.com/doi/abs/10.1080/02508060408691773)
10) Integrated Agri-Aquaculture with brackish waters in Egypt. (file:///C:/Users/racor/Desktop/report.pdf)
11) Integrated Agri-Aquaculture Systems (https://www.researchgate.net/publication/226829080_Integrated_Agri-Aquaculture_Systems)
12) Integrated Agri-Aquaculture Systems: A Resource Handbook for Australian Industry Development (http://www.backyardaquaponics.com/Travis/03-012.pdf)

APPENDICES

Appendix A: Agenda of the regional workshop and group photograph

25 June 2019	
08.30-09.00	Registration
09.15-09.30 09.30-09.45	Opening of the regional workshop (Regional Programme Leader) Introduction of FAO Water Scarcity Initiative (WSI leader)
09.45-10.30	Presentation of the project, conduction and objectives of the workshop • General overview of the project, methodology and achieved results • Workshop objectives and approach
10.30-10.45	*Coffee break*
10.45-11.45	Presentation of the three national reports Main findings, experiences, challenges and opportunities from the national assessments on desert and arid lands agri-aquaculture sector carried out in the three selected countries (i.e. Algeria, Egypt and Oman) by the national teams. Questions & answers, discussion and recommendations.
11.45-12.30	Open discussion on the best use of water for integrated agri-aquaculture (IAA) farming systems in arid lands.
12.30-14.30	*Lunch break*
14.30-15.45	Presentation from other participating countries Use of non-conventional waters for IAA farming systems National strategies for best implementation of water management practices.
15.45-16.00	*Coffee break*
16.00-16.45	Presentation of a regional roadmap framework for upscaling Main steps to promote and develop effective sustainable non-conventional water use practices for IAA farming in the NENA Region.
26 June 2019	
09.00-12.30	Working group session • Working group 1: Water management: which are the most suitable water saving systems for the region? • Working group 2: Integrated farming systems: which are the most suitable integrated agri-aquaculture farming system for the region.
12.30-14.30	*Lunch break*
14.30-15.45	Working group session (cont'd) Presentation of outcomes from each working group • *Plenary and Working Group presentations* • *Questions & answers, discussion and recommendations*
15.45-16.00	*Coffee break*
16.00-16.30	Integration of working group recommendations into the regional roadmap FAO staff will facilitate the integration of working group recommendations within the regional roadmap.
16.30-17.00	Closure of the workshop (Regional Programme Leader)

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Group photo of the participants at the regional workshop. Garden of RNE Office, Cairo, Egypt.

Appendix B: Case studıes of the use of non-conventional water in agriculture in support to sustainable agri-aquaculture development in desert and arid lands in NENA region

Appendix B.1: Algeria case study

Tarik Hartani, *FAO Consultant, Algeria*.

Summary

Development of aquaculture using non-conventional sources of water has developed slowly in Algeria since 2008. Currently there are approximately 600 farmers assessing development potential, generally operating on a small scale as they develop techniques and approaches to arid aquaculture development, although some larger commercial scale operations have also been developed. Production in 2017 is estimated at approximately 5 000 tonnes, primarily of tilapia, some catfish and carps integrated with more conventional agricultural crops such as date palm, cereals and market garden products. Farming experience is limited, often to just the last three to four years only in a more hobby-oriented approach. Development in extensive and semi-intensive systems is further hampered by limited understanding and training in production and culture practices, although peer-to-peer training is growing and some farmers have been able to benefit from overseas training visits. Water use is currently based around more convention water use, particularly from groundwater sources drawn into holding basins which then feed the farm. Water quality is occasionally an issue depending on the underlying rock substrate type, with many desert water sources officially classified as brackish water. Non-conventional sources of water have nonetheless been identified, and include desalinated water and treated wastewater and the use of Chotts, temporary slightly salt water lakes in desert areas, but all with the potential to benefit aquaculture-agriculture systems in arid environments. An analysis of farmer questionnaire and interview responses showed that integrating aquaculture with agriculture in arid environments is achieving benefits. This includes significantly reducing and in some cases eliminating the need for fertilization of crops, which are benefitting from increased nutrients from fish farm water added to crops, and dual use of the water means increased production from the same volume used. There remains a difficulty at present, however, in terms of making the aquaculture component of the system economically viable. The Algerian Governments Horizon 2035 programme has strong plans to increase aquaculture-agriculture production through the use of non-conventional sources of water, supported by legislation updated in 2008 on the integration of aquaculture with agriculture. Overall, aquaculture integrated with agriculture is seen as a positive development for Algeria with firm plans to increase overall production. This case study report concludes with a series of recommendations, which includes the setting up of demonstration sites in the use of non-conventional water, improved training and extension activity and research required to better understand the needs of non-conventional water in aquaculture-agriculture systems in arid environments.

Overview of the agriculture-aquaculture sector

Contribution to national food security

Currently, Algeria is one of Africa's leading food importers, with 75 percent of its food needs coming from imports. There is insufficient and inefficient agricultural production in Algeria but a large and growing demand for agri-food products that has caused a gradual shift in the food-model, towards imports, making Algeria a structurally importing country and therefore strongly dependent.

Twenty percent, by value, of all imports are food products. Algeria is one of the largest grain consuming countries in the world, for example, but local production covers just 25 percent of national demand. Production is dependent on rainfall, which is low in Algeria. The dairy industry in Algeria has a similar same configuration, importing 60 percent of its milk powder consumption every year, and will massively increase given the average annual growth of the Algerian dairy market is estimated at 20 percent. Agricultural products in total amount to 30 percent by volume of the country's total imports, and instability in world prices places great uncertainty on the total food bill each year. The share of agriculture in GDP increased from eight percent in 2000 to 12 percent in 2016. The value of agricultural production in 2017 was 3 060 billion Algerian Dinar (DZD), of which about one third (1 014 billion DZD) corresponds to the animal production (meat, fish). Another important factor in the overall economics of food production is the percentage of household budget spent on food, which currently stands at almost 45 percent.

Agriculture and aquaculture are connected through social, political and economic aspects of food security in Algeria. It also enables the stabilization of populations of different regions of the country and thus contributes to regional economic development. The ability to improve food security has several natural constraints, however, such as scarcity of water and soil resources, and from the configuration of agricultural structures in which small scale farms, characterized by low productivity and accrued technical, human and organizational deficits, predominate. In this context, the policy of promoting and developing the agriculture-aquaculture sector comes in response to issues of food security, the policy dealing with the many challenges faced, particularly those related to national agricultural production, land optimization, effective use of water resources and strengthening of the implemented policies.

In 2015, total fish production from capture fisheries and aquaculture is estimated at 105 200 tonnes. The largest proportion consists of caught small pelagic species, among which seven out of every ten caught are sardines (*Sardina pilchardus*), round sardinella (*Sardinella aurita*) and horse mackerel (*Trachurus* spp.) (MPRH, 2014). Most production is consumed nationally, but Algeria also imports 30 000 to 40 000 tonnes annually. Some fish are exported which are mainly frozen filleted and canned fish, limited to 1 500 and 2 000 tonnes over the period 2010 to 2015, generating an average revenue of 90 million US dollars per year. Annual national fish consumption is low in a global context, estimated at 6 kg per capita per year in 2015, well below the global average of 20 kg achieved in 2016 according to FAO.

Aquaculture is a small proportion of overall fish production, totalling 4 200 tonnes in 2017, with all sectors combined (MPRH, 2014; MADRP, 2017). Several development plans and programs over the past ten years have led to the establishment of around 20 aquaculture facilities creating up to 100 jobs. Some private aquaculture projects have also been supported but are not yet operational. Production from aquaculture is an emerging activity and has grown since the 2000s while remaining modest at 2 200-2 600 tonnes annually over 2011 to 2014, reducing to 1 300 tonnes in 2015, but increasing to 5 000 tonnes in 2017.

Fisheries and aquaculture constitute a small component of the economic activity contributing 0.6-0.8 percent of Algerian GDP, supporting approximately 80 000 jobs (representing 0.75 percent of the working population, amounting to 11.9 million people), through eleven jobs defined in the professional training directory. The number of professionals working in the sector has grown since 2010, when it was estimated that 70 000 jobs were supported. These are relatively young people on average (60 percent of them are under 35 years old), although in the artisanal fishers category, 40 percent are over the age of 45 and two-thirds were brought up in families of fishers, making it a family-learned profession.

The aquaculture sector, including aquaculture integrated with agriculture, fisheries, together with hygiene and health security among others, are under the responsibility of the Department of Fisheries and Fishery Resources, supported the Department of Agricultural Services (DAS) in the wilayas (districts) and the Departments of Veterinary Services (DVS) at a central level. There are significant numbers of people in the DAS at a municipal level who dedicate a very small part of their time and effort to help in aquaculture extension activity and provide support-advice to fish farmers. There are also many veterinarians from the DVS who are seconded to work in mixed teams with inspectors of the Departments of Fisheries and Fishery Resources, who are also in contact with inspectors from other ministries, including the Ministry of Interior, Office of Municipal Hygiene, Ministry of Commerce and Ministry of Health to support integrated agri-aquaculture development.

Stakeholders such as the National Coast Guard Service (under the supervision of the Department of National Defence), the Port services (Ministry of Public Works and Transportation) or the structures responsible for dams and lakes (Ministry of Water resources and the Environment) play an important role and are large in number. With 64 landing sites in the country, it can be estimated that several other hundreds of people are working for the sector overall, since they work in the fields of shipbuilding and naval repair, processing and marketing of fishery and aquaculture products.

Status of aquaculture integrated with desert agriculture

Potential of aquaculture development

The aquaculture potential in arid areas of Algeria is hypothetically huge because of the vast land surface (over 1 200 000 km^2) but also the private nature of agricultural activity in Algeria, which encourages private investment, tempered by availability of high quantity of underground water. In recent years fish farming in irrigation ponds was part of a program of fry distribution to farmers developed by the fisheries department, the last of which dates to June 2017. In arid zones currently, it has been estimated that there are approximately 1 200 irrigation ponds managed and operated by approximately 320 farmers practicing fish farming (Table B1.1). They represent nearly 50 percent of the 626 farmers known to be practicing fish farming throughout the national territory. According to statistics, total aquaculture production by all practicing farmers in 2014 was 2 411 tonnes, with production estimated at 5 000 tonnes in 2017.

Table B1.1
Seeding program for irrigation basins in arid areas
(Department of Fisheries and Fishery Resources, 2017)

Wilaya	Number of basins	Number of farmers practicing fish farming	Targeted species
Bechar	193	25	Tilapia ad catfish
Adrar	217	59	
Tindouf	65	3	
Saida	11	10	Red tilapia and catfish
Naama	18	10	
Msila	38	30	Common carp, Crucian carp and tilapia
El Bayadh	65	20	Silver carp and other species
Ouargla	100	50	Tilapia, Common carp and African sharptooth catfish
El Oued	100	10	
Biskra	100	65	
Ghardaia	100	30	
Laghouat	100	5	Tilapia
Illizi	100	2	Tilapia
Tamanrasset	1	1	Silver carp and Bighead carp
Total	**1208**	**320**	

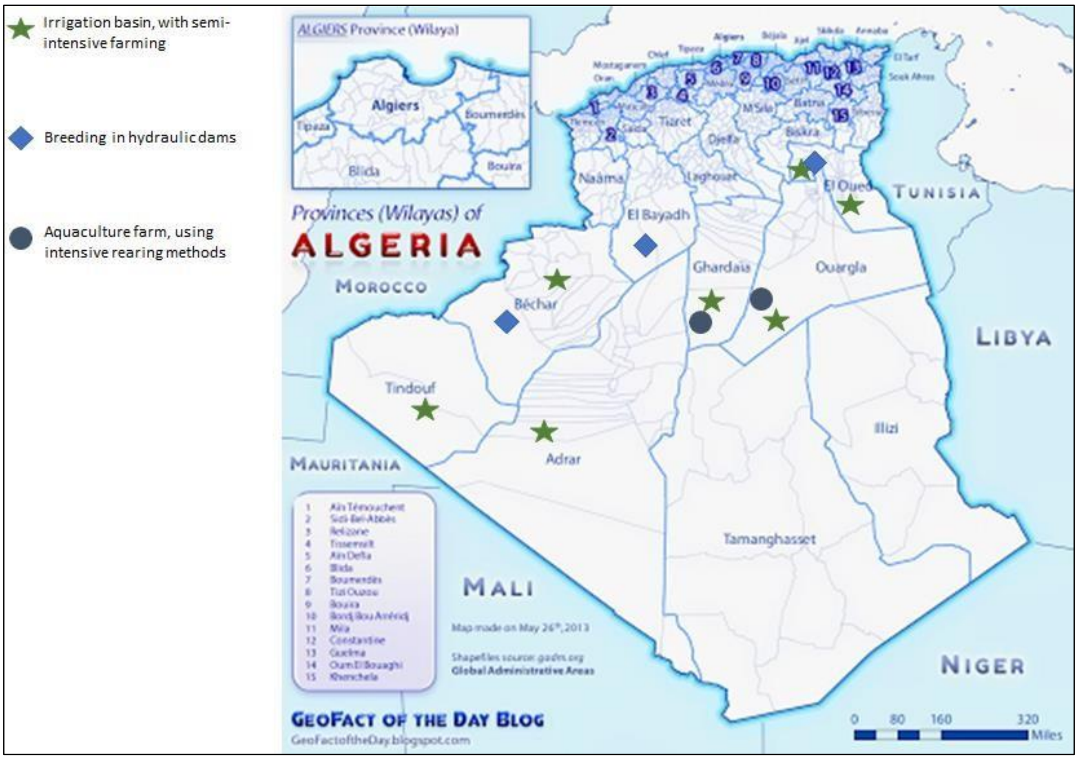
Current situation on inland aquaculture in the desert

Inland aquaculture in arid environments is developing, especially since 2008. In recent years, initiatives to introduce and develop aquaculture have been conducted in the wilayas of southern Algeria (Figure B1.1). As a result, today there are two prevailing approaches used:

- Large-scale intensive breeding (Figure B1.2): in which closed recirculating aquaculture systems (RAS) are used, in which fish are intensively bred using commercial feed and controlled aeration systems.
- Small and medium scale breeding that can be divided into two sub-categories:
  - Extensive aquaculture in dams: involves the release of fry from different species of freshwater fish into dams and irrigation basins (Figure B1.3A). DGFA and the National Center for Research in Fisheries and Aquaculture carry out fish restocking campaigns in water bodies for environmental purposes and to help fishing communities. In arid areas, there are currently seven dams or hillside reservoirs where farming is carried out in floating cages distributed between Biskra, El Bayad, Laghouat and Bechar.
  - Semi-intensive Saharan aquaculture integrated with agriculture: consisting of small and medium-scale farming in concrete or earthen irrigation basins located in agriculture holdings (Agri-aquaculture) where flows of water and organic matter support agriculture activity; and, in some cases, agriculture activity in part support fish production (e.g. through home-made feed production) giving reciprocal flows of energy and nutrients (Figure B1.3B).

Figure B1.1

Fish farming practices undertaken in arid region of Algeria. Information derived from survey undertaken for this report



Map source: Anonymous, 2013.

Figure B1.2

Intensive aquaculture conducted in Hassi Ben Abdellah, Ouargla

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Approximately ten aquaculture projects are currently in progress in desert areas, giving an overall production capacity of approximately 1 700 tonnes per year, of which nearly 1 000 tonnes are produced at the Hassi Ben Abdellah site in Ouargla (Table B1.2).

Figure B1.3

A) Release of fish fry, as an aquaculture model in Djorf Torba dam in Bechar (Bensalem, 2018) and

B) Example of integrated agriculture-aquaculture model undertaken in Biskra

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Table B1.2

Operational inland aquaculture projects in southern Algeria wilayas (DGFA, 2017)

Location	Direction of Fishing and Fishery Resources in the Wilaya	Project name	Sector	Production capacity (tonnes)
Hassi Ben Abdallah	Ouargla	Pescado de la duna	FPP	1 000
Biskra	Ouargla	Ferme d'élevage aquaponie	Aquaponics	-
Hassi Lefhel (Ghardaia)	Ouargla	Ferme Essahra	FPP	450
Adrar	Bechar		FPP	20
Adrar	Bechar		FPP	20
Adrar	Bechar		FPP	200
Tindouf	Bechar		FPP	20
Tamanrasset	Bechar		Spirulina farming	10

The Horizon 2035 vision within the strategic development plan for the inland aquaculture sector identifies several projects completed or underway (MREE, 2017; MADRP, 2017), as follows:

- 150 floating cages farms in water bodies (freshwater) producing 12 000 tonnes of fish and 1 440 direct jobs, with revenues expected amounting to 4.8 billion DZD (=Algerian dinar: 1US$=0.00838 DZD) for an investment cost of 8.7 billion DZD.

- 195 fish farms in ponds producing 29 000 tonnes, with revenues expected amounting to 11.6 billion DZD for an investment cost of 48.5 billion DZD, and the creation of 3 400 direct jobs.
- 42 shrimp farms producing 2 100 tonnes, an investment cost of 16.8 billion DZD, revenues amounting to 2.1 billion DZD and 300 direct jobs created.
- 100 inland fish concession holdings, producing 5 000 tonnes, revenues amounting to 1 billion DZD, an investment cost of 0.1 billion DZD, with 300 direct jobs created.
- More than 1 900 irrigation basins that integrate fish farming with agriculture for a family production of 1 900 tonnes, revenues amounting to 0.38 billion DZD, an investment cost of 0.76 billion AD, with the creation of 3 800 direct jobs.

Legal framework for aquaculture activity

Several regulatory texts exist for the regulation of general aquaculture and aquaculture integrated with agriculture activities; notably:

- **Executive Decree No. 04-373** of the 21st of November 2004: defining the methods of granting the concession for the establishment of an aquaculture structure, amended and supplemented by Executive Decree No. 07-408 of the 25th of December 2007, amended and supplemented by Executive Decree No. 10-93 of the 14th of March 2010, amended and supplemented by Executive Decree No. 12-231 of the 24th of May 2012.
- **Executive Decree No. 07-208** of the 30th of May 2007: setting out the conditions for operation of fish farming and aquaculture activity, the different types of structures, conditions of their establishment and rules of their operation.

  Article 2 of this decree defines the different types of aquaculture establishments that can be put in place, among others "fish farming establishments" defined as breeding establishments for marine or freshwater fish, including conditions for the establishment of aquaculture plant (Chapter 1).

  Article 4 sets out the content of the application file for the establishment and operation of an aquaculture plant/facility, particularly in land areas under private ownership. This file consists mainly of the following components:

  - A draft study of the aquaculture plant.
  - A certified copy of the national identity card for natural persons.
  - A copy of the association articles and a copy of the official journal of legal announcements establishing the company for legal persons.
  - The title proving the ownership of the land or a document proving the lease of the land is established for a minimum period of 25 years.
- **Order of the 28th of November 2010:** sets out the content and the standard model of the provisional and final authorization relating to the establishment and operation of an aquaculture plant/facility.
- **Executive Decree No. 04-188** of the 7th of July 2004: lays down the methods of capture, transportation, marketing and introduction of brood stock, larvae, fry and spat in aquatic environments; as well as methods of capture, transportation, storage,

importation and marketing of fishery and aquaculture products that have not reached the minimum regulatory size suitable for breeding, cultivation or scientific research.

- **Order of the 17th of February 2008:** lays down the terms and conditions of storage and warehousing of broodstock and fishery and aquaculture products that have not reached the minimum regulatory size. This order allows the establishment of:
  - Storage plants, which are defined as the conservation of broodfish and fishery and aquaculture products that have not reached the minimum regulatory size, outside normal fish farming facilities, in temporary facilities for a short period of time, for the purpose of:
    - Maintaining future broodstock during and after stock selection operations.
    - Maintaining the optimal living conditions for future broodfish and fishery and aquaculture products while waiting for their sale or stocking.
  - Storage facilities, which are defined as the conservation of broodfish and fishery and aquaculture products that have not reached the minimum regulatory size, outside the normal breeding facilities, for long periods of time in specialized permanent facilities for the purposes of:
    - Selecting future breeders.
    - Preserving pure and performing strains.

  Article 4 of the Order of the 17th of February 2008 defines permanent specialized facilities as:

    - either earthen or paved basins, with an elongated shape to maintain a good flow of water;
    - or masonry-built basins compartmentalized by boards or grids.
    - Facilities must be designed to be drained preferably by gravity and fed by a continuous supply of high quality oxygenated water at a rate of:
      - 0.5 l/min/kg for particularly fragile fish
      - 0.2 l/min/kg with good aeration for fragile fish.
      - 0.2 1/min/kg with a moderate aeration rate for resilient fish.
      - 0.1 l/min/kg with good aeration for resilient fish.

- **Ministerial Circular No. 91 of the 3rd of December 2014:** sets out the terms and conditions for the implementation of the sustainable development agenda for fish farming integrated with agriculture (see also section on Agriculture legislation), and describes the procedures and good practices pertaining to the identification of farms, orientation and maturation of projects, authorization acquisition and support. The main elements of Ministerial Circular No. 91, as issued by the Minister of Fisheries and Fishery Resources are as follows:

  Framework of the new program

  The purpose of this circular is to define and clarify the implementation methods of the new sustainable development aquaculture program 2014-2020. Unlike the previous ones, this program has been developed by involving all the stakeholders of the aquaculture sector (administrations, professionals, researchers, banks, insurance, etc.). As such the success of the program is secured by avoiding constraints that would potentially arise during the maturation and implementation of projects. It was developed taking into account past implementation experiences of old projects related to fish farming integrated with agriculture. Following a broad consultation process, the program was consolidated through many local and national workshops organized in recent months (FAO workshop, FAO expertise, scientific workshop at the University of Khemis Miliana), in which recommendations have been made allowing its expansion, and enhancing its operationality.

Objectives of the program:

In the short term and in the first stage, the aquaculture development program has identified the following sectors: *freshwater fish farming in floating cages at dams and hillside catchment reservoirs, fish farming / shrimp farming in ponds or in integrated basins, fish farming integrated with agriculture and inland fisheries*. This program aims at the establishment of fish farming holdings integrated with small-scale agriculture and in type activities through the implementation of support schemes empowering all stakeholders.

The principles of the program:

This circular aims at setting up new methods for promoting and supervising the program at the local level, to ensure the efficient implementation of integrated fish farming projects. This new program is characterized by:

- Decentralization of administrative procedures for the granting of authorizations: different authorizations will be provided and issued locally.
- Awareness raising of farmers to direct them towards integrated development projects.
- Technical and practical support of farmers [(networking with the National Center for Fisheries and Aquaculture Research and Development (NCFARD), training, etc.].
- Establishment of local one-stop shops for the promotion, management and supervision of projects.
- Facilitation of implementation of a project of fish farming integrated with agriculture by farmers in their agricultural holdings.

This Circular also sets out the main guidelines for the different steps and standard procedures and good practices to be undertaken for the completion and monitoring of an integrated fish farming project.

Procedures and good practices:

1. *Identification of priority agricultural holdings:*
   - Identify priority agricultural holdings. The priority agricultural holdings selected must meet the criteria defined in Annex 1 of the Circular. They must provide all necessary facilities for the implementation of integrated fish farming projects.
2. *Orientation and maturation of projects:*
   - Provide guidance to farmers and raise their awareness on the usefulness of fish farming integrated with agriculture.

- Provide guidance to farmers and raise their awareness towards a simple and mastered technology, allowing them to have appropriate support during the implementation of the project, (Annex 2 of the Circular: technical requirements for fish farming integrated with agriculture).
- The NCFARD and the DPRHW will have to provide support to farmers in the phase of maturation of project ideas.
- A special effort and priority will be given to the promotion of fish farming integrated with agriculture projects aimed at young people from the training system of the fisheries and agriculture sectors and the university.
- The farmer must prepare a technical and economic study of his project by a design office.

3. *Preparation and submission of the authorization file:*
    - The farmer must proceed to the recruitment of a qualified staff as soon as the authorization is obtained (Aquaculture Technician, Aquaculture Agent, etc.).
    - The authorization application file for the establishment of a project of fish farming integrated with agriculture must be submitted to the Department of Fishery and Fishery Resources of the wilaya (DFFRW), with a dated receipt recorded in a logbook duly signed by the farmer.
    - The eligibility of the project is subject to the commission agreement established by the DFFRW, DAS and DRE.
    - The Directorate of DFFRW must ensure the ability of the farmer to provide the financial resources needed to start the project.
4. *obtaining the authorization:*
    - The Director of DFFRW shall ensure that the authorization for the exercise of fish farming integrated with agriculture is issued within a period not exceeding seven days. It must determine the area intended for fish farming integrated into agriculture after the validation of the study by the NCFARD.
    - The DFFRW must send, for information, a copy of this authorization to the central services of the Ministry of Fisheries and Fish Resources within eight weeks.
5. *Support to the financing of the investment project:*
    - To benefit from the Support System for Productive Investment in the fisheries and aquaculture sectors (SAIPA), the farmer must join the Chamber of Fisheries and Aquaculture.
    - Wilaya and Inter-Wilaya Chamber of Fisheries and Aquaculture puts in place a one-stop office for farmer guidance led by executive coaches.
    - After obtaining the authorization, the DFFRW must direct farmers towards financing their projects through the various financial support mechanisms under the Support System for Productive Investment in the fisheries and aquaculture sectors (SAIPA).
    - The DFFRW, must ensure that the farmer files his investment plan at the one-stop office.

- A compliance committee, composed of the one-stop office coach, the director of the chamber (President), the head of the aquaculture department of the DFFRW and the President of the Chamber, as well as the Director of Agricultural Services, the Director of the Chamber and the President of the Agricultural Chamber shall verify the conformity of the file according to the eligibility conditions of each support system.
- After validation of the file by the compliance committee, DFFRW ensures that the farmer, according to the size of the project, files his file, accompanied by a letter of orientation, at the level of the secretariat of the appropriate support mechanism (ANSEJ, ANGEM, CNAC, ANDPME, ANDI, FNDPA, BADR, etc.) to obtain support for productive investment. The farmer will have to follow up with these institutions for a rapid study in line with the validity period of the feasibility study.

a. To the execution of the investment project:

- Upon obtaining authorization to practice, the farmer and the project team designated by him must undergo training in the technical and management fields of fish farming integrated in agriculture provided by the establishments of sector training.
- The services of the DFFRW must accompany the farmers in all the steps to obtain the different authorizations from the different administrations.
- DFFRW services can also direct the farmer to NCFARD to attend training and practical development courses at the Center's demonstration, extension and experimentation stations.
- The DFFRW must ensure that farmers recruit qualified personnel from the product of training, professionals, etc.

b. To start up and operation of the investment project:

- The DFFRW must support farmers attempting to gain fiscal and parafiscal advantages from financial institutions, within the framework of SAIPA.
- After obtaining all authorizations and during implementation, the farmer is assisted by the DFFRW to get fry and feed from freshwater fish farmers.
- In the interest of the viability of the project, the DFFRW must raise the awareness of the farmer on the importance of acquire an insurance policy.
- The DFFRW must ensure that the farmer recruits a qualified project manager.

c. To the monitoring of the operation of the establishment:

- The farmer must provide the DFFRW and the NCFARD with easy access to farm data.
- Monitoring and administrative support of the integrated fish farm will be provided by the DFFRW and the wilayas fisheries and aquaculture chambers.
- The DFFRW will ensure that a database specific to farms integrated with agriculture will be set up and forwarded to the NCFARD.
- An information sheet of the fish farm integrated with agriculture developed

and duly filled by the DFFRW, will be transmitted to the plant, according to the standard model provided by the Ministry of Agriculture, Rural Development and Fisheries (MARDF).

6. *Special provisions:*
   - This circular may be supplemented or modified as required or cancelled.

Support scheme for the development of aquaculture activities

The support scheme for the development of aquaculture activities do not differ from that of agricultural activities. It is a general loan scheme established by the Algerian State to encourage investment among young people through the National Agency for Microcredit Management in Algeria (Agence Nationale de gestion du Micro-crédit en Algérie) (ANGEM) and those over 40 through the National Unemployment Insurance Fund (Caisse Nationale d'Assurance chômage) (CNAC). In addition, there are zero-rate bank loan schemes set up by the MARDF such as the RFIG or Ettahadi loans.

Technical coaching and training of farmers

The Wilayas Directorate of Fishing and Fishery Resources and their local branches provide through local chambers, supervision, monitoring and extension of aquaculture activities and as such organize periodic training programs for outreach and extension to groups of approximately twenty farmers. There are also professional training centers and universities providing training for farmers. In addition, since 2014, a collaboration framework with the People's Republic of China has been implemented that allows up to fifteen farmers each year to benefit from a 25-day trip to China, to learn about the practice of fish farming integrated with agriculture undertaken there.

Professional aquaculture organizations

Across the country, 17 Directorates of Fisheries and Fishery Resources for aquaculture and fishing, associated in wilayas in which there are fisheries and aquaculture chambers. Furthermore, there are several relatively recent associations recognized within various wilayas (Table B1.3). There are also unlisted associations yet to be indexed by State services, such as the one encountered in Ghardaia (led by Mr. Benamar).

Table B1.3

List of associations active in the field of freshwater aquaculture

Wilaya	Name of the Association
Adrar	Association of Agricultural Activities (AFAK)
	Association de promotion des activités aquacoles (Association for the Promotion of Aquaculture Activities)
Béchar	Association de la Femme Rurale de Béchar (Association of the Rural Woman of Bechar)
	Association des pécheurs de la pêche récréative Djorf Torba (Recreational Fishermen’s Association of Djorf Torba)
Ghardaïa	Cultural and Human Association (TAGEMI)
Tamanraset	Association of In Salah (TIDIKET)
	“Sahara Spirulina” Association

At the time of our investigations, there were no associations developed in the field of agri-aquaculture. However, there have been several awareness-raising initiatives conducted since then by local institutions, to demonstrate the benefits of associations in addressing food problems, marketing problems and training needs.

Agriculture

Current state of agriculture and its contribution to food security

Within the framework of the Government's general policy and its program of action approved in accordance with constitutional provisions, the agriculture sector is expected to play an increasingly significant role in the country's food security (MREE, 2017). Currently is contributes by 12 percent to the country's GDP. The agriculture sector is the number one consumer of water, with an area of 1.2 million hectares (ha) irrigated using 6.1 billion m3 in 2016, representing more than 70 percent of the available water resources. The area cultivated, and water requirements, are expected to increase by 2035 to an irrigated area of 2.1 million ha, needing an estimated 12.4 billion m3 of water (MREE, 2017).

The Ministry of Agriculture coordinates the agriculture and forests related elements of the national policy and ensures their implementation in accordance with existing laws and regulations. It reports the results of its activity to the Head of Government and to the Council of Ministers according to the established terms, conditions and deadlines required. The Minister of Agriculture exercises his/her ministerial powers on:

- all activities related to the preservation, development and extension of agricultural heredity, ensuring and promoting production.
- activities related to the development and operation of the national forest fund and the protection of flora and fauna.
- participation, in liaison with the Minister of Water Resources, in the definition of the agricultural water policy. It determines the conditions of the development, valuation and use of water resources for agricultural purposes.
- defining the agro-industrial integration policy with the ministers concerned.
- initiatives to suggest and provide any measure of economic integration by promoting the national manufacturing of products, equipment and materials useful for the development of the activities of his area of expertise. The Minister participates, as far as he is concerned, in the development of the general policy on land use planning. He develops any action promoting food security in the country.

To carry out the defined tasks, the Minister of Agriculture:

- suggests and elaborates all governmental support measures to producers.
- initiates and implements all legislative or regulatory measures governing his area of competence and ensures its application.
- develops draft laws and regulations relating to:
    - the operation of agricultural, forestry and pastoral lands.
    - the use of steppe and forest trails.
    - the application of rules governing the production of seeds, seedlings and

breeding animals.

- the practice of veterinary and phytosanitary activities.
- agricultural orientation in general.

- promotes the development of frameworks for meetings and technical and professional information exchanges that contribute to the consolidation of food security in the country.

Legal framework for agricultural activity

This section presents the regulations (laws, decree, and orders) that constitute the regulatory scheme for the sectors of agriculture, fisheries, forestry, and water resources, and highlight those which could constitute the legal anchoring of the integration of fish farming with agriculture. Texts related to agriculture are as follows:

- **Law No. 90-25 of the 18th of November 1990:** on land policy, including the following relevant articles:

  Article 33: Notwithstanding the legal category of ownership of the land, any activity, any technique and any project must contribute to the promotion of the productive potential of the agricultural holdings.

  Article 34: Any infrastructure establishment or construction within agricultural holdings located on lands with high and/or good potential can only be accomplished only under the aforementioned Article 33 after express authorization has been issued, in the forms and conditions defined by the legislative provisions relating to town planning and building law.

- **Law No. 08-16 of the first of Shaaban 1429 corresponding to the 3rd of August 2008**: on agricultural policy, including the following articles:

  Article 45: For the purposes of this law, all activities corresponding to the control and the exploitation of a life cycle of a plant or an animal and constituting one or many stages necessary for the development of this cycle, are agricultural in nature, as well as the activities that take place while the act of production continues, including storage, packaging, processing and marketing of plant or animal products where these products are exclusively derived from the agricultural holding/farm. Agricultural activities must be of a civilian nature.

  Article 47: A farmer, within the meaning of the act, shall be deemed to be any natural or legal person who practice an agricultural activity as defined in the provisions of the aforementioned Article 45, which participates in the conduct of the operation, benefits from the results and bears the losses that may result. The terms and conditions for a beneficiary to qualify as a farmer are laid down by regulation.

Executive Decree No. 96-63 of the 27th of January 1996: defining agricultural activities and laying down the terms and conditions for a beneficiary to qualify as a farmer. **Article 5** of this decree defines the activities carried out in fishery establishments as being of agricultural nature with activities carried out in fishery establishments defined by Article 17 of Legislative Decree No 94-13 of the 28th of May 1994, laying down general rules for fishing.

Legislative Decree No 94-13 of the 28th May 1994: Article 17 states fishing establishments shall be deemed to be any establishment in the national domain supplied by sea water, fresh or brackish water for the purposes of catching, and rearing/growing of marine or freshwater animals and plants.

Law No. 87-19 of the 8th of December 1987: determines the operation method for agricultural lands within the national domain and sets out the rights and obligations of farmers, with the following articles of relevance:

Article 6: By this law, the State grants concerned farmers, a right of perpetual use on all the lands constituting the agricultural holding. This right of perpetual use is granted against a fee paid by beneficiaries, the basis of which and methods of recovery and allocation are set out by the Finance Act.

Article 7: The State grants to agricultural producers a right of ownership over all the property which makes up the assets of the farm, other than the land. This right of ownership is assigned for a fee. The assets completed by a collective, after their establishment, are the property of the collective farmers.

- **Law No. 10-03 of the 5th of Ramadhan 1431 corresponding to the 15th of August 2010:** sets out the terms and conditions of the operation of agricultural lands which are part of the private domain of the State. Article 4 is of relevance.

Article 4: The concession is the act by which the State consents to a natural person of Algerian nationality, hereinafter referred to as "concessionaire operator", the right to use agricultural land in the private domain of the State as well as that the superficiary property attached thereto, on the basis of specifications set by regulation, for a maximum of 40 years on a renewable term, subject to the payment of an annual fee, the basis of which and methods of recovery and allocation are set out by the Finance Act. For the purposes of this Law "superficiary property" means all the property attached to the agricultural holding, in particular buildings, plantations and hydraulic infrastructures.

Regulations relating to health aspects are as follows:

- **Executive Decree No. 04-189 of the 7th of July 2004**: laying down hygiene and sanitation measures applicable to fishery and aquaculture products.
- **Joint Ministerial Decision of the 5th of January 2011:** setting out the thresholds for the presence of chemical, microbiological and toxicological contaminants in fishery and aquaculture products.

Legislation relating to water resources are as follows:

- **Law No. 05-12 of the 28th of Joumada Ethania 1426 corresponding to the 4th of August 2005**: relates to water resources and use and contains the follows articles of relevance:

Article 1: The purpose of this law is to establish the principles and rules applicable to the use, management and sustainable development of water resources as a national community property.

Article 3: The principles on which the use, management and sustainable development of water resources are based are: inter alia, The right of use of water resources, vested in any natural or legal person governed by public or private law, within the limits of the public interest and in compliance with the obligations laid down by this law and the regulatory texts adopted for its application.

Article 37: Aids and benefits of any kind may be granted to individuals who implement techniques for water and soil conservation and combating water erosion in catchment basins of surface water.

Article 68: the water resources administration provides, at the request of anyone who wishes to establish the duly authorized structure of water withdrawal in the natural hydraulic public domain for public or private use, any hydrological and hydrogeological information, as well as any information on qualitative and / or quantitative protection requirements.

Article 71: Any use of water resources, including water intended for agricultural use and non-conventional waters, by natural and legal persons, whether governed by public or private law, by means of water sampling structures or facilities or for **aquaculture purposes**, may only be carried out by virtue of an authorization or a concession, issued by the competent authority in accordance with the provisions of this Law and its implementing regulations.

Article 72: the authorization or the concession of use of water resources confers upon its holder the disposition, for a definite duration, of a flow or a volume of water determined on the basis of the global resources available in year average and needs corresponding to the use in question.

Article 73: the authorization or the concession of use of the water resources gives rise to the payment of fees set out by the Finance Act. Methods for recovering these fees are set by regulation and are specified in the authorization or concession documents.

Article 75: are subject to the authorisation schemes of water resources use, the operations relating to:

- The construction of wells or boreholes for the withdrawal of groundwater.
- The establishment of source capture structures not intended for commercial operation.
- The construction of diversion, pumping or storage structures and facilities, with the exception of dams, for superficial water withdrawal.
- The establishment of any other structures or facilities for the abstraction of groundwater or surface water.

Section 2 of the legal regime of the concession for water resources use, contains the following key articles:

Article 76: The concession for the use of water resources in the natural hydraulic public domain is a public-law act issued to any natural or legal person, whether governed by public or private law, who makes such a request, in accordance with the conditions laid down in this Act and the procedures prescribed by regulation.

Article 77: are subject to the regime of the concession of the use of water resources, the operations relating to, in paragraph 8, the establishment of facilities and the implementation of specific operations relative to surface water reservoirs and lakes, with a view to developing aquaculture and inland fisheries or port activities and water sports.

Professional organizations

There are 48 agricultural service directorates and 48 agricultural chambers across the wilayas of the country, where the development programs of the Ministry of Agriculture are presented at the local level by the production sector (citruses, cereals, milk, dates, beekeeping, etc.). In addition to national associations in the agricultural sector, there are thousands of professional associations at the level of local communities approved by the Ministry of Interior and local authorities.

Farmer support schemes

There are 34 support schemes for agricultural activities listed under programs such as the Subsidized credit granted by the Bank for Agricultural and Rural Development (RFIG), investment credit granted by the Algerian Bank for Rural Development (Banque algerienne pour le développement rural) (Ettahadi) and the Regulation system of agriculture products for wide consumption (SYRPALAC) support scheme.

Non-conventional waters

Regulatory definition of non-conventional waters

Non-conventional waters, also called low quality waters, include the following:

a. Treated wastewater

Treated wastewater is raw water collected by city sanitation systems and rural drainage systems that undergo minimal treatment at either a wastewater treatment plant (anaerobic or aerobic biological treatment plant) in constructed cascade lagoons. The method of treatment to be implemented depends on the origin of the raw water, but in the absence of a strong industrial activity the method of treatment of these waters is based on biological oxidation in settling and clarification basins. The quality of these waters is determined based on quantitative and qualitative criteria such as, for example, the presence of mineral salts, oxygen content, suspended solids, pH, temperature and biochemical oxygen demand. In terms of re-use in crop irrigation, treated water must contain: <1 000 faecal coliforms/100 ml and <1 nematode egg/l.

b. Brackish waters

The definition used is that of the Venice System (1958) as brackish water containing more than 0.5 and less than 30 g/l of total dissolved salts (TDS). In practice, the electrical conductivity of water (EC) is measured at a temperature normalized to 25°C expressed in decisiemens per meter (dS/m) and functional relationships are applied as follows: (after Ayers and Westcot, 1985; FAO, 1990; Tanji, 1990; Richards, 1954.)

- TDS (mg/l) = EC (dS/m)*640, if EC is >0.7<5 dS/m (generally occurs in north Algeria).
- TDS (mg/l) = EC (dS/m)*800 if CE >5 dS/m (generally occurs in the south Algeria).

- Unsalted water when EC < 0.7 dS/m.

Depending on whether water is used to irrigate heavy soils (clay to clay-loam) or light soils (sand to sandy-loam), the following definition is generally used:

- Heavy soils: Salt content of water between 1 and 8 dS/m (0.64 to 6.40 g/l).
- Light soils: Salt content of water between 3 and 12 dS/m (1.92 to 9.60 g/l).

In Saharan regions, including Algeria, most of the waters are considered brackish water in terms of mineral composition, and they are therefore considered non-conventional waters, for the most part unfit for human consumption without prior treatment. The water resources sector in Algeria also includes treated Mediterranean Sea water (desalinated waters) as fit for the population's consumption. At the regulatory level, there are texts setting Algerian standards for the use of non-conventional water in irrigation. These are:

- **Executive Decree No. 07-149 of the 3rd of Joumada El Oula 1428 corresponding to the 20th of May 2007,** laying down the concession terms for the use of treated wastewaters for irrigation purposes.
- **Interministerial decree of the 8th of Safar 1433 corresponding to the 24th of January 2012**, setting out the specifications of treated wastewater used for irrigation purposes.

Use of non-conventional waters in Algeria

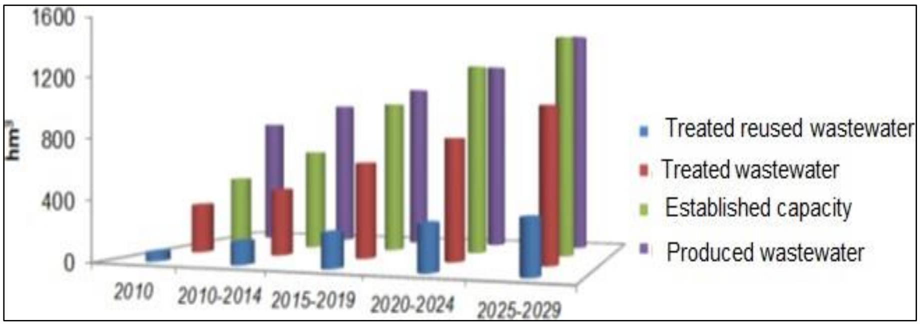
The use of non-conventional waters in Algeria is relatively recent (2000s) but is limited due to technical, regulatory and cultural reasons. Use of these waters vary according to the region but in general, in the west of the country, in the Tellian highlands and in the south of Algeria the use of non-conventional waters has become a support to water requirements, in particular for agriculture. For agriculture, water supply amounts to 6.78 billion m^3, within which a small fraction of treated wastewater is used, amounting to approximately 60 million m^3, with an outlook of 100 million m^3 in the long term. This total volume for agriculture primarily comes from groundwater (4 billion m^3) and surface water (2.78 billion m^3).

Identification of existing water potential

The water potential available in the country is estimated to be at 19.4 billion m^3 / year according to the National Water Plan (NWP) issued in 2010. This potential consists of 14.4 billion m^3 of renewable water resources, of which 11.4 billion m^3 comes from surface water, 3 billion m^3 is groundwater and 5 billion m^3 comes from non-renewable sources of brackish water, the latter exclusively located in the south of the country, according to the Ministry of Water Resources in 2017.

Added to this potential are other non-conventional resources, consisting of 770 million m^3 of desalinated water and 640 million m^3 of treated wastewater, output from nearly 100 treatment and purification plants, which is expected to increase (Figure B1.4). The mobilization of these non-conventional waters is made possible thanks to major efforts from the State in terms of investments in hydraulic infrastructures.

Figure B1.4
Estimates of output (million m^3) from treated wastewater production in Algeria
(data from Ministry of Water Resources 2017)



Current situation regarding the exploitation of non-conventional waters in different sectors

Agriculture, forestry and aquaculture

When it comes to brackish water, the use of this non-conventional water is done without distinction between the agriculture, forestry and inland aquaculture sectors. On the other hand, it seems that only the agricultural sector benefits from a share of the 600 million m^3 wastewater treated produced (25 percent maximum) with a wide variety of mitigation strategies in the various fields.

Water resources and aquatic environment

In addition to treated water from water treatment plants, and use of water resources from lagoons and groundwater, an additional water resource potential to support Agri-aquaculture requirements comes from Chotts. Chotts are salt lakes in the Magreb, that spend a large proportion of the year as dry beds but for periods fill with water derived from a spring thaw in the Atlas mountain range which permeate through rocks, and from occasional groundwater and rainwater sources (see Demnati *et al*., 2017 for a review). For example, Chott Chergui is a water reserve located at an altitude of 1 000 m in the high plateaus of southern Oran, with a surface area of 2 000 km^2. It is characterized by high salinity and an arid climate, with 6 to 7 dry months, a minimum temperature of 30 to 40 °C during the hottest months, an average annual rainfall of 276 mm but with an evaporation rate of 2 150 mm/year.

Numerous artesian springs with a low salinity also exist on the chott, such as the spring of Ain Skrouna which emits water at a constant temperature of 26 °C at a rate of 420 l/s. A project of water retrieval and hydro-agricultural development is underway in Ain Skrouna, and involves the construction of two dams (10.7 and 8 km^2) for the irrigation of 7 150 ha of land for agricultural purposes. The existing fish fauna in the chott consists of tilapia species and *Gambusia* spp. The chott is considered to have an important aquaculture potential, coupled with agricultural farming activities, based on a combined intensive and semi-intensive production system, using the hydro-agricultural reservoirs as an intensive system (500 to 600 t/year), then discharging into extensive systems using boreholes or other water sources (minimum 100 t/year).

In addition, the Oued Rhir, in the Ouargla and El-Oued territory located in the south-eastern region of Algeria, is 136 km long and four to 15.6 m wide, with a water depth between 0.3 and 1.06 m and a flow rate ranging from 0.105 to 5.340 m^3/s, flowing at a velocity ranging from

0.041 to 0.921 m/s. Oued Rhir water is salty (containing 11-19g/l of salts) with an average temperature of 23.5-26°C. This basin has quite significant exploitation possibilities, and aquaculture development should be permitted.

Scientific Research

Several pilot projects are being conducted by the scientific research sector to test the potential of non-conventional waters in agriculture, agri-aquaculture and hydroponics (without the use of soil). One specific example is tilapia breeding trials using a closed recirculating water system in Biskra, carried out by the Center for Scientific and Technical Research on Arid Regions and research conducted at the University of Ouargla (Bensalem, 2018).

Investigation

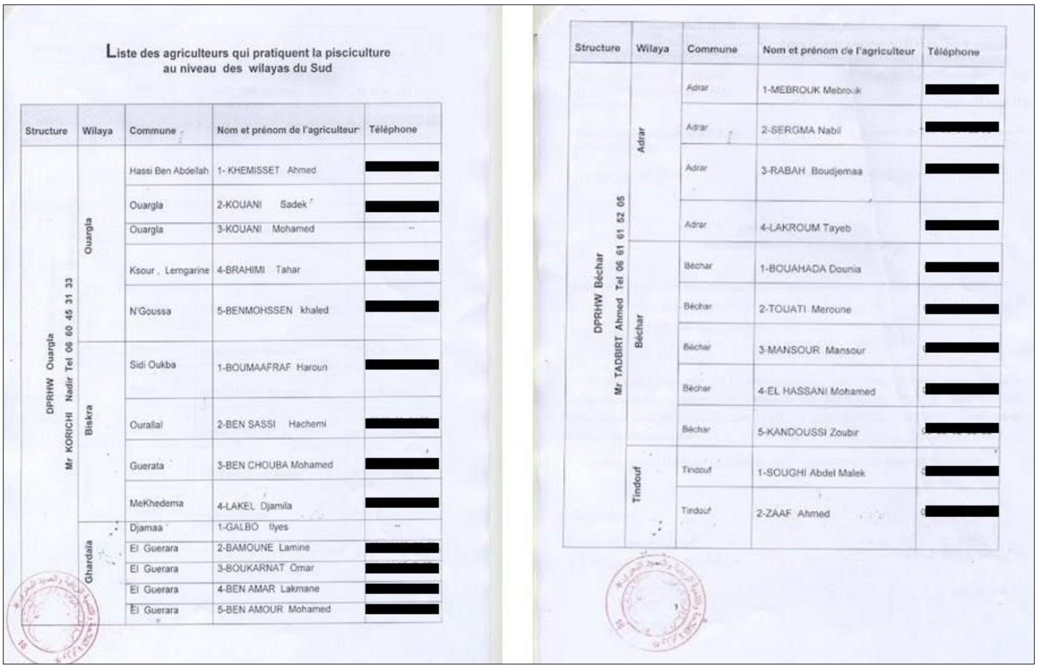
Data gathering through the questionnaire (pilot farms)

A questionnaire was prepared, tested then presented to about fifteen farmers across seven wilayas of southern Algeria, namely Tindouf, Bechar, Adrar, Ouargla, Ghardaia, Biskra and El Oued. Selection of farmers was according to a directory established and provided by the General Directorate of Fisheries (Figure B1.5). For the study, representatives of aquaculture institutions at the central and regional level (directors of aquaculture and fisheries) and farmers practicing aquaculture activities were interviewed, as part of the questionnaire process. The main purpose of this questionnaire was to:

- describe the fish farming practices in agricultural holdings (cultivated species, farming model, infrastructure, feeding method, possible marketing).
- describe irrigation practices with aquaculture waters (irrigation technique, fertilization method, selection of crops, and so on).

Figure B1.5

List of aquaculture farmers operating in Southern Wilayas of Algeria, as supplied by General Directorate of Fisheries. Contact details redacted to protect privacy



Liste des agriculteurs qui pratiquent la pisciculture au niveau des wilayas du Sud

Structure	Wilaya	Commune	Nom et prénom de l'agriculteur	Téléphone
DPRHW Ouargla Mr KORICHI Nadir Tel 06 60 45 31 33	Ouargla	Hassi Ben Abdellah	1- KHEMISSET Ahmed	[redacted]
		Ouargla	2-KOUANI Sadek	[redacted]
		Ouargla	3-KOUANI Mohamed	--
		Ksour . Lemgarine	4-BRAHIMI Tahar	[redacted]
		N'Goussa	5-BENMOHSSEN khaled	[redacted]
	Biskra	Sidi Oukba	1-BOUMAAFRAF Haroun	[redacted]
		Ourallal	2-BEN SASSI Hachemi	[redacted]
		Guerata	3-BEN CHOUBA Mohamed	[redacted]
		MeKhedema	4-LAKEL Djamila	[redacted]
	Ghardaïa	Djamaa	1-GALBO Ilyes	--
		El Guerara	2-BAMOUNE Lamine	[redacted]
		El Guerara	3-BOUKARNAT Omar	[redacted]
		El Guerara	4-BEN AMAR Lakmane	[redacted]
		El Guerara	5-BEN AMOUR Mohamed	[redacted]

Structure	Wilaya	Commune	Nom et prénom de l'agriculteur	Téléphone
DPRHW Béchar Mr TADBIRT Ahmed Tel 06 61 61 52 05	Adrar	Adrar	1-MEBROUK Mebrouk	[redacted]
		Adrar	2-SERGMA Nabil	[redacted]
		Adrar	3-RABAH Boudjemaa	[redacted]
		Adrar	4-LAKROUM Tayeb	[redacted]
	Béchar	Béchar	1-BOUAHADA Dounia	[redacted]
		Béchar	2-TOUATI Meroune	[redacted]
		Béchar	3-MANSOUR Mansour	[redacted]
		Béchar	4-EL HASSANI Mohamed	[redacted]
		Béchar	5-KANDOUSSI Zoubir	[redacted]
	Tindouf	Tindouf	1-SOUGHI Abdel Malek	[redacted]
		Tindouf	2-ZAAF Ahmed	[redacted]

Census of all aquaculture farms integrated with agriculture

Our study mainly focused on the regions of southern Algeria where integration of aquaculture with irrigation-based agriculture is a highly strategic activity, based on available climatic and economic reasons. It should be noted that freshwater fish farming in these areas is a growing sector, so it was difficult to accurately estimate the number of such farms, which are believed to count in their thousands. Interview/questionnaire results are detailed in Table B1.4. During interviews, it was observed that peer-training was being undertaken, encouraging and allowing the success of farmers undertaking agri-aquaculture activities to be passed on and encouraging others to follow a similar pattern of production.

Table B1.4

Outputs from farmer survey questionnaire

Name	Location	Main agriculture activity	Aquaculture						Comments: water quality (WQ) perception + other comments made
			Experience (Years)	No. of basins	Basin size	System used	Species grown	Member of Association	
Sadek Kouani	Ouargla	Date palm, various market garden products	4	2	10m x 10m x 1.5m	Semi-intensive	Tilapia, catfish	No	WQ: Very good Fertilizing effect from fish activity. Occasional capping of the network drip lines due to water quality. Possibility of bird attacks in case of unfilled basins.
Lamine Bamoun	Ghardaia	Palm, forage and dairy	3	-	-	-	Grey and red tilapia, catfish	Yes	WQ: Very good.
Lokmane Benamar	Ghardaia	Fruit trees (pear, citrus)	3	-	-	Semi-intensive	Grey and red tilapia, catfish	Yes	WQ: Very good.
Haroun Boumaraf	Guerta-Biskra	Palm, market gardening	3	4	3x 200m2, 1x 400m2	Semi-intensive	Tilapia and catfish	No	WQ: Very good. Since the introduction of fish farming irrigation water, I have noticed a reduction of date palm fertilization frequency from one year every 3 years to 1 year of every 5, which represents a considerable benefit. On the other hand, I have a cold-water management problem especially during winter because grey Tilapia cannot bear temperatures below 8°C unlike red Tilapia. Therefore, I try to pump underground water with a relatively appropriate temperature.

									No feeding problem, feed is sold in the form of seeds and is expensive (about 12 000 DA/Qx) + transportation cost from Ain Bessem to Biskra. I also have problems selling fish in Biskra market because small resellers do not accept this type of freshwater fish.
Redouane Mebrouk	Reggane -Adrar	Date palm, Grenade, fig, various market gardening (10ha)	3	8	Various sized (2m, 3m, 4m) 5m wide, 1m deep	Semi-intensive	Tilapia, catfish	No. Farmer attended field visit to China	WQ: very good It is very beneficial because the output is 2 times higher since fish introduction in the irrigation basins, compared to using conventional water.
Tayeb Lakroum	Adrar	Date palm, olive trees, wheat, various market gardening	3	12	10m x 10m x 2.3m, others 3.5m x 5m x 1.3m	Semi-intensive	Red and grey tilapia, catfish	No	WQ: very good The fertilization method has changed compared with before 2015. I am using 40 percent less fertilizers. The efficiency has risen significantly. For example, before 2015, the palm tree yielded 50 kg but now it yields 150 kg. Olive tree was not yielding but after fish farming water irrigation, it is producing. Fish food is produced locally, and it consists of cereals and other agricultural residues because of high prices
Mirouti	Reganne -Adrar	Date palm, cereals, grenade, fig, vine, melon +	5	12	4 at 6m x 3m x 1.5mm, 5 at	Semi-intensive	Red and grey tilapia and catfish	No	WQ: very good Since the integration of aquaculture, I totally stopped using fertilizers and I am using directly the drip irrigation technique without mixing suspended matter with water in the basin or by adding a filter and mixing suspended matter. Sometimes, I gather the filtered residues and leave them to dry then I put them at the seguias level so that they are channeled to the plants

		market gardening			5m x 5m x 1m and 4 at 2m x 5m x 1m.				during irrigation. Since introducing of irrigation boxes, there is no weed problem in the basin. Fish feed is very expensive, that's why I prepare it myself with bread, oats, morsels, lettuce and dromedary offal. There is a high market demand for fish and my production is not sufficient to meet the requests. Many farmers in Reganne (about 70) have started fish farming in concrete irrigation basins but also in traditional terracotta basins. In Sali, there are 20, also in El Fekara we find fish in the ponds of farmers.
Abdelmalek Soughi	Tinfouf	Date palm, various greenhouse and outdoor market garden products (10ha)	3	1 3	15m x 10m x 1m, 6m x 5m x 1m, 9m x 2m x 1m.	Semi-intensive	Grey tilapia, catfish, starting red tilapia	No	WQ: very good Feeding problem, currently consisting of bread, rice, soya, rich in protein green pea. Fertilization method (farm manure) has not been changed since the introduction of the fish farming water, yield has improved considerably, fish is sold to small retailers.
Mohamed El Hassani	Bechar	Cereals, vegetables	0.5	1	4m x 5m x 1.5m	Extensive, feeding bread	Red and black tilapia	No	WQ: Good for carrots and garlic but I have noticed a whitish layer seen on the soil that can affect the cereal yield.
Ghazali	El Oued	Cereals, various market gardening	0.8	1	5m x 5m x 1m	Extensive, feeding bread	Grey tilapia	No	WQ: Bad, problem of soil salinity. A feeding problem, currently consisting of bread problem of soil salinity, water is initially non-saline

In addition to the farms identified in Table B1.4, the Ouargul farm, located at Hassi Ben Abdullah in Ouargla has been developed through an Algerian-South Korean partnership. The site is defined by mild winters and a hot summer climate. The site is developed for shrimp farming, although other edible freshwater fish species are also reared. The site is maintained by 12 engineers and others employees, working to produce one tonne of whiteleg shrimp (*Penaeus vannamei*) per year. Main problems encountered by the site relate to sector organization and marketing activity.

There is also aquaculture activity conducted in Dams and one such site at Abadla, in Bechar was visited. The climate is characterized by mild winters and hot summers. Staff from the National Agency for Dams and Transfers operate the site, within which barbels and carps are grown in cages, depending on water level in the dam, or water is pumped onto land depending on land availability. The overall production capacity is 500 tonnes per year. The main problems encountered appear to be related to the potential for the dam silting, being a threat to fish farming activity. In a press excerpt issued by the Director-General for Fisheries and Aquaculture, it was noted that there are 40 dams managed by 55 licence holders, with an estimated production capacity of 2 000 tonnes per year of various fish species, with current annual production being 200 tonnes of freshwater fish, such as Nile tilapia.

Methodology of water resources use

Interviewed farmers had irrigation basins ranging in size from 10m^3 to over 1 000m^3, including breeding and production, and they were asked how they use the available water resources in their farm for fish farming activity, and how they exploit these waters in subsequent agricultural activity. In most cases, good quality groundwater was used, albeit slightly degraded due to a high overall hardness. Temperature related problems were identified as a major cause for concern, since water temperature is too low in winter and too high in summer, the latter increasing the risk of mortality in tilapia. In winter some farmers avoid water stagnation and cooling during the night by daily pumping of water to renew the water in the irrigation basin, to maintain it at an acceptable temperature.

The breeding of fish generates output water that is enriched with nutrients and residues from the accumulation of suspended particles and used for irrigation of plant crops. Irrigation techniques used were the seguia gravity-fed and drip irrigation systems. Investigations showed that irrigation and fertilization practices have changed compared to the time when there was no fish farming. Notably, very often the usage of chemical or organic fertilizers (farm manure) has significantly decreased or totally stopped. Some farmers also place residual particulate material that clog around irrigation filters at the bottom of the fish breeding tanks around the base of plants as a supplementary manure, and the suggestion is that this has very beneficial agronomic effects.

Analysis and processing of collected data

Data showed that, in in Southern Algeria in more than 90 percent of cases, the dominant model of aquaculture production, when integrated with agriculture, is use of semi-intensive production in which low stocking densities are employed but species are supplemented with feed. Within this, shallow irrigation basins (<1.50 m) are used to grow mostly red and gray tilapia, and catfish. Fish are fed with farm-produced feed which are low in animal protein but high in plant and plant waste materials including wheat bran, corn bran, bread and date waste. It is determined that this is not suitable as a diet for the reared species concerned, and that this will impact growth and efficiency in the semi-intensive systems used.

For most farmers, the acquired experience in fish farming is recent (post-2015), and thus it is not yet possible to draw up an objective assessment of the sustainability and effectiveness of the integration of aquaculture and agricultural activity in Algeria. From interviews conducted, the following key points emerged:

- Most farmers who undertake agri-aquaculture practices use water from both conventional or non-conventional resources, and brackish water, found throughout the Algerian Sahara, is used for irrigation and fish farming.
- Groundwater is mostly used because of the scarcity of rainfall in the Saharan environment, where rainfall is often less than 50 mm per year. The quality of groundwater resources is strongly affected by local geological formations that are rich in limestones, carbonates and sulphates which increases the mineral salt content (brackish water). Some existing dams in Bechar, Biskra and El Bayad receive surface water runoff and these are generally low in mineral salts, but these are not currently used for agri-aquaculture.
- After groundwater has been pumped, the water renewal rate in small basins is high and storage of water rarely exceeds periods of two to three days. The short duration results from the relatively small basin size and significant needs for irrigation in the arid environment. Secondly, fast water renewal into basins maintains water quality for the fish which farmers consider is essential for fish survival. There is a possibility that this short duration may not be compatible with enhancing the optimal enrichment of irrigation water with organic matter and other by-products of fish farming, prior to use on agri-products.

Standards for farming water and products

Fish farming water quality standards are specified in relation to parameters with limit values that vary depending on whether it is cold water or warm water. At the international level, there are recommendations issued by the World Health Organization regarding the use of treated wastewater in aquaculture, for example (WHO, 2006). In addition, other standards on farming waters are applied, such as in Morocco. The limits used for aquaculture in Morocco are defined in Tables B1.5 and B1.6 for water quality and heavy metal standards respectively. Biological parameters are also set, covering coliform counts which must be less than 2 000 faecal coliforms/100 ml in cold water and less than 200 faecal coliforms/100 ml for warms waters.

Table B1.5

Limits for water quality parameters for aquaculture production undertaken in cold and warm waters in Algeria

Parameters	Limit value	
	Cold water	**Warm water**
Temperature (°C)	5<T<20	8<T<30
pH	5 to 9	5 to 9
Dissolved oxygen (mgO2/l)	>5	>3
Suspended matter	<25	<50
COD (mgO2/l)	<20	<30
BOD5 (mgO2/l)	<3	<6
Free chlorine (mg/l)	<0.02	<0.02
Conductivity (µS/cm)	<350	<3 000
Un-ionized ammonia (mg/l NH3)	<0.025	<0.025
Ammonium (mg/l NH+4)	<0.50	<1
Nitrite (mg/1 NO-2)	<0.5	<0.5
Detergents (mg/l)	0.5	0.5
Sulfates (mg/l)	<200	<200
Dissolved or emulsified hydrocarbons (µg/l)	<10	<10
Polycyclic or aromatic hydrocarbons (µg/l)	<0.2	<0.2
Phenols (µg/l) in the absence of any chlorination	<1	<1
Cyanides (µg/l CN-)	<50	<50
Silver (µg/l Ag)	<3	<3
Fluorides (mg/l F)	<0.7	<0.7
Pesticides (µg/l	< 0.1 for an individual substance <0.1 in total	< 0.1 for an individual substance < 0.1 in total

Table B1.6

Limits for heavy metal parameters for aquaculture production undertaken in cold and warm waters in Algeria.

Parameters	Limit value	
	Cold water	**Warm water**
Selenium (µg/l Se)	<10	<10
Barium (mg/l)	<1	<1
Boron (mg/l B)	<2	<2
Manganese (mg/l)	<0.1	<0.1
Mercury (µg/1 Hg)	<1	<1
Lead (µg/l Pb)	<20	<20
Arsenic (µg/l As)	<50	<50
Total Chromium (µg/l Cr)	<50	<50
Cadmium (µg/l Cd)	<5	<5
Cupper (µg/l Cu)	<40	<40
Zinc (a) (mg/l Zn)	<1.3	<1.3

Strategy of using non-conventional waters in aquaculture and agriculture

Non-conventional water use strategy for aquaculture and agriculture is being developed. Nevertheless, the following are recommended:

- Perform field studies on available water resources by applying a duly validated monitoring protocol. Involvement of academics recognized for their competence in this field is necessary whenever possible.
- Promote synergy between national and international development projects (development plan of Directorate-General for Fisheries and Aquaculture, Diveco European Union project, FAO project, and others), as a means to better understand and develop agri-aquaculture in desert environments.

Constraints and benefits of non-conventional water use and aquaculture products

The constraints of non-conventional water use and aquaculture products are the following:

- The lack of a system to monitor the quality of waters (physico-chemical and microbiological) as well as the performance of fish farming, especially for small scale farmers.
- Unawareness of the proper diet of fish with, in the case of many farmers, the use of a diet mainly consisting of residues of plant origin.
- A very limited social and dietary acceptance of freshwater fish by populations of South Algeria which, historically, use sheep and to a lesser extent camel as their main sources of protein.

The advantages of using non-conventional water are the following:

- Natural enrichment of soil with nutrients and thus the reduction of fertilizer inputs for crops.
- Valorization of water is generally poorly and/or improperly used.
- Establishment of an economic activity which is currently being tested by farmers in a hobby-oriented mode but with strong potential for development into a more structured economic activity.

Plan of action through a roadmap

Based on the various interviews conducted by the National team, a strategy is proposed for the development of aquaculture integrated with agriculture using non-conventional waters, through the following actions:

- Conduct fish production trials at two or three strategic locations by appointing a multidisciplinary monitoring group to undertake the study. This will require experts to better develop aspects of production, including more appropriate feeds for fish, and to assess the production process to provide a productive and efficient system of production of both fish and agricultural crops. The idea is to promote the establishment of large regional demonstration sites where innovators (farmer-aquaculturist champions) could come to implement their ideas and meet institution representatives and interested national and foreign and private and public investors. An efficient information system (easily accessible and up-to-date) will have to be implemented to successfully support the innovations.

- Strengthen the skills of producers through training and extension and technical support. This should include development of "leader breeders" where it would be possible to introduce farming records for monitoring preselected indicators (such as chemical parameters of water, growth rate of reared species, feed use, annual production, and so on), and for these leaders to pass on their knowledge more locally as an extension to the peer-to-peer training.
- Agri-aquaculturists grouping in various forms should be promoted, including associations and cooperatives, to strengthen agri-aquaculture within the regions.

Conclusions and general recommendations

At the end of this study on the state of aquaculture integrated with agriculture using non-conventional waters in southern Algeria, it appears that:

- There is a large potential for fish production development with different types of non-conventional waters. This involve millions of cubic meters of water with various origins each year (wells, Chotts, dams, sewage water, etc.). Exploitation methods are different from what was known in West Africa for example (Halwart and Van Dam, 2010).
- For most farmers integrated fish farming is a marginal activity. Although the perception of aquaculture is positive, there is a challenge in making the fish farm element of Agri-aquaculture farms economically viable.
- Farmers knowledge of fish farming requirements (species, water temperatures, feed requirements and so on is generally insufficient. The interviews showed that most respondents are unaware of the food requirements of farmed species, nor minimum, maximum and optimal temperature of the farmed species.
- There are currently no standards in relation to use of non-conventional sources of water, given the diversity of such water sources, which are known to include high levels of limestone and fluoride in El Oued, for example, and elevated concentrations of sodium chloride in Touggourt as another example.

Therefore, we recommend the establishment of demonstration sites in which protocols would be set up for a leading farmer per region (Eastern Highlands, Central and West, South East, Central and West) in partnership with the NCFARD, the DFFRW and the DAS. In this context, measurements of weather conditions, temperature, pH, salinity and the composition of water would be carried out on a regular basis. Fish weighing, mortality rates and the quantities and nature of feed would also be taken in consideration in the context of the overall analysis. This information can be shared among the regional farmers to improve use of non-conventional water resources and improve farming practices generally.

We also recommend a socio-economic study on the profitability of integrated aquaculture according to local conditions, to include a study on improving the social acceptability of freshwater fish by populations in various places of southern Algeria.

- Associations of fish farmers do not appear to be very dynamic on the ground, and there is a reluctance on the part of farmers to be interested in grouping to improve systems, instead relying on development of their own individual strategies of stock management.

- Most farmers interviewed in the survey do not belong to a professional association. It is true, however, that the fish breeding activity is relatively recent development (less than 5 years old), which perhaps explains why grouping initiatives have not so far taken place. This is despite the efforts made by local fisheries administration, on awareness raising and extension activities. It was noted that associations created at the level of the wilayas have a minimal impact in the daily management of aquaculture farms.

Final recommendations for the development of aquaculture integrated with agriculture in arid regions result from this study and in part from conclusions of the El Oued seminar on the promotion and development of Saharan aquaculture, organized by the Government of Algeria outside the scope the this project (Sadek, 2018), as follows:

- Select the best farms in the field of aquaculture integrated with agriculture and consider them models for the practical training of farmers.
- Provide support to farmers with incentives to reach commercial production sizes.
- Provide support towards the practical training of new farmers/investors.
- Establish professional farmer associations for the promotion of projects on aquaculture integrated with agriculture, to improve the impact and achievement of desired results, and to reinforce the technical capacities of these associations in the field of freshwater aquaculture especially in the four southern Wilayas of Adrar, Bechar, Ghardaia and Tamanrasset.
- Coordinate with various stakeholders involved in the activity of aquaculture to ensure a better management of the technical aspects of the integrated farming both aquaculture and agriculture products.
- Conduct research to identify plants using non-conventional water from boreholes, Chotts, dams, sewage water and others, and particularly halophytes able to cope with brackish water, that could for example be integrated with shrimp farming.
- Provide technical support to graduates of institutes who have received agricultural lands by providing fry and fish feed during the start-up phase.
- Develop a unified and standard training program for farmers on aquaculture integrated with agriculture.
- Prepare a technical manual for aquaculture integrated with agriculture depending on the specificities of each wilaya.
- Follow up with farms that use wastewater from carp pond farming for the irrigation of fruit trees, with the help of NCFARD, for example the case of the farm at Boumerdes.

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Appendix B.2: Egypt case study

Sherif Sadek, *FAO Consultant, Cairo, Egypt*

Summary

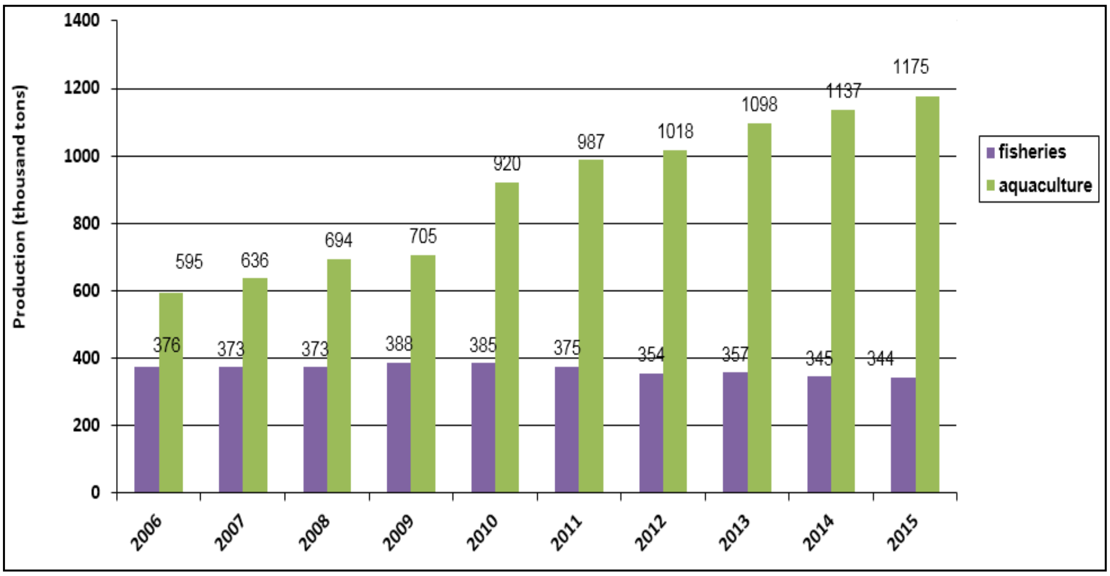
Since 2010 Egyptian desert-based aquaculture and agri-aquaculture systems, using non-conventional water sources have become more economically developed, through government and private-backed ventures. Over the intervening period production from aquaculture farms integrated with agriculture production has increased from 700 tonnes to 2 200 tonnes in 2017. Approximately 100 commercial aquaculture desert farms have been set up in desert regions of Egypt based predominantly in ten governorates within the broader Nile delta, high Egypt near the Nile valley and Sinai Peninsula. Although eight fish species are produced the main species is Nile tilapia (*Oreochromis niloticus*), which accounts for 90 percent of desert-based aquaculture production. Water for desert farms comes from underground saline water reserves, desalination plants and/or agricultural drainage, and varies in salinity between 0.5 and 26 g/litre, and temperature from 22 to 26 °C. European seabass and Gilthead seabream offer additional fish species in higher salinity areas. Integration between fish culture in tanks and flow-through systems and agriculture crops and livestock derive from the increase in use of water from fish culture being applied to crops that have some level of salinity tolerance using sprinkler and spray systems when water is exchanged. Most of the commercial farms have adopted flow-through systems which irrigate agricultural land, to enable production of vegetables, fruit, arable crops and clovers for feeding livestock. The flow of fish farm water containing microalgae and other debris has acted to consolidate sandy soils, which has also reduced water usage on vegetable and crop plot. Some have introduced biogas production using fish farm particulate wastes and vegetable matter to generate gas for heating and cooking. The success stories in this report show how some companies and government departments are acting to develop agri-aquaculture systems more fully and to establish best practices. Aquaponics, linking fish production with soil-less plant production in recirculating systems offers an additional alternative, but better research is required to evaluate the most effective practices. Overall, integrated agri-aquaculture systems in Egyptian deserts seem to offer an efficient process for aquaculture and agriculture to co-exist within the same farm, reducing overall water use and offering other benefits. The report concludes with several recommendations, focused on improved research to establish the best approaches and management practices for agri-aquaculture production, training and extension activity to support rural desert community action in setting up such systems, and improvements needed in governance and financial resourcing to improve development of agri-aquaculture systems further.

Introduction

Egypt had a projected population 100.3 million in 2019 (UN DESA, 2019) and aquaculture production provides a cheap source of good quality protein for the population, in addition to export markets. Between 2006 and 2015, aquaculture production almost doubled (98 percent increase) from 595 thousand tonnes in 2006 to around 1 175 thousand tonnes in 2015 (Figure B2.1), mostly finfish and shrimp. Conversely, fisheries production has decreased 8.5 percent over the same period, from 376 thousand tonnes in 2006 to 344 thousand tonnes in 2015 (Figure B2.1). By 2015, Egyptian fish farms produced 77 percent of the country's total freshwater and marine fish production from capture fishery and aquaculture sectors.

Figure B2.1

Egyptian fisheries and aquaculture production (tonnes) between 2006 and 2015 (Source: GAFRD, 2017)



The total market value for aquaculture production was estimated at about $US 2.3 billion in 2015 (1 $US = 7.78 Egyptian pounds). Between 2006 and 2015 the annual per capita consumption of fish in Egypt increased from 17 kg fish per person in 2006 to 20 kg fish per person by 2015, slightly above the world average (FAO, 2016) at that time. Increasing population, the rise in per capita consumption of fish products and slowing capture fishery supply has necessitated the rapidly increased production from aquaculture. The total carrying capacity of intensive fish farming in the Egyptian desert has been estimated, based on water volumes available, at approximately 135 thousand cubic meters (m^3), within which the average stocking density can be 16 kg/m^3 (GAFRD, 2007; GAFRD, 2017).

Most aquaculture capacity in Egypt is privately owned and managed, and in 2015 approximately 99 percent of all aquaculture production was undertaken by private companies or family run businesses. Most of the Egyptian fish farms are in the Nile delta region and most production occurs in earthen ponds. There are, however, four types of land-based aquaculture production systems in Egypt, as follows:

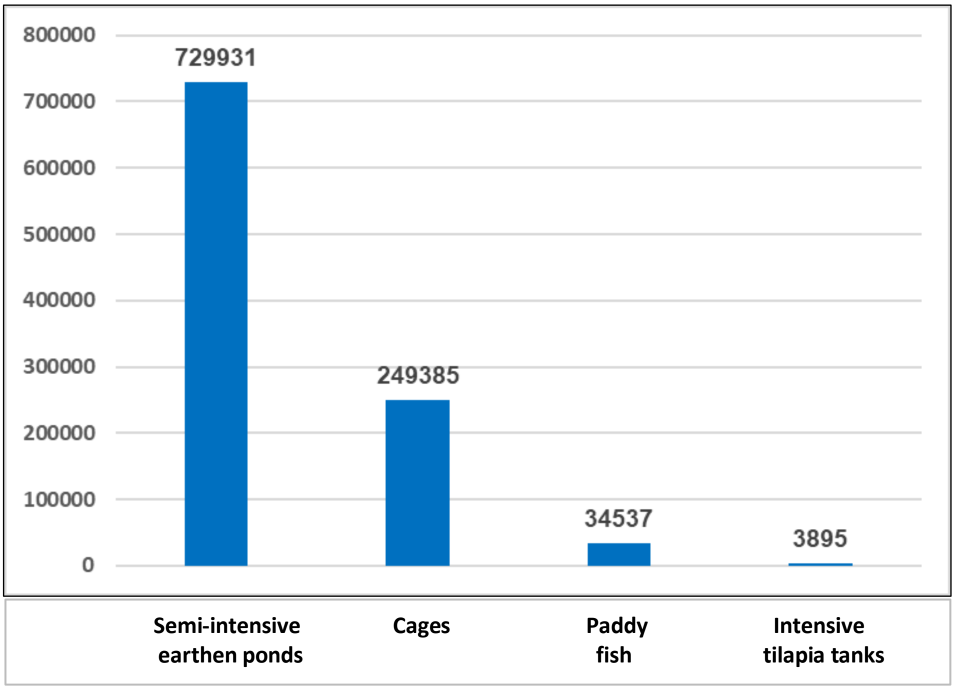
- semi-intensive earthen ponds: 71.7 percent
- cages: 24.5 percent
- paddy field: 3.4 percent

- intensive flow through tanks: 0.4 percent

Production of fish in desert-based integrated agri-aquaculture system is a relatively small but important section of aquaculture production, using intensive flow-through tanks to produce tilapia along with animals and agricultural crops. Figure B2.2 shows that the total production from intensive flow-through tank culture in 2015 was 3 895 tonnes, compared to 729.9 thousand tonnes from earthen ponds and significant quantities from other production systems. Although small, fish production from desert integrated agri-aquaculture represents 57 percent of the intensive production undertaken, by value, and is growing quickly. The first intensive fish culture projects in the desert were reported in 2010 with production of 700 tonnes but this had increased three-fold by 2015, to reach 2 200 tonnes in total and continues to increase, playing an important role in developing integrated food production whilst making best use of water resources available in desert and arid environments.

Figure B2.2

Egyptian aquaculture production (tonnes) per type of farming system in 2015
(source: GAFRD, 2017)



General overview on the desert integrated agri-aquaculture

Demographic regions

The Egyptian desert covers an area of approximately 1 million km^2 and is divided into three regions: The Western Desert (covering 67 percent of the desert area), Eastern Desert (22 percent) and Sinai Peninsula (11 percent). Desert areas are relatively sparsely populated, with just one percent living in these regions, while 99 percent of Egypt's population are living on just five percent of its land area, concentrated along the valley of the Nile and the northern Nile delta (Sadek, 2011).

There are 100 artisanal and commercial desert-based aquaculture farms in Egypt, with 72 percent belonging to the private sector and 23 percent to the government sector. In addition, there are approximately 100 small freshwater reservoirs located in the desert in ten different governorates within the broader Nile delta, high Egypt near the Nile valley and Sinai

Peninsula, used for plant irrigation primarily but associated with fish culture too. Figure B2.3 shows the geographical distribution of Egyptian desert agri-aquaculture integrated farms that use groundwater as their primary water source. The commercial farms are in 10 governorates, distributed over three main geographical areas, as follows:

- **Nile Delta region:**

  Contains 22 farms. Several private desert-based fish farms are integrated with agriculture activities, mainly near the desert highway between Cairo and Alexandria and between Cairo and Ismailia.

- **High Egypt region:**

  Contains 55 farms. During the last five years several artisanal private agriculture organizations have reclaimed land, with areas ranging from 1 to 85 ha, and have started to use groundwater to generate shallow reservoirs to irrigate crops, but in addition to produce tilapia and African catfish. Groundwater used to fill the reservoirs has a salinity of less than 1 ppt and is used to create reservoirs between 300 to >10 thousand m^2 in size, to a water depth of 3m, primarily for plant irrigation, but increasingly for fish culture too. The farms are located mainly in Beni-Suef, Menia, Sohag and Assuit governorates.

  The main agriculture crops produced are vegetables, mostly corn; fruits produced during the summer; and wheat and chickpeas during winter. There would appear to be two main advantages of associating fish production with agriculture crop production in these conditions. Firstly, production of fish provides an additional harvestable product, besides the main plant crop; and secondly the microalgae that are produced in fish farm effluents result in improved compactness of sandy soils when the effluent water is added to the land during irrigation, which in turn can decrease the seepage of water from crop-producing land after irrigation water is added.

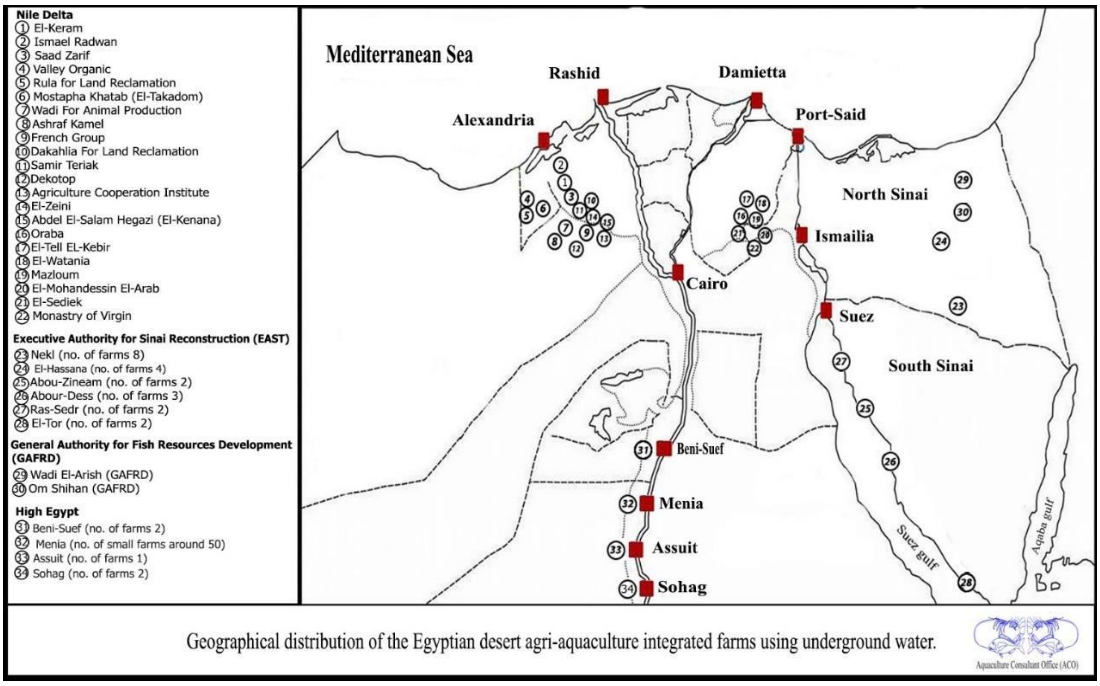
- **Sinai Peninsula:**

  Contains 23 farms. All farms in the Sinai Peninsula are governmental projects, aimed at Bedouin communities. The Executive Authority for Sinai Development (EASD) has implemented 21 Bedouin community projects for integrated agri-aquaculture integrated development, in six community centers based at Nekl and El-Hassana in North Sinai; and Abou-Zineam, Abour-Dess, Ras-Sedr and El-Tor in South Sinai (Figure B2.3).

  In addition, the EASD is undertaking construction of five other projects in both North and South Sina, which are expected to be finished at the beginning of 2018 (Invest-Gate. 2016). Further, GAFRD has established two intensive tilapia farms integrated with agriculture activities at Wadi El-Arish and Om Shihan in North Sinai.

Figure B2.3

Geographical distribution of Egyptian desert agri-aquaculture integrated farms using groundwater sources



Although desert-based aquaculture and agri-aquaculture has made considerable advances over the last decades, it faces certain challenges, particularly with respect to efficient and economical utilization of water sources.

Water resources

El-Guindy (2006) noted that the main water sources utilized for aquaculture purposes are groundwater and agricultural drainage, each of which can vary in salinity from 1 to 30 g/litre and in temperature from 22 to 26 °C. This author has previously raised concerns, with relevant authorities, about the use of groundwater aquifer systems in Egypt, estimating a potential safe pumping yield of 1 744 million m^3 per year. The same author also defined several key issues that should be taken into consideration to achieve a sustainable use of underground water for aquaculture purposes, summarised as:

- research is required to understand gaps in the existing capacity to use brackish water affectively.
- action plans on effective and sustainable use of underground brackish water resources need to be developed more fully (assessing quantity, quality, potential uses and time issues).
- a mechanism for inter-ministerial coordination for brackish water utilization needs to be established.

Abdel-Shafy and Mansour (2013) and Abdel-Shafy and Kamel (2016) have described how Egypt is extremely dependent on the River Nile, for its water resources, but this water resource and water resources generally, are becoming scarcer on a per capita basis. Abdel-Shafy and Mansour (2013) showed that renewable water resources were 2189 m^3/capita/year in 1966, but that by 2013 this was down to approximately 670 m^3/capita/year. The reduction is mainly due to the continuous annual increase in population at a rate of 2.2 percent per annum. With continued population growth, water resources are expected to drop to 500 m^3/capita/year by 2025.

Abdel-Shafy and Kamel (2016) and Sharaky *et al*. (2017) have estimated that groundwater resources contribute a smaller but no less significant contribution to water resources, providing approximately 20 percent of the total potential water resources. Within this, the Nile aquifer provides 87 percent of total groundwater pumping in Egypt. Overall, there are three types of groundwater available in Egypt, namely shallow local aquifers, aquafers recharged by rainfall and those considered as deep non-replenishable aquifers (although see AbuZeid and Elrawady, 2008 for more detailed discussion of “non-replenishable” aquafers). Shallow and recharge aquifers predominate in the Nile Valley and Delta system, with total removal being approximately 4.6 BCM/yr (Abdel-Shafy and Kamel, 2016), against availability of 200 000 BCM of freshwater in the New Valley Oasis alone, for example. The largest non-renewable aquifer is the Western Desert-Nubian Sandstone Aquifer (see AbuZeid and Elrawady, 2008), which sits under Egypt, Libya, Sudan and Chad. Overall exploitation of non-renewable groundwater in Egypt is estimated at a rate of 1.65 BCM/year, primarily concentrated at the Western Desert Oases with removal of 0.5 BCM/yr.

Water use is an important part of water resources exploitation and the agricultural sector utilizes about 86 percent of the available water supplies. The drainage water from agriculture is collected by an extensive drainage network. Currently about 5.5 Billion Cubic Metres (BCM) of drainage water are being reused, mostly after mixing with additional freshwater. This amount is expected to increase to 9.6 BCM by the year 2017. In general, this use of treated wastewater is of tremendous potential importance to Egypt. Agriculture is located, along with the population, close to the banks of the Nile, and its main branches and canals. Currently, the inhabited area is about 5.3 million ha and cultivated agricultural land extends to approximately 3.3 million ha. Several studies (Abdel-Shafy and Aly, 2002; World Bank, 2009); Abdel-Shafy and Mansour, 2013) have showed that the per capita crop area declined from 0.17 ha in 1960, to 0.08 ha in 1996 to about 0.04 ha in 2012. The sharp decline in the per capita of both cultivated land and crop area resulted in a decrease in per capita crop production. This directly affects food security at individual, family, community and country levels, and within this context the importance of water resources, particularly in desert/arid environments cannot be underestimated (Simas, Morelli, and El Sadani, 2009).

Cultured species

Egyptian desert fish farms are a combination of artisanal and commercial entities and between them produce various finfish. There are eight main finfish species produced:

- Nile tilapia (*Oreochromis niloticus*)
- Red tilapia (*Oreochromis mossambicus* x *Oreochromis niloticus*)
- Flathead grey mullet (*Mugil cephalus*)
- Thin lip grey mullet (*Liza ramada*)
- North African catfish (*Clarias gariepinus*)
- Eels (*Anguilla Anguilla*),
- European seabass (*Dicentrarchus labrax*)
- Gilthead seabream (*Sparus aurata*)

In addition, there are a number of exotic species produced, mainly koi (*Cyprinus spp*.), fantail (koi variety) and molly (*Poecillia spp.*). In 2010 Nile tilapia, mullet species and North African catfish were the main species cultured in the desert, accounting for 99.5 percent of total desert aquaculture production (Sadek *et al*., 2011). Within this, Tilapia spp. is by far the largest cultured species, amounting to 90 percent, followed by Mullet *spp*, Northern African catfish and others at 6.5 percent, 3 percent and 0.5 percent respectively (GAFRD, 2017).

Production system Management-fish

Most commercial desert aquaculture farms purchase fish fry from tilapia hatcheries located in the Nile delta, but five have their own hatcheries with a production of approximately 20 million fry/year. A field survey by Sadek *et al*. (2011) showed that the development of these commercial farms is affected by various factors, including feed price (34.1 percent); lack of technical experience (14.6 percent); water supply (12.2 percent); feed quality (7.3 percent); cost of electricity (4.9 percent); marine fish diseases (4.0 percent); credit availability (22.9 percent); fingerling supply; and other factors

Artisanal and commercial agri-fish producers, operating in desert environments, generally undertake intensive culture of fish stock, in which culture density is crucial and fish are provided with all their nutritional needs through the application of pelleted feed. They operate slightly differently in their management approach, however, a key difference being whether aeration is applied, that impacts the amount of water required and culture density, impacting overall production levels. Artisanal producers generally operate intensive culture systems with a stocking density of 10 kg/m^3, sometimes slightly larger, but do not use adequate water aeration systems that would allow them to increase their stocking density of fish. Conversely, commercial desert fish farms tend to apply aeration systems. These come in three forms: paddlewheel, air injector and splasher; ranging from one to three horsepower (HP) per aerator, which provide increased dissolved oxygen in the water column of tanks and raceways, and this in turn allows for higher stocking densities and increased production per unit of water used.

The warm water present in Egyptian desert farms naturally start with a lower oxygen level (warmer water holding less oxygen), which is readily used by fish during and post feeding and for maintenance activity at other times. Other processes in the water column, such as bacterial processing of dissolved and particulate fish wastes, plus fish use, means water oxygen levels can vary the significantly over the course of a day. With the application aeration (3 HP/350 m^3 tank volume), Sadek et al. (2008) have been successful in increasing the stocking density to 20 to 35 kg/m3, leading to an overall increase in production. Similarly, Algazzar, Osman and Sadek (2008) undertook an experiment to grow tilapia over a six-month cycle, and by their estimate the most cost-efficient production scenario for the desert is achieved at a stocking density of 17 kg/m^3, providing individual weight gain of 510 g per fish, a feed conversion ratio (FCR) of 1.3:1, and a production cost of USD 0.73/kg. Fish were held in twelve circular tanks (250 m^3 each), using groundwater sources, with a water exchange rate of 20 percent per day, and used aeration from 4 HP aerators attached to paddlewheels and air-injectors to achieve this level quality of production.

Introduction to production systems management for integrated systems

Van der Eijden and Verdegem (2009) highlighted the importance of water exchange in commercial tilapia desert farm El-Wataneya Fish Farm using Nile River when using groundwater. Water in concrete fish tanks is normally replaced at a rate of 25– 35 percent/day but can be as high as 60 percent/day in the latter stages of the fish production cycle, when fish size affects the total amount of oxygen required and the amount of fish wastes generated is high.

At the El-Wataneya farm all fry and nursery tanks were aerated with air-blowers, while grow-out tanks are equipped with 2 HP paddlewheels which maintained more consistent and higher levels of oxygen. In the system developed, Van der Eijden and Veregem (2009) also highlight the importance of water re-use, with waste-water from the fish farm used to develop other crops. The water removed from tanks, containing fish farm effluents, was pumped to a sprinkler irrigation system that irrigated 25 hectares of arid land, forming an integration between fish farming and agriculture, which included the growing of peppers, bananas, mangos and flowers (mainly gladiolas). In terms of profitability, tilapia was most profitable, followed by bananas, vegetables and flowers. The farm was also able to add tilapia, grass carp, common carp and silver carp in to drainage ponds on site and this yielded an additional 2 tonnes/year crop of fish without any supplementary feeding being required and without the application of additional water resources.

Nowadays, most commercial Egyptian farms are using flow-through systems (FTS) that provide irrigation for agriculture and an opportunity to produce three different crop types (fish / plants / sheep) within an integrated production system. At the time of writing, two commercial farms have upgraded to a water-efficient recirculation aquaculture system (RAS). Opportunities for integration come from a combination of hydroponics and RAS fish culture, combined referred to as aquaponics, which forms an integration between fish production and soil-less plant production.

Culture practices of aquaculture integrated with agriculture: Success stories and new projects

Following on from understanding specific constraints in the operation of desert-based agri-aquaculture systems and establishing some broad reasons why such systems would nonetheless offer benefits in arid environments, this section describes several success stories and projects in the early stages of development, where agriculture and aquaculture are integrated to form a coherent system of food production. The success stories, developed in the Egyptian desert using agri-aquaculture integrated systems, are a combination of governmental and private projects. The cases were selected to reflect activities that have impacted different socioeconomic groups within the aquaculture sector specifically and have or will contribute strongly to aquaculture sustainability in the arid zones of Egypt. These stories promote and endorse the idea that more needs to be achieved, while emphasizing how current and future agri-aquaculture integration projects have evolved in Egypt, particularly in terms of sustainability, meeting market opportunities and reducing the food/nutrition gap within isolated desert areas of Egypt. It is anticipated that shining a light on these success stories, will have an immediate impact on decision makers, and will also lead to a variety of other activities that will bring about a wider sectorial awareness and adoption of the positive lessons learned.

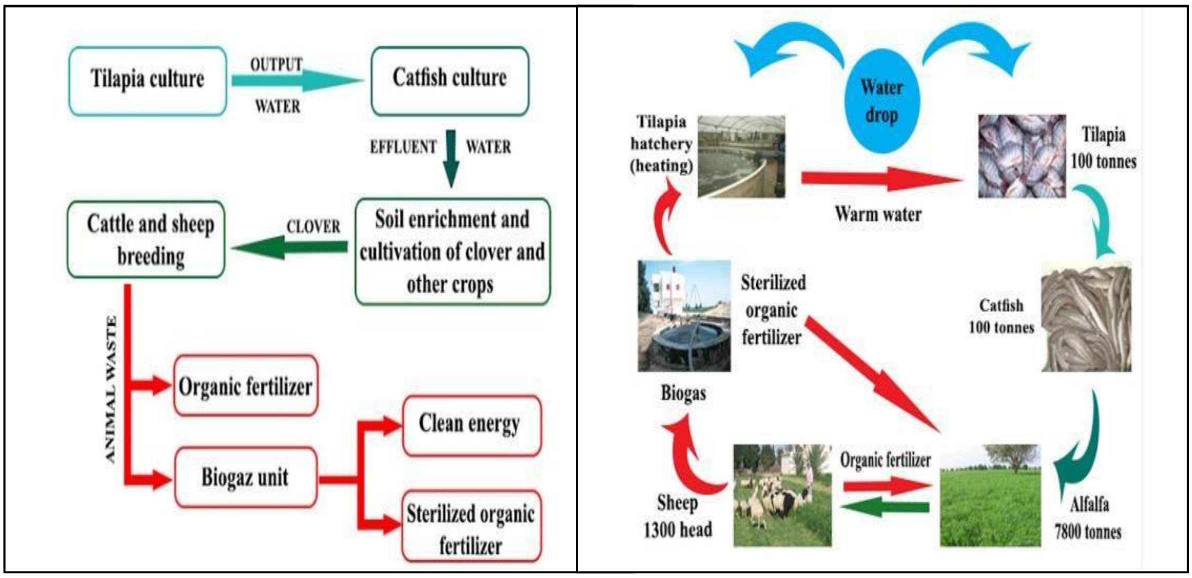
Story 1: *El-Keram:*

El-Keram is a trading investment company, located between Cairo and Alexandria in the desert of Beheira, about 140 km northwest of Cairo. The company has applied a methodology that involves nutrient sharing and waste recycling to produce a combination of aquaculture and agriculture products, and generation of biogas. Since 1990, El-Keram has demonstrated the efficient utilization of every drop of water that is pumped from its desert wells (at a rate of 120-300 m^3/hr). The philosophy is based on the concept “one drop for more crops”.

The El-Keram aquaculture systems have been carefully designed so that the outputs from each stage in production forms the input for the next stage. This is summarized schematically in Figure B2.4, which shows the water input point going to fish production (hatchery and on-growing), with waste water and waste then being applied to grow plants, including alfalfa to feed to sheep, and sheep dropping used to generate biogas. At each stage water is re-used along with specific waste outputs to support the growth of the next product in the chain (Figure B2.4).

Figure B2.4

El-Keram agri-aquaculture integrated system in the Egyptian desert. Left hand side shows how outputs from one part form the input to the next stage in production; right hand side shows flow of water from initial input to fish culture, through remaining production systems



In 2010 El-Keram decided to integrate the production of two different fish species, as well as arable, animal and biogas production. Fish tanks are aerated and maintained at relatively high stocking density that enables production of 100 tonnes of tilapia (200- 250g wet weight per fish) annually, alongside 100 tonnes of catfish (approximately 1 kg wet weight per fish). The effluent water from the fish farm is used to irrigate land to produce 7 800 tonnes/year of Egyptian clover, which provides fodder to produce 1 300 sheep/year. Finally, the manure generated from livestock is used to produce biogas, which is used to provide the heat needed within the tilapia hatchery, to heat staff houses and cooking. The end outputs include fish, alfalfa and sheep for sale but has the benefit of reducing costs in heating, and the more efficient use of water resources. Compared against a non-integrated system producing similar amounts of fish, the El-Keram system uses significantly less water, but can irrigate 31 percent more land area, and produce more clover and sheep than the non-integrated system. In 2010 it provided a 67 percent reduction in the amount of water used (water conservation), whilst also reducing waste to zero (Table B2.1).

Between 2010 and 2017 El-Keram has developing their system further, primarily to become more efficient with more economical utilization of water resources compared to 2010, and further consolidation may be possible. Effluent fish farm water is rich in algae and debris which makes the sand soil structure more compact than previously, and this is helping to decrease water seepage. In 2010 the clover alphalpha (*Medicago sativa*) consumed 50 m^3 of effluent water fish farm per acre of clover per day, which is the equivalent of around 10 thousand cubic meters of water used for 200 days of growth. Between 2010 and 2017, the water consumption for alfalfa has decreased by something like 15 percent, to 0.85 water units, giving an overall water conservation of 72 percent in 2017 versus 67 percent in 2010, compared against a non-integrated farm (Table B2.1).

Table B2.1

Comparison between the El-Keram agri-aquaculture project system (fish/clover/sheep/organic-fertilizer/biogas) in the Egyptian desert in 2010 and 2017, against a non-integrated agriculture system producing the same stock of products

Modified from Sadek (2011)

Item	Non-integrated agriculture production systems	El-Keram integration systems in 2010	El-Keram integration systems in 2017
Water units	3	1	0.85
Nile tilapia (tonne)	100	100	100
African catfish (tonne)	100	100	100
Clover: alphalpha *Medicago sativa* (tonne)	4 500	7 800	7 800
Sheep (head)	1 000	1 300	1 300
Warm water	Nil	Yes	Yes
Organic fertilizer	Nil	Yes	Yes
Waste	Variable	Nil	Nil
Irrigated land (ha)	42	55	55
Water conservation (percent)	0	67	72

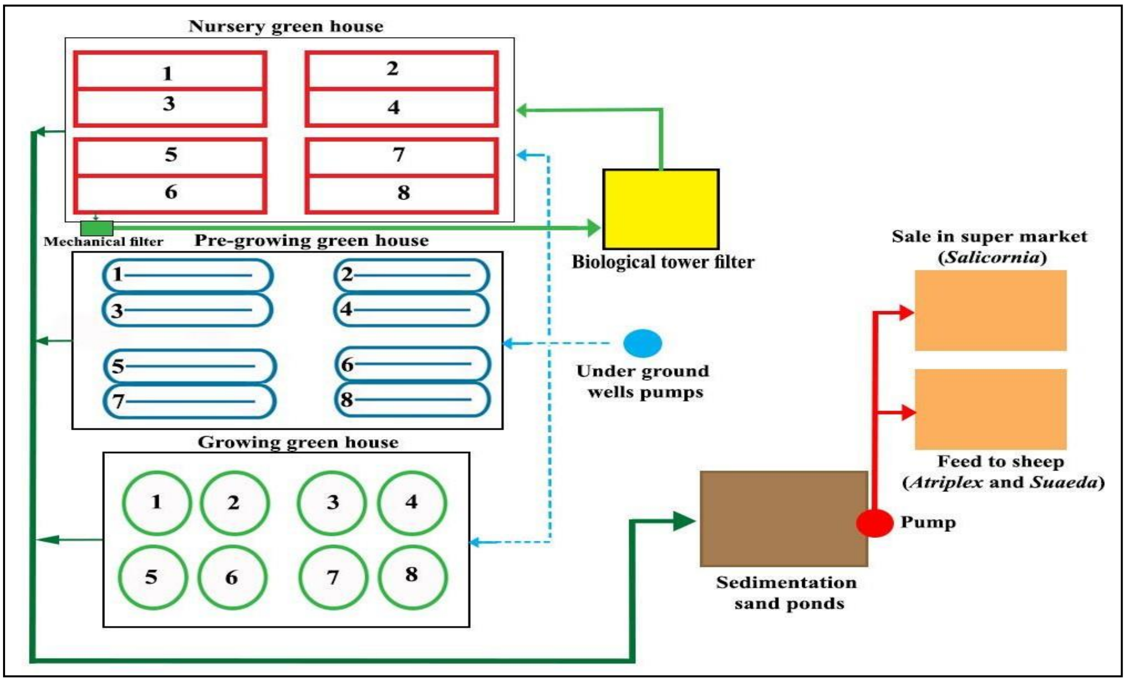
Story 2: *Rula for Land Reclamation (RLR)*

The RLR is a private commercial desert intensive fish farm affiliated to the Wadi Group in the Wadi-El-Natroun area (El-Beheira Governorate) of Egypt, who produce European seabass (*Dicentrarchus labrax*) and gilthead seabream (*Sparus aurata*) using brackish groundwater with a salinity of greater than 26 ppt and a temperature of 21 °C. RLR conducted commercial experiments to determine the general behaviour and effects of fish stocking density on fish growth, feeding and mortality over a 28-month growing period for seabass, and 14-month period for sea bream. For seabass this involved three critical periods of growth; being five months for the nursery stage, seven months for pre-growing to the fingerling stage and 16 months for on-growing to harvestable size. For seabream the nursery phase took approximately 3 months and the growout phase approximately 10-11 months.

The nursery section used both a flow-through system (FTS) and recirculating aquaculture system (RAS), the latter with water cleaned through a mechanical filter (circulation rate 97 m^3/hr) to remove particulates and connected to a biological tower (25 m^3 media) to remove dissolve waste components from the water. Both the pre-growing and on-growing phases used a tank-based FTS. The system was composed of fourteen D-ended concrete raceways and circulation tanks of varying water volumes (100 m^3, 180 m^3 and 340 m^3) used for the three rearing phases (Figure B2.5).

Figure B2.5

Schematic of the agri-aquaculture integrated system at Rula for Land Reclamation in Wadi El-Natroun, Behera Governorate, Egypt; using brackish groundwater (>26 ppt and 21 °*C*) to produce European seabass and Gilthead sea bream, and using fish farm waste water to grown halophytic plants



For seabass, the nursery stage was undertaken using the small tanks stocked at 2.5 kg/m3 with fish with an initial body weight of 0.15 to 0.20g. Pre-growing fish were on-grown from a starting weight of 38g to 51g to an end weight of 200g to 250g at a stocking density of 5 kg/m^3. Finally, the on-growing phase stocked fish at 10 kg/m^3 in the 340m^3 tanks, which were grown on till harvest. All fish were grown in varying degrees of brackish water ranging from 7.5 percent, 30 percent and 40 percent. No additional data is available for the sea bream.

Over the production period the average water consumption required for each stage in the production process varied, being 1.7m^3, 6.3m^3 and 18m^3 for the nursery, pre-growout and on-growing phases respectively (Figure B2.6), the total amount required to produce one kilogram of fish was estimated to be 26 m^3. There were positive results gained through the utilization of the RAS during the nursery phase with low volumes of water used per kg produced, and a general thought that RAS could and should be applied for all the growing phases as a means to further reduce total water consumption. The company established the possibility to produce sea bream and sea bass in desert environment using brackish water, and in doing so managed to achieve a mean FCR of 1.9:1 (feed used:fish produced) over the full 28-month period for European seabass (Figure B2.7) and an FCR of 1.8:1 for gilthead seabream over a 14-month growth period (Figure B2.8). Approximately 50 percent of the European seabass harvested weighed between 700g and 800 g, while 25 percent were 400g to 600 g and 15 percent were 200g to 300 g. The remaining 10 percent weighed one kilogram, which suited a specific niche market. Approximately 66 percent of the gilthead seabream harvested weighed 200g to 300 g, while 19 percent weighed >300 g, and 15 percent weighed <200 g (Sadek *et al.*, 2011).

Figure B2.6

Water consumption for the three production stages per kilogram of European seabass and Gilthead seabream (nursery and growing only) at Rula for Land Reclamation (RLR) site in Egypt (Sadek *et al*., 2011)

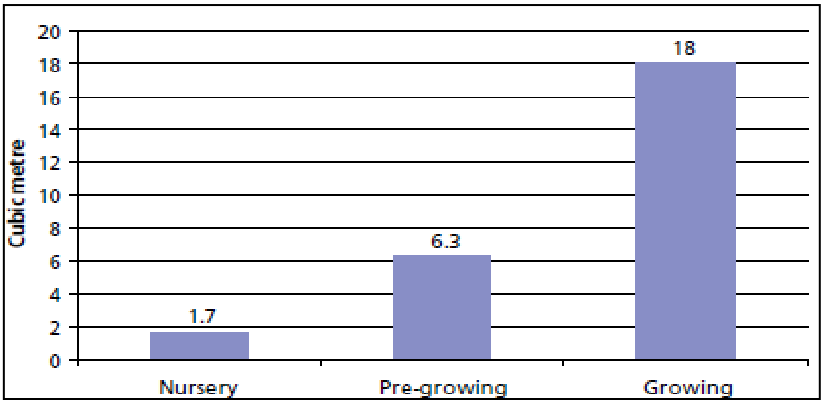


Figure B2.7

FCR of European seabass during three growing stages for 28 months in RLR, Egypt (Sadek *et al*., 2011)

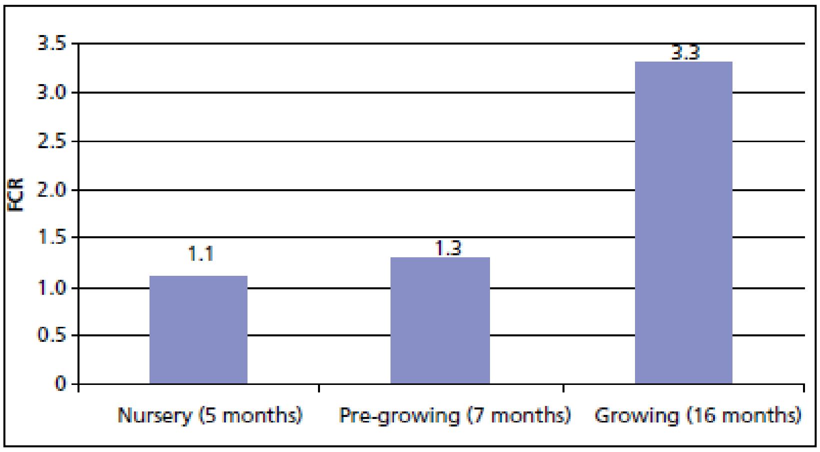
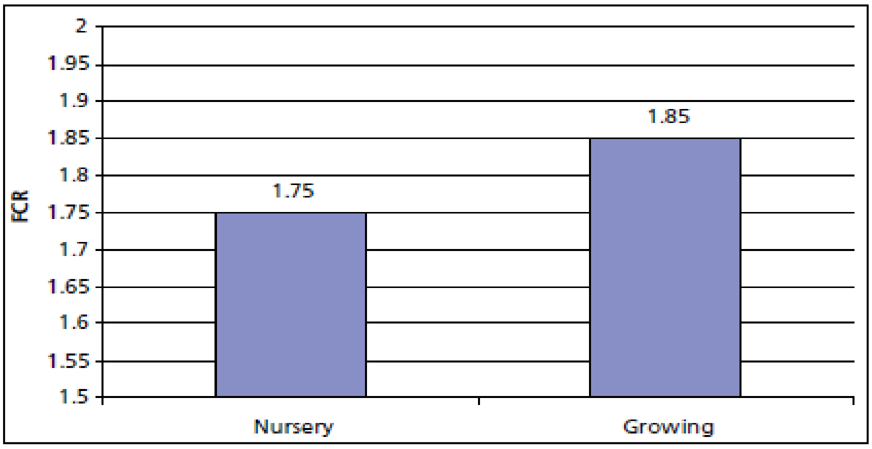


Figure B2.8

FCR of gilthead seabream during the nursery and growing stages for 13 months in RLR, Egypt (Sadek *et al*., 2011)

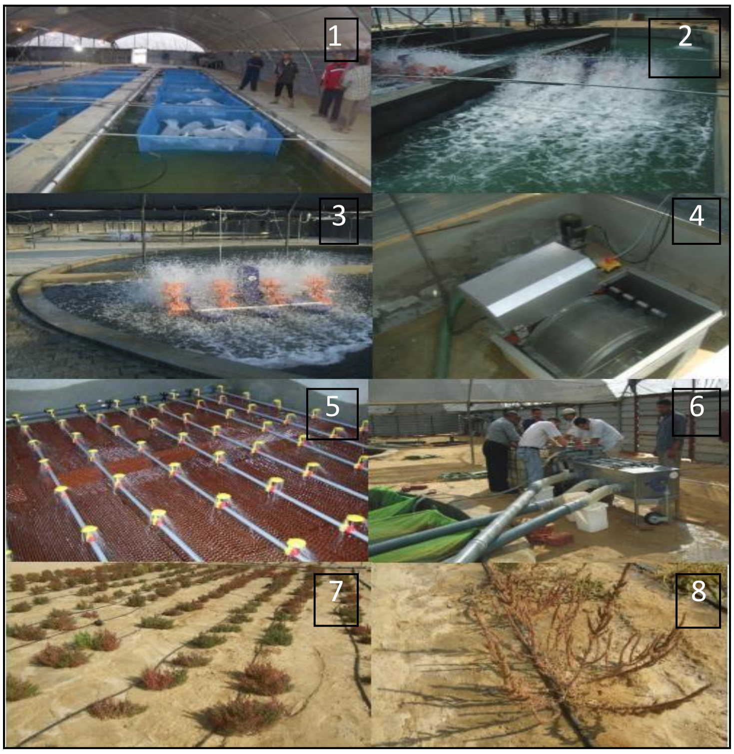


Assessments by Van der Heijden and Verdegem (2009), Van der Heijden *et al*. (2013) and Van der Heijden, Blom-Zandstra, and Sadek (2013) appraised the site and determined that to keep their farm management more cost-effective and more environmentally friendly, RLR had to look for alternative uses for part of their farm land. Following advice, they started to grow three halophyte plants (Atriplex, Suaeda and Salicornia), which were kept watered using the saline (26 ppt) effluent from the fish farm containing ammonium and other nutrients, to both irrigate and proide additional nutrients to then produce further products. Salicornia plants (*S. europaea* and *S. procumbens*) can grow closely to each other (distance 3 – 5 cm) as they do not grow large, having to be harvested at an early stage for sale in the supermarket. Atriplex and Suaeda should be planted with more space than Salicornia (ca. 40-50 cm) and these species harvested to feed sheep. In addition, three trees (Acacia, Moranga and Lebbek) which can tolerate the salinity of the water, have also been cultured surrounding the intensive fish farm, and the halophyte planting area (Figure B2.9).

The early success was tempered, however, and today the RLR site within the El-Beheira Governorate is inoperative due to the high cost of electricity, which in the end represented more than 30 percent of the total production cost and made further use unprofitable. A sister company of the Wadi group, Wadi for Fish Production (WFP) has, more recently, established 50 High Density Polyethylene (HDPL) cages with diameter of 11.5 m next to El-Rayan lake, a brackish inland water lake (>20 ppt) in Fayum governorate. The farm produces the same two marine species as RLR, but is able to do so with a lower cost.

Figure B2.9

The agri-aquaculture integrated system at RLR in Egypt, showing European seabass (*Dicentrarchus labrax*) and gilthead seabream (*Sparus aurata*) integrated with halophyte plant production. 1) Raceway nursery 100 m^3; 2) Pre-growing D-ended raceway 180 m^3; 3) Growing phase round tanks 340 m^3; 4) Mechanical filter 90 m^3/hr; 5) Media of the biological filter with water injection; 6) Grading European seabass at size 60 gm/fish; 7) *Salicornia* irrigated with the effluent fish farm water and 8) *Suaeda* irrigated with the effluent fish farm water



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Story 3*: Integrated agriculture-aquaculture-tourism systems*

El-Riad Lake

El-Riad Lake is an abandoned open-cut sand mine, with a total area of 10 hectares, which has progressively filled with water with a salinity of 2 to 4g/litre through groundwater seepage, that has created this lake. The lake is used in what can be considered a semi-integrated aquaculture-agriculture-tourism system (Sadek, 2011).

El-Riad Lake, over the last decade, has developed as a semi-integrated system between different activities; including extensive fish culture, horticulture, growing of wheat and barley crops, and development of local tourism activities (Figure B2.10). From an Agri-aquaculture perspective, a variety of fish species (tilapia, carps and mullets) are grown in polyculture using extensive methods, which involves stocking and leaving fish to feed themselves from productivity in the lake, and to self-seed. These fish can be harvested through netting at regular intervals with sufficiently large fish removed and smaller fish returned and allowed to grow further. Water is pumped from the lake onto surrounding sandy banks, to provide irrigation for production of agricultural crops, vegetables and flowers which are also harvested. Around the lake tourism is slowly developing, with the building of small and simple bungalows for guests to stay, and development of an adjacent pit-lake that allows tourists to fish with rod and line (Figure B2.10).

Figure B2.10

El-Riad Lake Company, Ismailia, Egypt. Use of abandoned open-cut sand mines for integration of an agri-aquaculture and tourism system. 1) Green garden area integrated with extensive tilapia and catfish culture in lake; 2) Island in the middle of the lake used for local tourism fishing; 3) Tourism building under construction next to the extensive aquaculture lake; and 4) Tomatoes crops on the bank of the lake irrigated using water from the lake

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El-Gouna Park

A preliminary study undertaken in 2002 (Anonymous, 2002) showed that brine effluent water from the desalination plant of the El-Gouna resort (Orascom Company), located 22 km north of Hurghada in the Red Sea Governorate, was suitable for growing hybrid red tilapia, grey mullet, gilthead seabream and European seabass. Since then this water has been used to fill a locally available abandoned open-cut sand mine, and supplies water with a salinity of 12 to 15 ppt to the created lake at a rate of 3 000 m^3 per day. The project has developed into what is now El-Gouna Park and the lake is stocked with a low density of red tilapia, mullet and European seabass, as an extensive form of polyculture. The park is attracting El-Gouna resort visitors as an entertainment place, who can spend the day fishing and cook the fish caught, under the shade provided by planted mangrove trees, with a small fee payable for each activity (Figure B2.11).

Figure B2.11

El-Gouna Park in Red Sea Governorate, Egypt, is an integrated aquaculture-agriculture-tourism system, using effluent brackish-water discharge (salinity 12 ppt) from the resorts' desalination system, to fill an abandoned open-cut sand mine (1) associated with the culture of mangrove trees to create a resort entertainment place, showing growth after 8 years (2); the entertainment includes fishing for which fees are paid (3) and recent development has extended the lake developed with new mangrove planting (4)

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Story 4: Agri-aquaculture integrated development projects for Bedouin communities for in the Sinai Peninsula

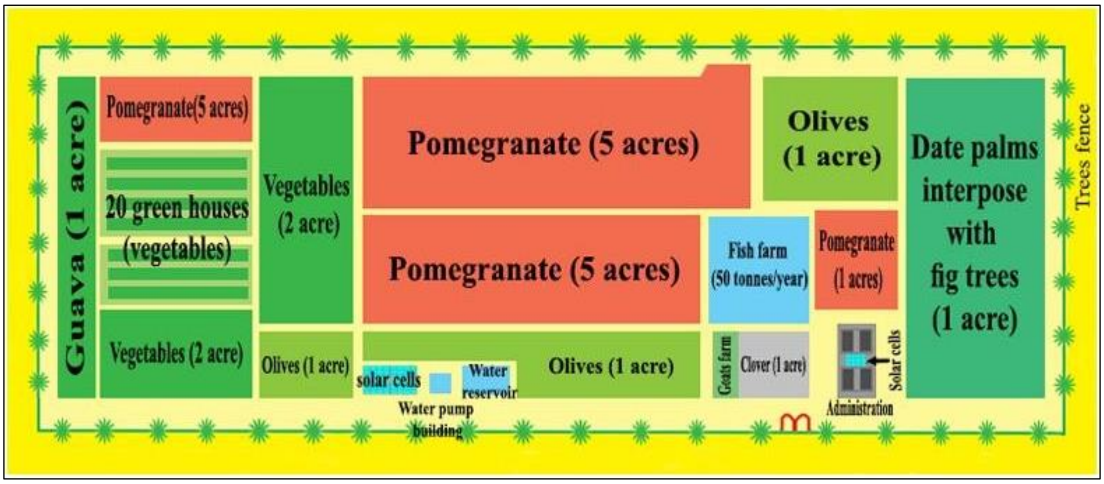
EASD has implemented agri-aquaculture integrated development projects for 21 Bedouin communities based around six community centres at Nekl, El-Hassana, Abou-Zineam, Abour-Dess, Ras- Sedr and El-Tor). The centres cover a large area and projects are distributed over 1 500 acres in North and South Sinai. A further five projects coordinated through EASD are near completion in both North and South Sinai and expected to finish at the beginning of 2018. EASD is looking to transfer their expertise in various fields of agriculture reclamation through these extension projects aimed at Arab Bedouins peoples becoming farm workers. As part of a second phase in the project, EASD intends to handover the management of the existing systems to Arab Bedouins, so management is taken into their own hands under a cooperative system, allowing EASD to move onto construction of other similar farms.

One example of this approach is the Wadi Tal Village Farm at Abu-Zneimah in South Sinai, Egypt (Figure B2.12). The farm is 32 acres in size and the cooperative is supported by 120 Bedouin families. Desert land has been reclaimed to produce several crops, including date palms, figs, olives, pomegranate, guava, clover and vegetables produced under HDPE greenhouses (Figure B2.13). In addition, water is pumped from a surface well with a salinity ranging from 8 to 12 ppt, directed to fish farm ponds lined with HDPE to produce tilapia and mullet spp. with a target production of 50 tonnes per year. In addition, the project is supplied with solar power to produce sufficient clean energy. Manure is provided via a small goat farm located in the middle of the area, which is collected an added to plant crops.

Figure B2.12

Images from Wadi Tal Village Farm, Abu-Zneimah, South Sinai, Egypt. 1) Wadi Tal village farm perimeter, 2) Water reservoir, 3) Fish pond lined with HDPE, 4) Tomatoes produced in open field next to vegetable greenhouses, 5) Bedouins working inside greenhouses and 6) Small goat farm providing meat and manure

Figure B2.13
Schematic layout of 32-acre Wadi Tal Village agri-aquaculture integrated Farm system at Abu-Zneimah in South Sinai, Egypt. Courtesy of Executive Authority for the Reconstruction of Sinai, Ministry of Housing, Utilities and Urban Communities Central Agency for Reconstruction



The estimated cost to establish one agri-aquaculture integrated development project is around 3 to 4 million Egyptian pounds (Invest-Gate, 2016).

Story 5*: The 1.5 million feddans reclamation of land project*

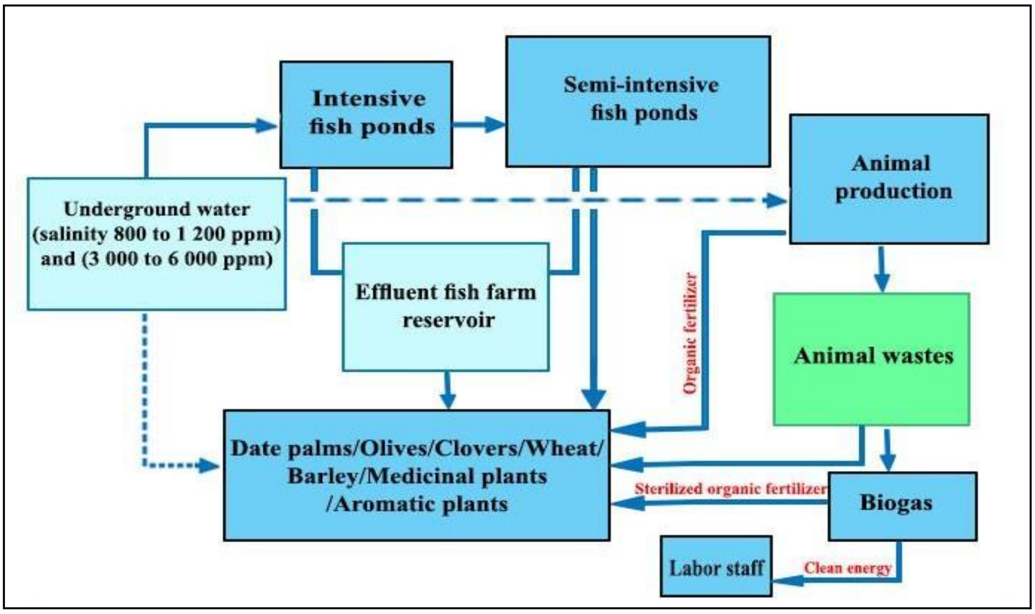
In December 2015, the Egyptian Government planned to establish a mega-project to reclaim one and a half million feddans (1 feddan = 1.038 acres = 1 557 000 acres) of marginal desert land in areas of the Nile valley and delta at a cost of Egyptian Pounds (EGP) 33 billion. The land is to be used for commercial and agricultural development and among other uses to increase production of crops, vegetables and other products to feed, but also to house, the increasing population of Egypt. The project will be implemented over three phases, with reclamation of 500 thousand acres in each. The land to be reclaimed will span eight governorates (Giza, Minia, Qena, Aswan, The New Valley, Sinai, Ismailia, and Marssa-Matrouh), mainly in the areas of Farafra, Dakhla Oasis, Toshka, El-Amal, West Almrashda and West Minya. The project will be managed through Egyptian Countryside Development Company, who will oversee the development activity (American Chamber of Commerce in Egypt, 2016)

The project involves, in part, the digging of wells and use of groundwater to provide the necessary water resources, with pumping from wells using solar energy. The well water salinity ranges between 0.8 ppt to 1.2 ppt and other groundwater sources targeted (currently in the Magara Depression, south east of El-Katara) range between 3 ppt and 6 ppt, although Invest-Gate (2016) proposes there is need for studies to be carried out to assess the best economic crop production approach using water at this salinity. The proposition in some areas, however, is to integrate aquaculture and agriculture (Figure B2.14), with fish farm waste water used to irrigate plant crops which can resist slightly saline water, thus reducing the overall amount of water used for both types of production. Several plants crops are targeted for production, mainly date palms, olives, clovers, wheat, barley, medicinal plants and aromatic plants.

Invest-Gate (2016) notes that the 1.5 million acres provides employment opportunities of up to 5.6 million people, through side projects in the fields of agriculture and industry, pointing out that the project is based on the establishment of economic development communities in agriculture and industry, not just the conversion of land from desert to “green land”, and to create communities, villages and infrastructure to support development.

Figure B2.14

Schematic outline of an agri-aquaculture integrated system planned during the first phase of the 1.5 million feddans (acres) reclamation land project, undertaken in eight governorates within Egyptian deserts (2015-2018). (Source: Invest-Gate, 2016)



Story 6*: Aquaculture-fruit production system*

El-Zeini for Agriculture Investment Company, part of the El-Zeini Group, has reclaimed approximately 33 ha of desert land located 85km south of Cairo on the Cairo-Alexandria desert road, to cultivate grapes and mangoes trees, and to undertake intensive culture of tilapia, using the fish farm effluent water to irrigate grapes and mango trees. Grape production covers an area of 30 feddan, on which different varieties are grown including superior seedless and flames seedless grapes. Water consumption for grapes totals approximately 3 000 m^3/acre/year, with highest use from April to July when monthly water consumption ranges between 500 and 700 m^3 per month per acre. From September to March, the monthly consumption is lower at 30 to 50 m^3/month/acre. Growth in the first year achieves 7 tonnes of grapes per acre, but this almost doubles to 14 tonnes/acre by the third year of production.

Mango production takes place on an area measuring 40 feddan, growing different varieties including Keitt and Naoum. Water consumption for mango production ranges between 3 000 and 3 500 m^3/acre/year. Highest usage occurs from April to July each year with a monthly water consumption of 750 to 900 m^3 per month per feddan. During the period from September to March, water consumption reduces to one-third the summer level, with a monthly water consumption of 150 to 300 m^3/month/acre. The company achieves production of 4 tonnes/acre by the third year but can reach 8 tonnes of mangoes per feddan by the fifth year.

The company is undertaking the culture of fish with fruit to create an integrated aquaculture-fruit system, with plans to increase the amount of fish culture in future. Presently the fish farm produces tilapia in tanks with a total water volume of approximately 1 000 m^3, split between nursery activity (25 percent) and for on-growing (75 percent). The tilapia are grown to a commercial size of 250g to 300g wet weight per fish (3-4 fish/kg), stocked at a density of 33 kg of fish/m^3. Fish production is divided into two growth cycles per year (six months per cycle), starting with a fingerling size of 10 to 20 gm/fish. Overall the fish farm can produce approximately 44 tonnes/year of commercial size tilapia.

The tilapia tanks on site (Figure B2.15) need to be wholly or partially drained on a daily basis, and replenished with freshwater, in order to maintain sufficiently high oxygen levels, and to remove unwanted dissolved and particulate wastes from the tanks. The amount of water replacement varies from 30 to 100 percent of the water volume in tanks each day, and this level of water removed from the tanks each day supports part of the water needs for the fruit crops. At present the total water requirements for the cultivated grape plants and mango trees is estimated at around 1 190 m^3/day from April to September and 340 m^3/day during October to May, and not all of this can currently be supported through water replacement in the fish tanks. However, the company has plans to develop the aquaculture section further, to a total volume of 2 500 m^3, and at current water replacement levels the aim is to support all the water needs for irrigation of the grapes and mangoes completely.

Figure B2.15

Tilapia fish farm at El-Zeini for Agriculture Investment Company site on Cairo-Alexandria desert road, 85km south of Cairo. 1) Tilapia harvesting in 120 m^3 tank; 2) Grading tilapia in nursery tank using an artisanal grader to harvest tilapia fingerlings in weight range 5g to 10g; 3) Red tilapia with an average weight of 30g/fish and 4) 2HP Paddlewheel aerator in 18 m^3 on-growing tank

Story 7*: Water use efficiency using hydroponics and aquaponics*

Due to the water scarcity in Egypt, outlined above, and existing water sources becoming polluted or high in salts, a new approach to farming is being developed using hydroponic and aquaponic farming methods. Several private projects have been established during the last five to seven years, located mainly in desert zones.

Hydroponics (growing plants without soil) and aquaponics (integrating fish production with soil-less plant production) means there is no need to spray large areas of land with fertilizers and water use is reduced by 90 percent compared to the water-usage required for soil-based traditional farming methods. Hydro-and aquaponic production provides for efficient water use, stocking at high density, generates minimal waste and can operate close to markets and in almost any environment providing water is available. Aquaponic methods gives the capability to produce fish and plants in high densities, making both production methods particularly useful for desert and arid zones.

Four Egyptian pioneer private companies have developed these systems: Hydrofarms is using the hydroponic system covering an area of 2 100 m^2; Bustan Aquaponics, Agrimatic Farms and Al-Haggag Aquaponic Farms are developing their respective aquaponic systems. There are three main hydro/aquaponic plant-types produced, being lettuce, greens and herbs (Table B2.2). Hydrofarm has been successful in harvesting product up to eight times per year, more than from traditional soil-based farming methods. However, aquaponic systems, in particular, offer the opportunity to diversify products.

Table B2.2

Main hydro-and aquaponic plant types (lettuce, greens and herbs) produced by private companies in Egyptian desert and arid zones.

Lettuce	Greens	Herbs
- Mixed baby leaf salad - Romaine - Green oakleaf - Red oakleaf - Green butterhead - Green batavia - Mixed cut salad	- Gargeer (Arugula) - Wild rocket - Watercress - Purple kale - Green kale - Cavolo nero kale (Dinosaur) - Swiss chard - Baby spinach - Spring onions	- Rosemary - Thyme - Sage - Mint - Tarragon - Marjoram - Chervil - Chives - Sweet genovese basil - Lime basil - Cinnamon basil - Purple basil - Parsley

Bustan Aquaponics has a site covering 7 acres in Giza Governorate, containing four aquaponic system each composed of four fish tanks connected to hydroponic beds. Each aquaponic unit produces around six tonnes of tilapia per year and tens of thousands of lettuce heads, plus tomatoes, spring onions, endive, basil, pak-choy and water cress, among others (examples shown in Figure B2.16). The second aquaponic system, Agrimatic Farms have developed their aquaponic system over an area of one acre near Cairo and produce different kinds of lettuce, mint and basil, integrated with tilapia production in tanks. Al-Haggag aquaponic farms has taken aquaponics a step further by using the waste particulate material that settles out from the tanks of their tilapia RAS system, to feed the larvae of the black soldier fly (*Hermetia illucens*) and the red wiggler earthworms (*Eisenia foetida*), which then consume a wide variety of organic matter including the remains and waste that is generated from packing vegetables and fruits (Figure B2.17).

Figure B2.16

Example integrated aquaponic system showing 1) Nile tilapia culture in tanks; 2) results from first trial to culture the freshwater prawn (*Macrobrachium rosenbergii*) in the aquaponic system; 3) Kale production in an aquaponic bed and 4) Mixed baby leaf salad product. Bustan aquaponics company, Giza, Egypt

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Figure B2.17
Production of red wiggler earthworms (*Eisenia foetida*) (top pictures) and larvae of the black soldier fly (*Hermetia illucens*) (bottom pictures) using particulate waste from Recirculating Aquaculture System RAS) tilapia production and waste from aquaponic produced vegetable and fruit packing system

Aquaculture marketing and trade of desert ecosystem production

All fish

About 98 percent of fresh and marine fish produced in Egypt is marketed internally for domestic consumption while the remainder is exported to international markets. Egyptian fish exports is mainly composed of fresh, frozen and processed tilapia, sold primarily to Middle East markets. Egypt exported a relatively small 1 540 tonnes of fresh tilapia products to Gulf countries in 2016, for example (pers. comm. General Authority for Veterinarian Services, Ministry of Agriculture and Land Reclamation).

Many stakeholders are involved in the domestic fish marketing chain including fishers and aquaculture producers, traders, agents, intermediaries, processors and transporters. The market chain from production to consumption encompasses primary, secondary and retail markets, but involves sales agents, suppliers, wholesalers and retailers.

Egypt is a net importer of fish and fishery products, although imports vastly exceed exports in quantity and value terms. In 2006, Egypt imported 250 920 million tonnes (MT) of fish with a value of 1.0 billion EGP. This increased by 2015 to 292 111 MT valued at EGP 5.7 billion. Overall, imports have, for many years, provided at least 20 percent of the total supply of fish to the Egyptian market. Most of the imports (70 percent) are frozen fish products, mainly small pelagic fish like mackerel, herrings, hake and other marine fishes. Fishmeal represents about 20 percent of imports and the balance (10 percent) includes canned tuna and sardine, and fresh or chilled fish products. The Netherlands is the most important supplier of Egyptian fishery imports followed by Norway and the United Kingdom.

In 2006, Egypt exported 4 339 MT valued at EGP 19.9 million (CAPMAS, 2007), fluctuating but increasing in the following years to reach 19 698 MT in 2015, valued at EGP 238.6 million (CAPMAS, 2017). The main products exported are fresh and chilled fishes (mostly cultured Gilthead sea bream and European sea bass), representing about 50 percent of all exports. Frozen, fresh and salted fish products represent more than 90 percent of all exports. The principal destination of Egyptian exports is Gulf counties, which accounts for almost 75 percent of products shipped. Exports to these countries are primarily fresh or chilled, frozen, salted and canned fish in oil. Some countries in the Middle East, such as Saudi Arabia and Lebanon, receive smoked products and fresh fish from Egypt mostly, but also canned products.

Desert-produced fish

Currently most, if not all, of the limited production of desert-produced fish are consumed within Egypt. The primary species produced is tilapia.

CAPMAS (2007 and 2017) have compared the average prices of tilapia in the Obour Whole Sale Fish Market (OFM) in Great Cairo governorate between 2006 and 2015. In this context the prices of tilapia produced from desert farms depends on quality, size (weight), season, market structure, supply/demand, consumption behavior of consumers and sale dead fresh fish versus live fish. Tilapia prices are known to follow a seasonal pattern. When supplies are scarce tilapia prices increase. Demand behavior may also contribute to inter-seasonal price fluctuations. A SWOT analysis and a discussion with stakeholders was undertaken to assess the possible approaches to support desert-produced tilapia marketing systems, an approach that can be used to devise an appropriate marketing strategy. Results from the SWOT analysis are in Table B2.3.

Table B2.3
SWOT analysis for the development of desert tilapia farming products marketing systems in Egypt

Strengths: - Almost all Egyptian people eat tilapia - Already a large number of people involved in tilapia production and marketing - High export potential for fish and fish products - Environmentally friendly activity - Potential to increase production to meet demand, whilst efficiently using water resources available	**Weakness:** - Limited number of farmed species in desert environments, main culture fish is tilapia - Poor fish market infrastructure (Unhygienic conditions, inadequate ice facilities, poor handling, other) - Retail traders not equipped to market products (unhygienic sales conditions, inadequate chilling facilities to retain fresh product, other) - Shortage of legal hygiene requirements, controls and inspection of fresh fish throughout the market chain, between aquaculture farms and consumer - Inadequate of tilapia processing facilities; traded only as whole fresh without processing apart from sorting and icing - Lack of concern from the government to support development agencies and NGOs to improve systems - Weak aquaculture and fisher's cooperative societies and traders associations.
Opportunities: - High seasonal demand for freshwater fish, mainly in spring and summer - Opportunity to sell live fish live, with price point 15 to 30 percent higher, compared with dead fresh fish - Increase employment opportunities, and maintain productive rural communities in-situ - Increase in fish price can increase incomes - Improvement of socio-economic conditions or rural poor - Export potential	**Threats:** - Problems in uniform supply of fish (shortage in winter season due for low water temperature which can cause mortality) - Higher marketing costs, reduced profits; marketing organizations require 5 to 6 percent of wholesale price as commission - Sales are controlled by powerful intermediaries, i.e. agents, causing higher retail prices for consumers - No standard practices for handling, washing, sorting, grading, cleaning and icing of fish - An almost total lack of credit facilities for retail traders

Governing regulations

There are several institutions who have direct functions and responsibilities within the fisher and aquaculture sector (Table B2.4). The Egyptian Ministry of Agriculture and Land Reclamation (MOALR) maintains a division dedicated to the promotion and expansion of the Egyptian fish industry. The General Authority for Fish Resources Development (GAFRD) was established by Presidential Decree No 190/1983, falling under the Ministry of Agriculture, with a remit to draft legislation and regulations affecting fisheries. In this role GAFRD also manages fish farm licensing, aquaculture land use regulations, and supports extension and research services. GAFRD's stated goal is to enhance the development of aquaculture, increase production, and transfer knowledge to the fish farming community.

Table B2.4

Key institutions of relevance to the Egyptian aquaculture sector, and their role/influence (after Macfadyen *et al*., 2011)

Institution	Key function and responsibility related to aquaculture
Ministry of Agriculture and Land Reclamation (MOALR).	Overall management of the sector, setting policy, legislation (decrees, laws and regulations).
The General Authority for Fish Resource Development (GAFRD)	Licensing of all fish farms and hatcheries, leasing of land within 200 m of lakes, data collection, and extension/training, management of capture of wild fry, designation of suitable aquaculture areas, running of government hatcheries and feed mills.
Ministry of Water Resources and Irrigation (MWRI).	Approval for inlet, outlet and quantities of water used by fish farms, approval of fish farm establishment.
Ministry of Defence.	Approval of sites near the country border zones.
Central Laboratory for Aquaculture Research, National Institute of Oceanography and Fisheries (NIOF). Various universities under the Ministry of Higher Education WorldFish Center.	Fisheries and aquaculture research, education, training and extension.

The GAFRD cannot operate wholly independently, however, and a major constraint for the development of Egyptian desert aquaculture, in to a larger proportion of the overall aquaculture production, is that the MWRI currently prohibits the pumping of freshwater from groundwater systems, needed to establish more fish farms. Several workshops, conferences and meeting have been held to discuss this issue, but it has not been possible to achieve an official acceptance from the MWRI.

Law No 124/1983 on fishing, aquatic life and the regulation of fish farms is the main body of legislation on fisheries, and contains several provisions on aquaculture. The Act is administered by the GAFRD. The law, as it currently stands, allows agriculture drainage water as only the source of aquaculture activities. The MOALR is attempting to revise the current provisions, and submitted a new law for consideration by the Egyptian government in 2010 but is still under study.

Applied research, education and training

Kara *et al*. (2016) analysed and undertook a critical assessment of the developments in aquaculture research, education and training priorities in North Africa over the last twenty years, and evaluation of future requirements which has contributed to selection of actions needed for a long-term vision (to 2035). The authors assessed the strengths and weaknesses in development in the four countries (Morocco, Algeria, Tunisia and Egypt). The research on Egypt showed the country has many specialized research structures for aquaculture, including

10 universities offering training and research, 2 faculties, 2 institutes, and a central laboratory and benefits from WorldFish, an international non-profit organization dedicated to developing livelihoods using aquaculture and fisheries, based in Cairo. In all cases, however, the analysis showed a lack of coordination between aquaculture stakeholders and a relative weakness in technical training and skills and monitoring of producers (Kara *et al*., 2016). The Aquamed project (POEU, 2014) determined that Egypt is in a paradoxical situation, with the country produces significant quantities of aquaculture products and development of desert agri-aquaculture systems, but with an apparent low level of support for research and development in the field. The quantity of research publications on desert-based aquaculture and agri-aquaculture integrated systems remains low, compared to the number of researchers in the field of aquaculture within the country. The total number of fisheries and aquaculture researchers, doctoral and masters students is estimated at just 350 persons, most of whom work on aquaculture generally and not on desert-based aquaculture specifically, which equated to just 4.1 researchers/million inhabitants in 2012.

Only three scientific research programs are related to the desert agri-aquaculture integration system, two undertaken by the Academic of Science in South Sinai Peninsula (Dr Mohamed Essa, personal communication), and a third by Faculty of Agriculture in Alexandria University, and the total budget for all project is low, at around EGP 5 million.

Research and training on desert-based agri-aquaculture integration is desperately needed the sector continues to request support from government, non-governmental institutions and farmers. It is hoped this document highlights the urgency with which funding is needed and should help decision-makers and experts to identify the best solutions for the sector, which has a high potential in the region.

Conclusions

This document is a short synopsis on the current status of desert-based agriculture-aquaculture systems in Egypt. Overall, integrated agri-aquaculture in Egyptian desert systems seem to offer an efficient process for aquaculture and agriculture to co-exist within the same farm, offering several benefits:

- Development of fish farming and farming of agricultural products in desert environments offers the chance to increase production without further overcrowding the Nile valley and Delta.
- Fish farming and crop cultivation in desert systems offers increased opportunities to improve the livelihoods of the rural poor, either through development of small-scale private systems, or through employment at commercial organizations.
- Agri-aquaculture systems in the desert offer increased food production opportunities that can be sold locally to generate income and improve food security, sold nationally or internationally to reduce reliance on imports.
- Fish farms offer the opportunity to store water in arid environments; an important factor, since ordering water from the irrigation district can take time, and can be expensive.

- Integrating fish farming into agricultural systems can assist in reducing water use through irrigation of crops, using pressurized systems like drip or sprinkler systems to supply fish water effluent to crops such as vegetables, fruits and wheat; and because fish farm wastewater contains nutrient rich fish wastes it provides additional nutrients (fertilization) to the crops.
- Integrated agri-aquaculture systems increase food production and in combination reduce water required through re-use. After several years, existing agri-aquaculture farms have succeeded in further reducing water use (by up to 15 percent) and therefore improving water conservation for irrigation. Effluent fish water contains microalgae and other debris such as fecal material, that improves the structure of sandy soils when sprayed onto it, making it more compact, and this in turn is helping to decrease water seepage.
- Productivity and income for the farmers can be increased; by using the same volume of water to produce multiple crops; and increasing income generated by producing more and varied products such as fish, plants and animal products, and for biogas generation that can be used locally, or on the farm to support energy requirements.
- New farming methods using aquaponic (fish production and soil-less plant growth) recirculating systems has the potential to drastically reduce the water resources required to produce fish and a range of lettuce, greens and herb varieties.
- There may be opportunities to generate tourism interest in the integrated systems. Extending the use of abandoned open-cut sand mines (see examples above) can benefit from fish production using extensive (non-feeding) methods. Open-cut sand mines naturally fill with slightly saline water and several have been developed for tourism/entertainment use. Fish can be grown in the lakes generated and harvested occasionally to provide additional food resources. Other open-cut sand mines can also by filled using waste water from desalination plants, as the source of water. The water seepage into these areas also provide water for growing crops, that can also be tended and harvested as a food resource, and together provide an integrated agri-aquaculture-tourism system.

There are also, clearly, some challenges that need to be addressed, including

- providing increased opportunities for desert-based aquaculture development.
- improvement in legislative requirements for the management and control of production in integrated systems, where legislation and regulations does not specifically mention such systems.
- improvement in the available financial resources for research, extension activity and training in desert-based agri-aquaculture systems, to determine the best approaches, right species for the environment and to improve yields.
- overcome the weaknesses and threats identified in the SWOT analysis undertaken.

Recommendations

Fish in Egypt contributes to national food security and livelihoods, particularly for the rural poor where fish production, and development of agri-aquaculture systems provides a significant employment opportunity and a main source of cheap animal protein. The average yearly consumption of fish in Egypt has increased from 17 kg fish/capita in 2006 to 20 kg fish/capita in 2015. The increase in fish consumption has been achieved despite an increasing population, is driven by domestic production of fish using aquaculture techniques directed to meeting domestic supply needs, as well as some economically incentivized changes in consumer preferences among low-income consumers.

Desert-based aquaculture is still a small proportion (<0.2 percent) of total Egyptian aquaculture production. Expansion of such production, towards the carrying capacity mentioned previously (2.15 million tonnes), will require a large investment in time and resources. Desert agri-aquaculture integration systems can, nonetheless, contribute to the national social and economic development, including impact on poverty alleviation in mainly isolated desert areas. The use of reclaimed land for both plant and fish production can be a component of improvement in the livelihood of poor rural households (e.g. income generation, employment and family nutrition).

Egyptian desert agri-aquaculture integration systems is a potential alternative to other food production activities where opportunities for agriculture, alone, are limited; remembering that fish do not consume water, they merely use it, fish farming is a clean production system and fish farming discharge water has value for agriculture.

The following recommendations are provided to assist in achieving the sustainable development of durable agri-aquaculture integrated systems in Egypt:

- Carry out environmental, social and economic assessments on the potential use of fresh and brackish groundwater for desert-based agri-aquaculture integrated production systems.
- Estimate the water requirements and salinity tolerance of common Egyptian plant, aquatic animals and livestock production (fish, crustaceans, cloves/horticulture/fruits, animal production) to reflect the quantity and quality of water available.
- Encourage the setting up of biogas unit within the agri-aquaculture integrated system to provide additional energy resources (such as heating and cooking).
- Encourage the use of recirculating aquaculture systems (RAS) in feasible desert aquaculture projects, as a means to reduce water requirements.
- Conduct a review and evaluate specific research projects that have studied the integration of aquaculture with crop irrigation and animal production to see what lessons can be learned.
- Evaluate and develop aquaculture best management practices for desert aquaculture systems, using the standard practices for culture, handling, washing, sorting, grading, cleaning and icing of fish produced from desert farms.
- Evaluate and develop best management practices for integrated systems producing fish, crops and livestock to ascertain the most efficient and cost-efficient methods available.
- Define approved veterinary drugs for treatment of fish diseases, based on the World Organization for Animal Health (OIE).
- Conduct research to identify useful but non-conventional crops that will tolerate the use of brackish water in desert environments.
- Study the characteristics of water and effluent use in integrated aquaculture in other

countries that may provide opportunities for additional development and best practices.

- Establish pilot projects that integrate small-scale intensive fish farming with agriculture and demonstrate the economic and water conservation opportunities of such activities. Focusing on experiences of Bedouins in the Central Sinai Peninsula Area may be beneficial.
- Examine the opportunities for cost-effective aquaponic technological solutions, with reasonable product prices; considering consumption of water, electricity requirements and fertilizers in the aquaponic system compared against more traditional soil-based agriculture.
- Provide credit facilities for artisanal and commercial desert aquaculture, to be able to develop small, medium and large-scale systems.
- Develop appropriate regulations for access to water and water use, through an inter-ministerial task force.
- Improve management and control in the value chain.
- Provide institutional and organizational support, government support, extension services, and more research and knowledge in fish marketing. In addition, the establishment of modern wholesale markets in large urban areas, and establishment of well-functioning assembly markets at important fish landing sites may help sustainable fish marketing systems in Egypt.

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Appendix B.3: Oman case study

Dr Fatma Rashid Al-Kiyumi, **Dr Saif Ali Al-Khamisi**, **Dawood Suleiman Al-Yahyai**, **Ishaq Omar Al-Jabri**, **Zahir Saif AlSalmani**, **Halima Rashed Al-Azari**, **Waleed Salim Al-Abri**, **Ahmed Yousuf Al-Busaidi**. *FAO consultants, Ministry of Agriculture and Fisheries, Oman*

Summary

Aquaculture is a promising industry for Oman that can contribute to increased food security and overcome issues of water use in desert and arid environments present in Oman. The Ministry of Agriculture and Fisheries (MAF) have conducted many initiatives to develop it in sustainable manner. This includes developing integrated aquaculture and aquaponic sectors. The real development started in 2012 with a development project conducted by MAF and funded by Agriculture & Fisheries Development Fund (AFDF). In this project, ten local farmers where supported financially and technically to establish freshwater tilapia integrated farms. In 2016, MAF conducted another project on aquaponics, which was also funded by AFDF. This project is still active and ten local farmers are supported to establish aquaponic units in their agriculture farms. The production of tilapia increased from 3 tonnes in 2013 to 70 tonnes in 2017 and currently there are 18 integrated fish farms distributed in many Wilyates of Oman.

There are many scientific and development researches conducted by MAF and Sultan Qaboos University (SQU) on aquaponics and integrated aquaculture and have contributed to the development of these sectors. These researches have also provided valuable information on different aspects of these types of aquaculture including biological, technical and economic components. MAF in its plans for development of these sectors has cooperation with many stakeholders such as the private sector, farmers, farmers associations, academic institutions and other governmental authorities. Three success stories are included in this review to show how integrated agri-aquaculture systems can be developed in Oman.

Integrated agri-aquaculture and aquaponic sectors do face many obstacles in Oman, however, such as lack of technical knowledge among farmers, limited availability of high skilled technician, having no fish feed factory and limited availability of technical equipment. All these obstacles were addressed by MAF and there are plans presented to overcome these issues that will lead to more full development of aquaponics and agri-aquaculture systems in Oman’s arid desert environment.

Background, characteristics and resources of the sector

History and general overview

Aquaculture is the fastest growing food-production sector worldwide, and has seen a sustained annual growth rate of 8.1 percent per annum between 1970 and 2012. As the population grows, there is an increasing demand for fish as a source of healthy animal protein, and with the stagnation in supply from fisheries globally, aquaculture becomes vital source of fish supply. The Food and Agriculture Organization (FAO) reported that aquaculture production worldwide was over 74 million tonnes in 2014 (FAO, 2016). Globally, aquaculture accounts for about 50 percent of fish supply for human consumption but is expected to increase to 62 percent by 2030 (FAO, 2016), making it a very important form of food production. Oman is, however, a small producer, and only produced 282 tonnes from aquaculture in 2014 (MAF, 2015).

To promote economically viable and sustainable aquaculture, the use of aquaponic farming systems has great potential to add to national food security and should become a commercially successful production system in Oman in the future. Aquaponics presents an ideal investment opportunity for new small and medium-sized enterprises (SMEs) in Oman where site requirements, establishment and operating costs are low. A new business can be established with a small number of modular units, which can be expanded upon as the investor gains experience and additional financial resources and establishes new sales outlets for their products (Goddard, Al-Oufi, and Opara, 2010).

Water is the main element to achieve social and economic progress in agri-aquaculture systems and is the foundation of success in development of the sector. Aquaponics traditionally uses less water than other methods of production. First introduced in 2010, its use allows the country to maintain and utilize water in a sustainable manner in Oman. The Sultanate of Oman is described as having an unstable water availability, suffering from water scarcity, because of its location within an arid region. There are two sources of water in the Sultanate of Oman; traditional resources depend on the rains (rain-water) estimated at 15.8 billion m^3/year and non-conventional resources include seawater desalination and use of treated wastewater. The annual average rainfall is 100 mm, except in mountain areas such as Jabal Akhdar and Jabal Shams in the Dakhilya region, which has a variable rainfall up to 300 mm per year.

Despite limited water availability for agri-aquaculture, the Sultanate adapted scientific methodologies and developed its vision and national strategies based on these along with a five-year plan for agriculture sector sustainability with input from all the concerned authorities including the Ministry of Agriculture and Fisheries, Ministry of Regional Municipalities and Water Resources, the General Authority for Electricity and Water and other concerned authorities in order to achieve the overall vision.

Aquaculture in Oman is in its early stages. The Ministry of Agriculture & Fisheries (MAF) is the main governmental authority responsible for aquaculture in Oman. Many efforts have been conducted by MAF to develop aquaculture in a sustainable manner. In 2006, MAF established an Aquaculture Centre to carry out scientific research that provides the basis for the commercial growth of this sector. Suitable sites for aquaculture have been also allocated for investments. To ensure the sustainability of the sector, MAF produced Best Aquaculture Practices (BAP) guidelines to be used by investors considering development. There are many governmental authorities involved in the aquaculture sector and the BAP guidelines also the authorities easily follow the process of applications in a uniform manner. MAF also works with international organizations to develop aquaculture in Oman in sustainable manner, and to date includes cooperation with FAO on several studies including development of a Strategy for Aquaculture Development and safety and quality of Aquaculture Products.

Fish culture systems, distribution and characteristics

At December 2017, there were 18 agriculture integrated tilapia production farms in the Sultanate, which are distributed in different Wilyats (i.e. administrative regions), including Barka, Masnah, Sohar, Shinas, Badbed, Al Mudeibi, Ibra and Nakhl (Table B3.1; Figure B3.1). Production from these farms has increased from 5 tonnes in 2014 to 20 tonnes in 2015 and reached 30 tonnes in 2016 (MAF, 2016). There is also one farm producing local shrimp (*Penaeus indicus*) in the region of Bentot in the Wilyat of Mahut, which has an average production of 70 tonnes in 2016, all of which was sold in local markets. In September 2017, a marine cage farm producing European seabream (*Sparus aurata*) was established in the Wilyat of Quriyat (Muscat Governorate) with an expected production of 3 000 tonnes.

Table B3.1

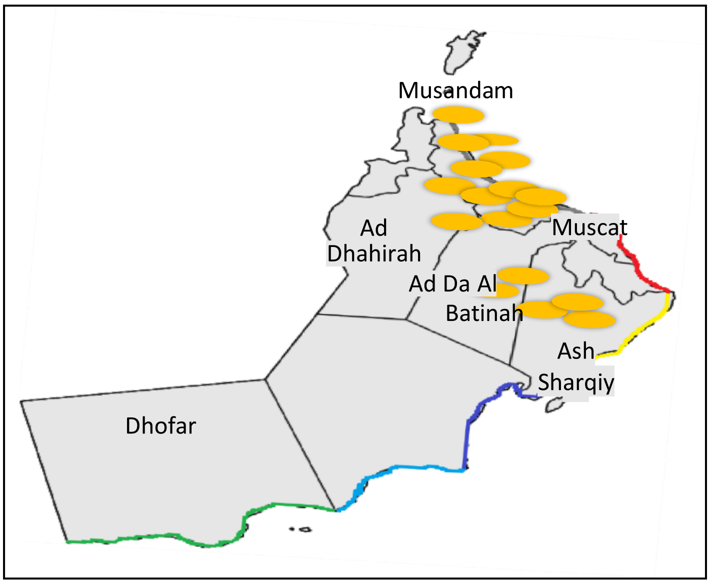
Number of integrated tilapia farms in each Wilyat within the Sultanate of Oman in 2017

Wilyat	**No. of farms**
Shinas	1
Sohar	2
Al-Masinah	3
Barka	5
Nakhal	1
Bidbid	1
Ibra	1
Al-Mudhaibi	2
Manah (Hatchery)	1
Smail	1
Total	**18**

Cultured Species

In Oman, the main cultured species in integrated agri-aquaculture is Nile tilapia (*Oreochromis niloticus*). This species was introduced in the early 1980s by the Ministry of Health as a biological treatment against mosquitoes (Personnel communication). It was placed in natural freshwater bodies (wadis) and has since spread over Oman through these wadis. For aquaculture purpose, this species was selected for its good growth, high tolerance to natural environmental fluctuations, and due to its high acceptance from customers in Oman, especially by foreign nationals present in the Sultanate. A good broodstock strain was imported from Thailand for breeding by the tilapia hatchery in Manah.

Figure B3.1
Distribution of Integrated aquaculture farms in Oman (Directorate of Aquaculture Development data)



Integrated culture practices

Hydroponics (Soil-less culture)

Hydroponics is the technique of growing plants in soil-less conditions, with their roots immersed in a nutrient solution. Terrestrial plants may be grown with their roots in the mineral nutrient solution only or in an inert medium, such as perlite, gravel, or mineral wool. This system helps to minimize the challenges of climate change and helps in production system management for efficient utilization of natural resources and mitigating malnutrition. Aeroponics is another technique, more or less similar to hydroponics with only difference that under aeroponics plants are grown with fine drops (a mist or aerosol) of nutrient solution, also known as the liquid hydroponics method. Plants grown in solution culture have their roots suspended directly in a nutrient solution. It can further be classified into circulating methods (closed system)/ continuous flow solution culture, using: (i) nutrient film technique (NFT); and and (ii) deep flow technique.

There are many advantages of growing plants under soil-less conditions, over soil-based culture. These gardens produce the healthiest crops with high yields and are consistently reliable; gardening is clean and easy, requiring very little effort following the initial set-up. Here nutrients are fed directly to the roots, and plants grow faster with less water and smaller roots, meaning plants may be grown closer together. It requires only one-sixth of the overall space and one-twenty of total water needed, growing plants under soil-less culture in comparison to soil-based culture. There is also no chance of soil-borne insect pests, disease attack or weed infestation. Overall soil-less culture provides efficient nutrient regulation, higher density planting, leading to an increased yield per acre along with better quality of produce. It is also effective for the regions of the World which have a scarcity of arable or fertile land for agriculture and where water is in short-supply such as in arid desert environments. The value of this technology includes reducing irrigation as water is recycled within a closed system of green houses, and a cost saving from reducing the use of chemical fertilizers, with a boost in the level of production capacity and excellent quality control. According to an agriculture census in Oman, conducted in 2013, the number of greenhouses with a soil-less system of production is 293.

Although it has many advantages, hydroponics has some limitations. Application on a commercial scale requires a high degree of technical knowledge and high initial investment, though returns are also high. Considering the high cost, the soil-less culture methods are limited to production of high value crops. Great care is required with respect to plant health control. Finally, higher energy inputs are necessary to run the system.

Aquaponic systems

In aquaponics, plants cultured hydroponically (without soil, on neutral media) absorb nutrients which are excreted directly by fish which have been integrated into the hydroponic system or dissolved wastes generated by the microbial breakdown of organic fish and faecal particulate wastes. Fish feed, faecal material and dissolved wastes produced by the fish provides most of the nutrients required for plant growth (Box B3.1). As the aquaculture effluent flows through the hydroponic unit, fish waste metabolites are removed by nitrification and direct uptake by the plants, thereby also acting to treat the water (nutrient removal), which flows back to the fish-rearing component for re-use. In aquaponics fish are grown in tanks, but aquaponics has several advantages over conventional recirculating aquaculture systems (RAS). It takes advantage of natural biofiltration and reduces the use and costs of inorganic nutrient solutions. In aquaponics, some supplementation of the macronutrients, particularly calcium and potassium, and the micronutrient iron, is generally required, however (Rakocy *et al*., 2004). The recirculating systems are designed to raise large quantities of fish in relatively small volumes of water, which is recirculated after treating the water (through hydroponics) to remove waste products. As water is recycled, beneficial nutrients and organic materials accumulate. These are then channelled into secondary crops in an integrated system. Plants grow rapidly in the dissolved nutrients that are excreted.

Box B3.1

Benefits linked to aquaponics.

There are a number of benefits linked to aquaponics. These include:

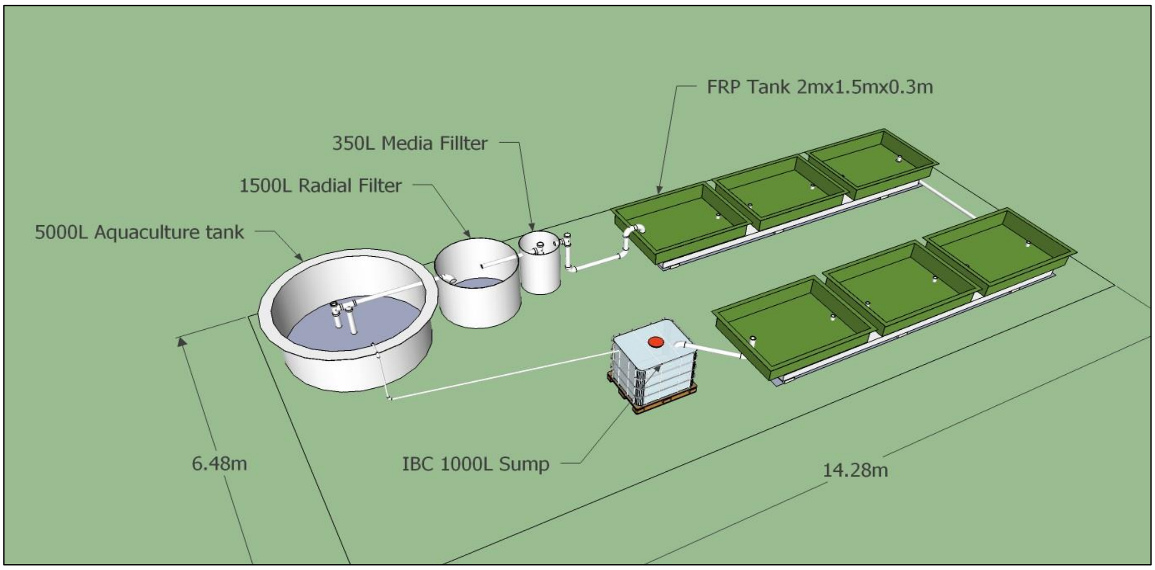
- Food access and food security benefits.
- Environmental benefits.
- Community development benefits, including employment.
- Reduced water requirement for intensive fish and plant production.
- The daily supply of feed to the fish supplies a steady flow of nutrients, which are recovered, after treatment, from the fish tank effluent and used to irrigate crops.
- Shared infrastructure and operating costs.
- Reduced land requirement.

New techniques, to more closely integrate fish and leafy crop production, is being evaluated in Oman, using a recirculating water system for fish production combined with hydroponic (soil-less) plant production. This gives potential in Oman to increase productivity of both fish and crops, whilst utilizing less water and lead to enhancement in profitability for farmers. The proposed techniques are well suited to an arid, dry environment, where aspects of water use, and food security are critical. The project has been running since 2017, funded by AFDF. Through this project, MAF is financially and technically supporting ten local farmers to establish their aquaponic farms. This project will provide the necessary data on which a cost-benefit analysis will be undertaken for integration of intensive production of fish and leafy vegetables in an aquaponics system. Aspects of food safety will also be examined through bacterial examination of the plants.

In Oman, small-scale fresh and brackish water fish culture has been developed extensively since its introduced in 2003 (Goddard, Al-Oufi and Opara, 2005). A national hatchery and extension programme for tilapia is under development by MAF. Past recommendations made from this activity have been adopted into integrated agri-aquaculture production, in this case using nutrient-enriched effluent from fish tanks to irrigate field crops.

Aquaponic systems require considerable capital investment, moderate energy inputs and skilled management. Both the fish and hydroponic vegetable production must be operated continuously, at near maximum production capacity, to allow sufficient recovery of capital and operating costs. Species should be selected with short production cycles and high value, which therefore suits tilapia production as the preferred species of fish grown. In tropical regions, tilapia is the most commonly grown fish, and in integrated systems is grown in combination with lettuce or herbs (such as basil and coriander). The current research would extend our knowledge of aquaponics in a dry, arid climate and provide further necessary information for commercial application. As part of the project, it is proposed that the existing experimental aquaponics unit at Al-Rumais (Figure B3.2) be modified and expanded to accommodate the project activity. This small Aquaponics unit in our Research Center, consist of one fish tank, six growth tanks, one biofilter, one dynamic filter and a sump tank.

Figure B3.2
Current layout of Al-Rumais aquaponic research unit



Integrated Agri-aquaculture systems in Oman

The first national project to develop freshwater and saline water culture of Nile tilapia in rural farms started in January 2012 and ran for two years. Undertaken by the Aquaculture Centre the project was funded by the AFDF. The project aimed to develop and raise the efficiency of aquaculture farms in various rural regions in Oman by providing all the services and facilities necessary for farmers, develop their potential and raise their competence to work in the field of aquaculture.

Sector performance

Production

As stated above, the aquaponic and integrated aquaculture sectors in Oman are still in their infancy and their contribution to the GDP is currently negligible. Their performance in term of investor applications and number of farms established, however, are increasing from one year to another. The production from integrated aquaculture has increased during the last seven years (Table B3.2). This increase is due to the augmentation of a number of farms and the continued interest from investors to establish integrated farms. The main starting point for development was in 2013 with the funded development project from AFDF. MAF supported this project financially and technically at ten local integrated farms in different Wilyates in Oman, as outlined previously. The production of tilapia in 2013 was three tonnes. In the following years, the number of farms increased from to 18 farms in 2017, and due to this increase, the production also increased and was approximately 70 tonnes in 2017.

There are also many applications within MAF from the private sector and people to establish integrated and aquaponic farms. These applications are in different stages of approval.

Table B3.2

Production of fish and shrimp through aquaculture in tonnes and total value in Omani Rial (OR) between 2011 and 2017 in Oman. (NA = not available).

Species	**Year**						
	2011	2012	2013	2014	2015	2016	2017
Nile tilapia (*Oreochromis niloticus*)	1	3	3	5	20	33	70
Indian white shrimp (*Penaeus indicus*)	157	165	350	277	150	70	NA
Total (O.R 1000)	363	401	775	701	450	225	NA

Human Resources

The employment level in this aquaculture sub-sector is relatively small at present, but is still progressively growing. Currently, with the very few number of registered integrated farm (= 18), it is nonetheless difficult to elaborate on the effect of this sector on the job opportunities provided.

Market

The market for produce from integrated and aquaponic farms in Oman is still small, limited by the small number of these farms in Oman. Currently, all the production from these farms consist of Nile tilapia, which is marketed locally in Oman through major hypermarkets. Some production is distributed locally around the farms area. MAF takes the initiative to support the tilapia farmers in marketing their production, through coordinated activity with Ministry of Commerce and Industry (MOCI). Nile tilapia as a national product and therefore included into the national program of support to national products developed by MOCI. In this program, all big hypermarkets are participating and they buy and support local products including fisheries products. The price of Omani produced tilapia reached 1.990 OR/kg (fresh and frozen) (Figure B3.3) and has good acceptance by customers due to perceived freshness and quality. The marketable size of tilapia is between 250-350g whole wet weight.

Figure B3.3
Local produced tilapia available at a hypermarket

©FAO/ Sadek, S.

Contribution to the economy

This desert/arid land agri-aquaculture is at early stage of development in Oman. Therefore, its contribution to the economy food in term of security, employment, poverty alleviation is still low and cannot be compared to the other economic sectors, although it is growing slowly. The production in 2017 was 70 tonnes worth 175 thousand OR. This is a very low value compared with other sectors.

Promotion and management

Institutional Frameworks

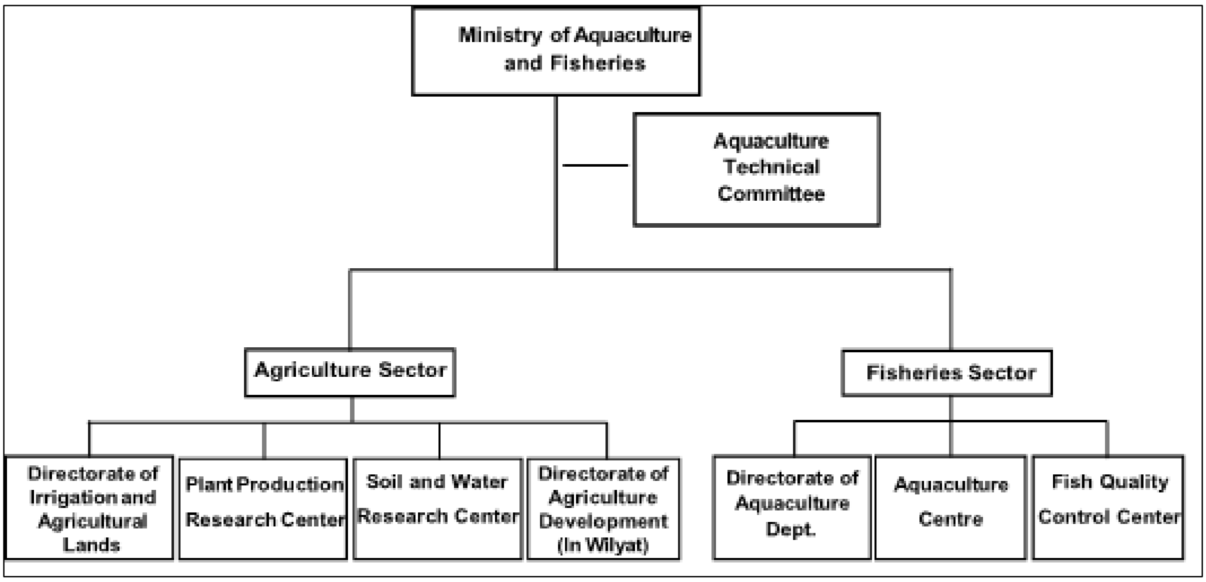
The agri-aquaculture sector is still in infancy in Oman. Having a single governmental organization responsible for management and development of any sector is a key criteria for the success of that sector. The Government of Oman, realizing this, appointed one governmental body to be responsible for all agriculture and aquaculture issues. MAF is the competent authority in Oman for this sector, although there are other Government stakeholders who work closely with MAF. There are different departments within MAF who are responsible and dealing with agriculture-aquaculture sectors. The Ministry of Agriculture and Fisheries has two subsectors, the fisheries sector and agriculture & animal wealth sector. The departments responsible for integrated agriculture-aquaculture and aquaponic issues in MAF are listed in Table B3.3, with an organizational chart shown in Figure B3.4.

Table B3.3
Departments related to integrated aquaculture and aquaponic in the Ministry of Agriculture and Fisheries (MAF)

Fisheries sector	Agriculture sector
Directorate of Aquaculture Department	Directorate of Irrigation and Agricultural Lands
Aquaculture Centre	Soil and Water Research Centre
Fish quality Control Centre	Plant Production Research Center
Aquaculture Technical Committee	Directorate of Agriculture Development in each Wilyat

Figure B3.4

Management of the agriculture-aquaculture sector



Fisheries sector

Directorate of Aquaculture Development is the main department responsible for aquaculture management and development. This department is responsible for receiving applications for any aquaculture or aquaponic projects. Monitoring and following up on the projects progress and ensuring its compatibility with approved best practices is also one of the important roles of this directorate. This monitoring is conducted in cooperation with other departments such as the Aquaculture Centre and Fish quality control Centre. Responsibilities are divided among four departments in this directorate: the One-Stop-Shop for Aquaculture; Development of Commercial Aquaculture; Development of Integrated aquaculture; and Aquaculture Monitoring.

One-Stop-Shop Department is responsible for receiving the applications from investors in relation to all aquaculture projects including integrated aquaculture and aquaponic projects; and with help of Department of Integrated Aquaculture, One-Stop-Shop ensures that the application is completed correctly and includes all the required documents in support of the application. If the application is complete, the Aquaculture Technical Committee evaluates it according to the requirements of the Aquaculture By-Law.

The Aquaculture Technical Committee, formulated under Ministerial Decision No. (102/2014) issued on 16/4/2014, is responsible for evaluating the applications related to integrated aquaculture and aquaponics projects and giving approval for these projects. This Committee, headed by Director General of Fisheries Resources Development, includes members from the Directorate of Aquaculture Development, Aquaculture Centre, Fish Quality Control Centre, Soil and Water Research Centre and Legal Department.

The Aquaculture Centre is responsible for conducting scientific and applied research in aquaculture, including integrated aquaculture and aquaponic. The research results are used to develop these sectors in a responsible manner. The Fish Quality Control Centre is also involved in aquaculture in relation to the quality elements of the cultured aquatic organisms and in ensuring that aquaculture projects comply with quality instructions and requirements, thus ensuring the safety of consumers for these products.

Agriculture sector

Aquaculture and aquaponic projects are integrated with agriculture, and some agriculture departments within MAF are therefore also responsible for management of these activities. The degree of involvement in integrated agriculture-aquaculture projects is different from one department to another.

The Directorate of Irrigation and Agricultural Lands is the main department responsible for managing the use of agricultural lands. This directorate is also responsible for introducing and disseminating new technologies in relation to sustainable and innovative use of water.

The Soil and Water Research Centre is but one of the research centres in the Directorate General of Agriculture and Livestock Research. This centre is responsible for conducting research on water requirements for different crops, soil survey and classification, water and soil salinity, irrigations methods and other activity related to agriculture, and use of water resources. This centre is directly involved in the scientific research on aquaponics and hydroponics, instigated by the Ministry of Agriculture and Fisheries, and this activity provides results, guidance and confidence to investors that wish to develop their own projects.

The Plant Production Research Centre is another research centre within the Directorate General of Agriculture & Livestock Research. This centre conducts research to ascertain and develop different crops and plants that are suited to conditions in Oman, and to determine the suitable conditions and best processes for planting these crops. Its researches and results are important for selecting suitable crops in aquaponic and hydroponic projects, for example.

In each Wilyat in Oman, there is Directorate of Agriculture development, which is responsible for all agriculture activities in that Wilyat. One of the responsibilities of this Directorate is to undertake approval of project proposal from farmers who want to install an aquaponic or integrated aquaculture system. In general, only the Directorates of Aquaculture Development and Agriculture Development (in each Wilyat) are responsible for approving aquaponic or integrated aquaculture projects; and other ministerial departments are involved indirectly through research, extension and management support.

Other stakeholders

Another important stakeholder is the Oman Farmers Association, which was established in 2005 under the name “Farmer Association for Al-Batinah Governorate” and formalized by Ministerial Decree No. 126/2009 on 26/10/2009. The association is based in Wilyat of Al-Suwaiq in North Al-Batinah Governorate. The main objectives of this association relate to its Primary governing law, which is to solve the problem and obstacles facing local farmers in North and South Al-Batinah Governorates and adopting new technology in farming. Objectives of this association include providing extension for farmers on best farming practices and safe use of pesticides. The association plays a vital role in the marketing of farmer products through development of wholesale contracts to customers inside and outside Oman, and export many products to Japan, Netherlands and Spain; such as beans, tomato and round pepper taking into consideration that these countries request very high-quality commodities. This quality requirement means the association has had success in developing the farming methods used by local farmers. Due to the success of this organization and to repeated applications from farmers in other Governorates, the name of this association has changed from Farmer association for Al-Batinah Governorate to the Oman Agriculture Association in December 2016. This change allows the association to open branches in different Governorates, which will work to help and support local farmers around Oman.

Currently there are 18 farms operating integrated agri-aquaculture and aquaponics farms. There are frequent meetings involving all farms and interaction with MAF to discuss farming issues and obstacles the farmers are facing. There are also periodic visits by specialists from MAF to farms to monitor the works and to provide extension activity to the farmers.

Governing regulations

The government recognized the importance of regulations and rules for sustainable management and development of aquaculture. Unregulated and uncontrolled aquaculture development would lead to many environmental, economic and social problems. All the rules and regulations for aquaculture are set into one framework that is transparent, enforceable and means the aquaculture sector can cope with other laws and regulations in the country and international laws.

The executive by-law for aquaculture and its quality control was issued in 2004 by Ministerial Decision No.36/20004 and amended in 2012 by Ministerial decision No.177/2012. This by-law contains 80 articles distributed in three parts and seven chapters. It covers different aspects of aquaculture such as licensing and requirements for aquaculture projects, quarantine procedures and quality issues. This by-law was amended in 2014 by the Ministerial Decision No. 102/2014, which added the formation of a technical committee for evaluation of aquaculture applications (MAF, 2014). According to this by-law, a company, group or individuals cannot start any aquaculture project without permission from the Ministry of Agriculture & Fisheries. This by-law also defined the composition and terms of reference for the Aquaculture Main Committee and Aquaculture Technical Committee. The aquaculture main committee is headed by MAF and has members from other relevant ministries including MAF, Ministry of Environment & Climate Affairs, Ministry of Housing, Ministry of Commerce & Industry, Ministry of Transport & Telecommunication and Ministry of Finance. The Aquaculture Technical Committee is headed by Director General of Fisheries Development and has members from different technical departments dealing with aquaculture within MAF. The Committee is responsible for evaluation of the applications for commercial aquaculture projects and presenting their recommendations to the general committee. The Committee has approval capability under the by-law for integrated aquaculture projects and aquaponics, reviewing applications and endorsing them by approval or rejection. This technical committee is also responsible for following up the approved aquaculture activities and reporting results to the general committee about the progress and activity for all aquaculture projects. The general committee is responsible for overall management and development of the sector.

Under the by-law, commercial and integrated aquaculture applications are maintained within MAF from the beginning until the final approval. For Integrated aquaculture, the investor applies to Directorate of Aquaculture Development using the relevant prescribed form noting the following:

1) The proposed site for the project and its area indicating the province / state / location coordinates.
2) A copy of the ownership of the agricultural land or the lease contract of the land allocated for the project.
3) Type of aquaculture species to be cultivated, source of fry and fingerling and quantity proposed.
4) The expected project starting date, duration and cost.
5) Data showing the source of water to be used in the project, its water quality and

nature, the quantity to be used and the way of discharging the waste water if the project is land-based.

6) Identify the aquaculture system that will be used.
7) A brief description of the project and how it will be managed.
8) A flow chart of the project components and production stages.
9) Any other data required, as determined by the competent authority.

The technical committee then evaluates the application and takes decision on it. If the committee approves the application, the investor will be given preliminary approval and the license will be given after construction of farm and meeting the requirements of the aquaculture by-law. The licensee shall commit not to harm the agricultural environment surrounding the aquaculture farm and to comply with the requirements and technical guidance issued regarding aquaculture farming. The by-law states some specific obligations for investors in integrated aquaculture. These include:

1) The integrated farming project must have sufficient sources of water, without causing damage to crops, as determined by the competent authority, in coordination with them.
2) The licensee shall respect water quality standards applied in the integrated farming system according to the quality standards specified by the competent authority.
3) The licensee shall use water discharged from farmed species ponds to irrigate cultivated areas and is prohibited to use it for any other purpose.

The other important by-law related to integrated aquaculture and aquaponic projects is the By-law on controlling the uses of agriculture lands. Ministerial Decision No. 272/2014, issued this By-law in 2014, and was amended by Ministerial Decision No. (10/2017) which was issued in January 2017. This by-law controls issues around changing of use of land, rent, and establishing houses or service buildings on agriculture lands. According to this by-law, any integrated aquaculture or aquaponic projects should get approval from Directorate of Agriculture Development in the Wilyat (Province) where it is located. The Integrated aquaculture or aquaponic projects area should not be more than 10 percent of the total area of the farm and it should be built on the vacant areas or the less fertile area inside the farm.

Applied research, education and training

There are many stakeholders in integrated aquaculture or aquaponic business such as farmers, farmers associations, governmental institutes, academic and research institutions. There is a specialized marine department at the College of Agriculture & Marine Sciences at Sultan Qaboos University. This Fisheries and Marine Sciences Department provides Bachelors in Marine Sciences and courses include aquaculture and fish nutrition. This department also sometimes conducts training courses for interested people in different aspects of fisheries. The department was established in 1986 and has conducted many researches and experiments on fish culture using freshwater, brackish water and treated sewage water.

At the Al-Sharqiuah University (Private University) there is a department specializing in marine and fisheries sciences. This Department offers Bachelor courses related to all fields of Marine Science, Fisheries and Aquaculture, viz. Biology, Physiology, Pathology and Behaviour of Fish, Capture Fisheries, Culture Fisheries, Fishing Gear and Craft Technology, Fish curing & Processing and Fishery Economics & Management, among others. It has a staff who are qualified in various fields, covering national and international experience in their respective fields of specialization and it strives towards creating an environment that enables teaching and research to attain high levels of excellence and in which its members can achieve their full potential, catering to the community and for nationally important development programmes. This department opened in 2014 and currently there have been no graduates from it.

Another institute specialized on aquaculture is Fishermen Training Institute, belonging to Ministry of Manpower. This vocational training institute gives vocational diplomas on aquaculture, which is equivalent to a technical diploma. Graduates from secondary school (Grade 12) can enrol in this institute and would study for 3 years. The first year covers basic educational requirements in subjects such as math, information technology (IT) and English. In the second and third years, students can enter aquaculture specialist courses such aquaculture techniques, fish biology and physiology, fish nutrition, water quality, marine fish farming, fish health, fish farm management, hatchery techniques and ornamental fish culture. This institute also provides shorter training courses for society, on ornamental fish culture and general aquaculture.

Several studies have been conducted by researcher and specialists at MAF and SQU related to the cost benefit analysis for the three-production system mentioned previously.

Economic considerations

Hydroponics Soil-less culture

The variable cost of components required to grow 5 800 kg of cucumber for one season in a cooled green house of using a soil-less culture system is 486.66 OR, against a revenue of 1 160 OR, thus generating a net profit of 673.34 OR, as broken down in Table B3.4. Infrastructure costs are excluded.

Table B3.4

Costs and profit from producing 5 800 kg of cucumber in a cooled greenhouse for one season. OR=Omani Rial).

Input	Quantity (units as defined)	Cost (OR)
Seed	1 000	50.00
Calcium	38 kg	12.16
NPK 12:12:36	48 kg	36.50
Magnesium	5 kg	2.20
Iron chelate	0.4	2.00
Nitric acid	4L	4.00
Fungicides	1L	10.00
Insecticides	1L	10.00
Irrigated water	30 m^3	37.50
Cooling pad water	one	283.30
Electricity	-	33.00
Insect trap	10 ps	6.00
Variable Cost	-	486.66
Revenue	5 800 kg	1 160.00
Net profit	-	673.34

Integrated agri-aquaculture system

The costs estimated for a tilapia integrated farm is based on a research study of indicators prepared by MAF to support small-integrated tilapia farmers in their process of establishing tilapia farms. It is based on farm with an area of 1 200 m^2 and yearly production of 36 tonnes. Table B3.5 shows the fixed costs, including purchase of tanks, pipes, water pumps and generator among other required items; fixed costs estimated at 42 000 OR. Each of the components in the fish farm has a specific shelf life and therefore depreciates at a specific rate per year, also shown in Table B3.5.

Table B3.5
Fixed costs for tilapia integrated farm.

Item	Cost (OR)	Shelf life (years)	Depreciation (OR/year)
Fish tanks	11 000	15	733
Plumping works	600	15	40
Shade	4 900	15	327
Water pump (2)	2 000	7	286
Air pump (2)	2 000	10	200
Air pipes and stones	550	5	110
Water heater	1 500	10	150
Sedimentation tanks and filters	14 000	15	667
Plastic boxes for water filtration	2 600	10	200
Electrical Generator	2 850	10	285
Total fixed costs	42 000		
Depreciation	3 185		

The total variable costs for this size of tilapia unit is 25 435 OR, consisting of fish feed, labour, electricity and other incidental costs, as shown in Table B3.6. The total investment cost in fixed and variable costs is therefore 67 435 OR.

Table B3.6
Variable costs of tilapia integrated farm.

Item	Quantity	Total (O.R)
Fish fingerlings (Male 100 percent)	120 000	6 000
Fish feed (FCR 1.5:1)	54 ton	15 400
Labour	-	2 200
Electricity	-	235
Other costs	-	1 600
Total variable costs	-	25 435

The tilapia unit proposed will produce 36 tonnes per year with revenue of 32 400 OR per annum. Table B3.7 shows the yearly revenue which shows an income of 6 965 OR per year, a return on investment of 20 percent, which gives a payback period of five years.

Table B3.7
Yearly Revenue of proposed tilapia farm.

Unit	Value
Production 350g/fish	36 000 kg
Revenues (Production in kg * price per kilo @ 0.90 OR/kg)	32 400 OR
Net income	6 965 OR
Rate Parity	0.6 OR
Annual return rates on assets	20 percent
Payback Period	5 years

This assumptions for this tilapia farm are based on the following farm management:

1) Buying about 120 000 fingerlings, weighing 1 g/fingerling), placed into nursery tanks until a whole wet weight of 250-350 g/fish is achieved.
2) Grow out takes place in tanks at a stocking density of 16.6 kg/m3.
3) The culture period from fingerling to 350 g/fish is 260 days.
4) Water is exchanged at a rate of 20-30 percent weekly and replaced waste water is used for plant irrigation purposes.
5) Mortality rate of the unit is 15 percent per culture cycle.
6) Production per cycle is 3.6 ton.
7) There are ten harvests per year across the farm.

Aquaponic systems

The calculations in this section were completed jointly by MAF and SQU, based on an aquaponic integrated farm producing tilapia with lettuce. The total Initial Capital and Annual Operating cost of the closed system is estimated at 9 049 OR in the first year, as showed in Table B3.8. Lettuce production was calculated on a monthly cycle with 80 bunches/bed/cycle produced and valued at 0.7 OR/bunch. The total fish production is calculated on a 4-month cycle and producing 60 kg per cycle valued at one OR/kg. The greenhouse had the capacity to hold three production units, each comprising one fish tank (5 000 L) and six grow beds. Total revenue (at full production) was calculated as 4 212 OR.

Starting from the second year, both annual operating costs and annual revenue would be adjusted with 3 percent inflation rate based on the type of inputs used and output produced. A 10 percent discount rate would be used based on the lending rate (about 5 percent, 2014 estimates) and average inflation rates (approximately 4.34 percent) (Goddard *et al*., 2015).

Use of aquaponics has good potential to add to national food security and should become a future commercial development in Oman to promote economically viable desert/arid land agri-aquaculture systems. Aquaponics presents an ideal investment opportunity for new SMEs in Oman. A new business can be established with a small number of modular units, which can then be further expanded as the investor gains experience and establishes new sales outlets for their products (Goddard, Al-Busaidi and Al-Kendi, 2010).

Table B3.8
Initial capital and operating Costs for an integrated aquaponics farm producing tilapia and lettuce. See text for assumptions.

Item	Cost (O.R)	% of total
Investment costs		
Greenhouse, including land preparation and installation	4 500	49.7
Fish tank (5 000 l)	300	3.3
Grow beds	1 200	13.3
Pipework	42	0.5
Air pump	276	3.0
Submersible water pump	40	0.4
Dissolved oxygen meter	327	3.6
pH meter	153	1.7
Nets	40	0.4
Styrofoam floatation	72	0.8
Sub-total (Investment costs)	6 950	76.8
Operating costs		
Total electricity consumption	69	0.8
Total water consumption	455	5.0
Tilapia fingerlings	15	0.2
Tilapia feed	44	0.5
Lettuce seeds	360	4.0
Coir planting pots	432	4.8
Ferrous salt	5	0.1
Labour and maintenance cost	720	0.8
Subtotal (Operating costs)	2 099	23.2
Total cost of the project in first year	9 049	100

Trends, Issues and development

There is general trend presently in schools and colleges to develop Students Company's in different sectors, including the aquaponic sector. There is currently a joint program between MAF and MOE to develop a training program for the students from levels 8-12 in different agriculture-aquaculture activities. Selected students will be trained in different aspects of aquaponics, for example, and those who are interested to continue and establish their own system after school/college will be funded and supported by the relevant governmental authorities and private sectors to do this.

As with many countries, Oman is facing several serious issues related to climate change, population rise, water scarcity and soil degradation; and in this context food security is also a significant issue. Aquaponics is a combination of hydroponics and aquaculture systems and as a closed loop system could alleviate some of the pressure on these issues, by improving food production whilst also limited water use and soil use.

In Oman, the industry of aquaculture and aquaponics faces a series of challenges, such as limited access to markets due to underdeveloped infrastructure; poor governance and a weak regulatory framework; lack of training and expertise; and limited access to financial aid for smallholder farmers, which prevents them from generating an adequate income through these systems. Challenges faced by aquaponics sector are described in detail in the following sub-sections.

Environmental challenges

The primary environmental challenge is water scarcity. The effects of drought can be clearly seen in the Middle East. In many regions, changing levels and patterns of precipitation, melting snow and ice and retreating glaciers are altering hydrological systems, affecting water resources and quality. Climate change is projected to reduce renewable surface water and groundwater resources significantly in most dry sub-tropical regions. Each degree of warming is expected to decrease renewable water resources by at least 20 percent for an additional 7 percent of the global population (Jiménez Cisneros *et.al*., 2014).

Water is vital for an aquaponic system. It is the medium through which plants receive their nutrients and the fish receive their oxygen. It is very significant to understand basic water chemistry and water quality to properly manage aquaponic systems. The plants, fish, and bacteria in aquaponics systems entail achieving optimum water temperature, pH and dissolved oxygen for maximum growth and health balance (Somerville *et al*., 2014).

Technical Challenges

pH Stabilization

Most plants need a pH value between 6 and 6.5 to enhance the uptake of nutrients. The fish species tilapia (*Oreochromis*) is known to be disease-resistant and tolerant to large fluctuations in pH value with a tolerance between pH 3.7 and 11 but achieves best growth performance between pH 7.0 and 9.0 (Ross, 2000). The pH value should be consistent to prevent the ammonia accumulation in the system. There is therefore an imbalance between the plant requirement and the optimum fish requirement on pH that needs to be overcome.

Nutrient Balance

Fish feed is the main nutrient input. It can be divided into assimilated feed, uneaten feed, and soluble and solid fish excreta (Neto and Ostrensky, 2015). Soluble excreta are mainly ammonia and are the most available mineral until it is successively transformed into nitrite and nitrate by nitrifying bacteria (Chen, Ling and Blancheton, 2006). Both uneaten feed and solid faces need to be solubilized from organic material to ionic mineral forms that are easily assimilated by plants. Minerals have different solubilization rates and do not accumulate equally (Seawright, Stickney, and Walker, 1998), which influences their concentrations in the water.

Phosphorous

Phosphorus (P) is a macronutrient, which is assimilated by plants in its ionic orthophosphate form. It is essential for both vegetative and flowering stages of plant growth. Sufficient phosphorus production will certainly be a major concern soon. Fish cannot convert phosphorus efficiently so is added in excess in fish feed and studies suggested that up to 65 percent of P could be wasted in form of aquaculture effluent sludge; recovery solutions should be developed to convert the solid form of phosphorus used in feed, into orthophosphate forms that can be used by plants, to achieve zero-discharge systems.

Pest and Disease Management

The challenge of pest and disease management is another aspect that needs further improvement (Vermeulen *et al*., 2013). A broader range of microflora than conventional hydroponic systems characterizes aquaponic systems, because the breeding of fish and biofiltration occurs in the same water loop. Conventional pesticides that are used in hydroponics cannot be used in aquaponics because of toxicity risk to the fish (Vermeulen & Kamstra, 2013) and aquaculture-hydroponic operations must be carefully managed to create optimum conditions that are disease-free for both fish and the plant rhizosphere. If there are disease outbreaks, these must be treated on fish welfare grounds, but profitability is unlikely because of the linked system. Root disease problems have been experienced when the nutrient solution used contains too much organic material, and thus this needs to be carefully controlled.

Socio-economic challenges

Fish feeding cost

High feed cost is a major economic challenge for Oman. It takes approximately 0.5 kg feed to produce 0.5 kg of farmed fish (feed conversion ratio = 1). In the Sultanate of Oman, most of fish feed is imported from a single producer in the Kingdom of Saudi Arabia and the price paid can be as high as 10 OR per 25 kg (= 400 Biaza per kilogram fish feed). Calculations suggested that the cost of plant nutrients in a head of lettuce is, conversely, very low, so the practical benefit of using more expensive fish waste as fertilizer for the plants will be a major challenge in system economics and profitability.

Marketing

Marketing is another socio-economic factor that needs to be developed. Statistics issued by the Directorate General of Marketing and Fish Investment indicated that the number of fish marketing outlets in the Sultanate's governorates reached 392 in 2016. According to a survey conducted by MAF in 2013, the combined capacity of all the Sultanate’s markets is just 1 500 tonnes of tilapia fish (Figure B3.5). Currently there is a program of subsidy for local production of tilapia, introduced by the Ministry of Commerce and Industry, which needs to include marketing and improvement in sales outlets.

The hypermarkets, hotels and restaurants are, nonetheless, promising outlet markets for tilapia fish, although farmers are facing difficulties to reach these outlets. Importantly, these markets are committed to purchase tilapia from local sources, although the farmers do have the choice to sell his products to any market.

An economic study done by MAF indicated that the cost of producing tilapia in Oman is about 0.6 OR per kg and the lowest selling price is about 0.9 OR. The price of tilapia at Omani markets is estimated to be 2.5–3.0 OR per kilogram, so overall there is a good benefit.

Figure B3.5

The limited capacity for marketing tilapia fish in one of the Sultanate's markets. for local farmers in producing tilapia

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Success Stories

Following on from understanding the principles and constraints in the operation of desert-based aquaculture-aquaponic systems, and establishing why they would nonetheless offer good benefits to Oman, this section provides some success stories of projects undertaken in Oman for the development of agriculture and aquaculture in integrated systems to form a coherent system of food production

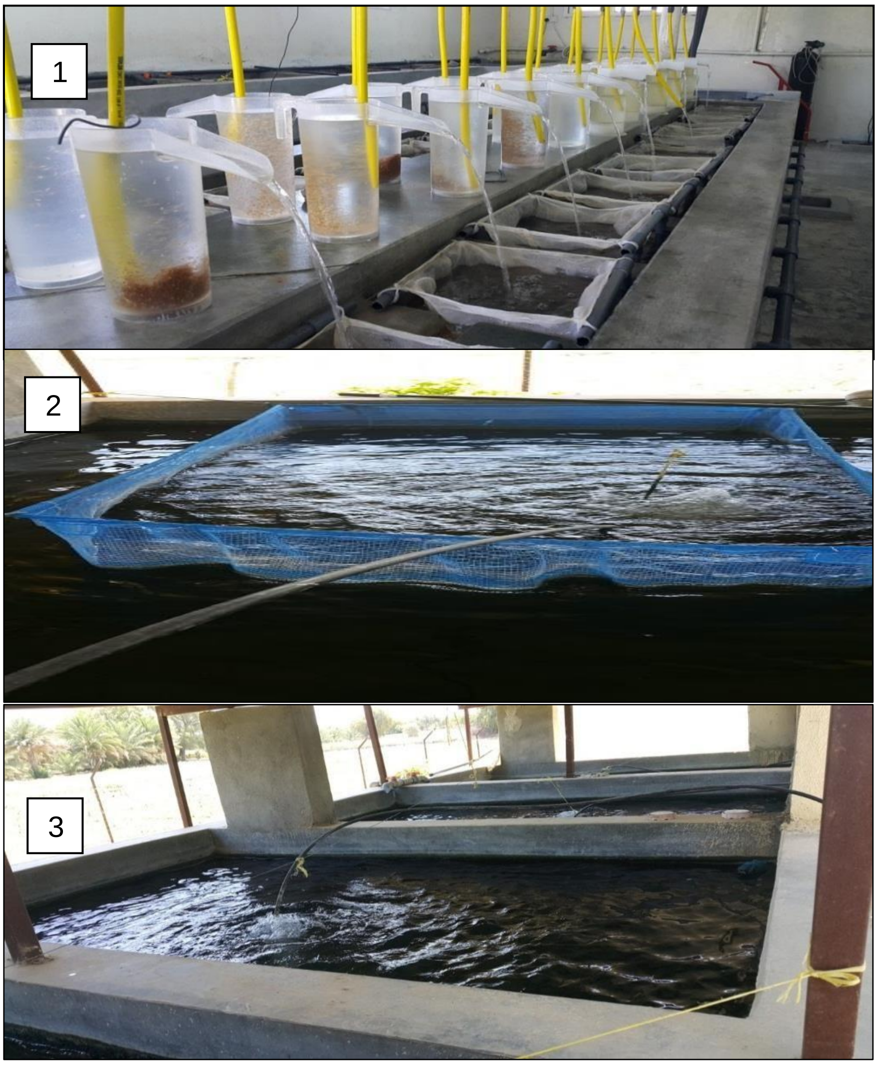
Story 1: Essa Al-Sultani

Essa Al-Sultani is a local young Omani who set up a tilapia hatchery in Wilyat of Manah (AL-Dakhalia Governorate). This young Omani Youth is from an agriculture region very far from the sea, set up his hatchery (Figure B3.6) from nothing. He first started to read about this issue and collect information from different sources to gain knowledge and information about hatchery techniques for tilapia. Then he travelled to different countries to see tilapia hatcheries in operation and to gain as much information as he could about the technology and equipment needed.

Essa Al-Sultani started his hatchery in 2010 with five concrete ponds, increased to 10 after one year. Currently, the hatchery has 31 different sizes of cement ponds. Initially, he tried growing six different types of fishes to determine which grew better in Omani conditions and selected two types for development, Nile tilapia (*Oreochromis niloticus*) and the variant, Red tilapia. The hatchery gained technical support from MAF at the with many visits undertaken by MAF specialists to the hatchery to help Essa build his hatchery business, which currently includes egg production, hatchery breeding tanks and broodstock rearing tanks (Figure B3.6).

Figure B3.6

Hatchery owned by Essa Al-Sultani in Wilyat of Manah (Al-Dakhalia Governorate) showing 1) Egg production unit, 2) breeding tank and 3) broodstock rearing tank



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Technical assistance was given on equipment installation, breeding techniques and fish rearing. Currently, this hatchery can produce 100 thousand fingerlings of tilapia per year and Essa has supplied fingerlings to all tilapia farms in Oman since 2013.

Story 2: Marwna AL Hooti

In Barka, in Al Batinah South Governorate, Marwan AL Hooti started his commercial farm in 2014. Marwan is a civil engineer who has undertaken many courses and training in aquaculture, both inside and outside of Oman. He started his project as a hobby, by raising and taking care of ornamental fish, which he then sold to interested people, which lead to him to increase production, and at the same time improve his pond design. After, he started developing a small production of tilapia, which can live in freshwater and saline water. In 2013, he started establishing further tilapia ponds at his farm and started growing tilapia purchased from Essa Al Sultani. His first harvest of tilapia was 1500 kg, which occurred in 2015. There were some challenges in working out the marketing of his tilapia for the first time; not knowing where to sell them and because people were not acquainted with the products from his company. Despite these challenges, he sold his tilapia in big super markets (Figure B3.7) and slowly people started to appreciate his produce. Marwan then developed his produce further through an integrate system and uses the same water to irrigate the crops like corn, some fruits and vegetables (Figure B3.7). Nowadays his production of tilapia is 2 000 kg/ year.

Figure B3.7

Marwan Al-Hooti's integrated agri-aquaculture farm in Barka (Al Batinah South Governorate), showing covered fish grower tanks (1 and 2), harvesting activity (3), first harvest for sale in hypermarket (4), marketing of fish products (5) and integrated crops grown with waste water from the fish farm (6)

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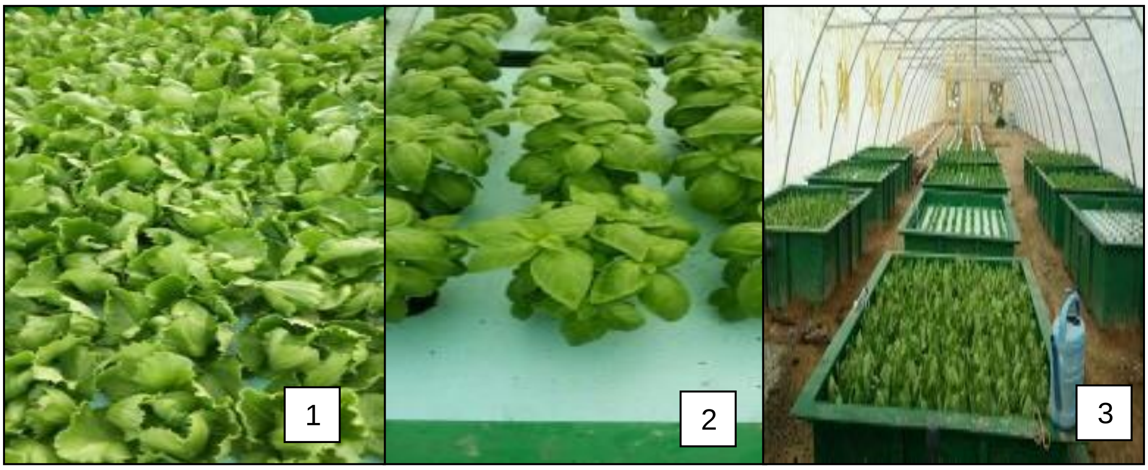
Story 3: Zayid Al-Siyabi

An aquaponics system in BidBid (Ad Dakhiliya Governorate), is one of the most successful aquaponic farms in Oman. It is owned by local Omani, a farmer, called Zayid Al-Siyabi. He started his farm before 2010 using soil-less hydroponic techniques to grow Sweet basil and Iceburg lettuce in cooled green houses. In late 2016, he gained a subsidy from the Ministry of Agriculture and Fisheries to adopt and aquaponic system in half of the green house, in which o place fish in tanks with crops grown above. Following initial success in phase one, he went on to complete the second half of greenhouse to grow his produce fully aquaponically (Figure B3.8).

The main factors that are helped the farmer to be successful with this aquaponics systems were ease of management of the unit, and availability of all nutrients required by the plants during the season, which enabled faster growth of agri-crops. The exception was iron, which is added weekly according to the crop requirements. One of the challenges the farmer has faced is fish disease, because the farmer is more familiar with agriculture, but steps were taken to overcome the initial problems.

Figure B3.8

Zayid Al-Siyabi's aquaponics farm grows Iceburg lettuce (1) and basil (2) grown under soil-less conditions in tanks below which tilapia grow (3)



Way forward

Introducing the concept of aquaponic systems in Oman can modify the future of agriculture. As it will attract investment to the country, which will positively reflect on national income. Integrated systems allow food growing while minimizing water use, recognizing that the country is subject to prolonged scarcity of water. Therefore, aquaponics will be solution for Oman, given the environmental and climate conditions will not impedes the operation of this system of food production. In addition, it is considered positively by farmers, mainly because aquaponics is beneficial to agriculture, and it can be a key to food security issues in the country. Based on an analysis of this sector in Oman and its current situation, plus growing interest from farmers and investors on these types of integrated aquaculture and agriculture, we can recommend the following roadmap.

Education and training

Education and training are important factors in development of aquaponic and integrated aquaculture in Oman. To enhance this education and training, the following can be done:

- Expand the Rumais Aquaponic unit within MAF to work as a demonstration and test facility for aquaponics in Oman.
- Establishment of extension farms and business incubators by MAF and other relevant authorities in the different Governorates of Oman. These farms can be used as training and information dissemination units for local farmers.
- Continuation and expansion of the joint program between MAF and MOE concerning training of school students on aquaponic techniques.
- Preparation of booklets and leaflets that demonstrate the different stages of

aquaponic development and fish-crop integrated farms.

- Creating as easy way and mechanisms to disseminate this information using new IT technologies and social media.
- Preparation of awareness programmes aimed at introducing these activities and demonstrating the expected benefits from them.

Research and development

Researches are needed to develop the most cost-effective techniques for these types of activities under the local Omani conditions. For this, we need:

- Fund more robust and continuous applied researches on different techniques in aquaponics and agri-aquaculture integrated farms in desert environments.
- Develop guidelines and protocols for sustainable activities in aquaponic and integrated agri-aquaculture.
- Selection of the best types of plants that can be used and suitable freshwater fish species.

Socio-economic aspects

Aquaponic and fish integrated culture activities can play an important role in the socio-economic development of Omani farmers and investors. Therefore, it is important to enhance these aspects, and this can be done through:

- Developing an incentive and support system to promote these activities especially for local farmers and small enterprises.
- Encouraging small and medium enterprises to invest in aquaponic and integrated aquaculture by facilitating the approval process for applications, provision of incentives and encouragement by the funding agency to fund such projects with suitable conditions.
- Enhancing the works and responsibilities of existing farmer's cooperatives.
- Encouraging the farmers to use salinity tolerant plants proposed by MAF.
- Provision of support from MAF for small desalination units to encourage farmers to apply hydroponic techniques to food production.
- Conducting detailed market studies for this sector and disseminating this information to farmers and investors.

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Appendix C: Technical data sheets for farms visited in each country

Table C.1
Technical data sheet for farms visited: ALGERIA

Category	Questions	Pescado de la Duna	Biofloc group	Mr Khmisset`s private farm
Location	Nearest city	Hassi Ben Abdellah	Hassi Ben Abdellah	Hassi Ben Abdellah
	Surface (sq m)	50 000	100 000	200 000
	Land property	private	government	private
	Soil quality (clay, sand, gravel)	sand/clay	sand	sand/clay
	Distance (km) to nearest urban area with > 50 000 people	20	20	20
	Distance (km) to the nearest aquaculture farm	5	15	2
Climate	Average temperature in summer (°C)	45	45	34
	Average temperature in winter (°C)	15	15	22
	Humidity in summer (%)	5	5-10	5-10
	Humidity in winter (%)	30	30	30
	Elevation (m)	220	220	220
	Total rainfall per year (mm)	20	15-20	50
	Number of days with rain	20	20	20
Water	Access to clean, contaminant-free water at site?	wells-underground water	Available	Available
	What is source of water at location? (rain-fed, well, underground water, municipal)	wells-underground water	wells-underground water	wells-underground water
	Water treatment?	Any treatment	Filter/RAS	Any treatment; integration only
	Availability of water (permanent/temporary)	permanent	permanent	permanent
	Salinity (ppt)	0.4	3-9	low
	pH of the water?	8 to 10	8 to 10	8
	Cost of water per cubic metre?	20 DZD	free	20 DZD

Electricity	Access to electricity at site?	Available	Available	Available
	Cost of electricity per kilowatt*hour?	-	-	-
	Number of daily hours of electricity at site?	24	24	20
	Access to backup electricity at site?	Available	Available	Not available
Integrated agri-aquaculture (IAA)	**Aquaculture species** Production (tonnes) Production cycle/year **Crop species** Production (tonnes) Production cycle/year	North African catfish, one production cycle of 8 month (300 tonnes/year)	Whiteleg shrimp (1 tonne/year)	Nile tilapia (20 tonnes/year)
	Farm-gate/market sale price of each species? (provide both if available)	North African catfish: 1 200 DZD/kg	Whiteleg shrimp: 700 DZD/kg	Nile tilapia: 600 DZD/kg
	Production systems	Open system	Biofloc	Fully IAA
	Cost of fingerlings of each species? Access to fingerlings	Produced in the farm	3 DZD/each	Free from CNRDPA (government)
	Cost of fish feed per kilo? Access to feed	1 USD/kg	1 USD/kg	200 DZD/kg
	Do they use chemical fertilizers?	No	Yes: Mg, NA, Ca; K	No
	Cost of fertilizers per kilo?	-	variable	-
	Farm-gate/market sale price of each aquaculture product?	North African catfish: 1200 DZD/kg	Whiteleg shrimp: 700 DZD; fingerlings 3 DZD each	Nile tilapia: 600 DZD/kg
	Farm-gate/market sale price of each agriculture product?	-	-	Tomato: 50 DZD/kg; Cucumber: 50 DZD/kg; Date: 150 DZD/kg; Olive: 100 DZD/kg
	Marketing of the aquaculture and crop species	Local market	Not marketed	Local market
Supplies and Equipment	Access to PVC pipe, connectors, and fittings?	Yes	Yes	Yes
	Access to water pumps?	Yes	Yes	Yes
	Access to air pumps, air stones?	No	Yes	No
	Access to greenhouse supplies? (shade-cloth, nursery trays, potting mix, etc.)	No	Indoor facilities	No
	Access to fish tanks, BC tanks, polyethylene barrels	Concrete tanks	Yes (4D-end and 3 circle tanks in PVC plus 6 incubators)	No

Table C.2
Technical data sheet for farms visited: EGYPT

Category	Questions	El Zerai	Agrimatic Farm	Bustan Aqaponics Farm	Unnamed farm
Location	Nearest city	El Sadat City	Cairo, El Abaur	Sheiken Zayed	El Sadat City
	Surface (sq m)	4 200	4 200 (used area)	3 400	4 200
	Land property	private	private	private	rent
	Soil quality (clay, sand, gravel)	sand	sand	sand	sand
	Distance (km) to nearest urban area with > 50 000 people	15	50	Barka	30 km
	Distance (km) to the nearest aquaculture farm	30	-	70	29
Climate	Average temperature in summer (°C)	40	35-40	40	36
	Average temperature in winter (°C)	18	18-25	-	18
	Humidity in summer %	70	70-80	-	25
	Humidity in winter %	80	60-70	30	60
	Elevation	120 m	-	-	20 m
	Total rainfall per year (mm)	80	-	50	50
	Number of days with rain	15	-	10	25
Water	Access to clean, contaminant-free water at site?	wells-underground water	Available	Available	No
	What is source of water at location? (rain-fed, well, underground water, municipal)	wells-underground water	Nile River	wells	underground water
	Water treatment?	desalination	Filtration/UV	-	no
	Availability of water (permanent/temporary)	permanent	permanent	permanent	permanent
	Salinity?	500 ppm	150-250 ppm	600 ppm	800 ppm
	pH of the water?	6.5-7	6-8	7	8
	Cost of water per cubic metre?	LE 4	LE 60		LE 50

Electricity	Access to electricity at site?	Available	Available	Available	Available
	Cost of electricity per kilowatt*hour?	-	LE 0.25	20 baisa	LE 0.20
	Number of daily hours of electricity at site?	permanent	24 hours	Available	permanent
	Access to backup electricity at site?	Electricity generator	Available	Available	Electricity generator
Integrated agri-aquaculture	**Aquaculture species**			Nile tilapia, 40 tonnes; 2 cycles	
	Production (tonnes)	one cycle per year	Tilapia		No fish
	Production cycle/year				
	Crop species				
	Production (tonnes)				
	Production cycle/year				
	Farm-gate/market sale price of each species? (provide both if available)		LE 10//kg	Tilapia: LE 20-25 / kg;	
	Production systems	hydroponic/ aquaponic	aquaponics	aquaponics	hydroponics
	Cost of fingerlings of each species? Access to fingerlings			LE 400-1000	-
	Cost of fish feed per kilo? Access to feed!		LE 8.5	LE 6.5-7 /kg	0.28
	Do they use chemical fertilizers?	yes	low	almost not	yes
	Cost of fertilizers per kilo?	variable	LE 200	-	LE 30
	Farm-gate/market sale price of each aquaculture product?	mango: LE 9-15; crops: LE 4-8	LE 10	LE 20-25/ kg	
	Farm-gate/market sale price of each agriculture product?		LE 24	LE 100/kg (baby leaf lettuce)	
	Marketing of the aquaculture and crop species	wholesale; distributor company, online supermarkets	one kind	intensive, social media	not

Supplies and Equipment	Access to PVC pipe, connectors, and fittings?	Available	Available	Available	Available
	Access to water pumps?	Available	Available	Available	Available
	Access to air pumps, airstones?	Available	Available	Available	Available
	Access to greenhouse supplies? (shade-cloth, nursery trays, potting mix, etc.)	Available	Available	Available	Available
	Access to fish tanks, BC tanks, polyethylene barrels	Available	Available	Available	no
Additional Notes		water saving rate; 80 percent			

Table C.3

Technical data sheet for farms visited: OMAN

Category	Questions	Al Musanaah Abdul Razak Farm	Issa Al Sultani Farm	Nasser Mawali Farm	Mousabah Al Mtairy Farm	Farm Samail-Aflaj project
Location	Nearest city	Al Musanna	Manah	Muscat	Fanja	Muscat
	Surface (sq m)	29 400	8 400	2 300	100 000	1 000
	Land property	private	private	private	private	belongs to all tribes
	Soil quality (clay, sand, gravel)	good	clay	clay	gravel (between mountains)	
	Distance (km) to nearest urban area with > 50 000 people	1	Nizwa	Barka	Barka	Samail
	Distance (km) to the nearest aquaculture farm	10	20	8	35	80
Climate	Average temperature in summer (^{0}C)	45	35	37	40-45	40
	Average temperature in winter (^{0}C)	18	20	22	15-25	20
	Humidity in summer %	high	50	90	60	70
	Humidity in winter %	average	30	30	10-15	40
	Elevation (m)	superficiality	150	-	170	132
	Total rainfall per year (mm)	Receptively few	105	100	100	20
	Number of days with rain	30	60	20	40	25

Water	Access to clean, contaminant-free water at site?	good, from wells	Available	Available	traditional system (Aflaj)	traditional system (Aflaj)
	What is source of water at location? (rain-fed, well, underground water, municipal)	wells-underground water	wells	wells	rain-underground water	Aflaj-underground water
	Water treatment?	desalination	-	-		
	Availability of water (permanent/temporary)	permanent	permanent	permanent	permanent	permanent
	Salinity?	3 000 ppm	500 ppm	600 ppm		400 ppm
	pH of the water?	7	7	7	7.5	6.5-7.5
	Cost of water per cubic meter?	OMR 2 400/year	OMR 100			
Electricity	Access to electricity at site?	Available	Available	Available	Available	Available
	Cost of electricity per kilowatt*hour?	20 baisa	0.026	20 baisa		0.026 USD/ hour
	Number of daily hours of electricity at site?	permanent	24 hours	Available	permanent	24 hours
	Access to backup electricity at site?	Electricity generator	Electricity generator	Available	Electricity generator	Electricity generator
Integrated agri-aquaculture	**Aquaculture species**	one cycle per year	Tilapia	Tilapia-Tropical fish	Tilapia	Tilapia/ 600 kg per year
	Production (tonnes)					
	Production cycle/year					
	Crop species					
	Production (tonnes)					
	Production cycle/year					
	Farm-gate/market sale price of each species? (provide both if available)	OMR 300/ ton OMR 800/ ton	35 OMR/ 1000	1.2 rial/ kg	Tilapia: 1200	1500/ kg

	Production systems	hydroponic/ aquaponic	The integration of agriculture	hydroponic		aquaponic
	Cost of fingerlings of each species? Access to fingerlings	OMR 1000/20	Tilapia 40	1000/50	-	Available/ locally
	Cost of fish feed per kilo? Access to feed	OMR 7 per 25 kg	0,72	OMR 0.28 per kg	0.28	280 baisa/k
	Do they use chemical fertilizers?	in hydroponics	no	-	no	no
	Cost of fertilizers per kilo?	OMR 1000	-	-	N/ A	N/ A
	Farm-gate/market sale price of each aquaculture product?	farm: 1,200/ market: 1,800	35/ 1000	1 OMR/kg	N/ A	1.500/kg
	Farm-gate/market sale price of each agriculture product?	15000/ ton-2000/ ton	35 OMR Marcet sale	-	N/ A	2/k
	Marketing of the aquaculture and crop species	good	one kind	farm to market to consumers	Available	from the farm
Supplies and Equipment	Access to PVC pipe, connectors, and fittings?	Available	Available	Available	local market	Available
	Access to water pumps?	Available on request	Available	Available	important	Available
	Access to air pumps, airstones?	Available on request	Available on request	Available	important	Available
	Access to greenhouse supplies? (shade-cloth, nursery trays, potting mix, etc.)	Available	Available	Available	Available	not Available
		Available	Available	Available	important	Available
Additional Notes			good farm, simple/ bio security is missing		bio security not available/ low production compare to the size/ high cost	simple/ the best for visitors

Appendix D: Photos of farmer to farmer visits

Algeria

Pescado de la Duna farm produces North African catfish (*Clarias gariepinus*) (the first three photos); Biofloc group produces whiteleg shrimp (*Litopenaeus vannamei*) (second three photos) in the desert area of Ouargla (800 Km south of Alger) and other small-scale integrated agri-aquaculture farms.
(Photos: ©FAO/ Valerio Crespi)

Egypt

Aquaponics farms visited in arid areas north of Cairo.
(Photos: ©FAO/Valerio Crespi)

Oman

Aquaponics farms visited in Oman and farmer-farmer exchanges and interaction.
(Photos: ©FAO/ Valerio Crespi)

The FAO Regional Initiative on Water Scarcity (WSI), initiated in 2013, identified that lack of water resources is a potential disaster scenario for the Near East and North Africa (NENA) region. The WSI initiative developed out of 31st Session of the FAO Near East and North Africa (NENA) Regional Conference held in Rome in May 2012, outcomes from the Hyogo Framework Agreement 2005–2015, and highlighted through work undertaken by the Arab Water Council in reports in 2004, 2012 and 2015.

Several projects were started, including use of non-conventional water resources in integrated agriculture-aquaculture (IAA) systems within the NENA region. Agriculture is the largest food production type in the region and the highest water use. Aquaculture production is also a major food sector and development of integrated systems, for increase productivity and to reduce overall water use in food production, is a useful approach. Water scarcity is particularly acute in arid regions of the NENA region, and is a finite resource, with IAA competing for water with other large sectors including domestic and industrial use. Non-conventional water resources are identified as a potential resource to develop IAA systems in a more unified way, reducing the burden of use on standard renewable water resources.

The principle objective of the work was to build broad partnerships to support greater understanding in implementation and use of non-conventional water resource in IAA systems. The activity was supported by WSI and FAO Global Knowledge Product on water. Work was undertaken to summarize current approaches using three selected countries: Algeria, Egypt and Oman, identified to be representative of cross-regional differences in non-conventional water use for integrated agriculture and aquaculture across the NENA region. Three country National Task Forces were set up and with support from national partners country-based reviews were undertaken, which evaluated current activity in each country through questionnaire surveys and interviews with farmers and other stakeholders. Farmer-to-farmer visits provided a key component of the activity that enabled sharing of best management practices on IAA. Activity was concluded with a regional workshop held in Cairo, Egypt on 25-26 June 2019 that aimed to finalize a broad roadmap for further development activity.

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